BUREAU ECONOMIC GEOLOGY
The University of Texas
Austin 12, Texas

Peter T. Flawn, Director

Report of Investigations—No. 49

Pleistocene Geology of Red River Basin in Texas

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JOHN C. FRYE[1] and A. BYRON LEONARD[2]

ABSTRACT

The Red River rises in northeastern New Mexico and extends across northern Texas and east of the Panhandle serves as the northern border of that State. The late Cenozoic geology of the Red River basin has been studied intensively in northwestern Texas and in Louisiana. This report summarizes the results of our studies of the late Cenozoic geology of the Red River basin in Texas. Late Tertiary terrace deposits have been identified as far east as Montague County and deposits of Nebraskan age have been recognized somewhat farther east. Terrace deposits of late Kansan and early Wisconsinan age have been traced essentially throughout the basin in Texas. In north-central and northeastern Texas the names Hardeman, Ambrose, and Cooke are proposed for the alluvial terraces that were formed during late Kansan and early and late Wisconsinan time. In northeastern Texas we found pimple mounds occurring on all terrace surfaces older than Wisconsinan. Varied and diagnostic faunas of fossil mollusks are reported from Kansan, early Wisconsinan, and late Wisconsinan deposits throughout most of the basin in northern Texas, and Pearlette Volcanic Ash occurs locally in the deposits of Kansan age. The Pleistocene history of the Red River has been a succession of alternating episodes of valley deepening, accompanied by progressive headward encroachment of nickpoints in northwestern Texas, and less extensive valley alluviation.

INTRODUCTION

This report is concerned with the Pleistocene geology of the Red River basin of Texas. The Red River crosses Texas from west to east, and east of the Panhandle it forms the northern boundary of the State. It is the southernmost large tributary entering the Mississippi River. Although the Red River basin is of major proportions, unlike the Arkansas and Missouri Rivers the Red River heads on the High Plains surface of eastern New Mexico and carries no drainage from the Rocky Mountains region. Therefore, of the major tributaries to the Mississippi from the west only Red River was free, at least in its headwaters region, of the direct influence of both continental and mountain glaciation during the Pleistocene. The region is, therefore, ideal for the study of the effects of climatic pulses during the Pleistocene as it is beyond the overt effects of glacial outwash or glacially induced diversions.

The lower Red River valley of Louisiana has for many years been the subject of intensive study of Pleistocene terrace surfaces and deposits. In 1938 Fisk described from Grant and LaSalle Parishes, Louisiana, a sequence of terraces that he named in ascending order (and from youngest to oldest) Prairie, Montgomery, Bentley, and Williana. He concluded that the major valleys of Louisiana were incised by stream erosion induced by the lowering of sea level during each of the major continental glacial episodes, and that the valleys were alluviated during the following interglacial interval because the sea level rose as the masses of glacial ice dissipated. Since this early work a succession of subsequent reports has been concerned, at least to some

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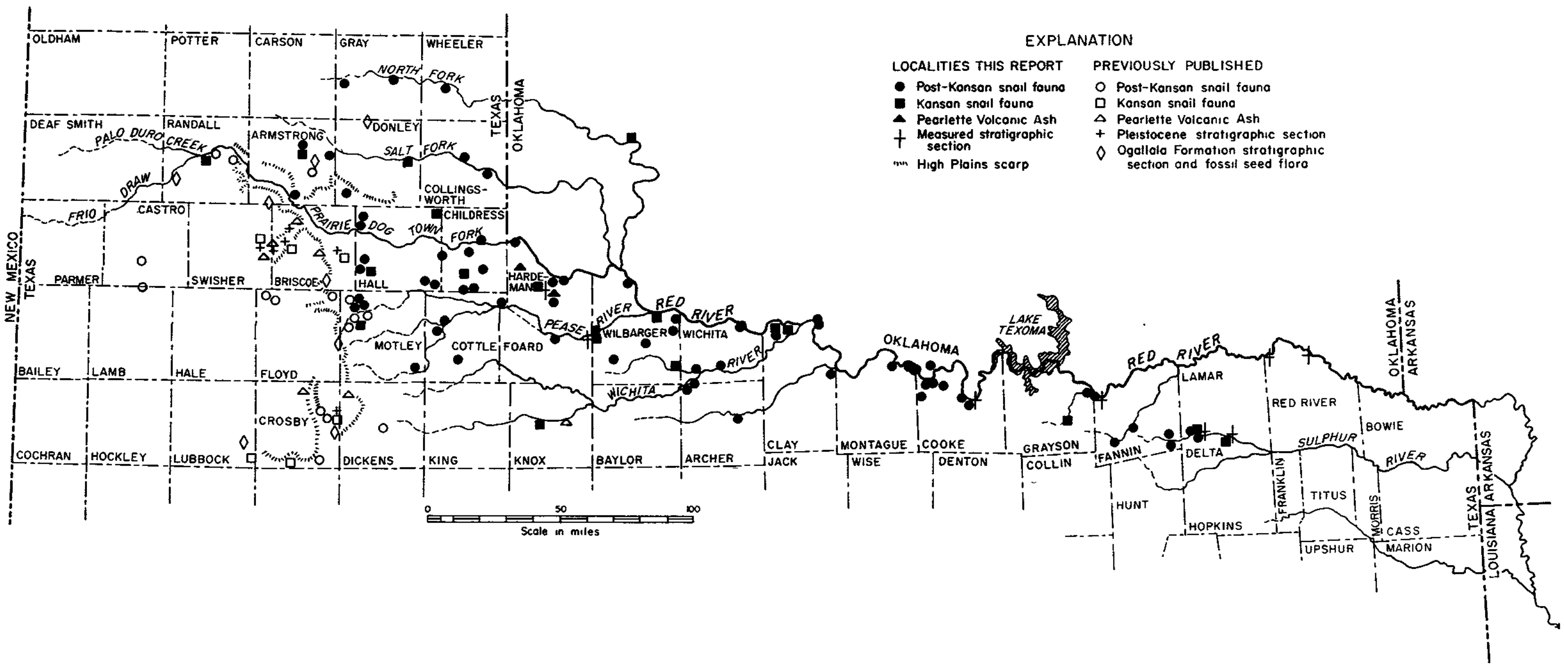

FIG. 1. Map of the Red River basin in Texas showing major tributary streams in Texas and location of molluscan faunas and measured sections used in this report.

degree, with the Pleistocene terraces of the lower Red River valley (Fisk, 1939; 1944; 1952; Murray, 1948; Schultz and Krinitsky, 1950). Although these reports presented additional data they in general supported the interpretations made by Fisk in 1938.

In the headwaters region of the Red River in northwestern Texas, intermittent studies of the late Cenozoic geology have extended through many years (Plummer, 1933; Evans and Meade, 1945). In Kansas, the late Cenozoic deposits have been correlated with the continental glacial sequence (Frye, Swineford, and Leonard, 1948; Frye and Leonard, 1952), and recently stratigraphic and paleontologic studies have extended these correlations with Pleistocene and Neogene units in Nebraska, Kansas, and Iowa into the headwaters region of the Red River in northwestern Texas (Frye and Leonard, 1957; 1957a; 1959).

East of the High Plains escarpment in Texas relatively little study has been devoted to the Pleistocene deposits of the Red River valley except in the area lying north of the northernmost bend of the Brazos River where Stricklin (1961) described the early Pleistocene history of a part of the Wichita River valley, a tributary to the Red River from the south.

In studies of stream gradients and terrace profiles elevation data are essential. In much of the Red River basin of Texas detailed topographic quadrangle maps are not available and therefore it has been necessary to utilize the sheets of the 1:250,000 Army Map Service series, which are available for the entire region, even though they lack the desired degree of detail.

The Red River basin occupies an irregularly shaped area in Texas, as shown in figure 1. At the New Mexico line, in Deaf Smith and Parmer counties, its north-south extent is relatively narrow. The basin widens to the east so that at the eastern edge of the Panhandle it includes all or part of Wheeler, Collingsworth, Childress, Cottle, and King counties. Eastward from there the basin is again constricted, particularly so east of the mouth of the Little Wichita River. The valley is here flanked on the south by high Cretaceous uplands, and in Cooke County the headwaters of the Trinity River drainage extend to within a mile of the Red River channel. East of Cooke County the basin again widens to the south so that adjacent to the Arkansas State line all or parts of Marion, Cass and Bowie counties are within Red River drainage.

The bedrock geology of the basin is shown on the Texas State geologic map. In its headwaters area the valley is cut in the Ogallala Formation, and, after crossing a very narrow belt of Triassic rocks, flows nearly half of the distance across Texas in Permian rocks. In northeastern Texas the Red River channel is entirely in rocks of Cretaceous age, but the major tributaries from the south cross an area underlain by several formations of Eocene age. The influence of bedrock control on the topography is most strikingly apparent along the eastern margin of the High Plains, where the eastern escarpment of this extensive plateau is a dominating topographic feature, and in Montague and Cooke counties where resistant limestone beds of Cretaceous age underlie an equally prominent escarpment facing northwest and north.

Field work for this study was carried on during two-week periods in the summers of 1959, 1960, and 1961, but data we obtained in the western part of the area during the summers of 1955, 1956, and 1957 also were used. The work was sponsored by the Bureau of Economic Geology of The University of Texas, and is part of a long-range program of studies of late Cenozoic geology and paleontology in western and northern Texas. Dr. Ada Swineford of the State Geological Survey, the University of Kansas, identified samples of Pearlette Volcanic Ash from two localities reported here for the first time.

The location of all fossil molluscan faunas, Pearlette Volcanic Ash localities, and measured sections reported here, as well as previously published localities used in this study, are shown in figure 1. Figure 2 lists fossil molluscan faunas from selected localities in the Red River basin. Figure 3 presents profiles of the gradients of the Red River and its principal tributaries and of the major terrace surfaces. Plates I, II, and III illustrate the topography and Pleistocene deposits of the basin.

STRATIGRAPHY OF LATE CENOZOIC DEPOSITS

During the past decade we have been concerned with the stratigraphy, paleontology, and correlation of late Cenozoic deposits of western Texas (Frye and Leonard, 1957; 1957a; 1959) and the studies reported here are, in large part, the eastward extension of these studies through the basin of the Red River valley to the Arkansas State line. As the lithology of late Tertiary deposits in the High Plains region resembles the Pleistocene sediments in the same region, it has been necessary to examine in detail the Neogene deposits as well as those of Pleistocene age.

The basis of recognition of time-stratigraphic units in the Great Plains differs widely between the late Tertiary and the Quaternary. Correlations of the late Tertiary have been made with the standard time-stratigraphic units of the European sequence (Miocene + Pliocene = Neogene) on the basis of contained fossil vertebrates, but correlations throughout the Great Plains region have been based on physical stratigraphy, fossil plant remains, fossil snails, and in a few places by petrographically distinctive volcanic ash (Swineford, Frye, and Leonard, 1955). Stratigraphic classification is based on the type localities of the Ogallala Formation and its subdivisions in Nebraska. As no attempt was made to re-evaluate the correlation of Great Plains sediments with the Miocene-Pliocene boundary as defined in Europe, the more general term Neogene is used here.

For the Quaternary deposits of the Great Plains, time-stratigraphic units defined in the midwestern United States are used. These are based on episodes of glacial advance and retreat. As these units were defined on deposits to the north and east of Texas, their correlation into this region is based primarily on physical stratigraphy (including the morphology and tracing of buried soils and the recognition of petrographically distinct volcanic ash lentils), assemblages of fossil mollusks, and physiographic expression and sequence (Frye, Swineford, and Leonard, 1948). Although fossil vertebrates are valuable for correlation within the Great Plains and may furnish a basis for correlation with defined units in Europe and elsewhere, the rarity of fossil vertebrates within the type sequence of the glaciated region renders them of less value for correlation with the midwestern standards of time-stratigraphic classification.

It is thus apparent that a different basis of definition is used on the two sides of the Tertiary-Quaternary (Neogene-Pleistocene) boundary, and it is apparent that such circumstances might lead to different interpretations of this boundary. It is possible to resolve such differences of interpretation in the central Great Plains because in this region the stratigraphic relations of late Tertiary and early Pleistocene deposits can be observed. The interval of time separating the two is represented by the Ogallala climax soil developed in the top of the deposits of Neogene age. Although there may be some doubt as to the precise placement of this time interval within the Plaisancian-Astian-Calabrian sequence of southern Europe, the boundary defined on this soil and associated unconformity is practical and usable throughout the Great Plains region.

The stratigraphy of the Ogallala Formation in the western Red River basin has been described (Frye and Leonard, 1959) and the locations of published measured sections are shown in figure 1. The Ogallala Formation consists predominantly of alluvial deposits of sand and silt, with locally coarse and thick gravel zones, particularly in the lower part; it contains buried soils, caliche-cemented zones, massive caliche, and locally silty clay. In the Red River basin of Texas its thickness ranges from a few feet to more than 300 feet in relatively short distances. The lowermost Valentine floral zone is restricted to the lowest parts of the sub-Ogallala erosion surface; elsewhere various parts of the Ash Hollow floral zone is in contact with the underlying rocks. In general the cemented zones of the Ogallala are significantly more resistant to erosion than the underlying Triassic and Permian rocks, and therefore the formation is well exposed in the east-facing escarpment and along canyon sides.

Rock-stratigraphic classification of Quaternary deposits in northwestern Texas has been based on type localities in Texas and correlations with units farther north. Deposits of Nebraskan age are largely included within the Blanco Formation, named for a type locality at Mt. Blanco in Crosby County, Texas; deposits of Kansan age are largely included within the Tule Formation, named for a type locality in Tule Canyon in eastern Swisher and western Briscoe counties, Texas. Eolian sands of Illinoian age in western Texas have been informally referred to as "cover sands," and terrace deposits of this age have not been given a formal rock-stratigraphic name. Within the deposits of Wisconsinan age, the Tahoka Formation (Evans and Meade, 1945) has been recognized as including some basin fills, and the name Peoria loess has been applied (Frye and Leonard, 1951) to loess deposits in the Panhandle area. Formal stratigraphic names generally have not been applied to the sediments underlying the several alluvial terraces of Wisconsinan age in western Texas.

In Louisiana, formal rock-stratigraphic names have been applied to the deposits underlying the surfaces of several of the recognized alluvial terraces (Fisk, 1938; 1952; Murray, 1948; Schultz and Krinitzsky, 1950), but because these units in Louisiana are not yet firmly correlated with the deposits underlying the Red River terraces in Texas these formal names have not been used in this report. East of the High Plains the Pleistocene deposits are intimately related to terrace forms and we consider them to be more properly morphostratigraphic units (Frye and Willman, 1962) than rock-stratigraphic units. We are here formally naming four of them as morphostratigraphic units from designated geographic type localities. The youngest of these is late Wisconsinan in age and is here named the Cooke Alluvial Terrace from exposures (measured section no. 2) in the bank of the Red River, 7 miles north of Gainesville, Cooke County, Texas. The second is early Wisconsinan in age and is here named the Ambrose Alluvial Terrace from exposures in the Red River bank (measured section no. 4) 1½ miles east of Ambrose, in Fannin County. The third is of Kansan age and is here named the Hardeman Alluvial Terrace from exposures along the valley wall of Groesbeck Creek (measured section no. 7) 5½ miles north and 4 miles west of Quanah in Hardeman County. The fourth terrace is a form that is underlain by late Wisconsinan, early Wisconsinan, and Kansan age deposits (measured section no. 5), and is here named Sulphur River Alluvial Terrace from a segment of the Sulphur River valley south of Paris in Lamar County. For the purposes of this report the other alluvial deposits under terrace surfaces are informally referred to by use of the tentatively assigned age of the terrace, except in the western part of the basin where the term Blanco Formation is used to designate the Nebraskan age deposits and the term Tule Formation is used for the Kansan age deposits.

Nebraskan deposits.—Preserved remnants of deposits of Nebraskan age are relatively unevenly distributed in the Red River basin. The Blanco Formation has been described (Frye and Leonard, 1957a) in Tule Canyon, has been studied on the south side of Palo Duro Canyon, and occurs below Tule Formation in the highway cuts at the north edge of Canyon, Randall County. Similar Blanco deposits are well exposed south-southwest of Memphis in Hall County (Pl. III, C). At all of these localities the Blanco deposits consist predominantly of sand and silt with some silty clay and are gray, greenish gray, dirty white, and tan in color. In strong lithologic contrast are the sands and gravels of the

Blanco Formation, well exposed in road cuts along the north side of Palo Duro Canyon, Armstrong County, the north side of Mulberry Canyon, Donley County, and north of Turkey, Hall County. At these localities the gravels contain cobbles several inches in diameter, including some cobbles of cemented Ogallala Formation.

There is an area east of the Panhandle where exposures of Nebraskan age deposits are rare, partly because the weakly resistant Permian bedrock has been eroded to such an extent that the uplands are at, or only slightly above, the Kansan terrace surface. Coarse Nebraskan gravels are exposed in pits at the highest upland level at Sherman Air Force Base in Wichita County and near Fish Creek in north-central Cooke County.

In Cooke and Grayson counties resistant Cretaceous limestones rise far above the level of the projected Nebraskan terrace and deposits of this age are observable only on the Oklahoma side of the valley.

From Fannin County eastward, well-developed Nebraskan alluvial deposits were not observed in the Red River basin of Texas. Through part of the distance to the Arkansas State line the upland topography does not stand high enough to contain these deposits. In other areas (e.g., southwest of Ben Franklin, Delta County, east of English, Red River County, and at Siefs, Fannin County) the Nebraskan deposits consist only of gravel veneers that cover the bedrock erosional surface. Such surficial deposits of residual Nebraskan gravels also occur in adjacent parts of Oklahoma and Arkansas (e.g., north of Terral, Oklahoma, and 6 miles east of Texarkana, Arkansas).

Kansan deposits.—The Tule Formation of Kansan age is based on a type locality in Tule Canyon (Plummer, 1933), a tributary to the Red River, and has been described extensively from localities in this part of Texas (Evans and Meade, 1945; Frye and Leonard, 1957a). Deposits of similar age have been described from the divide area of the Brazos and Wichita rivers by Stricklin (1961). In western Texas the Tule Formation commonly consists of a basal gravel that ranges widely in thickness and contains rock types representative of the drainage basin in which the deposit is located. The basal gravel is gradationally overlain by sand and silt or clayey silt that at some places contains lenses of Pearlette Volcanic Ash; in color it may be tan, tan brown, or gray, and in the area of Permian bedrock locally contains brick-red zones. At some places the Tule Formation contains abundant faunas of fossil snails. The top of the formation is characteristically marked by a well-developed soil profile displaying a prominent zone of caliche accumulation.

East of the High Plains, alluvial terrace deposits of Kansan age, the Hardeman Alluvial Terrace, are virtually continuous along the Red River valley and its major tributary valleys to the Arkansas State line. They also have been examined at many places on the Oklahoma side of the Red River (e.g., Pl. II, B). In general the texture of the basal gravels becomes finer eastward. In the Panhandle region the gravels contain cobbles with maximum diameters ranging up to 1 foot (Pl. II, C), whereas in exposures in Wichita and Clay counties, and eastward, the maximum pebble size rarely exceeds 3 to 4 inches. Furthermore, sand becomes more common and gravel less abundant in these deposits farther east in Texas. The Hardeman Alluvial Terrace deposits along the Wichita and Pease River valleys (which head at or near the High Plains margin) generally are similar to the deposits along the Red River valley, but the basal gravels along the valleys of the Sulphur River and the Bois D'Arc and Choctaw Creeks strongly reflect the adjacent Cretaceous bedrock (Pl.II, E).

Throughout the basin the Hardeman Terrace deposits grade upward from the basal gravels into sands and silts (Pl. II, F) as shown by measured sections included with this report. In the eastern part of the area the sands and silts compose a larger percentage of the total deposit, and lentils of Pearlette Volcanic Ash have not been found east of Hardeman County. The silts are tan and gray in color and under relatively undissected surfaces contain a well-developed, deep soil profile in their top (Pl. II, A). The thick, well-developed zone of caliche accumulation, so prominent in this soil in western Texas, disappears eastward; in northeastern Texas this soil commonly displays a podzolic profile. In much of the region the degree of soil development is such that the profile on the Kansan deposits can readily be distinguished in the field from the soil profiles developed in the sediments underlying the several younger terrace surfaces, but it cannot be distinguished clearly from the soil profiles that have developed in the sediments underlying the older surfaces east of the High Plains.

Illinoian deposits.—The deposits of Illinoian age are the least extensive and distinctive of the several units of alluviation in the Red River basin. In western Texas they occur incised into the Tule Formation but have not been given a formal stratigraphic name (Frye and Leonard, 1957a). East of the High Plains, although they occupy a distinctive position between the Ambrose and Hardeman Terraces, they are discontinuous and of minor extent except in the area east of Grayson County. Even in eastern Texas, Illinoian deposits are largely absent in such major tributaries as the Sulphur River.

In the Red River valley of northeastern Texas the Illinoian sediments generally are similar to those of Kansan age but contain less silt and generally display more reddish tan and less gray in their color range. These physical differences, however, are scarcely sufficient to distinguish the Illinoian sediments from those of Kansan age in the field, but the position of the Illinoian terrace surface is distinctive, as is the degree of development of the Illinoian surface soil profile, which is intermediate to that of the soils in Kansan and younger Wisconsinan sediments.

Ambrose Alluvial Terrace (*early Wisconsinan*).—In the Red River basin of Texas the terrace deposits of Wisconsinan age exceed all other Pleistocene units in volume and extent, with the possible exception of the Kansan. The Wisconsinan deposits are grouped into two units of unequal size. The more extensive unit that underlies the higher and older of the two terraces is the Ambrose Alluvial Terrace of pre-Bradyan Wisconsinan age. Along the valley of the Red River and its major western tributaries these deposits consist of basal gravels, well sorted and cross-bedded (Pl. I, G), grading upward into well-bedded sands and silts with some thin beds of silty clay (Pl. I, F); the predominant color east of the High Plains is red to reddish tan. The characteristics of these deposits in western Texas have been described by Frye and Leonard (1957a), and measured sections 3 and 4 herein describe them along the Red River in Fannin and Red River counties.

The surface soils developed on the Ambrose Terrace deposits are relatively immature but show distinct zonation. In western Texas they have relatively thin zones of caliche accumulation and in eastern Texas the B-horizons generally are less than 1 foot thick; unlike the soils on the older terrace surfaces, these are rarely podzolic profiles.

In the major tributary valleys of northeastern Texas the early Wisconsinan deposits present a strong contrast to those of the Red River valley. In these tributary valleys they generally lack a basal gravel and consist largely of gray to black sand, silt, and clay. Although locally they are incised into the deposits of Kansan age, they are commonly thin and overlap the surface of the Kansan deposits (note measured sections 5 and 6). In many areas the soils developed on them are humic-gleys.

Cooke Alluvial Terrace (*late Wisconsinan*).—Although late Wisconsinan (post-Bradyan) deposits of the Cooke Alluvial Terrace generally occur along the streams of the Red River basin in western Texas (Frye and Leonard, 1957a), they are quantitatively important only in the northeastern area. They consist predominantly of sand and silt with some clay, are moderately well bedded, and are predominantly red to tan, as shown by measured sections 1 and 2 and Plate I, E. The surface soils developed in these deposits are quite immature and the B-horizon is weakly developed or locally not recognizable.

Sulphur River Alluvial Terrace.—In the valley of the Sulphur River, the major tributary of the Red River in northeastern Texas, the late Wisconsinan deposits are quantitatively unimportant and do not compose a distinct terrace, but rather consist of thin surficial deposits of early Wisconsinan and Kansan age (measured sections 5 and 6). These deposits of late and early Wisconsinan and Kansan age make up the complex that underlies the one extensive terrace form of the valley. This is the complex we have named the Sulphur River Alluvial Terrace.

Deposits of the flood plain complex.—In the Red River valley of eastern Texas three recognizable surfaces occur at levels topographically lower than any of the Pleistocene terrace surfaces described. They consist of (1) channel bars; (2) a surface (generally covered by vegetation and with patches of sand dunes on it) 1 to 5 feet higher than the bars of the active channel; and (3) a somewhat higher surface (also covered with vegetation and displaying patches of sand dunes) 6 to 10 feet above the level of the channel bars (Pl. I, A and B). These deposits, all of Recent age, together compose a unit referred to here as the flood plain complex. The deposits consist predominantly of tan sand, with some beds of red clayey silt and others of humic-stained clayey, silty sand. Recognizable zonal soils have not been observed in any of these deposits, but at a few places there are thin accumulations of organic-rich clayey silt that superficially resemble humic-gley soil. It is judged that the deposits in the flood plain complex are relatively thin in comparison to the deposits under the several described terrace surfaces; however, as the thickness observable in outcrop is only a few feet and subsurface data are not available, this has not been established.

Generalities.—The alluvial deposits underlying the five Pleistocene terrace surfaces are similar in that in each there is a graded sequence from coarse materials at the base to increasingly finer materials upward, Furthermore, east of the High Plains, each cyclic sequence of alluvium becomes progressively finer textured eastward. It is not possible to distinguish Kansan from older alluvial deposits on the basis of surface soils, but for the terrace deposits younger than Kansan the degree of development of surface soils constitutes a usable criterion of relative age. Deposits of Illinoian age are a quantitatively important cyclic unit only in the eastern third of the Red River basin in Texas. The major tributary valleys to the Red River in western Texas contain a sequence of alluvial deposits similar to those in the main valley; in contrast, the Pleistocene deposits in the major tributary valleys in eastern Texas differ significantly from those in the Red River valley. The Red River terrace deposits display a progressively increasing influence of local bedrock from Nebraskan to Wisconsinan. In western Texas the Blanco Formation (Nebraskan) and the Tule Formation (Kansan) are formally recognized rock-stratigraphic units. East of the High Plains in the terrace sequence along the Red River the Hardeman Alluvial Terrace (Kansan), the Ambrose Alluvial Terrace (pre-Bradyan Wisconsinan), and the Cooke Alluvial Terrace (post-Bradyan Wisconsinan) are formal morphostratigraphic units. It is our judgment that future, more detailed work, will justify the application of formal names to the remaining recognizable terrace deposits either by correlation with previously named units in Louisiana or by the definition of units from localities within the area covered by this report.

FOSSIL MOLLUSCAN FAUNAS

Fossil molluscan assemblages have been used in this study in an attempt to extend eastward in the Red River basin the stratigraphic correlations previously established near the High Plains escarpment (Frye and Leonard, 1957a), and with localities farther north in the High Plains (Leonard, 1952; 1959; Taylor, 1960). In general, this attempt is regarded as successful, although available fossiliferous exposures are rare in certain stretches of the Red River valley and become exceedingly sparse in the easternmost part of the Red River drainage in Texas. In the region of the Cretaceous "high" in Cooke and Grayson counties, older terraces are no longer in existence, at least on the Texas side of the valley, and younger ones have largely been submerged by the filling of Lake Texoma. In the easternmost stretch of the Red River valley in Texas, the only satisfactory fossiliferous exposures of Kansan age available to us are in the valley of the tributary Sulphur River.

Previous studies of fossil molluscan assemblages in the Red River basin have been limited, within our knowledge, to those of Frye and Leonard referred to above, and a detailed study of a molluscan faunal assemblage made by Allen and Cheatum (1961), based upon an exposure near Byers, Clay County. Allen and Cheatum concluded that the Byers faunal assemblage is of Illinoian age. It must be admitted that the assemblage lacks certain elements characteristically present in Kansan molluscan faunas in the region, such as *Valvata tricarinata,* but in general the fauna has the characteristic composition of local Kansan molluscan assemblages. Furthermore, the deposits that contain this fauna are part of the Hardeman (Kansan) Terrace that contains other even more distinctive Kansan faunas listed here and has been traced almost continuously westward into areas where Pearlette Volcanic Ash and other data establish its Kansan age.

The dramatic response of the Great Plains region to climatic oscillations, that led in turn to wide variations in local ecological conditions, in large measure disposes of the frequently made criticism that fossil mollusks are of limited value in stratigraphic correlations because they underwent little evolution through the Pleistocene Period. Fresh-water and terrestrial mollusks are sensitive to changes in ecological conditions, and as molluscan faunal assemblages characterize a prevailing regional ecological regimen, they can be used for stratigraphic purposes as well as for paleoecological deductions. This is not to say that local fossil molluscan assemblages may not at times lack definitive character, and judgment must be exercised in evaluating the character of local faunas that occur in deposits of questionable stratigraphic position.

LATE WISCONSINAN MOLLUSCAN ASSEMBLAGES

Late Wisconsinan fossil molluscan assemblages in the Red River basin generally reflect the present living fauna in the local region and consist in large measure of long-ranging species that have been able to withstand the vicissitudes of numerous climatic fluctuations. Examples include *Helicodiscus parallelus, Hawaiia minuscula,* and some species of *Succinea,* among terrestrial gastropods, and some form of *Helisoma* and of *Physa* among fresh-water mollusks. In addition, a few gastropods of southern affinity, generally absent in older sediments, may appear in late Wisconsinan deposits. Conspicuous among the southern migrants are *Bulimulus alternatus* and *Helicina orbiculata tropica.*

East of the Panhandle portion of Texas, late Wisconsinan deposits in the Red River basin yield only sparse molluscan remains; the flood plain terrace complex generally is devoid of molluscan fossils, although meager collections were made at a few places. Cooke Alluvial Terrace (late Wisconsinan) deposits in this region consist almost entirely of sand and appear to have been extensively reworked as the Red River changed the details of its course within its valley.

EARLY WISCONSINAN MOLLUSCAN ASSEMBLAGES

More than 60 localities in the Red River basin yielded early Wisconsinan molluscan assemblages; 12 of these, selected from counties ranging from Donley County in the west to Lamar County in the eastern part of the basin are listed with their respective faunas in figure 2. Early Wisconsinan deposits yielded a composite molluscan fauna of nearly 40 species, but local faunas rarely contain more than a dozen kinds of mollusks; local populations are, however, abundant at many exposures.

The great majority of kinds of fossil mollusks found in sediments of the Ambrose Alluvial Terrace (early Wisconsinan) also occur in Kansan deposits. Three species, *Anguispira alternata alternata, Allogona profunda,* and *Carychium exiguum,* were not found in sediments older than early Wisconsinan, but these occurred at no more than one or two localities in the eastern part of the Red River basin and are judged to reflect nothing more than the greater tendency toward forest cover in the eastern stretches of the valley in Texas.

Certain species, while occurring both in late Kansan and early Wisconsinan deposits, are common in the former and of rare occurrence in the latter, among them *Gastrocopta procera, Gastrocopta tappaniana, Lymnaea palustris, Helisoma antrosa, Physa gyrina, Promenetus umbilicatellus,* and *Vertigo ovata.* Many of these should be expected to occur more abundantly in Wisconsinan deposits, and their limited occurrence is not readily accounted for; others, such as *Vertigo ovata,* may be reworked from older deposits, although this species occurs in Wisconsinan sediments in the midcontinent region. The relative rarity of *Lymnaea parva, L. bulimoides,* and *Physa anatina* probably reflects only the exigencies of local deposition, as these species are long-ranging in the Pleistocene and are present in the Red River basin today. Among the molluscan species reported here from early Wisconsinan deposits, no more than six occur also in late Wisconsinan sediments. This is remarkable and strongly indicates that the climatic deterioration that occurred with and/or following the Bradyan interval on the Great Plains, also profoundly affected the Red River basin, even in its eastern portion in Texas.

A similar degree of local extinction of mollusks is noted when early Wisconsinan faunal assemblages are compared with those from Kansan deposits. Approximately 40 percent of the species occurring widely in Kansan deposits in the Red River basin do not occur in early Wisconsinan deposits.

For the most part, the early Wisconsinan assemblages that are composed largely of terrestrial species indicate the predominance of forest-border ecological situations. In the eastern part of the Red River basin, however, the occurrence of *Anguispira a. alternata, Allogona projunda,* and *Triodopsis multilineata* attests to the persistence of forest vegetation there through early Wisconsinan time. It is significant that none of the branchiate fresh-water snails such as *Amnicola, Pomatiopsis,* and *Valvata* seems to have survived from Kansan assemblages. If Frye and Leonard are correct in their interpretatipn of the "cover sands" (1957a, p. 28) of the Texas High Plains, the widespread arid conditions occurring through at least part of the Illinoian interval probably account for the local extirpation, of the branchiate gastropods that form a rather conspicuous element of Kansan fossil molluscan assemblages. At any rate, ecological conditions in the Red River basin during early Wisconsinan time either were not

LOCALITY NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
AGE OF DEPOSIT	LATE KANSAN												EARLY WISCONSINAN											
COUNTY NAME	RANDALL	ARMSTRONG	DONLEY	MOTLEY	HALL	KNOX	FOARD	HARDEMAN	GREER (OKLAHOMA)	WILBARGER	CLAY	DELTA	DONLEY	CHILDRESS	WILBARGER	ARCHER	WICHITA	CLAY	MONTAGUE	JEFFERSON (OKLAHOMA)	COOKE	GRAYSON	FANNIN	LAMAR
FOSSIL MOLLUSCAN SPECIES																								
ALLOGONA PROFUNDA																					●			
ANGUISPIRA A ALTERNATA																								●
CARYCHIUM EXIGUUM													●							●				
BULIMULUS D DEALBATUS									●	●													●	●
BULIMULUS D RAGSDALEI												●									●	●		
GASTROCOPTA ARMIFERA	●							●	●			●			●	●	●	●			●			
GASTROCOPTA CRISTATA										●			●											
GASTROCOPTA CONTRACTA								●				●									●			
GASTROCOPTA PROCERA			●		●		●		●	●		●		●										
GASTROCOPTA TAPPANIANA			●		●	●	●	●	●			●	●											
HAWAIIA MINUSCULA	●	●	●	●	●		●		●	●	●	●		●	●	●	●	●	●		●			●
HELICODISCUS EIGENMANNI	●	●								●		●	●		●						●			
HELICODISCUS PARALLELUS	●			●	●	●		●	●					●	●	●	●	●	●	●				
HELISOMA ANTROSA									●	●		●							●					
HELISOMA TRIVOLVIS						●		●	●			●			●		●					●	●	●
HENDERSONIA OCCULTA												●									●	●	●	●
LYMNAEA BULIMOIDES	●		●	●	●	●	●	●	●	●		●										●		
LYMNAEA PALUSTRIS				●			●	●		●	●		●											
LYMNAEA PARVA	●		●		●	●	●	●	●	●			●											●
OXYLOMA RETUSA								●	●		●	●			●	●	●		●					●
PHYSA ANATINA								●														●		
PHYSA GYRINA						●		●			●	●			●									
POLYGYRA TEXASIANA									●			●				●	●			●	●		●	●
PROMENETUS UMBILICATELLUS			●	●				●												●				
PUPILLA MUSCORUM	●		●	●	●	●		●						●	●	●	●		●				●	
PUPOIDES ALBILABRIS		●	●	●	●	●	●	●	●		●		●	●			●				●			
RETINELLA ELECTRINA	●		●	●	●	●		●	●		●										●			
RETINELLA INDENTATA												●						●	●			●		
SPHAERIUM STRIATINUM						●				●		●						●						●
STENOTREMA LEAI					●			●	●	●		●	●									●		
STROBILOPS L LONSDALEI						●		●	●	●	●										●			●
SUCCINEA CF AVARA	●	●	●			●	●	●	●	●	●		●	●					●					
SUCCINEA CF GROSVENORI	●			●						●		●	●	●		●	●	●		●				
TRIODOPSIS MULTILINEATA												●										●	●	
VALLONIA GRACILICOSTA	●	●	●		●	●	●	●	●	●					●	●	●				●			
VERTIGO MILIUM		●	●	●	●			●	●	●	●	●	●											●
AMNICOLA CINCINNATIENSIS												●												
AMNICOLA LIMOSA PARVA								●				●												
CARYCHIUM PEREXIGUUM					●	●		●	●															
CIONELLA LUBRICA									●															
DEROCERAS AENIGMA		●	●		●		●	●	●	●	●	●												
DISCUS CRONKHITEI	●			●	●	●		●	●															
EUCONULUS FULVUS						●						●												
GASTROCOPTA PROARMIFERA	●	●	●	●	●	●	●	●		●	●													
GYRAULUS CRISTA			●					●	●	●		●												
GYRAULUS LABIATA			●	●	●	●		●	●			●												
LYMNAEA CAPERATA					●			●	●		●	●												
LYMNAEA REFLEXA						●			●		●	●												
PISIDIUM COMPRESSUM			●			●	●	●	●	●		●												
PLANORBULA VULCANATA			●					●	●	●	●	●												
POMATIOPSIS LAPIDARIA								●			●	●												
PUPILLA BLANDI	●	●	●		●		●			●														
PUPILLA MUSCORUM SINISTRA			●	●		●		●																
STROBILOPS TEXASIANA			●		●							●												
VALLONIA PARVULA			●		●		●		●															
VALVATA TRICARINATA	●		●					●	●			●												
VERTIGO GOULDII		●		●	●	●	●																	
VERTIGO OVATA		●		●	●		●	●	●	●		●												
ZONITOIDES ARBOREUS				●	●			●	●															
TOTAL NUMBER OF SPECIES	15	11	23	17	24	22	16	35	33	23	15	34	11	7	9	8	10	6	7	5	12	8	6	11

FIG. 2. Fossil molluscan faunas of late Kansan and early Wisconsinan age from selected localities distributed through the Red River basin in Texas.

suitable to the survival of populations of branchiate gastropods or there were barriers that prevented immigration after the stresses of Illinoian aridity had eliminated from the basin the branchiates that thrived during Kansan times. Higher prevailing temperatures may have been a more important barrier to return of branchiate gastropods to the region than was lack of suitable local aquatic environments, inasmuch as the species concerned are essentially northern in their distribution.

KANSAN MOLLUSCAN ASSEMBLAGES

We found no fossil molluscan assemblages assignable to the Illinoian in the Red River basin. The Byers local molluscan fauna, judged to be Illinoian by Allen and Cheatum (1961), is here referred to the Kansan fossil molluscan assemblages, for reasons noted earlier.

Approximately 60 species of fresh-water and terrestial mollusks were recovered from Kansan deposits in the Red River basin (a few rare occurrences and a few shells of uncertain identity have been omitted from figure 2). The Kansan localities listed on figure 2 represent a selected series ranging from Randall to Delta counties; in the selection a few records have unavoidably been omitted.

The great consistency of Kansan faunal assemblages from Randall to Delta counties not only aided us greatly in stratigraphic correlations in the Red River basin but also attested to the widespread uniformity and stability of ecological conditions in the basin during Kansan time.

The absence of known occurrences of the Pearlette Volcanic Ash in the Red River basin east of Hardeman and Knox counties, and the impossibility of direct tracing of the Hardeman Alluvial Terrace through the region of the Cretaceous high in Cooke and Grayson counties, place unusual importance upon the occurrence of characteristic Kansan fossil molluscan assemblages in Delta County where exposures occur in the Sulphur River valley. The molluscan assemblage listed (fig. 2, locality 12) is remarkable for the variety of contained species, 33 in all, for the occurrence in this latitude of so many kinds of mollusks of essentially northern distribution, and for the general similarity of the assemblage to Kansan assemblages recovered in western parts of the Red River basin.

Although the assemblages differ slightly in detail, as might be expected in local populations of any kind of animal (and because most of the localities were "hand picked" because time did not permit bulk sampling), the strong similarity between the assemblage reported from Delta County and those, say, from Hardeman County and Greer County, Oklahoma, is especially noteworthy. Inasmuch as the latter two localities are stratigraphically controlled by the occurrence of the Pearlette Volcanic Ash (Frye, Swineford, and Leonard, 1948), we have not hesitated to correlate Kansan deposits in Delta County on the basis of fossil molluscan assemblages.

Two late Kansan fossiliferous localities deserve special mention. At Canyon, Randall County (fig. 2, locality 1), late Kansan sediments along the south valley wall of Palo Duro Creek were, in the course of road construction, well exposed in the summer of 1961. The sediments consist of fine gray sand and silt and contain a sparsely distributed but surprisingly varied fauna (fig. 2), including the branchiate gastropod *Valvata tricarinata.* The hardy pulmonates, *Lymnaea bidimoides* and *L. parva,* were the only other aquatic gastropods recovered. The terrestrial snails reflect generally the conditions found in a prairie or woodland border situation, such as might be found along a sparsely forested and brushy creek, and many of them, such as *Gastrocopta armifera, Hawaiia minuscula, Helicodiscus parallelus,* and *Pupoides albilabris,* are extremely hardy species that have survived the vicissitudes of the High Plains climatic cycles of thousands of years. Others, such as *Oxyloma retusa, Discus cronkhitei,* and *Strobilops lonsdalei lonsdalei,* indicate the presence in the locale of well-watered areas containing trees and shrubs; *Oxyloma retusa* probably inhabited the marshy borders of ponds that supported *Valvata tricarinata.*

The easternmost late Kansan faunal assemblage reported here is from exposures in the channel banks of the Sulphur River, near Ben Franklin, Delta County, although other, less impressive assemblages are known somewhat farther east in the same valley. The molluscan assemblage reported (fig. 2, locality 12) was hand picked from exposures made in the course of straightening the channel of the Sulphur River near a bridge on State Highway 38. The most highly fossiliferous sediments, consisting of fine gray sand and silt, occurred a few feet above low-water level of the Sulphur River and could not be observed during periods of high water.

The molluscan assemblage is remarkable for the presence of a group of essentially northern branchiate gastropods, including *Amnicola cincinnatiensis, A. limosa parva, Pomatiopsis lapidaria,* and *Valvata tricarinata.* To our knowledge, these species in Kansan deposits in the Sulphur River valley are the southeasternmost occurrence of these fossil gastropods yet reported. Aquatic pulmonate gastropods associated with them include *Physa gyrina, Gyraulus crista, G. labiata, Lymnaea palustris, L. parva, L. caperata, L. reflexa,* and *Planorbula vulcanata;* the sphaeriid pelecypods *Sphaerium striatinum* and *Pisidium compressum* form conspicuous elements of the aquatic aspect of the assemblage.

The terrestrial elements of the faunal assemblage also are of special interest. The presence of *Polygyra texasiana, Retinella indentata, Hendersonia occulta, Strobilops texasiana,* and especially *Triodopsis multilineata* indicate woodland or woodland border environments. All in all, the fossil molluscan assemblage reflects a temperate, mesophytic environment. However, a conspicuous member of the assemblage is *Bulimulus dealbatus ragsdalei,* which, according to Pilsbry (1946, p. 12), lives "hidden under the dead reversed leaves that thatch the trunks of yuccas" in southwestern Texas near the mouth of the Pecos River. At first glance it is difficult to understand how the apparent ecological requirements of *B. d. ragsdalei* could be met under the circumstances that seem to account for the remainder of the Kansan molluscan faunal assemblage in the Sulphur River Terrace. However, if one assumes that the Cretaceous uplands then, as now, were well drained, open terrain supporting only prairie vegetation, the presumed ecological requirements of *B. d. ragsdalei* could be approximately met.

In terms of paleoecology, the Delta County assemblages also are of unusual interest inasmuch as the faunal assemblages confirm that in Kansan time climatic conditions in northeastern Texas and in the western reaches of the Red River basin were more similar than the conditions existing in the two extremes of the basin today. At the present time, the headwaters of the Red River drainage are in a semi-arid region where the average annual rainfall does not exceed 16 inches, and where the vegetative cover is dominated by short grasses, rare trees being limited to a narrow band along stream courses. In contrast, northeastern Texas in the Red River basin has an average annual rainfall exceeding 40 inches, and the vegetative cover is predominantly mixed deciduous and/or coniferous forest.

The living molluscan faunas in the two regions also present strong contrasts. In the headwaters area of the Red River basin, the molluscan fauna is depauperate and consists largely of species possessing great tolerance to strong fluctuations in temperature and rainfall, such as *Hawaiia minuscula, Pupoides albilabris, Gastrocopta armifera,* and species of *Helisoma, Physa,* and *Succinea.* No species characteristic of woodlands are known to occur in this area, except a few hardy southern immigrants such *as Bulimulus alternatus* that often exist in sparse woodlands and on open prairie slopes.

The living molluscan fauna in northeastern Texas is, on the other hand, a numerous and varied one, bearing the usual characteristics of molluscan assemblages found in mesophytic forests of this latitude. Conspicuous elements include species of *Allogona, Anguispira, Stenotrema, Polygyra, Bulimulus, Helicina, Strobilops, Triodopsis, Vitrina,* and others.

GENERALITIES

No fossiliferous exposure assignable to a Nebraskan age are known to us in the Red River basin, except exposures in Palo Duro Canyon, Randall County, from which vertebrate fossils but no mollusks are known. Other deposits of Nebraskan age in the basin are strongly weathered, so that if mollusks once occurred there as fossils, they have long since disappeared.

No molluscan fossils are known from **Illinoian deposits in the Red River basin.** Although a terrace intermediate in position to the Hardeman Alluvial Terrace and the Ambrose Alluvial Terrace is well defined in many places along the valley of the Red River, and judged to be of Illinoian age, no suitable exposures from which to recover fossil mollusks are known to us.

Kansan fossil molluscan assemblages, recovered for the most part from the Hardeman Alluvial Terrace, are correlated in the western portion of the Red River basin on the basis of association with the Pearlette Volcanic Ash as well as by stratigraphic position, and in the eastern reaches of the Red River valley in Texas on the basis of the striking similarity and remarkable consistency in faunal composition compared with fossil molluscan assemblages at western localities. Therefore, east of Hardeman County, fossil molluscan assemblages have been used with confidence for stratigraphic control of the Hardeman Alluvial Terrace.

General consistency in faunal composition exists between eastern and western fossil molluscan assemblages from the Ambrose Alluvial Terrace, although geographical variation from west to east is relatively greater than in the case of Kansan assemblages of mollusks. Such variaation is of lesser significance in the correlation of the Ambrose Alluvial Terrace, because this feature generally is well preserved and can be traced and correlated from place to place with a high degree of confidence.

Climatic conditions and local ecological situations were more uniform throughout the Red River drainage in Texas during Kansan time than those that prevailed during early Wisconsinan time, and much more uniform than the prevailing conditions in the two extremes of the drainage today. Kansan time in the Red River basin, as in the midcontinent region, probably was characterized by a somewhat cooler and much more equable climate than prevails today in the region.

Widespread aridity, which seems to have characterized the Illinoian interval in Texas, is judged to have been largely responsible for the extirpation of many species common to Kansan fossil molluscan assemblages, which do not reappear in early Wisconsinan assemblages of fossil mollusks.

Like post-Bradyan molluscan faunal assemblages elsewhere, those occurring in the Red River basin generally are depauperate and characterized by species that are now living in that area. Conditions during and/or after the Bradyan interval resulted in widespread local extinction of many species of mollusks that thrived in early Wisconsinan time.

PHYSIOGRAPHY

The late Cenozoic history of the Red River basin of Texas is most clearly recorded in the morphology of the valleys and their contained terraces. Although determination of age and correlation with other regions rests heavily on the fossils and volcanic ash that occur in the alluvial deposits below the terrace surfaces, much of the local, mile by mile, correlation of the terraces has been based on the physical continuity of the land form itself, the physiographic succession of the terrace forms, and the character of the developed soil profiles that underlie the several surfaces.

The projected profile of the channel of the Red River and its headwaters, together with profiles of the channels of three major tributaries in Texas, the surface of each of the major terraces, and the High Plains surface, are shown on figure 3. In order that all profiles could be directly comparable they were constructed by projection to an arbitrary east-west line, thus eliminating differences in horizontal distances that otherwise would have resulted from the curvature of channels and changes in directional trends of the valleys. The channel gradient is somewhat shortened and steepened by this method, but as the terrace gradients can only be plotted along the general trend of their containing valley the result renders all profiles and intervals between profiles directly comparable at any point.

The profile shows that the headwaters of Red River in eastern New Mexico are at an elevation approaching 5,000 feet above sea level, and that the Red River channel is at an elevation of approximately 275 feet at the Arkansas State line; thus the Red River declines in elevation more than 4,500 feet from its head to Texarkana. In Texas, the channel of the major headwater tributary to the Red River is at an elevation of approximately 4,175 feet where it crosses the New Mexico State line, and the channel of the Sulphur River, a tributary that enters the Red River in Arkansas southeast of Texarkana, is at an elevation of approximately 195 feet at the Texas-Arkansas line.

The profile (fig. 3) of the Red River channel is not smooth. Its major interruption occurs in Armstrong and Randall counties, Texas, where the gradient steepens sharply as the stream flows through the Ogallala Formation and Triassic rocks into Permian rocks. This segment of the valley contains the headward-migrating nickpoint that has produced the striking incision displayed in Palo Duro Canyon. That earlier positions of this nickpoint occurred farther east is shown by the steepened segment of the profiles of three terraces and by the High Plains escarpment capped by Ogallala deposits.

East of this prominent nickpoint only minor irregularities appear in the profile, which otherwise would approach the curvature of a stream profile at "grade." While the irregularities in eastern Armstrong, Donley, and Hall counties are, at least in part, the result of the apparent differential linear compression caused by the technique of projecting the profile to an east-west line, east of this area the alignment of the valley is sufficiently uniform that such mechanical effects cannot account for other slight changes in gradient. The distinct, though slight, change in gradient in Cooke and Grayson counties is attributed to the bedrock geology because in that area the stream flows on resistant Cretaceous limestones after having traversed an extensive region of relatively nonresistant Permian rocks. The abnormal straightening of gradient in Hardeman arid Wilbarger counties, and again in Wichita and Clay counties, however, cannot be accounted for by changes in competency of the bedrock. These reaches lie immediately above the mouths of major entering tributaries and, although our

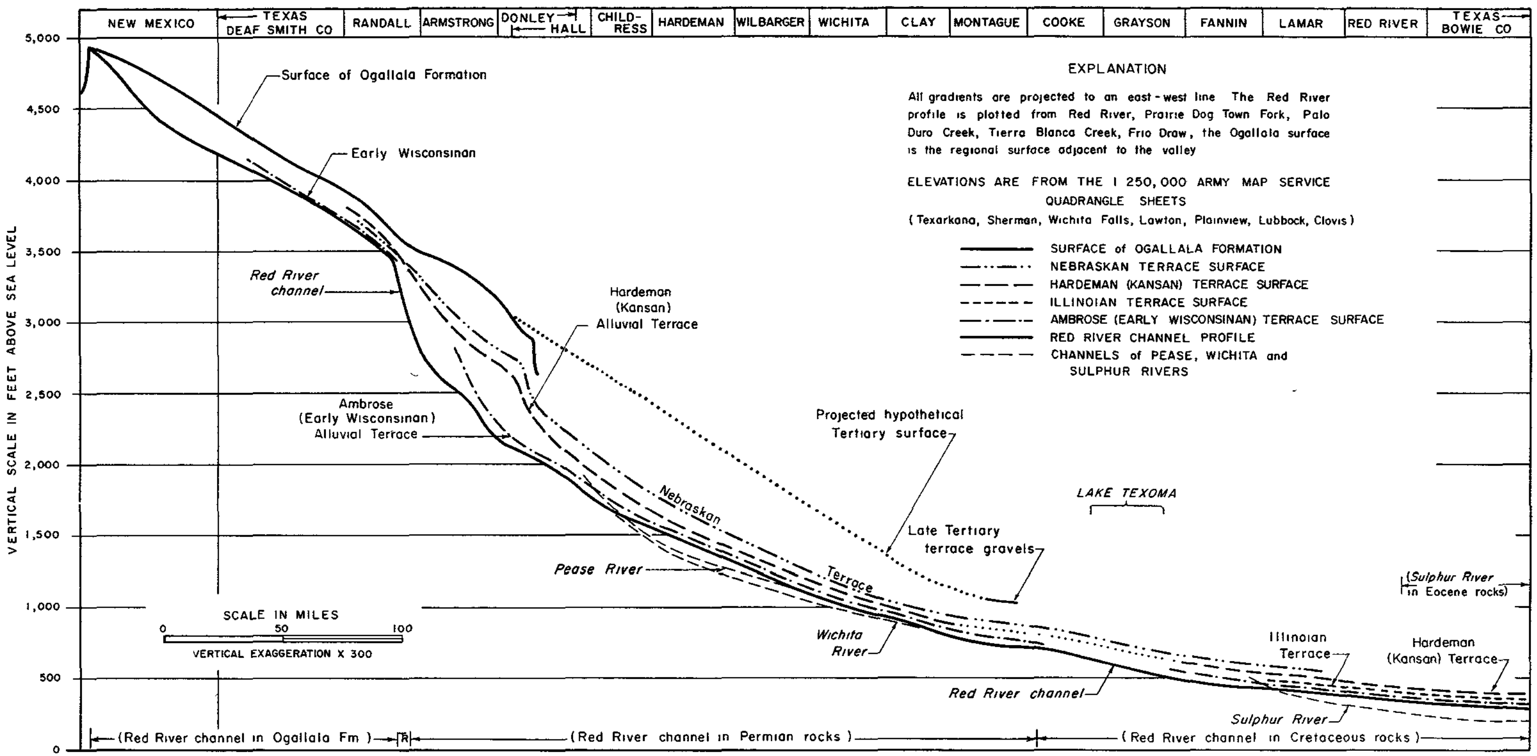

FIG. 3. Profiles of the Red River channel and major tributary streams in Texas, the major Pleistocene terraces, and the surface of the High Plains. In order to make comparisons possible among the several profiles they have all been projected to an east-west line.

work was not sufficiently detailed to demonstrate the point, we judge that these slightly anomalous segments are a result of the headward influence produced on the master stream by the sediment load introduced from the tributary streams.

The stream profiles of the Red River basin in Texas are most unusual in that major tributaries from the south have markedly more gentle gradients than does the Red River for considerable distances above their junctures with the master stream (fig. 3). At equal distances above their juncture, the channel of the Red River reaches a maximum of more than 100 feet above the elevation of the Pease River channel; the channel of the Wichita River at the same distance above its mouth is nearly 150 feet below the Red River channel (fig. 3). This is particularly surprising in view of the fact that the Kansan terrace surface is essentially accordant south from the Red River and caps the highest divide between the Brazos River and the Wichita-Red drainage (Stricklin, 1961). The younger Pleistocene terraces of the Wichita, however, conform more closely to the gradient of that stream, suggesting that the present discrepancy in gradients has developed progressively since the deposition of the Kansan alluvial sediments.

In contrast to this relation of the southern tributaries to the Red River in western Texas are the relations of the valley of the Sulphur River in northeastern Texas. Although due south from the Red River, in Red River County the Sulphur River channel is 100 feet lower than the Red River channel, the Kansan terrace surface in the Sulphur River valley is 175 feet lower than the Kansan terrace surface in the Red River valley. In the Sulphur River valley the Kansan deposits are scarcely 30 feet above the channel, while the Kansan terrace along the master stream due north stands 110 feet above the channel. This indicates clearly that downcutting by the Sulphur River took place before late Kansan deposition and that the valley has had little incision since.

We consider the striking difference in the Pleistocene history of these two groups of tributary valleys to be the result of differing response to the cyclic climatic changes of the Pleistocene (Frye and Leonard, 1957) on two significantly different bedrock terrains. The master stream, heading as it does in an extensive region of medium to coarse clastics of the Ogallala Formation, has been continuously supplied with an abundant source of durable particles for transport; the Wichita and Pease Rivers head near the High Plains scarp and flow eastward across fine-textured Triassic and Permian rocks and therefore have a lesser supply of these coarse to medium clastic particles. The Sulphur River heads on the southeastward dip-slopes of Cretaceous limestones and flows eastward through a region underlain by shales and siltstones of Eocene age and therefore largely lacks an abundant source of medium to coarse clastic materials. This physical setting allowed the Sulphur River during the early Pleistocene periods of higher rainfall (Frye and Leonard, 1957) to incise its valley more rapidly than could the Red River, or even the Wichita and Pease Rivers, and thus the Sulphur developed a gradient of lesser declivity.

The High Plains surface.—The High Plains surface of western Texas and eastern New Mexico furnishes the basis for definition of the level of the western part of the Red River basin in late Tertiary time. During the Neogene, streams flowing eastward and southeastward across this region alluviated their valleys and the deposits progressively overlapped the valley sides until most divide areas were buried and a coalescent plain of alluviation resulted (Frye and Leonard, 1959). At the beginning of Pleistocene time, an ancestral Red River flowed across this plain and began its history of cyclic cut and fill. East of the eastern escarpment of the High Plains in a belt several counties wide the position of the late Tertiary surface cannot be determined because existing bedrock divides have been eroded well below the projected level of the High Plains surface (fig. 3). In parts of this area, in fact, the bedrock divides fail to reach the level of the Nebraskan terrace (Pl. III, B). In Montague County, at several places west of the town of Montague, remnants of terrace gravels, resembling the lenticular channel gravels of the Ogallala Formation, have been observed that define the level of late Tertiary channels. Even though these late Tertiary gravels in Montague County are at an elevation 300 feet higher than the Red River channel due north and 150 feet higher than the comparable Nebraskan terrace in the region, they are distinctly lower than adjacent Cretaceous bedrock divides. This relationship suggests that the Neogene Ogallala sediments ceased to be a blanket deposit a relatively short distance east of the High Plains but continued an unknown distance eastward as channel fillings. Pleistocene dissection has left these deposits as isolated patches high in the local topography.

Within the High Plains the position of the earliest Pleistocene Red River channel probably was consequent to the depositional irregularities of the Neogene alluvial surface. The sharply accelerated rainfall of the early Pleistocene produced a rapid rate of erosion of the relatively incompetent Triassic and Permian rocks underlying the Ogallala and, we judge, proceeded more rapidly in the divide areas that were unprotected by late Tertiary coarse alluvium. Such circumstances must have rapidly produced an eastern escarpment to the higher surface that was protected by the extensive alluvial blanket. It is possible that the present High Plains scarp is not far west of the belt where the relatively weak Triassic and Permian rocks existed as broad interstream divides in late Tertiary time. It can be demonstrated (Frye and Le6nard, 1957a) that the present position of the High Plains escarpment in the interfluve areas is not significantly west of its location in Kansan time, but the westward (headward) migration of the nickpoint along the major stream channel, shown in figure 3, is marked.

Post-Tertiary erosion of the High Plains can be clearly determined by examination of the detailed stratigraphy of the Ogallala Formation (Frye and Leonard, 1959). For example, in western Donley County the prominent sag of the surface that connects with Mulberry Canyon can be demonstrated to be an erosional feature because in the lower part of this sag the Ogallala has been removed well into the Ash Hollow floral zone. Also, the bench on the edge of the High Plains in southern Donley County, reflected in the profile in figure 3, is known to be due to post-Ogallala erosion as it is floored by deposits of the mid-Ash Hollow floral zone, indicating the erosional removal of at least 100 feet of Ogallala sediments.

In the High Plains part of the basin the thickness of the Ogallala has a wide range not only along the scarp at the eastern edge (Frye and Leonard, 1959) but also east-west across the plateau. The headwaters of the Red River have cut through the Ogallala and into Triassic rocks near Buffalo Lake in the region near the Texas-New Mexico line. It may be that the incision into the less resistant Triassic rocks accounts for the somewhat anomalous profile of Frio Draw in this area (fig. 3).

Uplands east of High Plains.—The topography of the uplands east of Hall County contrasts strongly with that of the High Plains surface. From Hall County to western Montague County, more than 150 miles, the highest upland divide areas have been eroded to a level well below the projected late Tertiary surface (fig. 3). In much of this region the upland divides consist of gently sloping eroded bedrock surfaces with only local buttes that rise above the Nebraskan terrace level (Pl. III, B). In fact, in Knox and Baylor counties the uppermost surface of the divide between the Red River drainage (Wichita River) and the Brazos River drainage is at the level of the alluviated Kansan surface (Stricklin, 1961). The Kansan level also forms the crest of the divides between the North and South Wichita Rivers and between the North Wichita and Pease Rivers, with remnants of the Nebraskan terrace surface occurring only north of the Pease River in Hardeman County.

The character of the upland surfaces is sharply altered in southeastern Montague, Cooke, and Grayson counties where the belt of resistant Cretaceous limestones swings in a wide arc from a general northerly trend to an easterly trend, roughly paralleling the south side of the Red River. The prominent upland produced by these limestones as a gently eastward- and southward-dipping cuesta stands several hundred feet above the level of the Nebraskan terrace, and we have not found remnants of late Tertiary deposits in these uplands east of Montague County. The bedrock control on present drainage in this area is so complete that at one point a tributary to Trinity River heads approximately 1 mile from the Red River channel —although at an elevation several hundred feet higher.

East of this prominent scarp and cuesta slope the configuration of the upland divide areas becomes somewhat similar to that farther west. Above the Kansan terrace the erosional slopes are generally well graded and of gentle declivity. Remnants of Nebraskan gravels have been found at a few places at an appropriate elevation, but well-defined terrace surfaces of Nebraskan age have not been observed. In extreme northeastern Texas, where the uplands are in part developed on Eocene rocks, the erosional slopes are quite subdued and it is judged that the highest divides are below the Nebraskan level.

Pimple mounds and sand dunes.—Two special types of land forms are locally prominent in the Red River basin of Texas. For more than 100 miles west of the Texas-Arkansas State line "pimple mounds" occur in sporadic clusters on the surfaces of Illinoian and older terraces and on bedrock erosional surfaces (Pl. III, A and E), and in the stretch of more than 150 miles from Clay County to Hall County sand dunes are locally conspicuous features from the channel bank up to and including the Kansan terrace surface (Pl. III, F).

Pimple mounds of a similar type have been described in detail by Murray (1948) from their occurrence in DeSoto Parish, Louisiana, adjacent to northeastern Texas, and by Holland, Hough, and Murray (1952) from Beauregard and Allen Parishes, Louisiana. Murray (1948, p. 41) slates: ". . . more or less circular hillocks of earth, exist indiscriminately on Quaternary and Tertiary deposits alike in DeSoto and Red River Parishes." He states that the "mature mounds" generally are less than 75 feet across and average from 40 to 50 feet in diameter, but that "immature mounds" consisting of partly connected hillocks have been observed that have diameters as great as 300 feet. The material of the mounds is described as friable and contrasting with the higher clay content of the intermound material. Murray did not give a range of height for the nearby Louisiana mounds, but the features we have studied in northeastern Texas rarely exceed 5 feet from the level of the intermound surface to the crest of the mound, and commonly their height ranges from 3 to 4 feet.

In northeastern Texas the features here classed as pimple mounds have not been observed on Wisconsinan age terraces or on the surface of the flood plain complex, although at a few places some small hummocky sand dunes that superficially resemble the mounds have been noted on these younger surfaces. The mounds occur predominantly on terrace surfaces of Illinoian and older age and on relatively flat bedrock surfaces at or above the level of these terraces, but in a few places mound clusters have been observed on relatively gentle slopes. They range from 30 to 90 feet in diameter and are circular to elliptical in ground plan. The distribution of the mounds is irregular and in some places they have a maximum density of distribution that occupies from a quarter to a third of the area (e.g., 1 mile west of Slate Shoals, Lamar County).

Pimple mounds were extensively observed in this region but we were able to give them special study only in a few areas. One such area was approximately 5 miles south of Hagansport in Franklin County where the mounds are on relatively flat upland surfaces underlain by Eocene sediments. Here the mounds are relatively abundant (Pl. III, A) and several of them have been cut through by recent excavation (Pl. III, E). We also studied mounds in some detail west of Novice in Lamar County where they are developed on terrace deposits and Cretaceous rocks. In that area road cuts expose not only the materials under the mounds but also the deposits under the intermound areas. Observations of exposures in these two areas, and less detailed studies at other places in the region, show that a well-developed podzolic soil profile extends under both the intermound areas and the mounds themselves and that the B-horizon of the soil is not distorted under the mound. In other words, the entire height of the material that gives the mound its surface form is indistinguishable from, and is physically continuous with, the A-horizon of the soil under the intermound areas. One fresh road cut half a mile west of Novice gives a continuous exposure downward into the B-horizon from the intermound area, through a mound, and into the intermound area on the other side. Although the cut does not go through the crest of the mound it transects it about two-thirds of the distance from the edge to the crest and displays the relations quite clearly. On one side of the mound the A-horizon material (ash-gray fine sand and silt) is 7 to 8 inches thick; at the highest point on the mound cut by the excavation, the A-horizon material is slightly more than 3 feet thick; and on the other side of the mound the thickness diminishes to 10 to 12 inches. The B-horizon continues under the mound for the entire distance, essentially horizontal and with no observable change in character. By hand digging we established that the same relations obtained in several other mounds. Furthermore, we observed that mounds of this general configuration were common in the regions that display well-developed podzolic soils but did not occur on the youngest alluviated surfaces. The rare, hummocky, low sand dunes on the young terrace surfaces of this area are composed of tan sand, are generally asymmetrical in cross section, are more irregular in ground plan, and lack the underlying floor of B-horizon.

The observations of the pimple mounds reported here from northeastern Texas lead us to disagree with the theory of origin favored by Murray (1948, p. 45) for the mounds of northwestern Louisiana, namely, an origin by fluvial erosion. We propose the hypothesis that the pimple mounds originated after a period of unusual desiccation as a result of wind scour and deposition around clumps of vegetation on a surface that had been well covered by vegetation and on which a mature podzolic soil had developed. The fact that the B-horizon of the soil is essentially unmodified under the mounds and therefore had attained essentially its present morphology before they were formed, and the fact that the character of the mounds on surfaces of the several ages is similar, indicate that they formed well after Illinoian time. Furthermore, if the few low hummocky sand dunes on the Ambrose Terrace (early Wisconsinan) surface are judged to have formed at the same time as the mounds, their development must have been quite recent. As a sharp climatic change toward aridity in the Great Plains to the west of this area has been described as occurring at the Bradyan interval (Two-creekan) and a similar climatic change of world-wide importance has been inferred from evidence in deep sea cores (Broecker, Ewing, and Heezen, 1960), we judge that the mounds were developed during the latest part of the Wisconsinan Stage in a region that had been heavily forested and that has again returned to partial forest cover. Their relation to the existing cover of vegetation and the presence of an organic accumulation at the top of the A-horizon indicate that the mounds are not now in the process of active development.

West of the region of abundant pimple mounds there is an area, from Fannin to Clay counties, where a few scattered sand dunes occur on low terrace surfaces, but neither mounds nor dunes are distinctive elements of the topography. Farther west, particularly in Wilbarger, Hardeman, Childress, and Hall counties, sand dunes are quite common adjacent to the channel bank, on the low terrace surfaces, and on the higher terraces adjacent to their lip. Dunes occur on both the Texas and Oklahoma sides of the river, but generally where extensive dune tracts occur on one side of the river the other is free of extensive dunes, and the location of the dunes is, at least in part, related to the local alignment of the channel. Essentially continuous dune fields extend through belts several miles wide in part of this region but a more common pattern is a belt of dunes half a mile or less wide along the channelward margin of a terrace surface (Pl. III, F). Dune crests ranging from 10 to 25 feet above their base are common, and maximum heights exceed 40 feet. As these sand dunes generally occur on the surfaces of Pleistocene terraces and on the flood plain complex they add greatly to the difficulty of correlating the several surfaces through the region where they are extensive.

Pleistocene terraces.—The sediments underlying the Pleistocene terraces, the soils developed in the surfaces, and the fossil mollusks they have yielded have been described—it remains to describe the physiographic expression of the terraces as land forms. The east-west slope and the spacing of the major terraces are shown on figure 3; the character of the several surfaces are shown on Plate I, A, B, C, D; Plate II, C, D; and Plate III, F, G, and H; and a table showing the general height of the several terraces above Red River channel from Texarkana into the High Plains is given below.

The surfaces here called the flood plain complex are underlain by sediments of Recent age. In northeastern Texas it is possible to recognize three distinctive levels within this complex, even though they are all subject to more or less overbank erosion and deposition and adjacent to the channel are experiencing active lateral cut and fill. The highest levels do not exceed 10 feet above channel bars, except where dune tracts occur on the sur-

Approximate Height in Feet of Terrace Surfaces Above Red River Channel

County	Cooke Terrace (late Wisconsinan)	Ambrose Terrace (early Wisconsinan)	Intermediate Terrace (Illinoian)	Hardeman Terrace (Kansan)	Nebraskan	Tertiary
Bowie	17	30	65	105		
Lamar	17	30	65	110	165	
Fannin	20	45	70	115		
Grayson		45	70		160	
Cooke				110	160	
Montague					150	300
Clay	18	30		90	130	
Wichita	18	30		90	125	
Wilbarger		32		100		
Hardeman		35		100	210	
Hall and Donley		50 to 400		170 to 500	315 to 600	850
Armstrong		175		375	525	875
Randall	5	20		90	75	200

faces. In north-central Texas the three levels are indistinguishable and together form the active flood plain. On the High Plains above the major nickpoint in the channel these surfaces exist only as slip-off slopes, channel bars, or incipient point-bars, and the late Wisconsinan terrace becomes subject to flooding.

The late Wisconsinan Cooke Terrace (Pl. I, C) is a well-defined alluvial surface in the eastern two-thirds of the Red River valley of Texas and in the western one-third becomes merged with the active flood plain. Its physiographic expression, fossils, immature surface soils, and contained Indian hearths (measured section 2) all confirm its late Wisconsinan (post-Bradyan or post-Twocreekan) age. East of the High Plains its surface ranges from 12 to 20 feet above normal channel level, but west of the escarpment it is much lower. The surface of this terrace exhibits preserved channel scars and other evidence of the eroding and depositing channel that formed it. Although this level is present almost throughout the entire course of the river in Texas, at many places it is present only on one side of the channel where the stream is cutting against the deposits of a higher terrace or bedrock.

Along the Pease and Wichita Rivers the continuity of the Cooke Alluvial Terrace (late Wisconsinan) is similar to that along the Red. However, in the Sulphur River valley in Texas there is no recognizable terrace of this age. Here the post-Bradyan deposits merely form a thin veneer (measured sections 5 and 6) on the surface of the single Sulphur River Terrace of the valley. Graded valley side slopes are continuous with the surface of this terrace and the present channel of the Sulphur River is incised 20 to 30 feet below it. For this reason it could be contended that this major terrace should be considered as the late Wisconsinan terrace. However, we judge that the thin veneer of these sediments that appear to have resulted from overbank deposition did not materially modify a pre-existing terrace. In the Sulphur River valley this one terrace had its major development during late Kansan time, was modified somewhat during early Wisconsinan time, and alluviated a few feet during late Wisconsinan time.

The early Wisconsinan Ambrose Alluvial Terrace is the most distinctive and continuous land form of the Red River basin of Texas. It can be clearly recognized (Pl. III, H) in the major valley and all important tributaries (with the exception of the Sulphur River, as noted above) from the Arkansas State line into the High Plains and nearly to the New Mexico State line. Its range in height above channel level, as shown by the preceding table, is from less than 20 feet to 400 feet, but only in the area of nickpoint recession through Palo Duro Canyon (Pl. III, G) does it attain a height of more than 50 feet above the channel; in much of northeastern and north-central Texas its range is from 30 to 40 feet.

The surface of the Ambrose Terrace generally is almost featureless, with channel scars subdued or not recognizable (Pl. I, D). In some places the present channel is flanked by belts of this terrace on both sides, whereas in other areas the present channel is against bedrock that underlies higher terraces and the Ambrose is restricted to one side or the other of the valley.

A unique expression of the Ambrose Terrace occurs in northern Clay County where the terrace surface forms the floor of an abandoned segment of the Red River channel, now separated from the present channel to the north by a hill of Permian bedrock. This feature, called the "Charlie Channel," is located above the mouth of Wichita River and is separated from the Wichita River valley to the south by a spur several miles long, capped by Hardeman Alluvial Terrace (Kansan) deposits. It is apparent that when the Red and Wichita rivers were flowing on the alluvial fill that now composes the Ambrose Terrace their confluence was several miles farther upstream than it now is, and that the Red River channel was diverted to the north, past the bedrock hill, on the surface of this alluvial fill. With the limited time we had available in the field it was impossible to determine with certainty the mechanism of this diversion, but as extensive sand dunes now occur across the upstream end of the "Charlie Channel" it is reasonable to postulate that excessive alluviation in this area caused diversion through a col in the position of the present channel. The relation of the Hardeman Terrace (Kansan) to the valleys suggests that the confluence of the two rivers when they flowed at that level was still farther west and that there has been a progressive eastward (downstream) shifting of this confluence since Kansan time.

The intermediate terrace (Illinoian) has distinctive form only in the eastern half of the basin in Texas (Pl. I, C, and fig. 3) where it occupies a position intermediate in height to the Ambrose and Hardeman Terraces, as shown by the preceding table. It is less extensive even in this area than the major terraces above or below it. Its surface does not display the degree of smoothness of the younger terrace, and it does not have the depth or extent of dissection of the Hardeman. In some places it is difficult to distinguish it with certainty from the younger and older terraces. In western Texas the Illinoian generally does not form a distinctive terrace; rather, alluvial deposits of this age are found incised into Kansan deposits or partly overlapping them (Frye and Leonard, 1957a). Although Illinoian deposits were identified in the canyon of Tule Creek, a tributary dissecting the east scarp of the High Plains, they were not identified with certainty in Palo Duro Canyon along the main stem or upstream from it. In the region between the High Plains and Cooke County, small segments of the intermediate alluvial terrace (Illinoian) were recognized at a few places, but it was not possible to establish their continuity through this region.

The Hardeman Terrace (Kansan) is the most extensive of the Pleistocene terraces of the Red River basin in Texas and can be traced with essential continuity from the High Plains to the Arkansas State line. It is well developed along the main valley of the Red River and almost equally so in the major tributary valleys (Pl. II, D). East from Childress County, it ranges from 90 to 120 feet in height above the adjacent Red River channel (fig. 3) and maintains a similar position for considerable distances along the Pease and Wichita valleys, but farther up those valleys it becomes somewhat higher above the tributary channels and locally caps major interstream divides. Although in some areas the Kansan surface has been cut into sharply dissected hills, in much of the region the surface is preserved as a nearly featureless plain terminated by a sharply defined scarp. The heel of the terrace is commonly at a gentle angle to the valley side slope because of deposition of slope wash; at some places minor low fans occur below the mouths of minor gullies. In north-central Texas the shape of the terrace surface is locally modified by sand dunes, particularly along the channelward lip.

In the area of greatly steepened stream gradient through the canyons of Donley, Briscoe, and Armstrong counties, the alluvial deposits of Hardeman Terrace have been extensively removed by erosion and were observed only as remnant shoulders along the margins of the canyons (e.g., southwest of Clarendon in Mulberry Canyon and along Farm Road 284 on the north side of Palo Duro Canyon). Remnants of Kansan deposits also occur in the valleys of some minor tributaries, as illustrated by the fossiliferous deposits at the east edge of Hall County along Farm Road 256. These local Kansan terraces of the minor tributary valleys are, of course, at a higher elevation than the Hardeman Terrace of the adjacent major valley because of their short and relatively steep gradients. Deposits of Kansan age are well developed in the tributary valley of Tule Canyon (Frye and Leonard, 1957a), but above Palo

Duro Canyon on the High Plains they have been studied in adequate exposures only at the north edge of the city of Canyon in Randall County. In striking contrast to the terrace sequence east of Palo Duro Canyon, here the Tule Formation of Kansan age unconformably overlies the Blanco Formation of Nebraskan age. On the High Plains the Kansan deposits underlie the highest terrace of the valley (fig. 3). In extreme western Texas it has been impossible to identify a distinctive terrace surface of either Kansan or Nebraskan age (Frye and Leonard, 1957a).

In the re-entrant canyons into the High Plains and eastward across Texas the highest Pleistocene terrace is the Nebraskan. At a few places (e.g., Montague County) Tertiary deposits occur in a terrace position much higher than the Nebraskan, but east of the Ogallala Formation escarpment such occurrences are so rare that no continuity can be established for a possible Tertiary terrace. In fact, the Nebraskan terrace also occurs in discontinuous patches, in strong contrast to the very extensive, next lower (note intersecting gradients, fig. 3) Hardeman Terrace (Kansan). There are few areas where the Nebraskan terrace surface is preserved as an undissected upland plain. The Nebraskan deposits more typically occur as flat-topped hills and spurs with accordant summits, well demonstrated by the areas in Hall County 5 miles south-southwest of Memphis (Pl. III, C) and 2 miles north of Turkey. In the re-entrant canyons a few small shoulders of Nebraskan Blanco Formation, adequate to define the position of the terrace, have been examined (e.g., southwest of Clarendon in Donley County and along the Palo Duro Park road in Randall County).

To the east, we determined the position of the Nebraskan terrace by relating small discontinuous remnants of similar alluvial deposits to the clearly traceable lower level of the Hardeman (Kansan) Terrace surface that served as a reference. As a result, we are less certain of the identification of the Nebraskan terrace and the establishment of its gradient than we are of the identification and gradient of the Kansan and younger terraces in the basin.

In the Sulphur River valley, we were unable to recognize a definable position for the Nebraskan terrace, and therefore we have projected the position of the Nebraskan terrace in the divide area south of the Red River as a plane of reference for the Sulphur River basin.

A few examples will illustrate the type of field data used for the determination of the position of the Nebraskan terrace surface in the area east of Hall County. Along U. S. Highway 283, in Hardeman County north of the Pease River valley, pebbly, sandy silt occurs as thin upland deposits. These deposits, which veneer an extensive upland flat, are less than 50 feet below the crests of Permian bedrock divides that are capped by brecciated and recemented caliche, or pisolitic limestone (Swineford, Leonard and Frye, 1958), typical of the weathering effects on the late Tertiary surface. Furthermore, the Nebraskan veneers are nearly 200 feet above the Hardeman Terrace (Kansan) surface in the Pease River valley to the south. At the east edge of Sherman Air Force Base, north of Wichita Falls, Wichita County, a distinct area of upland surface is underlain by sand and gravel deposits exposed in small pits; the surface is 30 to 40 feet above the well-dated adjacent Hardeman (Kansan) Terrace surface and is interpreted as a remnant of the Nebraskan terrace. Along Fish Creek valley in north-central Cooke County on the upland, but below the highest bedrock level, gravels are exposed in abandoned pits. As the elevation corresponds to the projected elevation of the Nebraskan terrace, the lithology of the gravels is similar to other Nebraskan gravels, and the Hardeman (Kansan) Terrace is at an elevation 50 feet lower, this surface is judged to be Nebraskan.

East of Grayson County, we found no well-preserved areas of the upper surface of the Nebraskan alluvial terrace, but as far east as Lamar County we saw discontinuous patches of eroded Nebraskan gravels. In some places these gravels veneer the highest elements of the local topography, but at others they are somewhat lower than the adjacent bedrock divides. Although the position of the Nebraskan terrace shown in figure 3 and the table of terrace heights is based on this type of data from northeastern Texas, it is reasonable to assume that the original upper surface of the Nebraskan terrace deposits was slightly higher than is indicated.

In the Red River basin of Texas three alluvial surfaces can be identified and traced throughout all but the extreme western part: (1) the flood plain complex that includes the present channel; (2) the Ambrose (early Wisconsinan) Terrace, identified not only by the continuity of land form but also by the character of surface soils and approximately 50 localities from which fossil snails have been identified; and (3) the Hardeman (Kansan) Terrace, likewise identified by tracing, physiographic position, character of surface soils, a dozen localities that have yielded fossil snails, and in the region of west Texas by its deposits of Pearlette Volcanic Ash. The other terraces are identified primarily by stratigraphic (or physiographic) framing, the Nebraskan between the known Neogene Ogallala Formation and the Hardeman (Kansan) Terrace, the intermediate between Hardeman and Ambrose, and the Cooke Terrace framed by the Ambrose and the flood plain complex and confirmed by contained fossil snail faunas, Indian hearts, and the character of the surface soil.

CONCLUSIONS

The Red River basin stands in a unique position with regard to regional studies of late Cenozoic drainage history in interior North America. It is the only major western tributary to the Mississippi River that, at least in its headwaters region, has not been directly influenced by either mountain or continental glaciers. The Arkansas Valley to the north served, at least during the Kansan, as an eastward outlet for meltwaters and outwash from a part of the continental ice sheet (Frye and Leonard, 1952), but present data are insufficient to demonstrate that drainage from these continental glaciers crossed Oklahoma to enter the Red River drainage. The Red River basin of northern Texas thus serves as a connecting link between the nonglacial Neogene and Pleistocene deposits of the southern High Plains and the deposits of similar age in Louisiana that have been extensively described in recent years. However, as has been pointed out, the segment of the valley in Arkansas lies between the area described here and the described areas of Louisiana.

After the withdrawal of the early Tertiary seas from northeastern Texas there is no record of sedimentation in the Red River basin until Neogene time. During the late Tertiary there was extensive deposition by streams in western Texas (Frye and Leonard, 1959), and the meager record reported here indicates that stream deposits accumulated in a high-level ancestral Red River valley through much of the distance eastward across Texas.

During the Pleistocene repeated episodes of valley deepening were followed by relatively minor valley alluviation. The fact that the deepening was more profound than the subsequent alluviation is attested by the fact that (with the exception of the Illinoian) the alluvial fills did not reach the height of the bedrock floor of the preceding cycle. This was not true of alluvial terraces in major valleys farther north and east that were subjected to influences from continental and mountain glaciers.

The several Pleistocene terraces and their alluvial deposits have been referred to a particular cycle of glaciation in each case but have not been restricted within the relatively long time span of a glacial episode. This presents an apparent conflict with the prevalent terminology in Louisiana where the alluvial deposits under the several terrace surfaces are referred to interglacial ages (Fisk, 1938; 1939; 1944; Murray, 1948). It is our opinion that this conflict is one of terminology rather than one of interpretation. With the relatively precise time datum of the Pearlette Volcanic Ash (Frye, Swineford, and Leonard, 1948; Frye, 1961) used as a basis, it has been demonstrated that the alluvial terraces were deposited during the late part of each cycle while the glacier fronts were retreating. As in Louisiana, the alluvial terraces are interpreted as being deposited during the time of sea level rise after the maximum of the glacial episode; the two concepts presumably are in reasonably close agreement, even though the Louisiana terraces are referred to as an interglacial interval. In the Red River valley the available data indicate that valley deepening took place during the early and middle parts of a glacial cycle, that deposition of the alluvial terrace sediments took place during the retreating phase of the glacial cycle, with possibly some fine-textured materials accumulating during the early part of the interglacial interval, and that the interglacial intervals were, in general, times of erosional-depositional equilibrium that allowed the extensive development of surface soils.

The relation in time of the alluvial terraces of north Texas to the glacial cycles of northern North America appears to be the same as that of the alluvial terraces that can be traced into a glacial source (Frye, 1961). This is clear evidence that the climatic cycles that produced the terraces in

Texas coincided with the cycles of continental glaciation, that the early and middle parts of the cycle were characterized by significantly increased rainfall, and that the late (glacial retreat and rising sea level) part of the cycle was marked by sharply reduced rainfall. The periods of valley cutting in the Red River basin were (1) Tertiary, (2) early Nebraskan, (3) early Kansan, (4) early Illinoian, (5) early Wisconsinan (probably early Altonian), (6) Twocreekan and early Valderan, and (7) very minor trenching during Recent time. Episodes of valley alluviation were during (1) Neogene, (2) late Nebraskan and earliest Aftonian, (3) late Kansan and earliest Yarmouthian, (4) late Illinoian and perhaps earliest Sangamonian, (5) the Woodfordian Substage of the Wisconsinan, (6) the late part of the Valderan Substage of the Wisconsinan, and (7) minor alluviation during the Recent.

This described sequence of cut-and-fill obtains throughout the Red River basin except in the major tributary valleys in northeastern Texas, primarily the Sulphur River basin. In the latter basin we found no record of late Tertiary alluviation and the record of Nebraskan alluvial deposition is indeed meager. The typical cyclic cut-and-fill from Nebraskan through Kansan time is well displayed, however, and it is the post-Kansan history that is anomalous with respect to the rest of the basin. In the Sulphur River basin the Illinoian cycle is not recorded and erosion during the early Wisconsinan barely cut through the Kansan deposits into bedrock. On the other hand, deposition during the Wisconsinan completely filled these excavated valleys and overlapped the earlier Kansan deposits, leaving the present valley with but one prominent terrace surface. The Sulphur River heads on the east-southeast dip-slopes of Cretaceous rocks in northeastern Texas, and the drainage pattern suggests that some of its headwaters may have been pirated by Bois d'Arc and Choctaw Creeks during early Pleistocene time. The climatic implication of the alluvial sequence is that after Kansan time the precipitation of this local basin was sharply diminished.

The surface soils of the several ages of surfaces in the Red River basin form a graded sequence from young to old and from west to east. As, in general, each succeding episode of alluviation failed to reach the level of the preceding deposits and as there is no regional cover of loess, the soils appear now as surface soils rather than being buried in a sequence of sediments, as is common in the northern midwest. From youngest to oldest, the profiles range from azonal soils, consisting of little more than an inch or two of organic staining on the youngest surfaces, to profiles 5 to 6 feet thick with strongly developed B-horizons more than 2 feet thick. From west to east, the range is from soils with caliche zones several feet thick in the west to strongly developed podzolic soils in the east, and the contrast from west to east increases with the increasing age of the soil.

In summary, the Red River basin of Texas records the climatic history of the Pleistocene in the series of descending alluvial terraces, their contained faunas, and the soils developed in their upper surfaces. Correlation of these terraces has been made from western Texas to the Arkansas State line, but firm correlation with the several described terraces in Louisiana has not been attempted. It seems clear that such correlations down the Red River to the Mississippi Valley could be accomplished by appropriate investigations in the intervening area, and, in fact, certain possible correlations suggest themselves when terrace heights given here are compared with those given by Murray (1948) for western Louisiana. As the terraces of the Red River valley are climatically controlled without the direct influence of glaciation, it is interesting to speculate whether similar terrace sequences may occur in the valleys of the Trinity and other rivers that take an independent course across Texas directly to the Gulf.

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APPENDIX

LOCALITIES

LATE KANSAN ASSEMBLAGES

Locality 1. Kansas terrace sediments in south valley wall of Palo Duro Creek, exposed in road cuts at the interchange of U. S. Highways 60 and 87. and north of the Santa Fe railroad underpass, north side of Canyon, Randall County, Texas.

Locality 2. Dissected fill in small upland basin, on Whiteford Ranch, approximately 16 miles south and 10 miles east of Claude, Armstrong County, Texas.

Locality 3. Exposures in south valley wall of Salt Fork of Red River, approximately 17 miles northeast of Clarendon, Donley County, Texas.

Locality 4. Exposures in south valley wall of the Pease River, 2.3 miles south of bridge on U. S. Highway 70, Motley County, Texas.

Locality 5. Kansan sediments below Illinoian "cover sands" exposed in railroad cut, 1 mile north-northeast of Turkey, Hall County, Texas.

Locality 6. Exposures in cut along Santa Fe railroad, 100 yards west of crossing of State Highway 283, and 0.8 mile south of Brazos River channel, Knox County, Texas.

Locality 7. Terrace sediments in right bank of the Pease River, three-quarters of a mile south-southwest of Rayland, Foard County, Texas.

Locality 8. Terrace sediments along south side of Groesbeck Creek, 5½ miles north and 4 miles west of Quanah, Hardeman County, Texas. Fossils associated with beds of diatomite and Pearlette Volcanic Ash.

Locality 9. Terrace sediments exposed in right bank of the North Fork of the Red River, 2 miles east of Granite, Greer County, Oklahoma.

Locality 10. Hardeman Terrace deposits, 2.7 miles east-northeast of the junction of Farm Road 91 and U, S. Highway 283, north of Vernon, Wilbarger County, Texas.

Locality 11. Hardeman Terrace deposits, 5.5 miles west-northwest of Byers, Clay County, Texas.

Locality 12. Deposits near base of the Sulphur River Terrace, at border of the Sulphur River channel, 0.5 mile north of Ben Franklin, Delta County, Texas.

EARLY WISCONSINAN ASSEMBLAGES

Locality 13. Early Wisconsinan terrace deposits, 0.5 mile south of bridge on Farm Road 2162 on Mulberry Creek, 16.5 miles southwest of Clarendon, Donley County, Texas.

Locality 14. Exposure along ranch road, 1 mile northeast of the junction of Farm Road 268 and U. S. Highway 287 at Childress, Childress County, Texas.

Locality 15. Ambrose (early Wisconsinan) Terrace deposits along the Pease River, approximately 12 miles southwest of Vernon, Wilbarger County, Texas.

Locality 16. Ambrose (early Wisconsinan) Terrace deposits, 4 miles north of Archer, on the Little Wichita River, Archer County, Texas.

Locality 17. Ambrose (early Wisconsinan) Terrace deposits along the Red River, 0.5 mile southwest of the crossing of U. S. Highways 277 and 281 northeast of Burkburnett, Wichita County, Texas.

Locality 18. Ambrose (early Wisconsinan) Terrace deposits, 2.2 miles south of Spanish Fort, Clay County, Texas.

Locality 19. Ambrose (early Wisconsinan) Terrace on the Red River, north side of the Illinois Bend, Montague County, Texas.

Locality 20. Early Wisconsinan Terrace on the Red River, 6 miles northeast of Bysus, Jefferson County, Oklahoma.

Locality 21. Ambrose (early Wisconsinan) Terrace deposits, 6 miles north of Gainesville, Cooke County, Texas.

Locality 22. Ambrose (early Wisconsinan) Terrace deposits, 4 miles south-southeast of Carpenter's Bluff, Grayson County, Texas.

Locality 23. Ambrose (early Wisconsinan) Terrace deposits, along tributary to the Red River, 0.5 mile north of Bug Tussle, Fannin County, Texas.

Locality 24. Early Wisconsinan deposits along small tributary to the Sulphur River, 2 miles southwest of Roxton, Delta County, Texas.

Measured Sections

1. Section measured in cutbank of Red River, just upstream from bridge on State Highway 37, Red River County, Texas (1960).

	Thickness (feet)
Pleistocene Series—	
Wisconsinan Stage (post-Bradyan)—	
Cooke Alluvial Terrace—	
9. Surface soil, upper half A-horizon of fine sand and some silt, dark brown, crumb structure	0.5
8. Sand, fine, friable, tan, with clay streak at base	1.5
7. Sand, fine, thick bedded, tan; contains a few thin streaks of clay	2.5
6. Clay, red, massive	0.1
5. Sand, tan, with crenulate thin zones of red-brown clay interbedded with the sand in the lower part	1.5
4. Clay, red, massive	0.1
3. Sand, fine to medium, well bedded, tan; contains a few thin streaks of clay	2.5
2. Clay, red, massive	0.2
1. Sand, well bedded, tan to brown, largely covered in the lower part to the level of water in Red River	9.0
Total	17.9

2. Section measured in cutbank of small tributary entering the Red River upstream from bridge on U. S. Highway 77 north of Gainesville, Cooke County, Texas (1961).

	Thickness (feet)
Pleistocene Series—	
Wisconsinan Stage (post-Bradyan)—	
Cooke Alluvial Terrace—	
10. Sand and silt, laminated, reddish tan; contains thin lentils of clay and, locally, pendants of humic-stained sand from the top	3.0
9. Clay, red, plastic	0.1
8. Silt and fine sand, laminated so faintly that it appears massive; reddish tan	0.8
7. Clay, red, plastic	0.1
6. Silt with some clay and sand, massive with crumb structure (incipient soil), brown to red brown	0.3
5. Sand, medium, massive, loose, brick red; contains fossil snail shells	2.0
4. Sand, fine to medium, massive, reddish brown; thin beds of red to red-brown clay occur at top and bottom; contains a hearth of ashes and charcoal fragments with a maximum thickness of $1\frac{1}{2}$ inches and an exposed diameter of 2.5 feet	0.4
3. Sand, fine to medium, massive, friable, brick red	2.5
2. Silt and clay with some sand, massive; contains thin beds of red-brown clay	3.0
1. Covered to water level in Red River	5.0
Total	17.2

3. Section measured in cutbank of the Red River, northwestern corner of Red River County, Texas (1960).

	Thickness (feet)
Pleistocene Series—	
Wisconsinan Stage (pre-Bradyan)—	
Ambrose Alluvial Terrace—	
15. Sand, fine, with some silt; contains the surface soil of the terrace; top ½-foot friable A-horizon, light gray, becoming darker downward and more compact, yellow-gray at base	2.5
14. Silt, clay and fine sand, with a few pebbles, red	0.1
13. Silt and fine sand, pinkish tan	0.5
12. Silt, fine sand and clay, massive, compact, pale pinkish brown; appears to be the B-horizon of a soil, with bed 13 of the A-horizon	2.0
11. Silt and fine sand, massive to indistinctly bedded, tan to light purplish tan with some red mottling	3.0
10. Clay, silty massive to irregularly blocky, red brown	1.0
9. Silt and fine sand, bedded, tan to yellow brown	2.0
8. Silt and clay, massive, brick red	0.3
7. Silt, massive but with a few thin streaks of clay, gray	3.0
6. Silt and clay with some sand, blocky, red brown	1.0
5. Silt and fine sand, massive, gray tan	0.8
4. Clay and silt, blocky, red brown with some gray mottling	0.2
3. Sand and silt with pebbles, gray to dark gray at top; becomes clayey in uppermost part	2.5
2. Sand, light gray, loose; in lower part a zone of well-sorted fine gravel	9.0
1. Silt, sandy, dark gray. To water level in Red River	2.0
Total	29.9

4. Section measured in cutbank of the Red River, 6 miles north of Savoy, Fannin County, and 1½ miles east of Ambrose, Grayson County, Texas (1961).

	Thickness (feet)
Pleistocene Series—	
Wisconsinan Stage (pre-Bradyan)	
Ambrose Alluvial Terrace—	
5. Sand, fine to medium, friable, indistinctly but well bedded, brick red; surface soil has been removed at location of section; contains relatively abundant fossil snails	5.5
4. Clay and silt, massive to micro-blocky, black to dark red brown	4.5
3. Silt, fine sand and clay, gradationally more clayey in upper part, massive to blocky, reddish tan grading upward to dark reddish brown	5.5
2. Sand, fine to medium, and silt, massive to indistinctly bedded, compact, light brick red; contains abundant snail fauna in lower part	4.0
1. Silt and fine sand, massive to indistinctly bedded, brick red; in base a conglomerate of fragments of red shale in a red silt matrix; to water level in Red River	8.0
Total	27.5

5. Section measured in excavated channel of the North Sulphur River, 7 miles northeast of Cooper, in Lamar County, Texas (1961).

	Thickness (feet)
Pleistocene Series—	
Sulphur River Alluvial Terrace—	
Wisconsinan Stage (post-Bradyan)—	
6. Sand and silt, dark gray, friable, distinct bedding in lower part	3.0
Wisconsinan Stage (pre-Bradyan)—	
5. Silt and clay with some sand, black to dark gray and gray tan, massive with local bedding in lower part; conformable, but locally fills channels cut into lower beds and rests on Cretaceous shales. Outside these channels the thickness is	4.0
Kansan Stage—	
4. Clay, silt, and some sand, massive with blocky structure, gray tan mottled with brown in lower part, grading upward to brown mottled with rusty tan and black; caliche nodules dispersed throughout	3.5
3. Sand with some clay and silt, indistinctly bedded, gray to gray tan, caliche nodules abundant in upper part; locally well bedded; locally contains abundant fauna of fossil snails	3.0
2. Gravel with some sand and locally silt, gray, indistinctly bedded to locally cross-bedded; gravel consists predominantly of Cretaceous rock types including fossil marine mollusks but contains some chert and quartz; cobbles range up to 3 to 4 inches in diameter; contains fragmentary unionid shells and rare fragmented snail shells	3.5
Cretaceous System—	
1. Shale, clayey, calcareous, well bedded and compact, dark gray, with a zone of nodular limestone about midway. To water level in North Sulphur River	8.0
Total	25.0

6. Section measured in excavated channel of the North Sulphur River, half a mile north of Ben Franklin, Delta County, Texas (1961).

	Thickness (feet)
Pleistocene Series—	
Sulphur River Alluvial Terrace—	
Wisconsinan Stage (post-Bradyan)—	
5. Silt and sand with some clay, irregularly bedded, blocky, dark gray	3.0
Wisconsinan Stage (pre-Bradyan)—	
4. Clay, silt and sand, massive to blocky, dark gray, gradational at base; contains fossil snail shells in upper part	5.0
3. Clay, silt and sand, massive to blocky, gray tan to gray and locally mottled; contains a few fragments of snail shells	6.0
Kansan Stage—	
2. Silt, clay and sand, massive, mottled rusty brown, tan and gray; caliche nodules dispersed throughout; gradational at base; contains abundant fauna of fossil snails in upper part	3.0
1. Silt and sand, rusty brown and gray, indistinct bedding dips at a low angle; locally contains fossil snails; to water level in North Sulphur River	3.0
Total	20.0

7. Section measured in valley wall of Groesbeck Creek, 5½ miles north and 4 miles west of highway (U.S. 287–283) intersection at Quanah, Hardeman County, Texas (1961).

	Thickness (feet)
Pleistocene Series—	
Kansan Stage—	
Hardeman Alluvial Terrace—	
5. Silt, massive, friable, gray, bluish gray, tan; contains diatoms and sparse snail shells; some volcanic ash shards in lower part	12.0
4. Silt, sand, and Pearlette Volcanic Ash, massive to thick bedded, neutral gray with a few streaks and spots of tan; contains abundant fauna of fossil snails; contains some scattered gravel in base	4.0
3. Sand and silt with some clay and gravel, massive, pink tan	6.0
2. Sand and gravel, irregularly cross-bedded and irregularly cemented, gray to pink tan; gradational top and bottom	4.0
1. Sand, gravel, silt and clay, friable, pink tan, gray, brown; contains pebbles and cobbles of Permian limestones and shales. Rests on Permian shale and siltstone exposed to the bottom of Groesbeck Creek	6.0
Total	32.0

8. Section measured in road cuts 6 miles west of junction of Oklahoma Highways 37 and 87 at Idabel, McCurtain County, Oklahoma (1960).

	Thickness (feet)
Pleistocene Series—	
Kansan Stage—	
Hardeman Alluvial Terrace—	
7. A-horizon of podzolic soil, friable sand, ash gray to neutral gray	1.0
6. Sand, silt and some clay, compact, massive, mottled yellow, tan and red, grading into red brown at top; contains B-horizon of soil	4.0
5. Sand, medium to coarse, with some silt, massive to indistinctly bedded; pinkish tan streaked with gray tan, becoming mottled red and gray in uppermost part	9.0
4. Clay, gray with streaks of yellow tan	0.5
3. Silt, with some sand and clay and a few pebbles, massive, compact, mottled yellow tan and gray	7.5
2. Gravel and sand interbedded with sand and containing some silt, bedding indistinct, compact, brown streaked with gray; local zones of black iron cement	4.0
Cretaceous System—	
1. Shale, interbedded and variegated, tan, purple and gray	--
Total	26.0

9. Rayland measured section, ¾ mile west-southwest of Rayland, Foard County, Texas. Measured in south bank of Pease River valley (1959).

	Thickness (feet)
Pleistocene Series—	
Kansan Stage—	
Hardeman Alluvial Terrace—	
5. Sand and silt, massive to irregularly bedded, tan (the surface soil is removed by erosion)	5.0
4. Sand with some silt and (locally) clay; a few pebbles locally, massive to irregularly bedded, compact, gray; contains some dispersed caliche and fossil snail shells	5.0
3. Silt and sand, massive with vertical jointing, gray to dark gray; some caliche nodules in the lower part; contains abundant fossil snail fauna unevenly distributed	10.0
2. Sand with a few pebbles, irregularly bedded with some local cementation by $CaCO_3$, tan, reddish brown, and dark gray	4.0
1. Gravel, sand and silt, compact in upper part but bedded and loose in lower part, tan to brown. An irregular contact on Permian at the base	8.0
Total	32.0

Plates I–III

PLATE I

Wisconsinan and Recent terraces and deposits of the Red River in Texas

A. Channel of the Red River from left bank where both banks of the river are in Red River County, Texas. Taken from the Cooke Alluvial Terrace (late Wisconsinan) surface toward flood plain level on right bank (June 1960).

B. Channel of the Red River from Oklahoma side toward Clay County, Texas, just below bridge on State Highway 79 (June 1960).

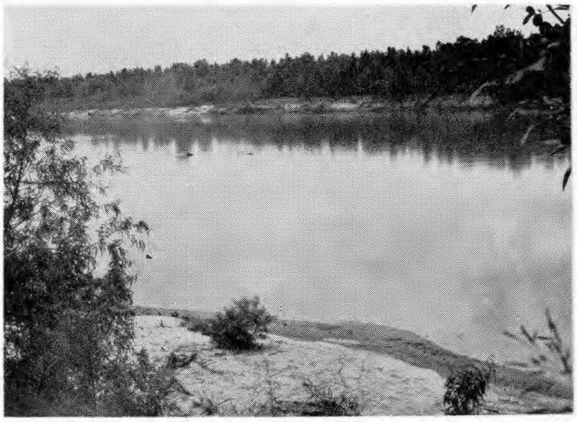
C. Eroded scarp of intermediate (Illinoian) terrace above the Cooke Alluvial Terrace (late Wisconsinan) surface, 9 miles north of DeKalb, Bowie County, Texas (June 1960).

D. Surface of Ambrose Terrace (early Wisconsinan), view toward the south, half a mile southeast of Riverby in northeast Fannin County, Texas (June 1960).

E. Upper part of alluvial deposits of Cooke Terrace (late Wisconsinan) in cutbank of the Red River, upstream from bridge on State Highway 37, 17 miles north of Clarksville, Red River County, Texas. Note very weakly developed soil profile in top of the terrace deposits (June 1960).

F. Ambrose Terrace (early Wisconsinan) in cutbank of the Red River at the northwest corner of Red River County, Texas (June 1960).

G. Alluvial deposits of Ambrose Terrace (early Wisconsinan) of Prairie Dog Town Fork of the Red River, three-fourths of a mile south of bridge on State Highway 70, Briscoe County, Texas. Note coarse texture of the deposits (July 1961).



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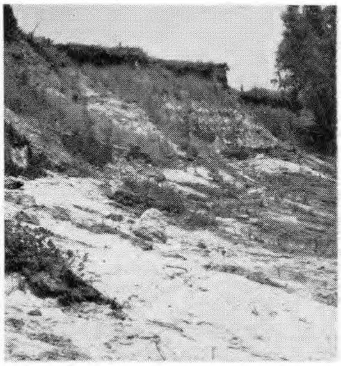

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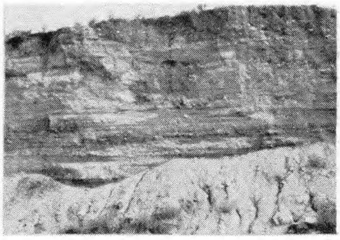

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PLATE II

Kansan terraces and deposits of the Red River basin in Texas

A. Strongly developed soil profile on Hardeman Terrace (Kansan) deposits, approximately 110 feet above the level of the Red River channel, 0.3 mile north of Forrest Chapel, Lamar County, Texas (June 1960).

B. Bedded alluvial sands of the Hardeman Terrace (Kansan) 8 miles northwest of Spanish Fort, Montague County, Texas (in Jefferson County, Oklahoma) (June 1960).

C. Hardeman Terrace (Kansan) surface showing coarse alluvial gravels (including cobbles derived from the Ogallala Formation) exposed in plowed field, 7 miles south of Memphis, Hall County, Texas (July 1961).

D. Hardeman Terrace (Kansan) surface under well irrigation in the Pease River valley, 1.2 miles south-southwest of Lockett, Wilbarger County, Texas (July 1961).

E. Kansan deposits containing snail fauna in the Sulphur River Terrace, lying unconformably over Cretaceous shales, in cut channel of Sulphur River near bridge on State Highway 24, southwest of Paris, Lamar County, Texas (July 1961).

F. Fossiliferous Kansan silts, Pearlette Volcanic Ash, sands and diatomaceous marl of the Hardeman Terrace exposed in the south bank of Groesbeck Creek, lying unconformably above Permian rocks, 5½ miles north and 4 miles west of Quanah, Hardeman County, Texas (July 1961).


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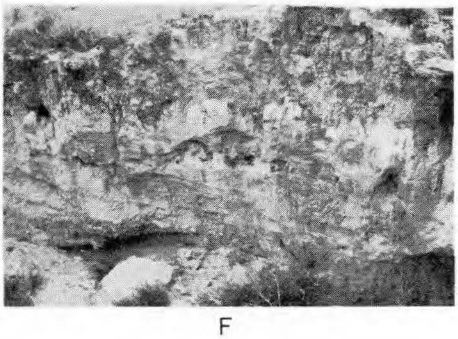
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PLATE III

Pleistocene features and deposits in the Red River basin of Texas

A. Mounds in hay field, 2 miles north of Mt. Vernon, Franklin County, Texas (July 1961).

B. "Medicine Mounds," erosional remnants cut in Permian rocks and standing above the projected level of the Nebraskan terrace but well below the projected level of the Tertiary surface; looking west, Hardeman County, Texas (July 1959).

C. Nebraskan deposits (Blanco Formation) at edge of dissected Nebraskan terrace, 5½ miles south and 1 mile west of Memphis, Hall County, Texas (July 1961).

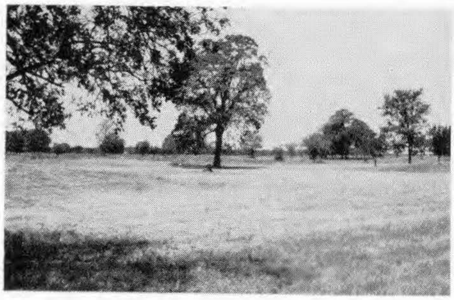
D. Fossiliferous Ambrose Terrace (early Wisconsinan) deposits in cutbank of the Red River, 6 miles north of Savoy, Fannin County, Texas (July 1961).

E. Horizontal cut through surface mound, west of State Highway 37, 5.1 miles south of Hagansport, Franklin County, Texas (July 1961).

F. Sand dunes capping the scarp of Hardeman Terrace (Kansan) on south side of the Red River, taken from the terrace surface looking north and showing the elevation of the dunes above the Kansan alluvial plain, 4 miles north and 4 miles east of Quanah, Hardeman County, Texas (July 1961).

G. Dissected surface of Ambrose Terrace (early Wisconsinan) in Palo Duro Canyon; Ogallala Formation caps the valley wall in the distance; 2.3 miles north-northeast from bridge on Farm Road 284 across Prairie Dog Town Fork of the Red River; view toward northwest, Armstrong County, Texas (July 1961).

H. Scarp of Ambrose Terrace (early Wisconsinan) along Wichita River valley 1 mile south and 2 miles west of Kadane Corner, Wichita County, Texas (July 1961).



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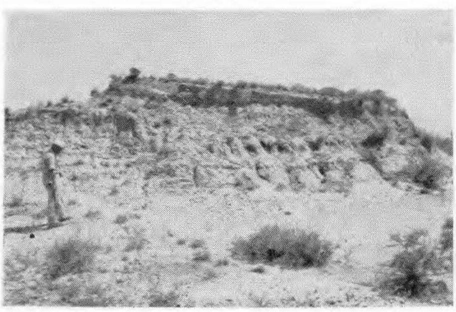

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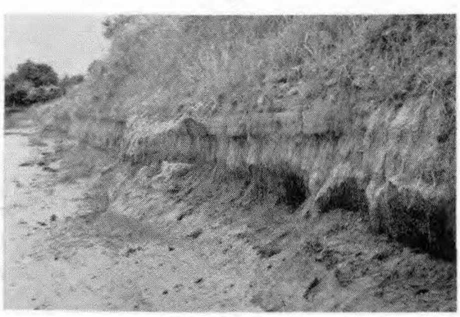

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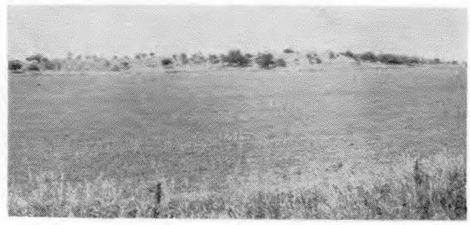

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