BUREAU OF ECONOMIC GEOLOGY
The University of Texas
Austin 12, Texas

JOHN T. LONSDALE, Director

Report of Investigations—No. 32

Studies of Cenozoic Geology Along Eastern Margin of Texas High Plains, Armstrong to Howard Counties

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JOHN C. FRYE[1] **AND A. BYRON LEONARD**[2]

ABSTRACT

The late Cenozoic (Pliocene and Pleistocene) geology of the eastern margin of the High Plains is described. The Pliocene Ogallala formation consists of fluviatile deposits, predominantly of sand but with some silt and local lenses of coarse gravel, resting on an erosional topography with several hundred feet of relief, developed on the bedrock. Distinctive fossil seeds collected from the formation permit correlation of floral zones as far south as Howard County with subdivisions (Valentine, Ash Hollow, and Kimball) recognized to the north in Kansas and Nebraska. The Ogallala becomes thin and discontinuous to the south where the upland surface of the High Plains merges with the Edwards Plateau, broken by remnants of the still higher surface developed on resistant Cretaceous limestones. The formation is distinguished at the top by the complex "Caprock" limestone, a product of weathering during the period of aridity that marked the latest phase of Tertiary time.

A complete and distinctive sequence of Pleistocene deposits, resting unconformably on the Ogallala formation and underlying bedrock, is recognized in this region. The Pleistocene is in general characterized by episodes of progressively deeper erosional incision of the late Tertiary alluvial plain with cyclic episodes of alluviation. The Blanco formation (Nebraskan) consists largely of sluggish stream deposits, accumulated almost to the level of the late Tertiary constructional plain. The Tule formation (Kansan) occurs widely throughout the region both as abandoned valley fills under the High Plains surface and as terrace remnants flanking streams that flowed outward from the Plains. In addition to previously described vertebrate faunas, the lenticular deposits of Pearlette volcanic ash studied as far south as Howard County and large and distinctive faunas of fossil mollusks permit precise correlation of this unit with deposits of this age northward across the Great Plains and into the glacial sequence of the Missouri Valley region. The Yarmouthian and Illinoian are marked by a strong climatic reversal toward aridity with the resultant regional accumulation of eolian sands—the "Cover sands"—on the uplands, and relatively minor development of alluvial terraces. The Early Wisconsinan has strong and almost independent development on the uplands and along the valleys. The Tahoka formation was deposited in lakes formed in undrained depressions on the High Plains as a result of the trend to more humid conditions. This formation is correlated with the extensive well-developed terrace systems throughout the region by the large and distinctive faunas of fossil mollusks found in both situations. Latest Wisconsinan and subsequent deposits are minor in comparison and their meager faunas and lithologic character reflect the return of semiarid conditions to the Plains region. As the headwaters areas of three independent drainage systems—the Colorado, Brazos, and Red rivers—are included in the area of study and were all found to display the same general sequence of Pleistocene events, the implications of these correlations may be projected beyond central western Texas.

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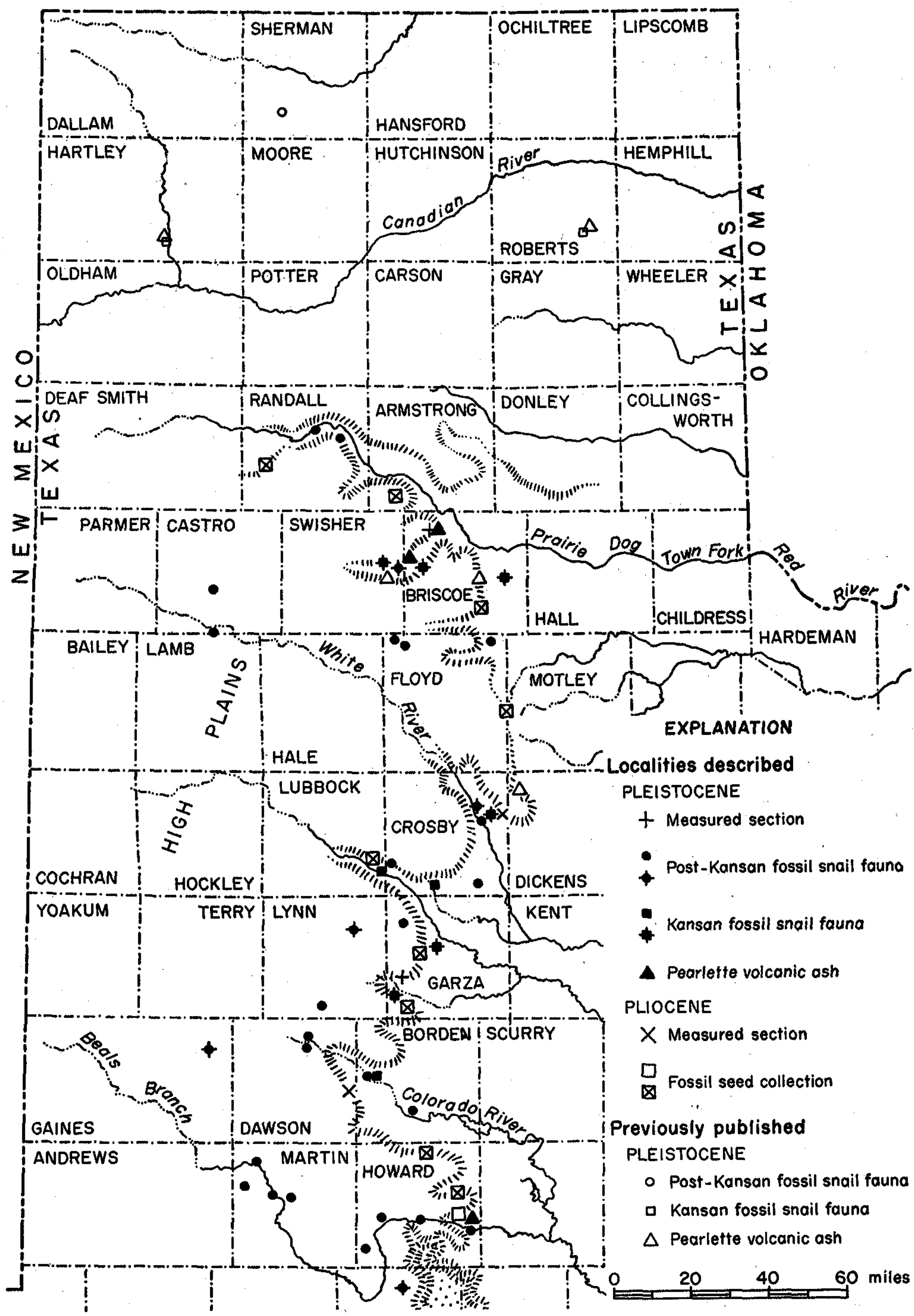

FIG. 1. Map of northwestern Texas showing the distribution of localities described in this paper.

INTRODUCTION

The eastern margin of the High Plains in central western Texas affords particularly good opportunity for study of late Cenozoic geology. The topography of the area is dominated by the southernmost segment of the late Tertiary mantle of fluvial sediments, isolated from the central and northern High Plains by the valley of the Canadian River. The eastern escarpment presents many exposures and the canyons that extend into the plains contain, in addition, a nearly complete sequence of Pleistocene terraces and deposits. The Canadian River, which crosses the Texas Panhandle north of the area under study, flows by way of the Arkansas River to the Mississippi. However, in the Plains to the south are the headwaters of drainage to Red River (which enters the Mississippi just above its delta) and of the Brazos and the Colorado rivers, each of which takes its independent course to the Gulf of Mexico. Therefore, the Pleistocene histories of adjacent High Plains canyons are indicative of independent drainage systems. These geographic relationships, that place nearby streams under control of three different base level situations, give special significance to late Cenozoic correlations in this region.

For three-quarters of a century fossil vertebrates of late Cenozoic age have attracted attention to central western and northwestern Texas; however, the abundant faunas of fossil snails in the Pleistocene received little study and the less abundant, but significant, fossil seeds of the Neogene have not previously been reported in the literature. Snail faunas previously described or listed in detail have been from a few localities only (fig. 1) in the Panhandle area (Frye, Swineford, and Leonard, 1948; Leonard, 1950; Frye and Leonard, 1951).

Field work on which this report is based has been discontinuously distributed over a decade. Several short periods were spent in the field from 1945 through 1949 when work was directed primarily toward correlation of Kansan age deposits with deposits in the northern Great Plains and with the glacial section of the Mid-West. This study was carried on largely by use of the distinctive petrography of the Pearlette volcanic ash bed and by fossil molluscan faunas (Frye, Swineford, and Leonard, 1948), but was accompanied by a reconnaissance of Pliocene and Pleistocene stratigraphy of the region. Field work directed specifically toward the present report consisted of several weeks in the fall of 1954 and summers of 1955 and 1956 under the auspices of the Bureau of Economic Geology of The University of Texas.

Knowledge of the late Cenozoic geology of this region is of considerable practical value. It is from these deposits that much of the irrigation water on the High Plains is pumped; Cenozoic deposits also are the parent materials of most of the surface soils. Workable sand and gravel deposits, and potentially valuable deposits of volcanic ash, occur within these beds.

Correlation of late Cenozoic strata in central western Texas has rested in the past almost entirely on the evidence of fossil vertebrates (Sellards et al., 1933; Evans and Meade, 1945). It is our purpose here to present the results of the regional integrated attack on the problems of correlation by use of fossil molluscan faunas, fossil seed floras, physiographic history, buried soils, lithology, and previously described volcanic ash petrography. From this approach there has emerged the basis for a framework of stratigraphic classification consistent with other parts of the Great Plains region. The data used are relatively widely spaced along the eastern margin of the Plains (fig. 1), and further detailed work is needed in this region to produce a desirable degree of refinement and certainty.

Major subdivisions of Cenozoic time in world-wide usage are based on type localities in western and southern Europe, and the use in North America of the time-stratigraphic series terms Miocene, Plio-

AGE			CENTRAL and WESTERN NEBRASKA (Condra and Reed, 1950; Lugn, 1939; Reed, 1948)	CENTRAL and WESTERN KANSAS (Frye and Leonard, 1952, 1955; Frye, Leonard, and Swineford, 1956)	WESTERN TEXAS— AREA OF THIS REPORT (Figure 1)
PLEISTOCENE	Recent	Almenan	(Alluvium; dune sand)	(Alluvium; dune sand)	(Alluvium and dune sand)
PLEISTOCENE	Wisconsinan: Late Wisc.	Almenan	Bignell loess (sand and gravel)	Sanborn formation: Bignell m. (sand and gr.)	Late Wisconsinan terrace deposits; minor upland depression fills; dune sand
PLEISTOCENE	Wisconsinan: Bradyan		*Brady soil*	Sanborn formation: *Brady soil*	
PLEISTOCENE	Wisconsinan: Early Wisc.	Scandian	Peorian loess Todd Valley fm.	Sanborn formation: Peoria m. (sand and gr.)	Tahoka fm.; Early Wisconsinan terrace deposits; "Cover sands" (locally)
PLEISTOCENE	Sangamonian		*Sangamon soil*	Sanborn formation: *Sangamon soil*	*Sangamon soil*
PLEISTOCENE	Illinoian		Loveland loess Crete sd. and gr.	Sanborn formation: Loveland m. Crete m.	"Cover sands" (major part); local terrace deposits
PLEISTOCENE	Yarmouthian		*Yarmouth soil*	*Yarmouth soil*	*Yarmouth soil*
PLEISTOCENE	Kansan		Sappa fm. (incl. Pearlette v. ash) Grand Island fm	Meade: Sappa m. (incl. Pearlette v. ash) Grand Island m.	Tule fm. (including Pearlette volcanic ash)
PLEISTOCENE	Aftonian		*Afton soil*	*Afton soil*	*Afton soil*
PLEISTOCENE	Nebraskan		Fullerton fm. Holdrege fm.	Blanco: Fullerton m. Holdrege m.	Blanco fm.
NEOGENE	Pliocene		Ogallala group: Kimball fm. Sidney fm.	Ogallala formation: Kimball m.	Ogallala formation: (Kimball floral zone)
NEOGENE	Pliocene		Ogallala group: Ash Hollow fm.	Ogallala formation: Ash Hollow m.	Ogallala formation: (Ash Hollow floral zone)
NEOGENE	—?——?— Miocene		Ogallala group: Valentine fm.	Ogallala formation: Valentine m.	Ogallala formation: (Valentine floral zone)

FIG. 2. Classification of Late Cenozoic deposits in the Great Plains region.

cene (Neogene), and Pleistocene is justified on the basis of paleontologic correlations between the two continents. In non-marine strata, fossil mammals have been the primary criterion for such intercontinental correlations (Simpson, 1947). This problem has received much attention and it is not our purpose here to examine correlations beyond interior North America. Because of inherent inexactness and uncertainties in such long-range correlations there has developed through the years a general acceptance of standard reference sections and sequences in interior North America. It is the correlation of the deposits in west-central Texas with these "North American standards" with which we are concerned (fig. 2). Our usage of European series names is in general consistent with present usage in the Great Plains. For the non-marine Pleistocene deposits the glacial sequence of the upper Mississippi Valley and adjacent region has, for a half century, been generally accepted as classic. For the late Tertiary Neogene strata, no single area enjoys comparable acceptance. The stratigraphy of the Miocene and Pliocene (Neogene) of western Nebraska has been described in detail and correlation with Nebraska type localities extended southward across Kansas (Frye, Leonard, and Swineford, 1956). As the area under study in west-central Texas is the southern part of this extensive depositional province, we will look to the type localities of western Nebraska as a stratigraphic sequence of reference for the Neogene of the Great Plains region.

The southern High Plains is topographically a plateau marked by distinct and prominent escarpments on the east (Pl. IA) and west but only arbitrarily defined on the south where (west of the prominent Cretaceous upland in south-central Howard County) the surface is essentially continuous with the Edwards Plateau. The area with which we are concerned is in general limited on the north by Prairie Dog Town Fork of Red River, but a more prominent physiographic break occurs farther north along the valley of the Canadian River.

The physiographic expression of the southern High Plains was described dramatically in 1901 by W. D. Johnson. He concluded that the surface of this plateau was essentially the surface of the mantle of late Tertiary deposits unmodified by erosion throughout Pleistocene time. Truly, the gross aspects of the land forms are controlled by erosion of this late Tertiary alluvial mantle, but the modification of the topography that occurred during the Pleistocene has produced the character and distinctiveness that we see in the present topography of the High Plains surface and margin (Evans and Meade, 1945; Frye, 1946). To be meaningful, a consideration of Pliocene and Pleistocene stratigraphy must include the relation of the several cyclic deposits to the erosional history of the region, but as the deciphering of this physiographic his-**tory is in part based on the dating and** correlation of the deposits, the two phases of the study were carried on jointly. These general relationships are shown by schematic diagrams and generalized cross sections in figures 3, 4, and 5, and are summarized later in the report.

We express our thanks to Ada Swineford, State Geological Survey, University of Kansas, for the petrographic examination and identification of several samples of Pearlette volcanic ash collected by us and reported here for the first time.

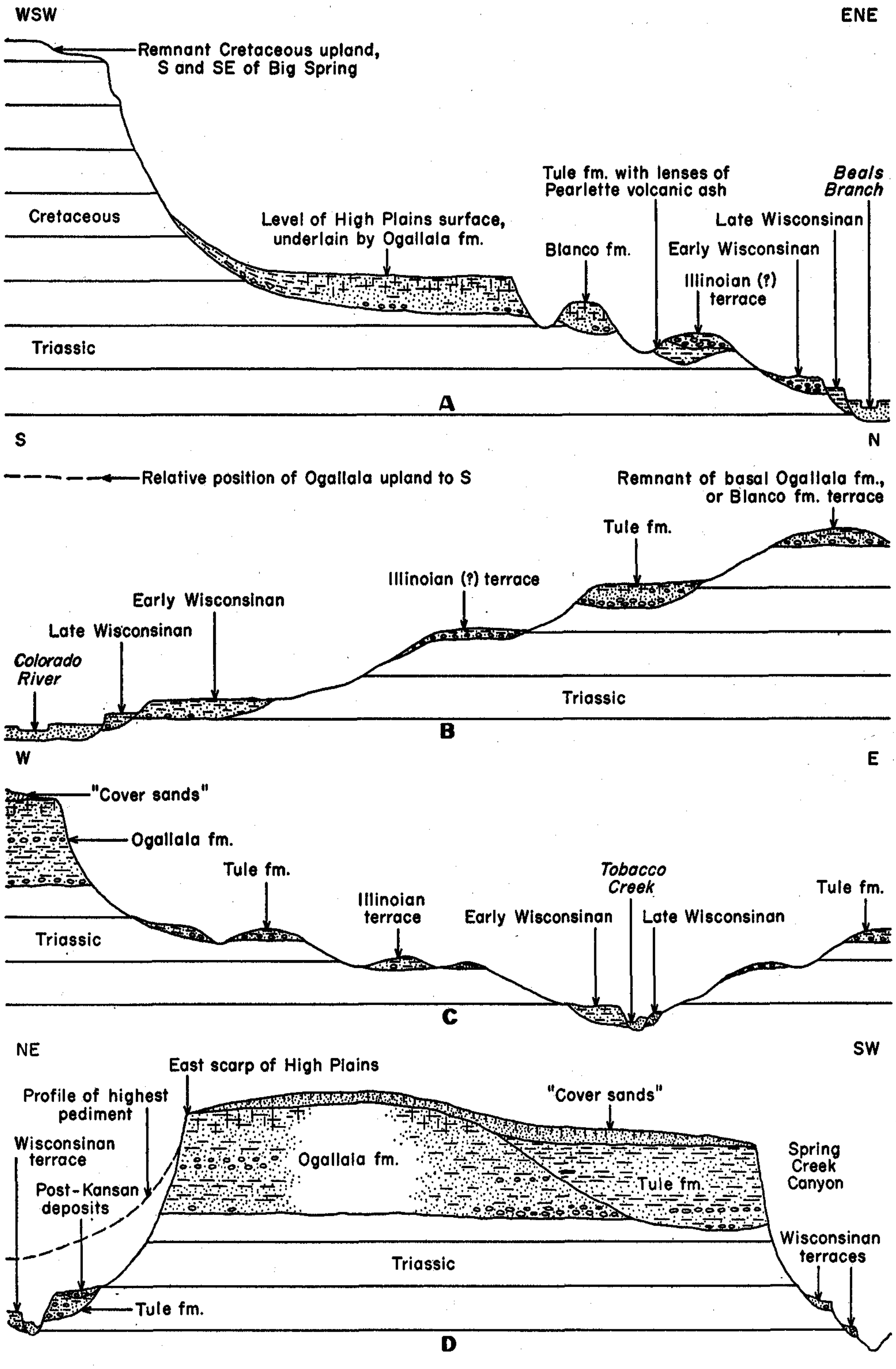
WSW
ENE
Remnant Cretaceous upland, S and SE of Big Spring
Cretaceous
Level of High Plains surface, underlain by Ogallala fm.
Tule fm. with lenses of Pearlette volcanic ash
Beals Branch
Late Wisconsinan
Blanco fm.
Early Wisconsinan
Illinoian (?) terrace
Triassic
A
S
N
Relative position of Ogallala upland to S
Remnant of basal Ogallala fm., or Blanco fm. terrace
Tule fm.
Illinoian (?) terrace
Early Wisconsinan
Late Wisconsinan
Colorado River
Triassic
B
W
E
"Cover sands"
Ogallala fm.
Tule fm.
Illinoian terrace
Tobacco Creek
Tule fm.
Early Wisconsinan
Late Wisconsinan
Triassic
C
NE
SW
East scarp of High Plains
Profile of highest pediment
"Cover sands"
Wisconsinan terrace
Ogallala fm.
Spring Creek Canyon
Post-Kansan deposits
Tule fm.
Triassic
Wisconsinan terraces
Tule fm.
D

FIGURE 3

STRATIGRAPHY OF NEOGENE DEPOSITS

GENERAL

The presence of late Tertiary non-marine clastic sediments under the surface of Llano Estacado, or the southern High Plains of northwestern Texas, has been generally recognized for more than three-quarters of a century. A relatively large number of early reports described the vertebrate paleontology, stratigraphy, and general occurrence of these beds (C. L. Baker, 1915; Cope, 1892, 1893; Cummins, 1891, 1892, 1893; Gidley, 1903; Gould, 1906, 1907; W. D. Johnson, 1901), and early work was summarized in 1933 by Sellards and others. During the past quarter-century, little has been published on the stratigraphy of the late Tertiary of this part of Texas, except for a few highly localized reports (Livingston and Bennett, 1944) and the material prepared for two field trips (Evans, 1949, 1956; Brand, 1953) that dealt briefly with the area from Garza to Briscoe counties.

Several local names have been applied to these widespread late Tertiary deposits. Those names receiving formal notice include Panhandle formation, Clarendon beds, Goodnight beds, Potter formation, Coetas formation, Hemphill beds, Loup Fork beds, and Blanco beds (in its expanded sense). As the history and usage of these terms has been summarized (Sellards et al., 1933, pp. 763–776) a review of them will not be repeated here.

In recent years the deposits of Pleistocene age have been formally recognized (Evans and Meade, 1945), distinguished from the Tertiary deposits, and the term Ogallala used (as it is in the central and northern Great Plains) in the sense of the type to apply only to Neogene deposits (Evans, 1956). In the area of Crosby and adjacent counties, Evans (1949, 1956) has proposed that two units of formational rank, the Bridwell formation overlying the Couch formation, be recognized within the Ogallala group. As these formations were proposed in guidebooks, full descriptions and detailed measured sections were not given, but it is stated that they are separated by an unconformity and the contained vertebrate fossils indicate an early Pliocene age for the Couch and a middle Pliocene age for the Bridwell. It is also suggested that the Bridwell fauna is equivalent in age to the Hemphillian of the Panhandle area. Recently these units have been discussed by Van Siclen (1957, p. 51) who states that they are in apparent conformity, and that they can be recognized in Hemphill County where, he concludes, they are stratigraphically below an important Hemphillian vertebrate fauna locality (Van Siclen, 1957, p. 55–56). Measured section no. 6 of this paper (p. 42) is at the type locality of the Couch and Bridwell formations (Evans, 1956, p. 28) and presents the typical lithologic succession of the area. If the Pleistocene "Cover sands" are included within the Bridwell, then the contact between the formations is approximately that between beds 4 and 5; if not, then this contact is approximately that between beds 3 and 4, based on the stated thickness of 155 feet for the Bridwell at this locality. We were unable to observe a disconformity of regional extent at either stratigraphic position.

The region over which the Ogallala deposits were studied for this publication ex-

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FIG. 3. Generalized and schematic cross-sections showing relations of Cenozoic deposits, Howard to Garza counties, Texas. Vertical exaggeration is not uniform.

A. East-central Howard County, illustrating the relation of the Ogallala formation and Pleistocene terraces to the remnants of Cretaceous upland.

B. Sequence of Pleistocene terraces along Colorado River, south-central Borden County, east of High Plains scarp.

C. Relation of fossiliferous Pleistocene terraces to the Ogallala scarp in northwestern Borden County.

D. Schematic diagram illustrating the relative position of the Kansan Tule formation deposited in minor valleys along the face of the scarp to the Tule formation deposited in major south-flowing valleys of the High Plains surface, subsequently dissected by Spring Creek.

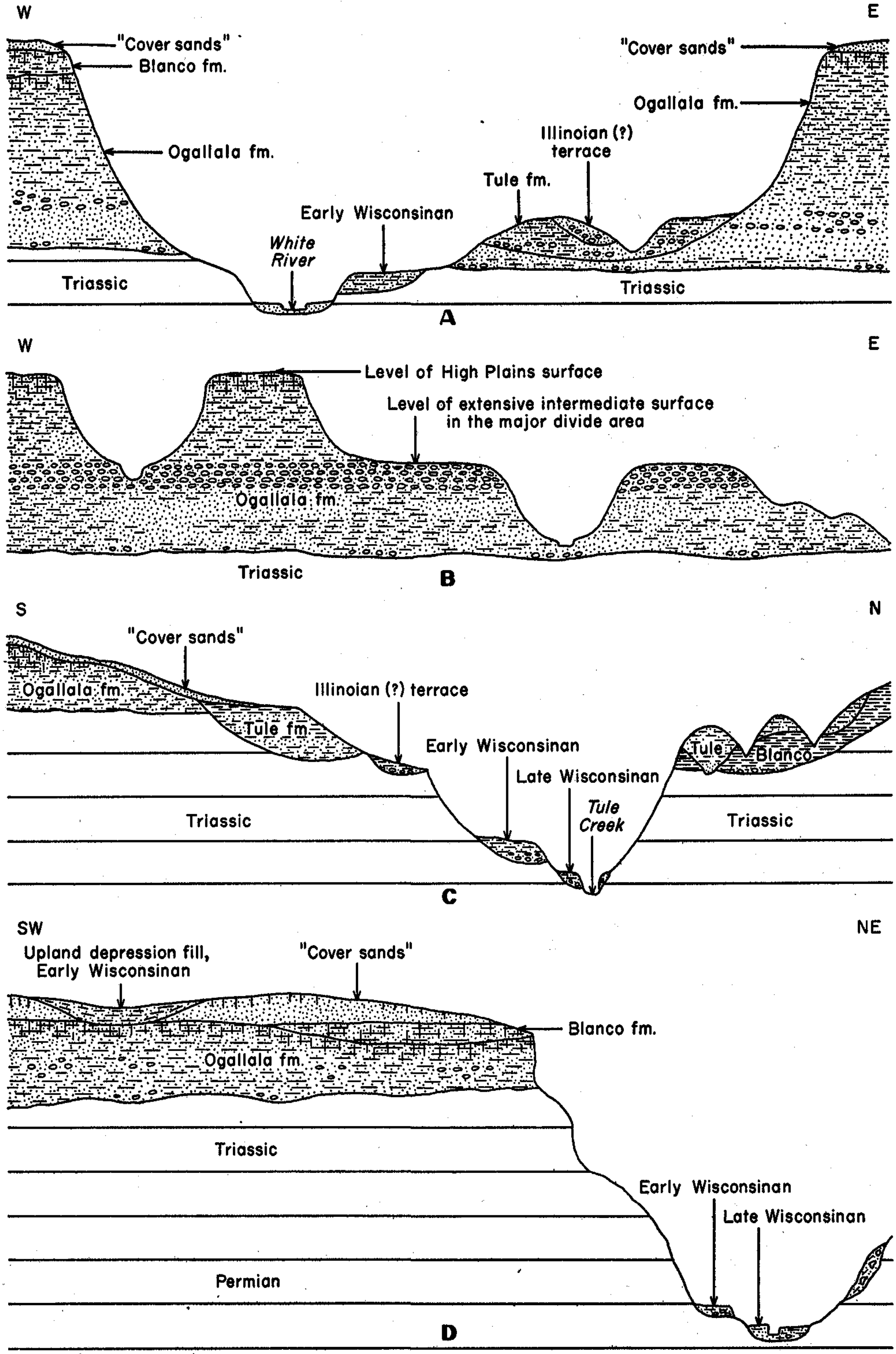
W
E
"Cover sands"
Blanco fm.
Ogallala fm.
"Cover sands"
Ogallala fm.
Illinoian (?) terrace
Tule fm.
Early Wisconsinan
White River
Triassic
Triassic
A
W
E
Level of High Plains surface
Level of extensive intermediate surface in the major divide area
Ogallala fm.
Triassic
B
S
N
"Cover sands"
Ogallala fm.
Illinoian (?) terrace
Tule fm.
Early Wisconsinan
Late Wisconsinan
Tule Creek
Tule
Blanco
Triassic
Triassic
C
SW
NE
Upland depression fill, Early Wisconsinan
"Cover sands"
Blanco fm.
Ogallala fm.
Triassic
Early Wisconsinan
Late Wisconsinan
Permian
D

FIGURE 4

tends more than 225 miles in a north-south direction. It is therefore necessary that we use a rock-stratigraphic classification that is recognizable throughout this region and is compatible with that used in the rest of the Great Plains. Although lithologic subdivision of the Ogallala in local areas may be both possible and desirable, we found that we were unable to recognize and trace rock-stratigraphic units within the Ogallala throughout the region under study and for that reason treat it in this paper as a formation and do not recognize formal members. The recent discussion by Van Siclen (1957) suggests that future, more detailed work may make possible the recognition of lithologic units within the Ogallala on a regional basis.

In the past, regional correlations within the Neogene deposits of western Texas have been based largely upon the evidence of fossil vertebrate assemblages. During the course of our work we found that the fossilized remains of plants are extremely useful for correlation of the Texas Ogallala, as well as in the central and northern Great Plains where they had been previously used. This has permitted the recognition of floral zones that can be correlated into Kansas and northward with type localities in Nebraska. It should be remembered that the floral zones as used in this paper are biostratigraphic units and not intended to be treated as members (rock-stratigraphic) of the Ogallala formation.

Details of the local lithology of the Ogallala are documented in eleven measured sections from Armstrong, Briscoe, Crosby, Dawson, Floyd, Garza, Howard, Lubbock, and Randall counties (pp. 40–51). From these sections and repeated observations of the formation at intermediate localities, certain generalities may be drawn concerning its lithology. The Ogallala formation of northwestern Texas rests upon an erosional surface of considerable relief and in exposures ranges in thickness from a feather edge where it wedges out against Cretaceous rocks that occur at or above its general upper surface (e.g., Dawson and Howard counties), to more than 300 feet (*e.g.*, Crosby County) where it fills former valley areas on the sub-Ogallala erosion surface. The formation consists predominantly of fine to medium sand, and the most common colors are hues of reddish tan to pale pinkish gray. It is generally marked by discontinuous and variable zones of weak cementation by calcium carbonate, except in the uppermost part where cementation is commonly dense and tough. Except for the uppermost part, there is no apparent continuity of the distinctive lithologic elements that are locally prominent and it lacks the more or less regular vertical change in lithologic character that has been observed in the formation farther north in the Great Plains (Frye, Leonard, and Swineford, 1956).

The preponderant monotony of the lithology, however, is locally broken by strongly contrasting coarse, well-bedded to cross-bedded channel gravels. Where such lenticular channel gravels occur, they contain cobbles up to several inches in diameter and attain maximum thicknesses of more than 50 feet. Measured section no. 20 contains a thin bed of channel gravels, and they are well exposed in Yellowhouse Canyon near the east line of Lubbock County, on high spurs in northern Garza County and southwestern Crosby County, and serve as a caprock of an intermediate bench in southwestern Motley County (fig. 4). Thin zones of relatively coarse gravel are shown by several measured sections.

FIG. 4. Generalized cross-sections showing relations of Cenozoic deposits, Crosby to Randall counties, Texas.

A. Generalized section across Blanco Canyon, eastern Crosby County, showing prominent fossiliferous Kansan (Tule formation) terrace.

B. Southwestern Motley County, illustrating the intermediate erosional bench developed on an extensive gravel zone in the Ogallala formation in the divide area between drainage of Red and Brazos rivers.

C. Generalized section across Tule Canyon in western Briscoe County, illustrating the sequence of deposits in the type area of the Tule formation.

D. The relation of the Ogallala formation and Pleistocene deposits to Palo Duro Canyon, eastern Randall County.

Section no. 10 records the unusual lithology of pebbles and cobbles distributed sparsely throughout a bed of fine sand with a concentration at the top resembling a deflation lag concentrate.

Lenticular bodies of gravel have been observed at most stratigraphic positions within the formation below the uppermost 40 feet. They are generally discontinuously exposed, but locally they have linear extent judged to be in the direction of the depositing stream channel. Although not clearly established, the channel gravels seem to be more common in the mid part of the floral zone correlated with the Ash Hollow of Nebraska; coarse well-sorted sands have been observed more often at still lower stratigraphic positions.

In addition to the distinctive "Caprock zone," which will be discussed later, there are only a few minor occurrences of rock types of sufficiently unusual character to merit notice. Locally, relatively thin, discontinuous zones of siliceous cement have been observed at several stratigraphic positions in the formation. Clay is rare in the formation, but beds of silty clay were observed at many places (*e.g.*, measured section no. 13). Volcanic ash lentils, common in the Ogallala of Kansas and Nebraska (Swineford, Frye, and Leonard, 1955) have not been observed in Texas south of the Panhandle area.

PALEONTOLOGY

Correlation of Texas Neogene deposits in the area under study with typical Ogallala formation is clearly attested by the contained vertebrate fossils (Evans, 1949, 1956) and fossilized remains of plants (Elias, 1942; Frye, Leonard, and Swineford, 1956; Leonard, 1957). The work reported here was carried on within a framework of relatively limited time in the field, and this prompted us in general to confine detailed study to those localities presenting a sufficient thickness of exposed strata to yield significant data on the succession of sediments. By so doing we observed very few indications of fossil vertebrate remains, in spite of their reported widespread occurrence, but were able to collect diagnostic fossil plant material from the majority of the sections studied. Our inability to observe abundant vertebrate material, or their relative scarcity in these deposits, does not, however, destroy their value for interregional correlation. So far as we have been able to determine, correlations based on fossil vertebrates are not in conflict with seed zone correlations described subsequently.

Although the Ogallala of Oklahoma and Kansas contains a series of diagnostic molluscan faunas (Frye, Leonard, and Swineford, 1956) no fossil mollusks have been observed in Neogene sediments in the area under study; in fact, characteristic soft limestones in which mollusks have been found elsewhere in the Ogallala are lacking in the southern High Plains.

Fossilized remains of plants, represented for the most part by preserved fruits or hulls of seeds, not only confirm the correlation of these sediments with Ogallala formation in its type area, but because of their widespread occurrence and well-known stratigraphic distribution, permit placement of local outcrops in a vertical

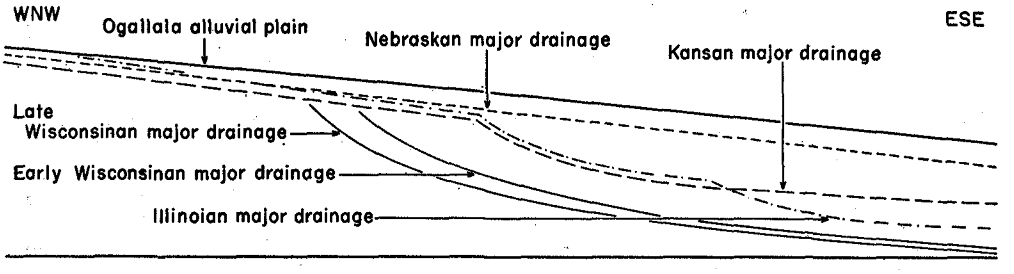

FIG. 5. Idealized profiles of major drainage on the Ogallala alluvial plain and on the surface of terrace deposits of each Pleistocene alluvial cycle.

sequence of floral zones judged to be equivalent in age to the three named stratigraphic subdivisions of the Ogallala formation (or group) recognized elsewhere. Floras in the southern High Plains are not as varied, nor are their occurrences as numerous as those reported by Frye, Leonard, and Swineford (1956, fig. 4) for northwestern Kansas. At least two species of common occurrence in Texas (*Biorbia papillosa, Panicum eliasi*) are unknown in more northern Ogallala sediments, but their floral associations make them equally as good stratigraphic markers as their northern counterparts.

A total of 15 different kinds of plant remains, including well-preserved but unidentified grass stems, were found in Ogallala deposits at 13 localities studied (Pl. II; text figs. 1 and 6). *Celtis willistoni,* unfortunately of least stratigraphic significance, occurs most frequently, followed in order by *Biorbia papillosa, Berrichloa conica, Panicum eliasi,* and *Stipidium intermedium;* other seeds are represented in our collections by single occurrences or by unidentified remains. The hackberry, *Celtis willistoni,* is the only tree represented; other plant remains are those of grasses and non-woody herbs.

Kimball floral zone.—A diagnostic Kimball flora was collected only at a single locality (measured section no. 2); other occurrences of seeds in the Kimball floral zone are limited to *Celtis willistoni,* which is not diagnostic of this zone. At the Briscoe County exposure, however, the flora is not only clearly diagnostic but unusually varied for this stratigraphic level. *Prolithospermum johnstoni, Berrichloa maxima,* and *B. minuta* are diagnostic of the Kimball zone (Elias, 1942; Frye, Leonard, and Swineford, 1956; Leonard, 1957). The occurrence of *Biorbia papillosa,* while not a contraindication of this zone, indicates that the bed from which the seeds came is probably low in the sequence of Kimball sediments. The occurrence of a single seed, presumed to be an undescribed species of *Prolithospermum,* is of unknown stratigraphic significance.

Ash Hollow floral zone.—Diagnostic Ash Hollow floras (Elias, 1942; Frye, Leonard, and Swineford, 1956) were collected at nine localities (fig. 6), and at two additional localities, *Celtis willistoni*

Berrichloa amphoralis Elias	Berrichloa conica Elias	Berrichloa cf. minuta Elias	Berrichloa maxima Elias	Berrichloa tuberculata Elias	Biorbia papillosa Leonard	Biorbia sp.	Celtis willistoni (Cockerell) Berry	Grass stems	Panicum eliasi Leonard	Prolithospermum johnstoni Elias	Prolithospermum sp.	Stipidium commune Elias	Stipidium intermedium Elias	Stipidium sp.	Floral Zone	Locality	County
							●								Kim.	See measured section no. 1	Armstrong
							●								A. H.		
		●	●		●		●			●	●				Kim.	See measured section no. 2	Briscoe
	●				●	●	●						●		A. H.		
							●								Kim.	10 mi. S, Crosbyton	Crosby
	●				●										A. H.	See measured section no. 10	Floyd
												●			Val.		
	●				●		●								A. H.	See measured section no. 12	Garza
	●			●	●				●					●	A. H.	See measured section no. 13	Garza
					●										A. H.	4 mi. S, jct. U.S. 80-T. 821	Howard
●					●		●						●		A. H.	See measured section no. 19	Howard
	●				●		●	●	●				●		A. H.	See measured section no. 18	Howard
							●		●						A. H.	See measured section no. 20	Lubbock
							●								Kim.	6 mi. N, 6 mi. E Canyon	Randall
							●								A. H.	4 mi. W, 7 mi. N, SE co. cor.	Randall
	●				●		●		●					●	A. H.	See measured section no. 22	Randall

FIG. 6. Check list of fossil seeds from the Ogallala formation of central western Texas. See Plate II.

was found in sediments judged to be equivalent to the Ash Hollow. The most characteristic plant in this floral zone is *Biorbia papillosa,* which occurs at every fossiliferous locality in which the Ash Hollow assemblage was present, followed in order by *Berrichloa conica, Panicum eliasi,* and *Stipidium intermedium.* Our studies confirm the opinions of Leonard (1957) that *Biorbia papillosa* in the Ogallala of the Texas High Plains is characteristic of the Ash Hollow assemblage; furthermore, this species seems to be ecologically and stratigraphically the analogue of *Biorbia fossilia,* which is known at least as far south as the southern tier of counties in western Kansas. *Panicum eliasi* seems intermediate in stratigraphic distribution between *P. elegans* and *P. e. nebraskense.* According to Elias (1942, p. 102), *P. elegans* occurs high in the Ash Hollow, while *P. e. nebraskense* is found in the basal part of the Ash Hollow. The plants associated with *P. eliasi* (*Berrichloa conica, B. tuberculata, Biorbia papillosa,* and *Stipidium intermedium*) all point clearly to a middle to lower Ash Hollow zonal position for *Panicum eliasi. Celtis willistoni* occurs in the Ash Hollow zone assemblages, but since it ranges throughout the Pliocene, its occurrence is not in itself important in the present context.

The genus *Krinitzkia,* represented farther north in Ogallala deposits by *K. coroniformis, K. auriculata,* and the rare *K. chaneyi,* seems not to be present in the area studied but may have been overlooked. It is probable that little early Ash Hollow sediments are present or exposed along the High Plains escarpment, but at one locality (measured section no. 10) definite evidence of the Valentine floral zone was found, indicating that beds equivalent in age to the early Ash Hollow should be present, at least locally. It may be that *Krinitzkia* or other floral elements of early Ash Hollow affinities will eventually be found.

Valentine floral zone.—Stipidium commune, a grass diagnostic of the Valentine floral zone, judged to be equivalent in age to the Valentine member of Kansas classification (or formation, Nebraska classification) was recovered from a sand lentil in coarse elastics at a locality in Floyd County (measured section no. 10). Frye, Leonard, and Swineford (1956) found *Stipidium commune* in Valentine deposits in Kansas but not *S. breve* or *S. coloradense* which Elias (1942, p. 80) reported as occurring in the basal part of the Valentine in Nebraska.

Characteristic seeds recovered from Ogallala deposits in the area under study are illustrated in Plate II. For fuller descriptions of Ogallala seeds, consult Elias (1942); *Biorbia papillosa* and *Panicum eliasi* were described and illustrated by Leonard (1957).

Ecological implications of fossil plants.—The fossil plants of the Ogallala formation in the area under study represent a typical mixed prairie flora, apparently dominated by grasses. *Biorbia* and *Lithospermum* are borraginaceous herbs; all other plant remains, except the hackberry, *Celtis willistoni,* are prairie grasses. The generally excellent preservation of the nutlets of the two borrages and the fertile glumes of the several kinds of grasses, leads to the conclusion that the preserved flora represents a significant part of the seed-bearing flora actually living at the time.

The relative paucity of the flora probably reflects a less humid climate and lower water table than prevailed during the deposition of the Ogallala in Kansas and Nebraska. Other observations support this deduction. Nowhere in Texas, from Palo Duro Canyon southward, have we observed in the sediments the color produced by reduced iron salts; furthermore, beds or lentils of diatomaceous marl, or soft marly limestones, so characteristic of Ogallala deposits north of the Texas Panhandle, seem to be entirely lacking. A corollary of this last observation is the seemingly complete lack of gastropods in the deposits under study. The oxidized state of iron salts associated with the sediments; absence of deposits indicative of ponds or lakes; and the composition of the floral assemblages together with the relative scarcity of fossil seeds in the sediments, point to a semiarid climate on a sparsely vegetated prairie. This picture, of course, is oversimplified; there must have been other plants, especially in local areas, not represented by fossilized remains. It should be pointed out, also, that our view of the Ogallala is limited to exposures along the eastern escarpment of the High Plains where deposits are thinner than they are said to be farther west beneath the High Plains surface

REGIONAL CORRELATIONS

The term Ogallala, now used by at least some workers in Texas, New Mexico, Oklahoma, Colorado, Kansas, and Nebraska, was first proposed by Darton in 1899 (p. 734, spelled Ogalalla in original definition) from an area in western Nebraska. Subsequent work (Darton, 1905, 1920; Elias, 1931, 1942; Hesse, 1935; Lugn, 1938, 1939) has refined the definition and recognized as type section the exposures on Feldt ranch approximately 2 miles east of the town of Ogallala, Nebraska. This definition clearly restricts the formation (or group) to beds of Neogene age, older than the regional unconformity that separates this unit from deposits that contain the well-known Blancan fossil vertebrate fauna.

The Ogallala of Nebraska was classed as a group (Lugn, 1938, 1939) containing four formations; at the base the Valentine (F. W. Johnson, 1935), next above is the Ash Hollow (Englemann, 1876; Lugn, 1939), locally the Sidney gravels (Lugn, 1938) are recognized above the Ash Hollow, and the Kimball (Lugn, 1938, 1939) comprises the uppermost part of the unit. In Kansas the Ogallala has been classed as a formation containing three members (Moore and others, 1951; Frye, Leonard, and Swineford, 1956), Valentine, Ash Hollow, and Kimball, the last including in its base the gravel lentils called Sidney in Nebraska classification; the units in Kansas have been referred to the Nebraska type localities. As has been stated, we here class the Ogallala of the area under study in Texas as of formational rank but judge the subdivisions Valentine, Ash Hollow, and Kimball to have insufficient regional lithologic distinctiveness to merit their recognition as members and therefore we treat them as floral zones.

The correlation of the Ogallala deposits in this part of Texas, northward across Oklahoma and Kansas to the type localities in Nebraska seems clear and firmly established. In this area, beds equivalent in age to the Valentine are thin and only locally present; it is judged that even as discontinuous occurrences they do not extend as far south as Howard County. The bulk of the Ogallala deposits studied fall within the Ash Hollow and Kimball floral zones; in some places the Kimball zone is directly in contact with the bedrock.

A very brief reconnaissance of the area lying east of the High Plains, particularly Hardeman to Haskell counties, did not bring to light any deposits equivalent in age to the Ogallala. At those places where it was possible to assign a tentative age to the Seymour deposits, they appear to be younger than any of the Ogallala. Recently, however, Van Siclen (1957) has reported outliers of Pliocene deposits as far east as Nolan, Fisher, and Kent counties.

Reconnaissance of the adjacent Edwards Plateau to the south revealed a general continuity of the High Plains surface with the surface of this Plateau, except where Cretaceous rocks project above it or where it has been dissected by Pleistocene erosion. Cretaceous uplands standing well above the Ogallala plain are well illustrated in southern Howard and northern Glasscock counties and in southern Upton and Crane counties, whereas the continuity of High Plains and Edwards Plateau surfaces is illustrated in Martin and Midland counties. The Ogallala deposits are relatively thin and discontinuous under this surface south of the area shown in figure 1, but they can be demonstrated to extend—discontinuously—across Ector and Midland counties at least into Crane, Upton, Reagan, and Crockett counties. In this area the deposits are judged to belong largely within the Kimball zone and are typified by thin sand accumulation overlain by thick caliche capped by the typical pisolitic limestone (southwestern Ector County, Pl. 1C).

The Pleistocene dissection of this surface is strikingly shown by the low scarp northeast of Penwell in southern Ector County. Here, very thin Ogallala veneers the upland surface and the linear sag in topography extends southeastward into northern Crane County where the deposits under its floor yielded a diagnostic Early Wisconsinan snail fauna.

It is questionable if the thin and discontinuous deposits that veneer this surface south of the area here under discussion should be included within the formal stratigraphic unit, the Ogallala formation. However, even though the name is not applied it seems clear that they are age equivalents and represent the feathering out to the south of this truly extensive alluvial deposit.

"CAPROCK" COMPLEX

The stratigraphic top of the Ogallala formation and of the Kimball floral zone consists of an impure, irregular, resistant limestone. This bed, which is perhaps the most distinctive lithologic entity within the formation, is traceable from Nebraska to west-central Texas and in general becomes thicker and more continuous southward. It attains its most striking development in this area and the counties adjacent to the south. In western Texas it is the only widespread resistant bed within the formation and at many places forms the capping rock of the High Plains escarpment and canyon walls. At many places the uppermost foot or two of this layer is usually hard and characterized by concentric and irregular banding that has led to the special names of "Algal limestone" (Elias, 1931, p. 136) and "Pisolitic limestone" (Swineford, Frye, and Leonard, 1956).

The origin of the caprock caliche of the Ogallala formation and similar deposits farther south in Texas has in recent years been assigned to action of groundwater evaporation (Trowbridge, 1926) accumulation in lakes or ponds of various types and sizes (Elias, 1931; Theis, 1936; Frye, 1945), and to a variety of origins that have in common the idea of movement of calcium carbonate in the surficial layer by processes considered to be more or less analogous to those classed as soil-forming processes (Price, 1933, 1940; C. L. Baker, 1933; Bretz and Horberg, 1949; Brown, 1956). It is our judgment that the weight of evidence favors the latter group for the reasons that have been stated elsewhere (Swineford, Frye, and Leonard, 1956).

As the general appearance and character of the caprock bed have been described many times in the literature, a detailed description here would be repetitious and we will confine ourselves to aspects of the problem that have bearing on the stratigraphy.

It has been generally assumed that the caprock bed with its characteristic upper zone of "pisolitic limestone" marks the top of the late Tertiary depositional sequence and that this deposit formed, to approximately its present character, before the beginning of Pleistocene time. This conclusion is given strong support by the local presence of abraded cobbles of this distinctive rock in the basal part of the unconformably overlying Blanco formation (Evans and Meade, 1945, p. 492), and our observations throughout the region give it general support. The "Caprock zone," however, is not a simple phenomenon, and it is our opinion that materials of more than one age have been loosely grouped under this heading.

In western Texas, deposits of each of the Pleistocene cycles (older than the Wisconsinan) contain, at least locally, strong accumulations of caliche in their upper parts (Pls. IIIB, IV) as a result of the development of "limestone-accumulating" soils under a relatively stable surface. On none of these has there been observed the distinctive lithology recently called "pisolitic limestone," but lacking this strongly distinctive bed it is in some places difficult to differentiate subsequent cycles of caliche that have accumulated in thin early Pleistocene deposits that overlie the Ogallala.

As the Illinoian "Cover sands" are generally clearly separable from the Ogallala, even where they are only a few feet thick and contain a well-developed soil caliche in the upper part, it is judged that multiple cycles of caliche development associated with the caprock are Nebraskan and perhaps Kansan in age. A caprock composed of two recognizable layers with greenish-gray, weakly cemented sand between them has been studied at several localities (*e.g.*, the rim of Yellowhouse Canyon northeast of Slayton); in these areas it was generally possible to determine a broad gentle sag on the Ogallala surface. As surface drainage of the Ogallala alluvial plain was probably not integrated over the entire surface by Nebraskan time, the gentle consequent or initial swales on this surface may have received thin deposits, equivalent in age to the Blanco formation, in the upper surface of which strong caliche accumulation has subsequently taken place. At no place where a multi-layered caprock has been studied have we observed the clearly distinctive "Pisolitic limestone" at the top of the complex; it is concluded that the relatively long interval of rigorous surface conditions existing at the climax of Ogallala deposition was required for its development, at least in the area under discussion.

PLEISTOCENE DEPOSITS

BLANCO FORMATION (NEBRASKAN)

The term Blanco beds, or Blanco formation, has been in use in central western Texas since the name was introduced by Cummins (1891, 1892, 1893). Although this early usage of the term was based on a type area in the mid-portion of Blanco Canyon, Crosby County, which has remained the type area, it was used loosely to include much of the late Tertiary of that region. Subsequent workers (Gidley, 1903; Gould, 1906; C. L. Baker, 1915; Sellards and others, 1933) noted these beds and, although arranging them above the Clarendon and Hemphill beds, retained them within the sequence of Pliocene deposits. It was not until the work of Evans and Meade (1945) and Meade (1945) that they were recognized as clearly distinct from the deposits here classed as Ogallala formation and properly classed as early Pleistocene Nebraskan. This dating was subsequently supported (Frye, Swineford, and Leonard, 1948) by regional stratigraphic, paleontologic, and petrographic work toward the northeast which established correlation of beds in this region with the glacial sequence exposed along the central Missouri Valley.

Although we have carefully restudied the Blanco formation in Blanco Canyon and at other places in this region we have little to add to the general lithologic descriptions and age assignment made by Evans and Meade (1945). The Blanco formation is more restricted in its distribution and available exposures than any other of the Pleistocene units and we failed to obtain additional paleontological data. Our discussion will be concerned primarily with the environment of deposition and paleoecological implications.

The vertebrate faunas of the Blanco formation in the type area have been studied intensively by Meade (1945), who reviewed previous studies in detail and presented evidence to show that the Blanco formation and its faunas are of Nebraskan age, although he conceded (Meade, 1945, p. 19) that this interpretation might be expanded to include Aftonian. In view of Meade's detailed studies, no attempts at collecting vertebrate fossils from the Blanco formation were made by us.

Both Evans and Meade (1945) and Meade (1945) rejected the views of other workers who had concluded that the typical Blancan deposits were fluviatile in origin, in favor of sedimentation in a large lake. In addition to the objections to this view that can be adduced from lithological evidence, such a theory of genesis overlooks the significance of the lack of molluscan and certain kinds of vertebrate fossils in the Blanco and leads, in turn, to a view of contemporaneous ecological conditions that we believe to be completely at variance with known facts. In our judgment, a lake of the dimensions and relative permanence postulated by these authors could scarcely have existed without producing large populations of aquatic mollusks, especially of small pelecypods, such as *Pisidium* or *Sphaerium*. Careful search by us for mollusks in Blancan sediments has been fruitless. In fact, reported fossil vertebrate faunas themselves do not justify the interpretation of humid climatic conditions deduced by Evans and Meade and by Meade; the only turtle listed by Meade (p. 519) is referred to *Testudo,* a genus of terrestrial tortoises, and no remains of fishes or amphibians, to our knowledge, have ever been reported from the Blancan beds of the Texas High Plains. All the known facts about the Blanco formation in this part of Texas clearly point to alluviation by streams of very low gradient flowing across a semiarid terrain.

That the Blanco was deposited by fluviatile mechanisms is attested by local channel deposits, including large abraded cobbles of Ogallala caprock, but the general fine texture of the sediments points with equal clarity to stream regimen of low gradient. Such a stream or streams, shifting, anastomosing, and with extremely unstable bottom conditions seems to account for the absence of fossil aquatic mollusks, which are unable to survive under such conditions. An unstable stream regimen likewise would account for the lack of fishes, amphibians, and aquatic turtles, the extreme paucity of beaver remains, and the lack of rodents with affinities to the muskrats.

Contemporary semiaridity of the local climate seems almost self-evident. Had a humid local environment prevailed during deposition of the Blancan beds, whether by lacustrine or by fluviatile mechanisms, the surrounding plain would certainly have supported some kind of terrestrial molluscan fauna, the shells of which would have been carried into the Blancan sediments by tributary streams. The absence of such molluscan remains, the lack of fossil amphibians or fossil microtine rodents—animals that might be expected to have thrived on the plains under humid climatic conditions—sustain the deduction of a semiarid, rather than a humid, contemporary environment.

Other observations can be marshalled in support of this environmental concept. It is well known, and has been pointed out by us (Frye, Leonard, and Swineford, 1956; Frye and Leonard, 1957), that the Pliocene of the Great Plains region was terminated by a prolonged trend toward progressive aridity that may have increased in the long interval leading to the pluviation that preceded early Pleistocene glaciation. That the High Plains region of Texas was a molluscan desert previous to the pluvial period that initiated Nebraskan glaciation is evidenced by the fact that, with a single exception (*Polygyra texasiana*), the fossil mollusks of earliest Pleistocene deposits in southern Kansas (Frye and Leonard, 1952) do not have southern affinities. The absence of molluscan migratory routes across northwestern Texas can only mean that Pleistocene amelioration of the arid climate prevailing there at the end of Ogallala deposition had either not yet produced an environment suitable for terrestrial or aquatic mollusks, or the time was so short that these animals had not yet immigrated to the region.

Finally, it should be observed that the conditions of deposition of the Blanco formation, postulated by Evans and Meade (1945) and by Meade (1945), are not basically different than those known to have prevailed in the subsidence area of southwestern Kansas, where beds of the same age (Hibbard, 1938; Frye and Leonard, 1952) occur. In southwestern Kansas, however, sediments of Nebraskan age yield a rich molluscan fauna including branchiate gastropods and sphaeriid pelecypods that require permanent water, a varied assortment of aquatic pulmonate gastropods, and numerous terrestrial gastropods, as well as beavers, microtine rodents, and a notable assemblage of amphibians (Taylor, 1941, 1942). The strong contrast between the evidences of contemporary faunas found in Nebraskan sediments in southwestern Kansas and those found in typical Blancan sediments along the High Plains escarpment in Texas cannot be without profound ecological significance.

TULE FORMATION (KANSAN)

The name Tule was first applied by Cummins in 1893 as follows (p. 199) : "The name is taken for the reason that the beds are well developed along Tule Canyon, in Swisher County, a tributary of the South Fork of Red River, reaching that stream at or near the mouth of Palo Duro Canyon in Briscoe County." The name Rock Creek beds, from a tributary to Tule Canyon, has been used locally in an interchangeable way with Tule. The fossil vertebrates have been studied and listed by several workers (Cope, 1893; Gidley, 1903; Troxell, 1915a, 1915b; Sellards and others, 1933, p. 797; Evans and Meade, 1945). Although these beds have generally been regarded as Pleistocene, and were assigned by Evans and Meade (1945) to middle or intermediate Pleistocene, they were not referred specifically to a late Kansan age until correlations of the fossiliferous deposits of northwestern Texas were made with the glacial deposits of the Missouri Valley region (Frye, Swineford, and Leonard, 1948).

The name Tule formation is here used as a regional unit to include all deposits of the Kansan cycle in the area under study. It is thus applied not only to the relatively slack water fills of the broad valleys that crossed the High Plains area, now exposed along more recently developed canyon walls (Tule and Spring Creek Canyons, figs. 3D, 4C), but also to high terrace deposits of the same age that flank some of the major canyons (fig. 4A), and to terrace deposits of equivalent age that occur beyond the escarpment of the High Plains (fig. 3C). As we judge all of these to be stream-laid sediments, although the results of differing stream regimen, and as they have been established to be age equivalents, it seems most appropriate to include these deposits in a single formation.

Details of local lithology are presented in the measured sections included with this report. Measured sections no. 5 (Briscoe County), nos. 23 and 24 (Swisher County) in the type area, and nos. 15 and 16 in Spring Creek Canyon (Garza County) are representative of lithologies commonly found in abandoned valleys that underlie the High Plains surface; measured section no. 13 (Garza County) is representative of these deposits where they occur in minor valleys adjacent to the High Plains escarpment; measured section no. 8 (Crosby County) describes Tule deposits in the prominent terrace near the mouth of Blanco Canyon; and measured section No. 3 (Briscoe County) illustrates the Tule formation where it constitutes a locally high level terrace well beyond the limits of the High Plains.

The data from these measured sections and repeated intermediate observations in the field show that generally throughout the region the Tule formation is a cyclical stream deposit with gravels in the base but with sand and silt in the upper part constituting the greater bulk of the formation. Some deposits assigned to the Tule may have accumulated in shallow undrained depressions existing on the Ogallala surface (measured section no. 4, Briscoe County; Pearlette volcanic ash locality on High Plains scarp, east-central Briscoe County, fig. 1) as it is quite possible that Kansan drainage was not integrated throughout all of the region; the local lithology and physiographic setting are suggestive of such an environment of deposition.

Lenticular deposits of Pearlette volcanic ash, useful for precise dating of late Kansan deposits (Frye, Swineford, and Leonard, 1948), are commonly found in the shallow, upland depression fills but have also been studied in the type area of the Tule formation (measured section no. 24), and in road cuts through the Kansan terrace deposits (fig. 3A) north of Beals Branch, eastern Howard County (5 miles south of junction of State Highways 80 and 821). Samples from these, and other previously unreported localities shown in figure 1, were studied petrographically by Dr. Ada Swineford and identified as assignable to the Pearlette bed.

Although our interpretation of the available data indicates that some thin, local deposits of Kansan age accumulated in shallow undrained depressions, that were perhaps consequent upon the Ogallala plain of alluviation, we conclude that the thick sequence of Tule formation exposed in Tule Canyon near the Briscoe-Swisher County line, and in Spring Creek Canyon (Garza County), accumulated in erosional valleys rather than in deflation basins. This conclusion is based on several lines of reasoning: (1) Deflation basins of younger age exist on the High Plains surface (Evans and Meade, 1945) and we had opportunity to study several of them. They are characterized by the nearby accumulation of much of the deflation product. As the Ogallala formation consists predominantly of sand, this material must have been removed in large quantity for a basin to be blown into the surface of the formation. In central western Howard County there is a basin judged to have been in part excavated by deflation, and here an extensive sand dune tract is immediately adjacent to it on the north and northeast. Such evidence of deflation product is not to be found adjacent to the type Tule area or Spring Creek Canyon. Neither is there evidence of lag concentrate in the base of the formation in these areas in spite of the fact that some gravels as well as coarse sand occur in the adjacent Ogallala formation. (2) As abraded cobbles of "Caprock" limestone have been observed in the base of both the Blanco and Tule formation, we conclude that this layer must have been at least partly indurated before the advent of Pleistocene alluviation and should have been most effective in preventing deflation except where breached by water erosion. Furthermore, unmistakable evidence of secondary solutional effects have been observed at many places at the top of this capping limestone (Pl. IC), but nowhere have we observed characters indicating eolian abrasion or scour. (3) A comparison of the lithology of the Tule between these areas and situations in terrace positions shows a strong similarity, with the only consistent contrast being the greater abundance of basal gravels in the terraces—consistent with steep gradients adjacent to the escarpment. It is evident that a deflation basin lake was not the environment of deposition at measured section no. 14. (4) There is not a marked contrast in the ecological requirements of the molluscan faunas in the Tule formation between Tule and Spring Creek Canyons on the one hand and the terrace situations on the other. Finally, (5) there is a strong suggestion of the reflection of this buried drainage system in the surface topography of the undissected High Plains surface. This was observed in eastern Swisher County where linear sags project toward areas of thick Tule. A similar topographic pattern, clearly unrelated to present surface drainage has been observed at many places on the High Plains surface (north-central Dawson County) and may be comparable in origin to the linear erosional sags, not occupied by significant surface drainage, farther south in Ector and adjacent counties.

Such a depositional history seems to be much more compatible with all the known facts than the concept of large deflation basins subsequently filled by extensive lakes. Ecological evidence from the fossil mollusks (Frye and Leonard, 1957) indicates that Kansan time was by far the most abundantly watered period between the arid interval at the climax of Ogallala deposition and the present. As the eastern escarpment developed after the close of Ogallala deposition and as the upper parts of the canyons notching the High Plains from the east contain terraces no older than the Wisconsinan, it seems logical to conclude that the filled and abandoned drainage system that venates the High Plains surface is predominantly Kansan in age. As the retreating eastern escarpment of the Plains must have been roughly coincident with a major drainage divide during the well-watered Kansan interval, it logically follows that the streams flowing off this scarp toward the east had steeper gradients (and thus retained their identity) than the southerly trending systems that crossed a much greater expanse of the High Plains.

Molluscan faunas.—A total of 55 kinds of Mollusca were recovered from Kansan deposits at nine localities distributed from Borden to Briscoe counties (fig. 7). Two localities are in the type area of the Tule formation sediments; the remainder are other terrace exposures of equivalent age east of the High Plains escarpment. These are in addition to the two localities (fig. 1) reported earlier from the Panhandle area (Leonard, 1950). For the most part, collections were made by hand-picking from the outcrop, rather than by bulk sampling, and it is likely that additional species will be found when bulk methods are employed.

Eighteen kinds of aquatic gastropods are included in the faunal assemblage, and at least four kinds of sphaeriid pelecypods, also aquatic in habit, were collected. The remainder of the assemblage consists of terrestrial gastropods with varying habitat requirements. It is obvious from the numbers and variety of Kansan molluscan assemblages that amelioration of the climactically rigorous Pliocene environment, referred to earlier, had endured for a sufficient period of time to permit the development of molluscan migration routes across northern and northwestern Texas, but it is worthy of note that a significant part of the assemblage has northern, rather than southern, affinities.

The most remarkable elements among the aquatic gastropods include *Aplexa hypnorum, Gyraulus crista, Lymnaea* cf. *megasoma, Menetus pearlettei, Physa* cf. *sayi,* and *Valvata tricarinata. Aplexa hypnorum* is a nearctic species, distributed in northern Europe, northern Asia, and in North America from Alaska and Hudson Bay south to the Ohio River. It does not now live in the central Great Plains region but was reported from Kansan deposits at several localities in Kansas by Leonard (1950). According to F. C. Baker (1928, p. 474) it is "characteristic of swales, stagnant pools, and ephemeral ponds, with *Stagnicola caperata, Physella hildrethiana* and *Sphaerium occidentale,* forming a peculiar ecological fauna." *Gyraulus crista* is another circumpolar species, widely distributed in Europe but not common in North America. It was found in the same exposure as was *Aplexa hypnorum* (measured section no. 23). *Valvata tricarinata,* found at three localities, is the only branchiate gastropod in the total Kansan assemblage. It is also a northern species, living today in northeastern United States, but extending as far west as Iowa and as far north as Great Slave Lake. *V. tricarinata,* because of its method of respiration by gills, requires permanent water as a habitat; its presence, therefore, in the Kansan assemblage of central western Texas has profound implications as to the adequacy and stability of water in the region in late Kansan time. *Gyraulus, Helisoma, Lymnaea, Menetus,* and *Physa* are pulmonate (*i.e.,* air-breathing) aquatic gastropods, less sensitive to fluctuations in water supplies than are branchiates. The great number and variety of aquatic pulmonate gastropods, capable of living in ephemeral pools and intermittent, slow-moving streams, as well as in permanent bodies of water, carries obvious implications concerning aquatic environments in the area during late Kansan time. The environmental significance of the specimen from Tule deposits in Garza County (measured section no. 15) referred to as *Lymnaea* cf. *megasoma* cannot be properly evaluated as the identity of the single individual is in doubt because of the state of preservation. *L. megasoma,* is a northern species, originally described from Manitoba. The four kinds of sphaeriid pelecypods, *Pisidium compressum, Pisidium* sp., *Sphaerium solidulum,* and *Sphaerium* sp., are capable of living in a variety of aquatic habitats, both lacustrine and fluvial.

Amnicola and *Pomatiopsis,* genera of branchiate gastropods of common occurrence in Kansan deposits in Kansas and Nebraska, have not yet been found in the area under study.

The 33 kinds of terrestrial gastropods vary from long-ranging species known from earliest Neogene deposits in the Great Plains to the Recent, to those which are restricted to the Kansan Age, or to early Pleistocene. In habitat requirements, the several species vary from those of widest ecological tolerance, capable of thriving under semi-desert conditions (*Bulimulus dealbatus, Pupoides albilabris, Succinea*[3]) to those which require the almost constant presence of water (*Carychium*). Some kinds prefer woodlands or woodland bor-

[3] The names *Succinea avara* and *Succinea grosvenori* are used in this paper in the sense of form-species, with the full understanding that the shells may not be properly assigned to these species when their affinities are better understood. The shells of *Succinea* are not reliable indices to species in most cases.

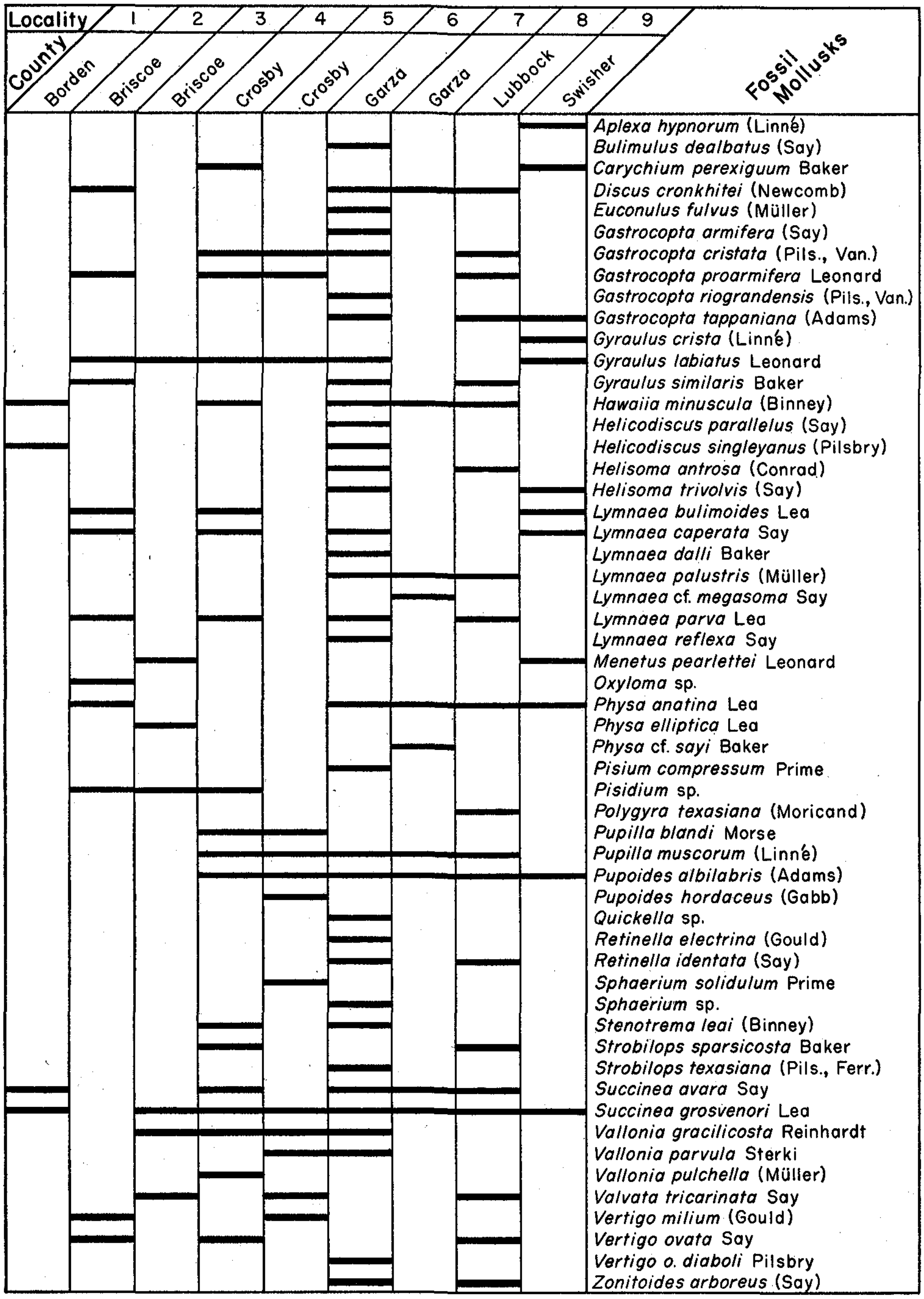

FIG. 7. Check list of fossil mollusks from Kansan deposits. The locality numbers refer to the following locations: (1) 3 miles E, on U. S. Highway 180, from W line Borden County; (2) see measured section no. 3; (3) see measured section no. 5; (4) 2 miles S Caprock, Crosby County; (5) see measured section no. 8; (6) see measured section no. 14; (7) see measured section no. 15; (8) 5 miles N Slayton, Lubbock County; (9) see measured section no. 23.

ders (*Euconulus fulvus, Retinella electrina, Strobilops, Polygyra, Zonitoides*), while others may live in open prairies (*Gastrocopta armifera, Hawaiia minuscula,* some species of *Succinea,* and *Vallonia*). From the nature of the assemblages, a picture of widely variable environment in the area may be thus deduced; this is exemplified among the localities studied. Locality no. 6, Garza County, for example, possesses a large assemblage of species consisting of many aquatic pulmonates as well as a wide variety of terrestrial species. The local environmental picture comprises, therefore, ponds or small streams, bordered by trees and woody shrubs, with areas of open prairie in the vicinity. The local habitat was obviously favorable for a variety of kinds of mollusks. In contrast, locality no. 1, Borden County, yielded only those species capable of living under adverse ecological conditions; the assemblage is small, and population numbers were extremely low. The Garza County locality is situated less than 2 miles from the present rim of the escarpment, where, in Kansan times, trees and other vegetation flourished under well-watered local conditions; contact springs probably provided a constant supply of water to support vegetation and aquatic gastropods. The Borden County locality, on the other hand, is situated much farther from the present position of the escarpment, on a high-level surface no longer confined to the present valley of the Colorado River. Here the ecological picture is that of a prairie, with relatively low water table, and devoid of trees or shrubs. Thus, at their best, local ecological conditions were much more favorable to mollusks in Kansan times than now but locally were little better than at present.

From the standpoint of stratigraphic paleontology, the Kansan faunas of this area of Texas seem less definitive than those in Kansan deposits of Kansas, Nebraska, and western Iowa. This is probably due in part, at least, to the fact that the Texas faunas are at present known only from nine localities, but local ecological conditions, and the time factor in migration, seem significant factors also. As a case in point, *Valvata tricarinata* is known to occur in only a third of the nine localities and in them is represented only by a few shells; in Kansas and Nebraska, *V. tricarinata* often occurs in local faunas in enormous populations, sometimes exceeding in numbers all other shells combined. Several definitive Kansan species of northern exposures have not been collected; these include *Amnicola limosa, Pomatiopsis cincinnatiensis, Gyraulus pattersoni, Oxyloma navarrei, Planorbula vulcanata,* and one or two others of rare occurrence.

Of greater importance in the present context, however, is the fact that Kansan molluscan assemblages in the area under study contain many species known to be definitive of the Kansan Stage of the Pleistocene. These species, which are diagnostic of the Kansan, include:

Aplexa hypnorum
Carychium perexiguum
Gastrocopta proarmifera
Gyraulus labiatus
Gyraulus similaris
Lymnaea reflexa
Menetus pearlettei
Physa elliptica
Strobilops sparsicosta
Valvata tricarinata

Among the restricted Kansan species, only *Carychium perexiguum, Gastrocopta proarmifera, Gyraulus labiatus, Menetus pearlettei,* and *Strobilops sparsicosta* are known to be extinct. So far as known, however, more than 90 percent of the Kansan species no longer live in Texas in the area under study, although many still live in North America under more favorable ecological conditions. Several other species, including *Discus cronkhitei, Gastrocopta tappaniana, G. cristata, Helisoma antrosa,* numerous species of *Lymnaea, Physa anatina, Pisidium compressum, Pupilla blandi, P. muscorum, Retinella electrina, R. identata, Succinea avara, S. grosvenori, Vallonia gracilicosta, Stenotrema leai, Vertigo milium, Vertigo ovata,* and *Zonitoides arboreus* are characteristic of Kansan assemblages, without being restricted to this Stage. Other species listed in figure 7 are either long ranging, and hence of little stratigraphic significance, or of such rare occurrence as to have little value. *Carychium perexiguum* and *Strobilops sparsicosta* are known in southern Kansas from Nebraskan as well as Kansan deposits; in the absence of Nebraskan faunas in this part of Texas, however, they become diagnostic Kansan sspecies. They are much more characteristic of Kansan than that of Nebraskan assemblages, even in the central Great Plains.

Mollusks of most frequent occurrence, whether from Kansan or later Pleistocene assemblages, are illustrated on Plate V.

Regional correlations.—Correlation of the Tule formation throughout the region is firmly established by the contained lenticular deposits of Pearlette volcanic ash that have been studied and identified by Ada Swineford, the large fossil molluscan faunas reported here, and the several vertebrate fossil collections summarized by Evans and Meade (1945). As these lines of evidence are independent of drainage pattern, they have permitted correlation across the divide areas separating the basins of Colorado, Brazos, and Red rivers. Outward from the margin of the High Plains, the terraces in each of these river systems can be traced by physiographic methods once the sequence and age relations of the several terraces have been established by regional correlation. It is fortunate indeed that the southernmost locality of Pearlette volcanic ash in eastern Howard County permits the projection of the Kansan terrace system into the Colorado River basin.

The correlation of the Kansan cycle of sediments southward across western Texas is in effect a continuation of earlier regional correlations of this cyclic unit into the Panhandle area (Frye, Swineford, and Leonard, 1948). In this earlier work, age correlations with the sequence of continental glacial deposits in southeastern South Dakota and western Iowa were established across Oklahoma, Kansas, and Nebraska. In the central Missouri Valley region, lentils of Pearlette volcanic ash and associated fossil molluscan faunas were found in sediments, judged to be retreatal Kansan outwash, resting on calcareous Kansas glacial till; these deposits, containing a weathered zone in the top, are unconformably overlain by Loveland loess (correlated with the Illinoian glacial cycle) which in turn contains the Sangamon soil in the top; the Loveland is in turn overlain by glacial till of Iowan age and younger deposits of Wisconsinan age. These relationships clearly establish the age of this cycle of sediments throughout the interior of the continent—including the Tule formation of western Texas—as late Kansan and as depositional equivalents of retreatal Kansan outwash. As it seems certain that the climatic pulses that produced the episodes of continental glaciation extended generally over the interior of the continent, it is logically expectable that the cycles of erosion and alluviation of streams heading in the Plains region would be in general coincident with the alluvial cycles associated with streams heading in the glaciated area.

In the region under study, the alluvial sequence is in general similar among the three river basins involved (figs. 3, 4, and 5). Eastward from the High Plains scarp, the Kansan cycle is represented by high terrace remnants that indicate that the general trend of the Kansan drainage was similar to the present, although the positions of channels have shifted. It was not within the province of this study to trace these terraces downstream along these valleys beyond the limits of the area shown in figure 1.

DEPOSITS OF ILLINOIAN AGE

Deposits of this area related to the Illinoian cycle contrast sharply with the earlier Pleistocene deposits. Not only are they more diversified in type and occurrence, but the dating is less exact. With the exception of a few localities, the Illinoian cycle is dated by framing between dateable Kansan and Early Wisconsinan.

Although geographically of wide distribution, the Illinoian cycle is the weakest of the major Pleistocene cycles as expressed by alluvial terrace deposits; in contrast, eolian deposits on the uplands occur over much of the area. As two distinct depositional provinces are represented, the upland deposits will be discussed first and then the alluvial terraces will be described.

Upland deposits.—Reddish sands with various amounts of silt and locally a trace of clay, containing a strongly developed soil profile in the top (Pl. IV), ranging up to more than 25 feet, but averaging less than 10 feet in thickness, occur extensively over the High Plains surface of this part of Texas. As these surficial sheet sands of this region have generally not been excluded from the Ogallala, by implication they have been included within it, although somewhat comparable red sands farther south (Pl. IC) were named the Judkins formation of Pleistocene age by Huffington and Albritton (1941). In this area the sheet sands lack the topographic expression of dune forms described from farther south and may include more than one age of deposit. Because of these differences, the informal name "Cover sands" is here used to designate these materials in this area rather than the geographic extension of the term Judkins formation. It seems certain that the Judkins formation sands belong within the complex called "Cover sands," although they may be only one phase of this more extensive unit.

At every place Cover sands have been observed resting on Ogallala formation, the contact is unconformable (Pl. IC; measured sections nos. 1, 2, 6, 9, 10, and 12), and at some places solutional effects are apparent in the top of the Ogallala "Caprock" limestone. These sheet sands overlap unconformably both Blanco and Tule formations and are overlain by upland depression fills containing rich fossil molluscan faunas (fig. 4). At some places (*e.g.*, 12 miles north of Lamesa) the upper few feet of the "Cover sands" appear to have been reworked by sheet wash and to be somewhat younger than the main body of the material. The sheet-wash veneers locally contain angular fragments of "Caprock" limestone from the highest elements of the topography and are thus clearly distinguishable from the more uniform sand below. The very sparse fauna they contain consists of a few terrestrial snails that range into the Early Wisconsinan.

The origin of the cover sands complex presents a difficult problem. These sands form an extensive surface mantle, which in many areas extends as an unbroken sheet from the highest upland surfaces down long gentle slopes and onto intermediate levels. These topographic relations preclude stream deposition, but the lack of clearly distinguishable dune forms, except in the southern part of this area (fig. 1) and farther south, casts some doubt on a concept of eolian origin. It is our conclusion that the gradational relation of the "Cover sands" of the Dawson to Randall County area with the clearly dunic topography of the Judkins formation farther south and the lack of any other known mechanism that could produce such a widespread deposit forces the acceptance of an eolian origin for these sands. In parts of the area, they may have initially displayed a subdued dunic topography subsequently modified by sheet wash, but in others, they may have been deposited as an eolian sheet sand moving over a surface devoid of all but scattered clumps of vegetation. An example of such an environment exists under present conditions farther south at various places on the Edwards Plateau, where sand is being swept by winds from one small hummock to another, each localized by a small mesquite bush, or other brushy plant, with essentially barren sand between. In these areas a recognizable dune form has not developed, but a foot or two of sand is in transit across the surface. The seemingly considerable distances over which sheet sands are now moving suggests that an adequate source for the "Cover sands" was provided by major valleys, such as the Pecos, and the Ogallala formation where the "Caprock" limestone was breached along Kansan drainage ways, many of which are no longer through-flowing water courses on the High Plains surface. This is consistent with the observations that these sands become less continuous northward within this area, and that the Recent sheet sands to the south thin out and disappear toward the east on the Edwards Plateau.

Such an hypothesis of origin requires a relatively sudden and sharp change in climate early within the Yarmouthian from the well-watered conditions of the Kansan and indicates that the formation of the "Cover sands" started during the Yarmouthian. Furthermore, the general conditions of surface stability that are evidenced north of Howard County since the deposition of the sheet sands suggest that the Early Wisconsinan was better watered than the Illinoian. The physical evidence consisting of the distribution and character of the sands and their contained soil profiles and the ecological implication of the fossil molluscan faunas are both compatible with such a history. The well-developed soil, with its thick caliche zone (Pl. IV), that occurs in the top of these sands at many places, when contrasted with the thinner, less calcareous, less red profiles on deposits of known Early Wisconsinan age in the same area, suggests essential surface stability since Illinoian time, and that the "Cover sands" (including the Judkins formation) are largely Yarmouthian and Illinoian in age.

Terrace deposits.—Alluvial terraces assignable to an Illinoian age are less extensive, well developed, or distinctive than the alluvial terraces dated as Kansan or Early or Late Wisconsinan. Beyond the High Plains scarp, Illinoian terraces have been recognized in normal physiographic sequence with Kansan and Wisconsinan terraces (fig. 3), but where terrace deposits of Illinoian age have been recognized within the High Plains canyons, these materials seem to be at the level of the Kansan deposits, or only slightly below them (fig. 4). These data indicate a sharp interruption of the Illinoian stream profiles within the valleys alluviated by the Tule formation, and that these eroding streams were less competent than either those of Kansan or Early Wisconsinan time (fig. 5). In other words, as Kansan streams were able to extend their valleys headward well into the Plains (as were the Early Wisconsinan streams), those of the Illinoian were capable only of extending their valleys headward into the valley deposits of the previous cycle and therefore had little effect in dissecting or modifying the topography of the High Plains proper. In fact, beyond the limits of the marginal valleys the Illinoian was probably a time of reduction rather than accentuation of topographic relief because of the choking and obliteration of minor valleys by encroachment of "Cover sands" beyond the capacity of existing streams to carry these sediments away.

Such an hypothesis is consistent not only with the terrace materials but also with the required environment for the "Cover sands," the fossil molluscan faunas of this Age, and the almost complete lack of Illinoian fossil vertebrates. It is also consistent with the ecological history of the central and northern Plains (Frye and Leonard, 1952, 1957), although the severity of this climatic reversal in central western Texas seems to have been greater than it was farther north.

The Illinoian terrace deposits contrast with the older Tule formation largely by being more poorly sorted and perhaps more strongly reflecting a local source. The character of Illinoian terrace deposits is shown by measured sections only in numbers 3, 8, and 14.

Molluscan faunas.—The Illinoian fossil molluscan assemblage, still imperfectly known in the area studied, comprises a total of 29 species, including six aquatic pulmonate gastropods, a single kind of sphaeriid pelecypod, and 22 kinds of terrestrial gastropods (fig. 8). The total number of localities available for study is small, and two of these, one Briscoe County locality (measured section no. 4) and the Dawson County locality, consist of meagerly fossiliferous "Cover sands" from

Fossil Mollusks	Borden: 2 1/4 mi. E on U.S. 180, W.	Briscoe: See measured section no. 3	Briscoe: 13 mi. E Silverton	Briscoe: See measured section no. 4	Dawson: 12 mi. N Lamesa
Discus cronkhitei (Newcomb)		X			
Gastrocopta armifera (Say)		X	X		X
Gastrocopta cristata (Pils., Van.)	X				
Gastrocopta holzingeri Sterki			X		
Gastrocopta procera (Gould)			X		
Gastrocopta riograndensis (Pils., Ferr.)		X	X		
Gastrocopta tappaniana (Adams)		X			
Gyraulus cf. *altissimus* (Baker)		X			
Gyraulus sp.	X		X		
Hawaiia minuscula (Binney)	X	X	X	X	X
Helicodiscus parallelus (Say)	X	X			
Helicodiscus singleyanus (Pilsbry)	X				
Helisoma antrosa (Conrad)		X			
Lymnaea caperata Say		X			
Lymnaea parva Lea	X				
Physa anatina Lea	X				
Pisidium compressum Prime			X		
Pupilla blandi Morse	X	X			
Pupilla muscorum (Linné)			X		X
Pupilla sp.			X		
Pupoides albilabris (Adams)	X	X	X		
Quickella sp.			X		
Retinella electrina (Gould)		X			
Succinea avara Say	X			X	X
Succinea grosvenori Lea	X	X			
Vallonia gracilicosta Reinhardt	X	X	X		
Vallonia parvula Sterki					X
Vertigo modesta (Say)	X				
Vertigo ovata Say			X		

FIG. 8. Check list of fossil mollusks from Illinoian deposits.

which only a few species of terrestrial gastropods have been obtained. The principal significance of these sparse faunas, situated unconformably below fossiliferous Early Wisconsinan depresion-fill sediments, is to prove beyond doubt that the "Cover sands" cannot be related to the Ogallala formation, as has been suggested by Evans (1949) and others.

The remaining localities, situated in typical alluvial terraces, yield a more numerous and varied fauna. Even these faunas lack great distinctiveness; they may be distinguished from Kansan assemblages by the absence of restricted Kansan species, discussed in a previous section, but they cannot at present be distinguished from Early Wisconsinan assemblages (fig. 9). In general, Leonard (1952) found the same to be true of Illinoian fossil molluscan assemblages in Kansas.

Ecologically speaking, the Illinoian assemblages of fossil mollusks now known from this part of Texas indicate a terrain of prairies with small amounts of timber and woody understory vegetation. Water supplies must have been rather meager and unstable, to judge from the lack of branchiate snails, or even any great variety of aquatic pulmonate gastropods. The local environment was obviously less humid than that which prevailed during Kansan time, which is in keeping with the observation that the Illinoian erosional-sedimentary cycle was much weaker almost everywhere on the Great Plains than was the Kansan cycle.

EARLY WISCONSINAN DEPOSITS

Early Wisconsinan sediments and contained molluscan faunas are widely distributed throughout the southern High Plains, as they are in the central and northern Plains (Frye and Leonard, 1952). Terrace deposits of this age generally follow the trend of existing streams, occupy a physiographic position below all earlier Pleistocene terraces, and stand a few to several feet above late Wisconsinan terraces or flood plain (figs. 3, 4, and 5). This general relationship is true throughout most of the Great Plains region. In strong contrast, the Early Wisconsinan deposits on the uplands of this part of Texas differ sharply from upland deposits of similar age in the central and northern Great Plains. In Nebraska and northern Kansas (Frye and Leonard, 1951) the uplands are extensively mantled by thick and almost continuous blankets of fossiliferous loess—the Peoria or Peorian loess—the thin southern limits of which have been reported from the northern part of the Texas Panhandle. In southwestern Kansas (Frye and Leonard, 1952) there are extensive sand dune tracts of this age, and the Monahans sands (Huffington and Albritton, 1941) of the southwestern Edwards Plateau may also be in part Early Wisconsinan in age. In this area (fig. 1), however, Wisconsinan eolian deposits have been observed on the uplands only on the lee of deflation areas, and the most prevalent deposits are lacustrine or pond sediments in many undrained depressions.

Terrace deposits.—Detailed description of these terrace deposits are presented in measured sections numbered 8, 17, and 24. Although locally they contain coarse gravels in the basal part, the Early Wisconsinan terrace materials are generally finer textured than the Kansan and Illinoian in the same vicinity and commonly contain one or more incipient buried soils in the upper part. The surface soils developed on these materials are weaker, less red, and contain much less conspicuous zones of caliche accumulation than do the surface soils on the Illinoian and older deposits. At many places the surface of the Early Wisconsinan terrace is a smooth, relatively undissected surface, wider than the combined width of the Late Wisconsinan terrace, flood plain, and stream channel. Terraces of this age can be recognized in almost every valley of any significant size and display about the same relation to channel position in the tributaries to the Red, Brazos, and Colorado rivers. These data, coupled with the ecological implications of the fossil molluscan faunas, all indicate that the Early Wisconsinan was a relatively well-watered period and that this cycle of erosion and alluviation was much more vigorous than any that has followed.

Although the Early Wisconsinan cycle is well represented in this part of Texas, it has not been possible to subdivide it or to say more than that it is pre-Bradyan, or Scandian (Frye and Leonard, 1952, 1955) of the Kansas region. It is true that incipient soils have been observed in the upper part of the deposits, but they lack the distinctiveness and continuity that are judged essential for a valid basis of subdivision.

Tahoka formation and related deposits.—In 1945, Evans and Meade (p. 459) proposed the name Tahoka clay for the "oldest deposits definitely recognized within modern playa basins. . . ." They stated "The deposit is here named the Tahoka clay for the town of Tahoka in Lynn County, which lies near Tahoka Lake, Mound Lake, and other playas around which the deposit is typically developed and well exposed." They dated the Tahoka deposits as Wisconsin in age (Evans and Meade, p. 498), described their correlation from basin to basin, discussed their origin, and presented measured sections of the exposed sequence. Additional measured sections are presented here (nos. 11 and 21). Due to the preponderance of silt and fine sand in these deposits, we here use the term Tahoka formation rather than Tahoka clay.

As will be pointed out, the Tahoka formation and shallow undrained depression fills of similar age that are widespread throughout the Texas High Plains contain a rich molluscan fauna. We are in essential agreement with Evans and Meade, that these deposits accumulated in lakes held in undrained depressions during the relatively humid Early Wisconsinan, but it is our judgment that the origins of these basins were diverse. That some of them were formed, at least in part, by deflation during the preceding period of aridity seems clear. The extensive basin area west of Big Spring in Howard County is an example of this type of origin. Here the Ogallala formation has been removed over a considerable area, flanked on the northeast by an extensive dune tract; the basin floor locally exposes Triassic bedrock, and the lacustrine deposits of the basin—even though locally highly gypsiferous—contain a diagnostic Early Wisconsinan molluscan fauna (fig. 9). Saline waters now occupy small secondary blowout lakes within the larger basin and Beals Branch has taken a course across one part of this lake-basin floor. Cedar Lake, Tahoka Lake, and others are smaller basins of probable similar origin.

However, many of the Early Wisconsinan faunas reported in figure 9 were collected from thin pond deposits that display none of the collateral physiographic evidence of deflation basins. Some of these local, shallow undrained depressions are thought to be consequent depressions on the High Plains surface as a result of the irregularities of "Cover sand" deposition, and others that display a definite alignment seem to be localized over the fills of early Pleistocene abandoned valleys. In such cases the shallow "saucers" lost contact with integrated surface drainage during the relatively arid period of the Yarmouthian-Illinoian and were occupied by semipermanent bodies of water during the episode of increased precipitation of the Early Wisconsinan. Some of these shallow basins became integrated with the surface drainage during this time; others still contain temporary ponds (Pl. IIIA) during periods of above normal rainfall.

Modification of the Early Wisconsinan basin fills by subsequent deflation has been described at length by Evans and Meade (1945). The Bradyan interval (Frye and

FIG. 9. Check list of fossil mollusks from Early Wisconsinan deposits. The locality numbers refer to the following locations: (1) 4 miles S Dimmitt, Castro County; (2) 7 miles S on Farm Road 1601, N line Crane County; (3) 10 miles N Lamesa, Dawson County; (4) 6 miles E, 2¾ miles S, NW corner Floyd County; (5) 2½ miles E, 1¼ miles S, NW corner Floyd County; (6) measured section no. 11; (7) railroad cut 3 miles SE Southland, Garza County; (8) 14¼ miles SSE Stanton on Texas Highway 137, Glasscock County; (9) 1 mile W junction U. S. Highway 80 and Farm Road 818, Howard County; (10) 1½ miles E on Texas Highway 176, W line Howard County; (11) measured section no. 21; (12) 9 miles N O'Donnell, Lynn County; (13) 6¼ miles N O'Donnell, Lynn County; (14) 16¾ miles SW junction Texas Highways 349 and 115, Martin County; (15) 11 miles E Canyon, Randall County; (16) ½ mile E Farm Road 669 on Colorado River, Borden County; (17) N side Tule Canyon, 2 miles E, W line Briscoe County; (18) measured section no. 7; (19) measured section no. 8; (20) 3 miles N, 3 miles W Kalgary, Crosby County; (21) 2 miles S Caprock, Crosby County; (22) 2 miles W Edgin, Floyd County; (23) measured section no. 17; (24) E edge Big Spring, Howard County; (25) 6 miles S junction U. S. Highway 80 and Farm Road 821, Howard County; (26) 7 miles NE Slayton, Lubbock County; (27) 10 miles E junction Texas Highways 349 and 176, Martin County; (28) 6½ miles E junction Texas Highways 349 and 176, Martin County; (29) 5 miles NE Canyon, Randall County; (30) measured section no. 24.

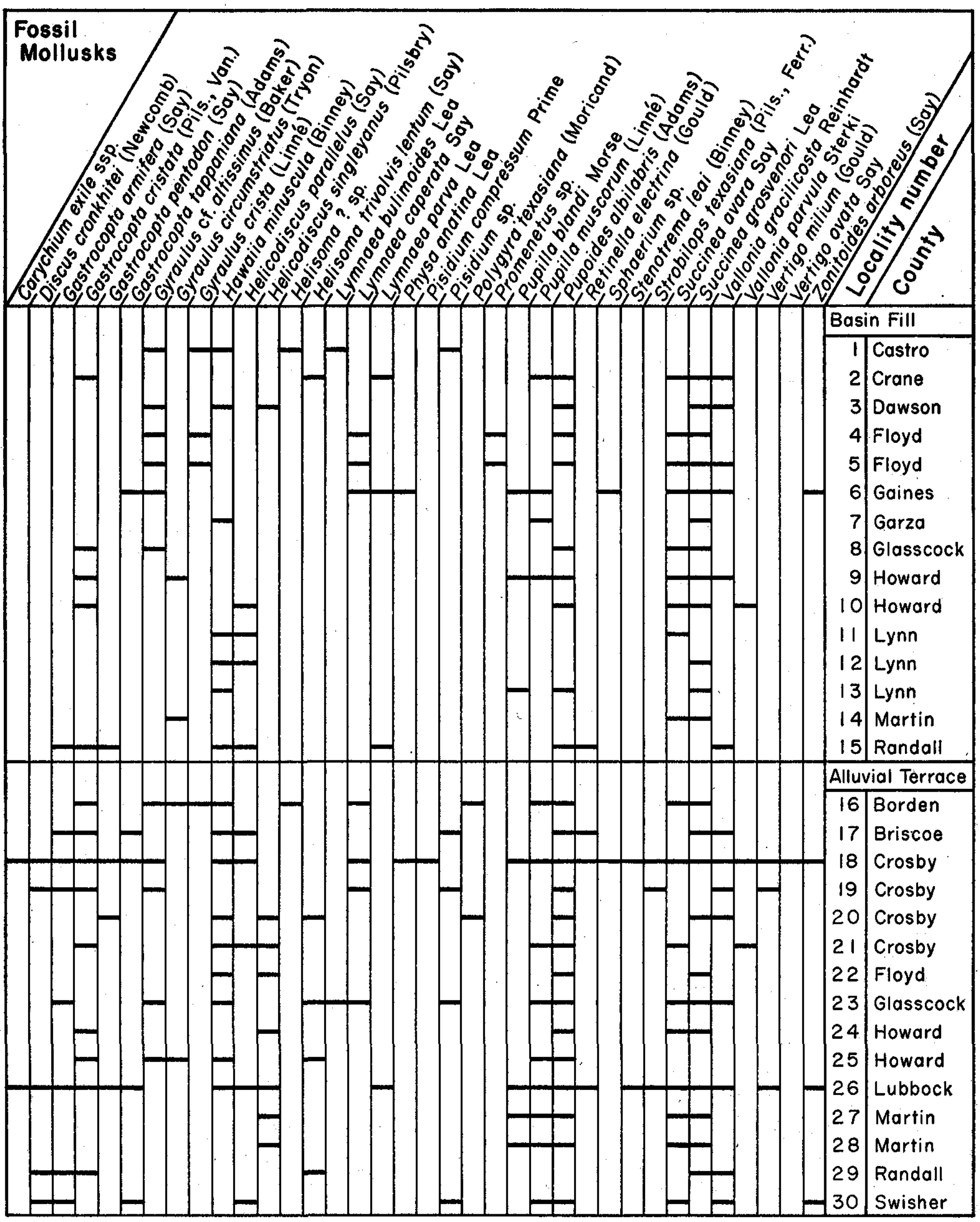
Fossil Mollusks
Carychium exile ssp.
Discus cronkhitei (Newcomb)
Gastrocopta armifera (Say)
Gastrocopta cristata (Pils., Van.)
Gastrocopta pentodon (Say)
Gastrocopta tappaniana (Adams)
Gyraulus cf. altissimus (Baker)
Gyraulus circumstriatus (Tryon)
Gyraulus crista (Linné)
Hawaiia minuscula (Binney)
Helicodiscus parallelus (Say)
Helicodiscus singleyanus (Pilsbry)
Helisoma ? sp.
Helisoma trivolvis lentum (Say)
Lymnaea bulimoides Lea
Lymnaea caperata Say
Lymnaea parva Lea
Physa anatina Lea
Pisidium compressum Prime
Pisidium sp.
Polygyra texasiana (Moricand)
Promenetus sp.
Pupilla blandi Morse
Pupilla muscorum (Linné)
Pupoides albilabris (Adams)
Retinella electrina (Gould)
Sphaerium sp.
Stenotrema leai (Binney)
Strobilops texasiana (Pils., Ferr.)
Succinea avara Say
Succinea grosvenori Lea
Vallonia gracilicosta Reinhardt
Vallonia parvula Sterki
Vertigo milium (Gould)
Vertigo ovata Say
Zonitoides arboreus (Say)
Locality number
County
Basin Fill
1 Castro
2 Crane
3 Dawson
4 Floyd
5 Floyd
6 Gaines
7 Garza
8 Glasscock
9 Howard
10 Howard
11 Lynn
12 Lynn
13 Lynn
14 Martin
15 Randall
Alluvial Terrace
16 Borden
17 Briscoe
18 Crosby
19 Crosby
20 Crosby
21 Crosby
22 Floyd
23 Glasscock
24 Howard
25 Howard
26 Lubbock
27 Martin
28 Martin
29 Randall
30 Swisher

FIGURE 9

Leonard, 1955) that marked a return of semiaridity to the Plains may have witnessed this eolian modification and the development of still additional deflationary "saucers" on the High Plains surface. In any event, the semipermanent to permanent lacustrine conditions of upland depressions have not returned to the Plains since Early Wisconsinan time.

Molluscan faunas.—Early Wisconsinan assemblages of fossil mollusks occur in lacustrine deposits of undrained depressions and less frequently in fluviatile deposits on the High Plains. East of the rim of the High Plains escarpment similar fossil assemblages occur in alluvial terrace deposits. Assemblages from the fills of depressions and those from typical terrace deposits are segregated on figure 9. The total fauna from both types of deposits comprises 36 species; the basin-fill assemblage comprises 28 species, but only a single aquatic gastropod (*Promenetus* sp.) known from basin-fill sediments is not also found in terrace deposits. The differences in the two assemblages are not regarded as particularly significant, but they do reflect a predictable distinction in the local environment in the two situations. With the exception of the single record of *Zonitoides arboreus,* species which inhabit woodlands or woodland borders, such as *Discus cronkhitei, Polygyra texasiana,* and *Strobilops texasiana,* are absent from basin-fill sediments. *Carychium* might be expected to have occurred in the shoreline facies of water-filled depressions, but its apparent absence there may be the result of our collecting methods; the two localities from which these minute shells are recorded were collected by bulk sampling and washing methods, while all other localities were collected by the hand-picking method. Two localities from which the largest assemblages were recovered (Crosby County, no. 18; Lubbock County, no. 26) are situated in unusually favorable positions; both are deep in canyons below gravel-iferous Ogallala formation, which must have resulted in a well-watered local environment. There is also some suggestion at these localities of redeposition of shells from fossiliferous Kansan deposits situated at adjacent higher topographic levels.

The molluscan faunal assemblages both from basin-fill deposits and from alluvial terraces in Texas correlate well with Early Wisconsinan molluscan assemblages, reported by Leonard (1952, fig. 5), from Kansas. There are some differences that might be expected from the geographical placement of the two areas and others that reflect differences in the nature of the sediments. The assemblages from Kansas were largely from loess, which accounts for the contrast in aquatic species between the faunas of the two areas. A single semi-aquatic species (*Lymnaea parva*), which undoubtedly lived near pools in the loess surface was reported by Leonard; in contrast, 13 species of aquatic mollusks, belonging to six different genera occur in Early Wisconsinan faunal assemblages in western Texas. None of the presently reported faunules is from eolian deposits, although a small but characteristic Early Wisconsinan faunule has been reported from a thin bed of loess in Sherman County, Texas (Leonard, 1952, fig. 5).

Early Wisconsinan faunal assemblages from the area under study are easily distinguished from Kansan assemblages on the basis of numerous extinctions, discussed above, but as previously mentioned, it is difficult and sometimes impossible to distinguish Illinoian assemblages from those found in Early Wisconsinan deposits. The end of Early Wisconsinan time in the southern High Plains, as elsewhere in the Great Plains region, was characterized by widespread extinctions of gastropods. The two species of *Discus,* most species of *Gastrocopta, Gyraulus,* and *Lymnaea, Pupilla blandi* and *P. muscorum, Vallonia gracilicosta,* most species of *Vertigo* and *Zonitoides arboreus* disappeared from the Great Plains, although without exception they all survive in North America, for the most part in higher latitudes or altitudes. A typical case in point is *Pupilla;* it was especially widespread on the Great Plains from Kansan to the end of Early

Wisconsinan time. It is known to occur in deposits of this age from the northern Great Plains to the Edwards Plateau and eastward at least as far as Comal County, where it has been reported in Pleistocene deposits along with *Discus* and other mollusks by Pilsbry (1948, p. 605). At present, *Pupilla* occurs nowhere on the Great Plains; the locality of occurrence nearest to our area is in northeastern New Mexico at altitudes above 7,000 feet.

From this example and many other similar ones (Leonard, 1952, figs. 7–15) it is obvious that Early Wisconsinan time in the southern High Plains was characterized by a much more stable, more humid, and cooler climate than exists there at present. Available data do not permit of interpretations of climatic fluctuations within the interval, since the thick sequences of fossiliferous deposits that allowed zonation of the Early Wisconsinan in Kansas (Leonard, 1951) are lacking. From the nature of the faunal assemblages on the High Plains surface and those in terraces below the rim of the High Plains escarpment, the general picture to be derived is that of humid prairie on the Plains, with tree and shrub-bordered streams flowing across and from the escarpment.

LATE WISCONSINAN DEPOSITS AND MOLLUSCAN FAUNAS

Late Wisconsinan stream deposits, although almost universally present along all existing valleys, are volumetrically insignificant. This episode is by far the weakest depositional cycle that has been recognized and may even be less important than the small active flood plains of the present streams. Although these deposits are described only in one measured section (no. 17), they were examined at many localities. Generally, the sediments are finer textured than other Pleistocene terrace materials, lack a clearly defined soil profile in their top, and reflect relatively local sources. The gradients on these terraces closely parallel the present stream gradients and generally are only a few feet above them.

On the uplands the Late Wisconsinan cycle is poorly expressed by basin fills except in the secondary “lee dunes” and local eolian deposits. This cycle has regional expression only in the southernmost part of the area shown in figure 1, and farther south, where regional sand dune tracts (including at least part of the Monahans sands of Huffington and Albritton, 1941) and sheet sands have experienced activity during this and subsequent time.

Late Wisconsinan fossil molluscan assemblages in western Texas (fig. 10), as elsewhere on the Great Plains, are meager, and in general reflect the sparse living fauna. A total of nine species of gastropods, including one based on fragmentary and probably reworked parts of a few shells (*Pupilla* sp.) comprise the total known late Wisconsinan fauna, with the exception of fragmentary and unidentifiable shells of unionid pelecypods, which occurred at a single locality. The gastropods are those species capable of surviving unstable and adverse environmental conditions, and they are, for the most part, long-ranging species as well. The Bradyan interglacial interval, which seems to have been particularly rigorous for mollusks and other animals, resulted in the elimination of most of the elements of the Early Wisconsinan molluscan assemblage from the Great Plains region.

The occurrence of *Gastrocopta pellucida parvidens* in Howard County is of interest; it occurs in a belt across northern New Mexico, northern Arizona and southern Utah, where it lives at relatively high altitudes. It has not previously been reported from Texas. All other Late Wisconsinan species (except for the questionable record of *Pupilla*) still survive on the southern High Plains.

Fossil Mollusks	Borden: 2 1/2 mi. E on U.S. 180, W 1.	Borden: 1/2 mi. E Texas 669 on Colorado R.	Glasscock: See measured section no. 17	Howard: 6 1/2 mi. E, 2 1/2 mi. S, Big Spring	Howard: 6 mi. S jct. U.S. 80 - Texas 821	Martin: 11 1/2 mi. S jct. Texas 349 - 115
Gastrocopta cristata (Pils., Van.)				X		
Gastrocopta pellucida parvidens (Sterki)				X		
Gyraulus parvus (Say)	X		X		X	
Hawaiia minuscula (Binney)	X			X		X
Helicodiscus singleyanus (Pilsbry)			X			X
Pupilla sp.					X	
Pupoides albilabris (Adams)	X	X		X		
Succinea avara Say	X	X	X	X		
Succinea grosvenori Lea	X	X				
Unionids, indet.		X				

FIG. 10. Check list of fossil mollusks from Late Wisconsinan deposits.

PHYSIOGRAPHIC DEVELOPMENT

The physiographic history of this region during the late Cenozoic is in general consistent with the sequence of events described farther north in the Great Plains (Frye and Leonard, 1952; Frye, Leonard, and Swineford, 1956), modified by the greater severity of the climatic fluctuations in this part of Texas. At the beginning of the Neogene, an erosion surface existed throughout the Great Plains south of Nebraska. In central western Texas and adjacent New Mexico, the topographic relief was only a few hundred feet. However, south of Howard County, remnants of more resistant Cretaceous rocks stood several hundred feet above the general topography. It was on this surface that reduced stream competence started alluviation in the late Miocene or early Pliocene in the deepest parts of the easterly and southeasterly-trending valley systems. It is judged that throughout remaining Tertiary time, the regional climate became dryer (Frye and Leonard, 1957) with resultant progressive alluviation along valleys, lateral overlap of the valley sides, and ultimate regional coalescence of the originally independently depositing systems to form an extensive, integrated plain of alluviation. In the southern part of this region and farther south, the remnants of higher upland on Cretaceous, and the thinness of the Pliocene Ogallala deposits, effectively prevented the integration of the alluvial systems and contributed to the existing physiographic differences between the continuous surfaces of the High Plains and the Edwards Plateau.

The progressive climatic dessication not only contributed to the deposition of the Ogallala sediments but may have finally produced the termination of alluviation. Reduced stream competency was a major factor in causing deposition in the High Plains region, but when the through-flowing streams were no longer capable of transporting significant quantities of clastic materials into the region, alluviation is judged to have ceased. It is our conclusion that such was the case, rather than an increase in stream competency sufficient to maintain a condition of erosional-depositional equilibrium across the High Plains. The trend toward progressive dessication demonstrated within the Ogallala itself and the extensive blanket of caliche that accumulated at or below this essentially stable alluvial surface, both point toward conditions of aridity during latest Tertiary time. The duration of this condition of regional stability is unknown, but it must have been significant as it was the time of formation of a major part of the "Caprock" limestone.

In western Texas, as elsewhere throughout the northern hemisphere, Pleistocene time was initiated by a climatic change. The causes for this climatic reversal are not fully understood and may have been somewhat affected by regional crustal warping. In any event, the amount of surficial water in the Texas High Plains sharply increased during the Nebraskan and shallow, broad valleys were incised into the Ogallala surface. It seems probable that this stream system failed to integrate the drainage of all of the High Plains surface and locally consequent depressions on the alluvial plain were left undrained. These streams were of relatively low gradient, roughly parallel to the surface, and at many places the late Nebraskan Blanco formation that partly fills them consists of fine-textured, slack water deposits. In spite of these subdued topographic conditions, the eastern scarp of the High Plains must have been initiated during the Nebraskan, judging from the physiographic relations of Kansan (Tule formation) deposits to the present front of the scarp. Nebraskan deposits have not been found adjacent to the east-facing scarp, which probably reached its approximate present position by Kansan time. Although the evidence is now destroyed, it seems more than probable that the Ogallala initially feathered out to the east, where its sediments partially filled valleys cut in bedrock. As these Tertiary deposits would have been more resistant to erosion than the underlying Permian and Triassic beds, the eastern limit probably became a low, highly denticulate escarpment during the early Nebraskan erosion cycle. Such an escarpment, once formed, retreated westward and was progressively better protected as it was etched more deeply into the thicker and more resistant portion of the Ogallala strata.

Accentuation of the escarpment of the Plains has been effected by each cycle of erosion during the Pleistocene. In the region of the Edwards Plateau, to the south, the underlying Cretaceous rocks were more resistant than the thin and discontinous Ogallala sediments and therefore this escarpment forms a recognizable and distinct physiographic feature in southern Howard County.

The Kansan witnessed a continuation of the trend toward humidity and seemingly was the period of greatest surface moisture during the Pleistocene. Kansan (Tule formation) deposits are widespread and occur as fills in abandoned valleys under the Plains surface, as terraces along major reentrant canyons, and along streams extending outward from the Plains. The configuration of the High Plains seemingly took its general present form during Kansan time, although the relief has been somewhat increased locally by subsequent erosion.

The immediately post-Kansan period (Yarmouthian and Illinoian) is marked by a strong reversal of climatic trend toward aridity. Some of the relatively low gradient streams that headed on the Plains were no longer able to maintain themselves and eolian activity became prevalent. Sand from deflation areas along these former valleys and from the channels of streams that did persist was moved across divide areas and formed the surficial mantle now recognized as the "Cover sands." Stream action during the Illinoian was significant as demonstrated by preserved terrace remnants, but far less extensive than that of the Kansan, or even of the succeeding Early Wisconsinan. In fact the position of the deposits indicates that the knickpoint of their profiles fell far short of reaching as far into the plains as did those of the Kansan and that in the headwater areas, the Illinoian streams were developed in the Kansan sediments, rather than being incised into the beds below. The Illinoian is the only major cycle of erosion in the Plains that failed to incise more deeply than the preceding cycle.

Surface stability existed during the Sangamonian in much of this region. This is demonstrated by the soil profiles that developed at many places in the "Cover sands," and except in the south, eolian transportation has not again been a regional agent of transportation. The Early Wisconsinan contains evidence of a return of humid conditions but fell short of reaching the degree of humidity displayed by the Kansan. The extensive loess deposits of the northern High Plains reach only into the Panhandle area and were not observed in the part of Texas covered by this study. Eolian sands of this age were widespread farther south but only locally developed here. The uplands, on the other hand, were characterized by ponds filling the undrained surface depressions that had developed during the preceding cycle by deflation and deposition. The degree, or duration, of the period of relatively high rainfall was inadequate to integrate many of these ponds into a well-ordered drainage pattern on much of the High Plains surface. Along existing valleys, however, the Early Wisconsinan streams, after incising their channels, produced extensive alluvial deposits that now form well-defined terraces throughout the region.

The Bradyan interval, judging from the wholesale, regional extinction of many molluscan species, must have been as severe as it was farther north and represented a return to aridity approaching the Yarmouthian. A weak and relatively minor cycle of erosion and deposition followed the Bradyan interval in Late Wisconsinan time. That this was not expressed by semi-permanent lakes in the uplands but rather by intermittent ponds, perhaps not unlike those of the present, is indicated by the lack of large or diversified molluscan faunas. In the valley areas also, the Late Wisconsinan cycle is weakly expressed by minor terraces, in some places scarcely distinguishable, that separate the modern flood plain sediments from the extensive Early Wisconsinan terraces.

MEASURED SECTIONS

No. 1. Ogallala formation exposed in tributary to Palo Duro Canyon, 4 miles N and 8 miles E of SW corner of Armstrong County, Texas (1955).

	Thickness *(feet)*
Pleistocene	
("Cover sands")	
11. Sand, medium to fine, brick red	15.0
Pliocene	
Ogallala formation	
10. Caliche, dense, platy, light gray to gray tan; forms resistant caprock	2.5
9. Silt, with some fine sand, irregularly cemented with $CaCo_3$, chalky white, to cream, to rusty tan	15.0
8. Sand, medium to fine, irregularly cemented with $CaCo_3$, reddish brown; locally weathers to rounded knobby forms, contains *Celtis willistoni* (Cockerell) in lower part	15.0
7. Silt, with some fine sand, thoroughly permeated with caliche to form conspicuous chalky-gray zone; scattered small lenses of uncemented brick-red sand	4.0
6. Sand, medium to fine, generally loose but irregular cementation in upper part, brick red	9.0
5. Sand, medium to fine, lower part contains disseminated caliche pebbles, upper part weakly cemented	6.0
4. Sand, medium to coarse, well sorted, loosely cemented, tan	1.5
3. Sand, medium to coarse, well sorted, loose, tan; contains lenses of gravel with pebbles of crystalline rocks ranging in diameter up to 3 inches	8.0
2. Gravel, silt, and sand, coarser at base grading to finer upward; irregularly cemented and platy caliche occurs at top; pebbles of crystalline rock and of limestone; contains abundant *Celtis willistoni* (Cockerell)	6.0
1. Gravel, silt and sand, poorly sorted, massive, pinkish tan, irregularly cemented (This unit rests unconformably on weathered Permian rocks.)	4.5
Total thickness measured	86.5

No. 2. Ogallala formation exposed in gullies and buttes and along road cuts of Texas Highway 86, 10½ miles west of Briscoe-Hall County line and 6 miles north of Briscoe-Floyd County line, Briscoe County, Texas (1956).

	Thickness *(feet)*
Pleistocene	
"Cover sands"	
14. Sand with some silt, massive, brick red, olive gray in lower few feet and concentration of caliche in upper few feet	12.0
Pliocene	
Ogallala formation	
13. Sand, fine, silt and caliche; caliche irregularly distributed in lower part to give cavernous appearance on weathering and is platy in upper part with dense, hard limestone layer at top, pink tan to dirty gray; forms caprock ledge of scarp	20.0
12. Silt and fine sand with small amount of clay, massive to granular, pale maroon grading to gray tan at top and bottom	7.0
11. Sand, medium, massive, pale pinkish tan, tough to irregularly and weakly cemented, contains some disseminated caliche nodules	10.0
10. Sand, medium, massive, pale pinkish tan, weakly cemented throughout with dense partly silicified zone at top	6.0
9. Sand, medium, massive, friable, pale pinkish tan, with irregular areas of caliche cement distributed through upper part; contains fossil seeds of *Berrichloa maxima* (Pl. II, fig. 9), *Berrichloa* cf. *minuta* (Pl. II, fig. 4), *Biorbia papillosa, Celtis willistoni, Prolithospermum johnstoni* (Pl. II, fig. 10), *Prolithospermum* sp.	4.0
8. Sand, medium to coarse, massive, tough, irregularly cemented with dense zone at top, gray to pinkish gray	22.0
7. Sand, medium to coarse, tough, massive, irregularly cemented, gray tan, nodular caliche increases upward; contains fossil seeds of *Berrichloa conica, Biorbia papillosa, Biorbia* sp., *Celtis willistoni,* and *Stipidium intermedium*	17.0
6. Sand, fine to medium, and silt, massive, pale pinkish tan, tough, a few scattered caliche nodules	15.0
5. Sand, medium to fine, and silt, massive, tough, densely permeated throughout with caliche nodules, pinkish tan	10.0

4. Sand, coarse to medium, and fine gravel, massive, uniformly weakly cemented, gray to pinkish gray	21.0
3. Sand, coarse, gravel and cobbles of crystalline rocks, massive, poorly sorted, largest cobbles 6 to 8 inches in diameter, weakly cemented throughout	4.0
2. Sand, fine to medium, massive, tough with zones of loose medium sand alternate with zones of fine sand and silt, pale gray tan	27.0
1. Sand, fine, and silt, massive, tough, tan to pale reddish tan; an irregular zone at base of cobbles and cemented coarse gravelly sandstone. Base unconformably on Triassic sandstone	16.0
Total thickness measured	191.0

No. 3. Pleistocene deposits exposed in cuts on north side of Texas Highway 256, 15 miles E of Silverton, Briscoe County, Texas (fig. 7) (1955).

	Thickness *(feet)*
Pleistocene	
Illinoian (?) deposits	
9. Sandy loam, brown, with disseminated caliche nodules in lower part	2.0
8. Silt and sand, massive, gray to pale reddish brown; zone of caliche nodules in middle and weakly cemented at top; contains a few shells of *Succinea grosvenori*	4.0
7. Silt and sand, massive, brown, weathers to columnar structure	1.0
6. Sand, fine to medium, with silt and clay, massive, tan to pale reddish tan; caliche in disseminated nodules; contains a few shells of *Succinea grosvenori* and *Columella* sp.	5.0
5. Sand, medium, well bedded, tan; sparsely fossiliferous; the following fossil snails were collected 2.1 miles west from beds judged to be in this stratigraphic position: *Discus cronkhitei, Gastrocopta armifera* (?), *Gastrocopta riograndensis* (?), *Gastrocopta tappaniana, Gyraulus similaris* (?), *Hawaiia minuscula, Helicodiscus parallelus, Helisoma antrosa, Lymnaea caperata, Pupilla blandi, Pupoides albilabris, Retinella electrina, Succinea grosvenori* (?), *Vallonia gracilicosta*	3.5
4. Gravel and fine sand, tan, interbedded; gravel is predominantly of caliche pebbles that range in diameter up to 2 inches but contains a few crystalline rock pebbles; erosional unconformity at base of this unit	2.0
Tule formation (Kansan)	
3. Sand, fine, and silt, massive, dark gray; contains the following fossil snails: *Discus cronkhitei, Gastrocopta proarmifera, Gyraulus labiatus, Gyraulus similaris, Lymnaea bulimoides, Lymnaea caperata, Lymnaea palustris, Lymnaea parva, Oxyloma* sp. (?), *Physa anatina, Pisidium* sp., *Pupoides albilabris, Vertigo milium, Vertigo ovata*	1.5
2. Silt, sand and clay, massive, gray to greenish gray; a few small caliche nodules	3.0
1. Silt and sand, massive, red brown; contains caliche nodules that range in diameter up to 1 inch	3.0
Total thickness of Pleistocene measured	25.0

No. 4. Pleistocene deposits on N rim of Tule Canyon, 5 miles ESE of Cogdill Ranch Hdq. No. 2, Briscoe County, Texas (1955).

	Thickness *(feet)*
Pleistocene	
"Cover sands"	
4. Sand, fine to medium, reddish brown with some silt and small caliche nodules disseminated throughout; weathers to blocky surface; contains the following fossil snails: *Succinea avara, Hawaiia minuscula.* Erosional unconformity at base of this unit which rests on underlying beds as low as the middle of bed 1 below	24.0
Tule formation	
3. Sand, fine, evenly bedded, gray; contains disseminated volcanic ash shards	4.0
2. Volcanic ash (Pearlette bed), thin bedded and locally interbedded with thin lenses of silty fine sand, gray	8.0
1. Sand, fine, silt, and some clay, massive to indistinctly bedded, olive gray; contains small caliche pebbles, more numerous in upper part. This unit rests unconformably on Ogallala formation exposed in canyon rim	28.0
Total thickness of Pleistocene measured	64.0

No. 5. Tule formation in the type area, south side of Tule Canyon on Farm Road 146, Briscoe County, Texas (fig. 7) (1955).

	Thickness *(feet)*
Pleistocene	
Tule formation (Kansan)	
29. Sand, fine, pale tan	2.5
28. Sand, fine, and silt, with some clay, dark red brown; dark gray soil profile in upper part	6.0
27. Sand, fine, and silt, indistinctly bedded, gray in lower part to pinkish tan in upper part; contains disseminated caliche and nodules in upper part	10.0
26. Silt, with some fine sand and clay; interval comprises a soil profile; upper ½ foot brown loam (A horizon); ½ to 2 feet below top is dark gray brown B horizon with well-developed columnar structure; lower 2 feet is C horizon, gray, with disseminated caliche; contains the following fossil snails: *Succinea grosvenori, Vallonia gracilicosta, Valvata tricarinata*	4.0
25. Sand, fine to coarse, well bedded to thin bedded, gray to pale tan	1.0
24. Sand, coarse, loosely cemented; the grains are quartz individually encased in $CaCO_3$	0.5
23. Sand, fine to coarse, well bedded to thin bedded, gray to pale tan	6.0
22. Sand and silt, thin bedded, contains lenses of marly limestone	0.3
21. Sand, medium, loose, pale tan	1.0
20. Silt and sand, massive, pale olive gray to gray	2.0
19. Sand, medium, thin bedded, olive gray	3.0
18. Silt, with some sand and clay, pale olive gray	0.5
17. Sand, medium, bedded, pale gray to pale olive gray	5.0
16. Sand, medium, indistinctly bedded, pale olive gray; partly covered	25.0
15. Sand, medium, grading upward into sand, silt and clay interbedded with marl	1.0
14. Sand, medium to fine, indistinctly to well bedded, pale olive green; contains numerous shells of *Succinea* sp.	15.0
13. Sand, medium to fine, and silt; contains some fragments of caliche and fossil snail shells	2.0
12. Bentonitic clay, olive green	2.0
11. Limestone, dense, gray	0.1
10. Sand, fine to medium, and silt with a little clay, indistinctly bedded, pale greenish gray; contains the following fossil mollusks: *Gyraulus labiatus, Menetus pearlettei, Physa elliptica, Pisidium* sp., *Succinea grosvenori*	20.0
9. Sand, medium to fine, massive, gray, mottled with pinkish tan	6.0
8. Sand, medium to fine, and silt, rusty tan	2.0
7. Sand, medium to fine, thick bedded to indistinctly bedded, gray to pinkish tan; contains some thin zones of silt	8.0
6. Sand, fine, silt and clay, olive green; checks on weathered surface	2.5
5. Sand, fine to medium, indistinctly bedded, pale greenish gray	4.0
4. Sand, medium to fine, pale olive gray, interbedded with fine sand, silt and clay, reddish brown	5.0
3. Clay and silt, indistinctly bedded, light gray; grades upward into sand and silt with small lenses of caliche gravel	7.0
2. Sand, fine, and silt, massive, pale olive gray; contains fragmentary snail shells	2.0
1. Caliche, dense, nodular, light gray; weathers to polygonal masses. The base of this unit rests unconformably on Permian rocks	1.0
Total thickness of Pleistocene measured	144.4

No. 6. Ogallala formation in arroyos near mouth of Blanco Canyon, 8.2 miles east of intersection in Crosbyton, south of U. S. Highway 82, Crosby County, Texas (1956).

	Thickness *(feet)*
Pleistocene	
"Cover sands"	
17. Sand, massive, mottled gray in base to reddish tan, caliche nodules disseminated throughout with caliche zone at top	15.0
Pliocene	
Ogallala formation	
16. Silt and sand, fine to medium, cemented throughout, platy in upper part with local thin lenses silicified	15.0
15. Sand, medium to fine, massive, weakly cemented to loose, gray to tan	5.0
14. Sand, fine, and silt, gray to tan mottled, densely cemented, massive to blocky	6.0
13. Sand, fine, and silt, massive, tan to reddish tan; uniformly cemented in lower part, grading to loose in upper part	20.0
12. Silt with some clay, deep maroon brown below to purple tan above, loose grading upward into cemented zone at top, weathers to granular structure	27.0

11. Sand, fine, and silt, in thick bands of gray and pinkish gray, with 1 foot caliche zone at top	17.0
10. Sand, medium, massive, tan	1.5
9. Sand, fine, and silt, with some clay, banded gray and pinkish gray	12.0
8. Sand, fine, massive, loose, tan, caliche stringers in base	3.0
7. Silt and sand, fine, massive, maroon drab, weathers to granular surface	3.0
6. Sand, medium, massive, loose, tan	4.0
5. Sand, medium to fine, massive, pinkish tan in lower part to rusty pink above; rectangular joint pattern; nodular, blocky caliche zone in upper 3 to 5 feet	25.0
4. Sand, fine, and silt with some clay, massive to blocky, tough, pinkish tan to buff; concentration of nodular caliche in upper 2 to 3 feet	12.0
3. Sand, fine to medium, with some silt, massive, caliche nodules numerously distributed throughout lower half, pinkish tan	25.0
2. Sand, medium to coarse, in lower part alternating with thin-bedded and cross-bedded gravel and sand with pebbles predominantly of crystalline rocks; in upper part massive, gray to gray tan	14.0
1. Sand, coarse to medium, thin bedded to cross bedded, alternate zones of olive gray to rusty tan; in lower part are thin lenses and discontinuous zones of coarse gravels and clay balls, gravels predominantly of crystalline rocks with pebbles of Triassic sandstone and shale and Cretaceous limestone; upper part thin-bedded sand with interspersed zones of clay balls and some coarse gravels. Base of section in bed of tributary channel. Triassic rocks crop out to west.	41.0
Total thickness measured	245.5

No. 7. Wisconsinan terrace deposits on E side of White River, E of Crosbyton, 1/8 mile S of gravel road, Crosby County, Texas (fig. 9) (1955).

	Thickness *(feet)*
Pleistocene	
Late Wisconsinan	
5. Sand and silt, with discontinuous small lenses of gravel, tan, uncemented; gravel lenses are less conspicuous in upper part and sand and silt more uniformly bedded; in lower 5 feet there are scattered shells of the following fossil snails: *Hawaiia minuscula, Helicodiscus parallelus, Succinia* cf. *avara.* This unit is unconformable on the beds below and in its lowest part in the exposure rests on the middle part of bed 1 below, the top of this unit forms a well-defined minor terrace with a crest below the middle of bed 4 below	12.0
Early Wisconsinan	
4. Sand with some silt, thin bedded, tan; contains discontinuous small lenses of gravel with pebbles up to 3 inches in maximum diameter, gravels are predominantly of abraded caliche but contain some crystalline rock types	15.0
3. Silt and sand with some clay, massive, gray	0.5
2. Sand, fine to medium, and some silt, thin bedded, tan to pinkish tan; although sharply contrasting with bed below, it is conformable	1.5
1. Silt, sandy, and very small amount of clay, calcareous, gray to gray green in lower part grading upward to brown black and black; upper part of interval is a "muck" with distinct prismatic structure; snail shells are distributed throughout the interval and the following were collected: *Carychium perexiguum* (?), *Discus cronkhitei, Euconulus fulvus, Gastrocopta cristata, Gastrocopta holzingeri, Gastrocopta proarmifera, Gastrocopta riograndensis, Gastrocopta tappaniana, Hawaiia minuscula, Helicodiscus parallelus, Helicodiscus singleyanus, Lymnaea parva, Musculium* sp., *Pupilla blandi, Pupoides albilabris, Retinella electrina, Stenotrema leai, Strobilops sparsicosta, Succinea avara, Vallonia gracilicosta, Vertigo milium, Zonitoides arboreus.* The base of the section is at the level of the channel of White River; a low flood plain occurs on the west side of the channel	6.5
Total thickness of Pleistocene measured	35.5

No. 8. Composite section of Cenozoic deposits exposed along U. S. Highway 82, starting at Silver Falls and extending eastward ½ mile, Crosby County, Texas (figs. 7, 9; Pl. IIIC) (1956).

	Thickness *(feet)*
Pleistocene	
Early Wisconsinan terrace	
7. Sand and silt, massive, gray to gray tan; unconformably below beds 1 to 6 and rests on Triassic rocks. Contains the following fossil snail shells: *Carychium exile*, ssp., *Discus cronkhitei, Gastrocopta armifera, G. cristata, G. pantodon, G. tappaniana, Gyraulus* cf. *altissimus, Hawaiia minuscula, Helicodiscus parallelus, Lymnaea caperata, Physa anatina, Pisidium compressum, Pupilla blandi, P. muscorum, Pupoides albilabris, Retinella electrina, Sphaerium* sp., *Stenotrema leai, Strobilops texasiana, Succinea avara, S. grosvenori, Vallonia gracilicosta, Vallonia parvula, Vertigo milium, V. ovata, Zonitoides arboreus*	15.0
Illinoian (?) terrace deposits	
6. Gravel, sand, and silt, gravels and cobbles predominantly of caliche with some of crystalline rocks, cross-bedded, irregular bedded to massive, tan; unconformably in channel in Tule formation below	1–25.0
Tule formation	
5. Sand, fine to medium, and silt, interbedded with thin beds of caliche gravel, massive in upper part, reddish tan to pink gray	27.0
4. Gravels and cobbles of caliche with some pebbles of crystalline rocks, interbedded with fine gravel and fine to medium sand; fine sand phases are well bedded and interbedded with coarse sand and gravel. The fine sand phase contains the following fossil snails: *Gastrocopta cristata, G. proarmifera, Gyraulus labiatus, Pupilla blandi, P. muscorum, Pupoides, albilabris, P. hordaceus, Sphaerium solidulum, Succinea grosvenori, Vallonia gracilicosta, Vallonia parvula, Valvata tricarinata, Vertigo milium*	13.0
Pliocene	
Ogallala formation	
3. Sand, coarse to medium, thin bedded and interbedded with gravel containing clay balls, tan to rusty brown; loose except for soft caliche irregularly distributed in upper 2 feet	23.0
2. Sand, fine to medium, with some silt, massive, caliche nodules throughout, weakly cemented, pinkish tan	12.0
1. Conglomerate of Triassic sandstone pebbles and cobbles with matrix of sand and silt, irregularly cemented, rusty tan. Unconformable on Triassic sandstone	1.0
Total thickness measured	116.0

No. 9. Ogallala formation in canyons along east scarp of High Plains, 2½ miles west of east Dawson County line and 2½ miles south of U. S. Highway 180, Dawson County, Texas (1956).

	Thickness *(feet)*
Pliocene	
Ogallala formation	
6. Silt and fine sand, densely but irregularly cemented, massive, gray to pink; weathers to rounded cobbles	14.0
5. Silty sand, massive, pink to gray tan; upper part relatively densely cemented	18.0
4. Sandstone with opal cement, pink and white, contains a few quartz pebbles	1.0
3. Gravel, coarse, cross-bedded to massive, lenses out in adjacent canyons both north and south, densely cemented; cobbles of crystalline rocks have maximum diameter of 10 to 12 inches	11.0
2. Sand, medium to fine, with scattered pebbles throughout, massive, tan to reddish tan; uppermost part well cemented with caliche	52.0
1. Sand, coarse to medium, bedded to cross-bedded with lenses of very coarse gravel of limestone quartz and igneous rocks, gray, weathers to rusty tan	15.0
Total thickness measured	111.0

No. 10. Ogallala formation exposed in re-entrant canyons in scarp, 1 mile west of Floyd-Motley County line and 7 miles north of U. S. Highway 70, Floyd County, Texas (1956).

	Thickness *(feet)*
Pleistocene	
"Cover sands"	
11. Sand, with some silt, red, massive, caliche throughout but concentrated in upper part	15.0
Pliocene	
Ogallala formation	
10. Caliche, sand, and silt, blocky in lower part to platy in upper part, tan to gray; upper 1 foot locally silicified	15.0
9. Silt and fine sand, with some caliche disseminated throughout, drab maroon; weathers to small prismatic granules	10.0
8. Sand, fine to medium, caliche nodules disseminated throughout and weak caliche cement, massive, pinkish gray	25.0
7. Sand, medium to fine with some coarse sand in lower 10 feet, massive to blocky, caliche nodules throughout and small amount of caliche cement, pinkish tan. Upper part contains a few fossil seeds of *Berrichloa conica, Biorbia papillosa*	55.00
6. Sand, medium to coarse and some silt, massive, pinkish tan; contains large caliche nodules (up to 2 inches in diameter) and scattered pebbles and cobbles of crystalline rocks up to 10 inches in diameter throughout, tough and somewhat cemented; the top is marked by a 6-inch zone of pebble and cobble concentrate suggesting eolian lag gravel	12.0
5. Gravel, coarse, with cobbles and sand, massive, loose; cobbles up to 10 inches in diameter predominantly of crystalline rocks	2.0
4. Sand, medium to coarse, well bedded to cross-bedded in lower part to massive in upper part, local discontinuous lenses of cobbles, irregularly weakly cemented in lower part to densely cemented in upper part	11.0
3. Sand, medium to coarse, thin bedded, well sorted, with a few thin lenses of crystalline gravels, loose, gray	13.0
2. Sand with large masses of gray to olive-green silt, clay and caliche; cobbles of brick-red Triassic shale in lower part; partly covered; upper part predominantly poorly sorted gravel, sand and silt, massive, irregularly cemented, mottled gray and pinkish tan; contains sparse fossil seeds of *Stipidium commune* (Pl. II, fig. 6)	17.0
1. Sand, coarse, contains lenticular masses of coarse gravels, pebbles, and cobbles of crystalline rocks with some of Triassic sandstone and shale, gray, olive gray, and tan; upper part well bedded to cross-bedded, loosely cemented. Base of section in channel of tributary to North Pease River	25.0
Total thickness measured	200.0

No. 11. Pleistocene deposits exposed along creek banks north of Cedar Lake, 17 miles east and 5 miles south of Seagraves, Gaines County, Texas (fig. 9) (1956).

	Thickness *(feet)*
Pleistocene	
Tahoka formation	
7. Sand and silt, massive to thick indistinctly bedded, greenish gray; in lower part contains the following fossil snails: *Gastrocopta tappaniana, Gyraulus parvus, Lymnaea parva, Physa anatina, Pupilla blandi, P. muscorum, Succinea avara, Vallonia gracilicosta, Zonitoides arboreus*	12.0
6. Sand, massive, loosely cemented, gray	1.0
5. Sand with a few caliche pebbles, loose, gray	3.0
4. Sand, loose, gray; locally contains caliche pebbles	4.0
3. Sand, silt, and small pebbles, massive, dark gray; contains the following fossil snails: *Lymnaea caperata, Physa anatina, Physa* sp., *Sphaerium* sp., *Succinea grosvenori*	2.0
2. Sand, massive, loose, gray, thickness is irregular	1.0
1. Sand with irregular lenses of conglomerate of caliche and limestone pebbles distributed throughout but more abundant in lower part, massive, gray. Base of section in bottom of tributary to Cedar Lake somewhat above lake bottom level	5.0
Total thickness measured	28.0

No. 12. Ogallala formation exposed on south side of Spring Creek Canyon, 5 miles south and 2½ miles west of Graham, Garza County, Texas (1956).

	Thickness *(feet)*
Pleistocene	
"Cover sands"	
6. Sand with some silt and caliche, red to rusty red	15.0
Pliocene	
Ogallala formation	
5. Sand and silt, loosely cemented with dense cement in top 3 feet, irregular patches of caliche throughout, tan. Upper 5 feet contains fossil seeds of *Biorbia papillosa* and *Celtis willistoni*	15.0
4. Sand, fine to medium, and silt, irregularly cemented in lower part to densely cemented in upper part; irregularly distributed thin lenses of fine gravel; pinkish tan in lower part to gray in upper part; upper part contains fossil seeds of *Berrichloa conica* and *Biorbia papillosa*	38.0
3. Gravel, sand, and silt, loosely cemented, gray	1.0
2. Sand, silt, and some clay, with scattered crystalline pebbles, massive, brick red grading upward into gray, caliche in upper part and ½-inch zone of black manganese stain at top	19.0
1. Sand, coarse, gravel and cobbles of crystalline and Triassic rocks, massive, loose, rusty yellow. Rests unconformably on weathered Triassic rocks	9.0
Total thickness measured	97.0

No. 13. Ogallala formation exposed in east scarp of High Plains, 3.8 miles west of Post, Garza County, Texas (1955).

	Thickness *(feet)*
Pliocene	
Ogallala formation	
12. Sand, medium to fine, massive, cemented with $CaCO_3$ throughout, pinkish tan; contains caliche nodules dispersed throughout; upper part is more densely cemented, gray to gray white in color, forms precipitous bluff (note Pl. IB). Lower few feet contain fossil seed flora consisting of: *Berrichloa tuberculata* Elias, *Biorbia papillosa* Leonard, *Celtis willistoni* (Cockerell), *Panicum eliasi* Leonard, *Panicum* sp., *Stipidium* sp.	27.0
11. Sand, fine, silt, and some clay, reddish brown, with irregular streaks and nodules of caliche dispersed throughout	8.0
10. Sand with some gravel, locally at base gravel lentils contain clay balls several inches in diameter; erosional unconformity at base of unit	13.0
9. Sand, fine to medium, irregularly to well cemented with $CaCO_3$, pinkish to grayish tan, massive, weathers to checked surface	10.0
8. Sand, medium to fine, rusty pink, conspicuously banded with nodular caliche	2.5
7. Sand, medium to fine, massive, rusty pink, disperse stringers of caliche with 1-inch band of caliche at base	4.5
6. Silt, fine sand, and clay, brick red, massive	4.5
5. Silt with some fine sand, indistinctly thick bedded to massive, pinkish tan	12.0
4. Sand, fine, silt and some clay, massive, pinkish tan, small caliche pebbles throughout	5.0
3. Sand, fine to medium, with some silt, thick bedded to massive, pale brick red to pinkish tan	2.5
2. Clay and silt with some fine sand, massive to blocky, checks on weathering, reddish brown	3.0
1. Sand, fine to medium, with some silt, massive, compact, gray to pinkish tan, irregular zone with clay pebbles at base. Base of bed unconformable on Triassic rocks	27.0
Total thickness of Ogallala measured	119.0

No. 14. Tule formation (Kansan) exposed in cut bank 2.2 miles W of Post, Garza County, Texas (fig. 7; Pl. IIIB) (1955).

	Thickness *(feet)*
Pleistocene	
Post-Tule terrace fill	
7. Gravel, predominantly of caliche, grading upward into sand and silty sand, tan, friable; occurs unconformably above Tule formation and occupies erosional channels cut into it; contains the following fossil snails: *Bulimulus dealbatus*, *Helicodiscus parallelus*, *Succinea avara*	10.0±

Tule formation	
6. Sand, fine, silt, and some clay, massive, light gray to dark gray at top	5.0
5. Sand and caliche gravels cemented with caliche, irregularly bedded, gray to rusty tan, weathers to prismatic blocks	10.0
4. Sand, fine, and silt, grading upward into silt and clay, massive to vaguely bedded, gray to greenish gray; contains thin humic zones at top. Yielded the following fossil snails: *Gastrocopta armifera* (?), *Gastrocopta cristata, Gastrocopta riograndensis* (?), *Gastrocopta tappaniana, Hawaiia minuscula, Helicodiscus parallelus, Helicodiscus singleyanus, Pupilla muscorum, Quickella* sp. (?), *Retinella electrina, Strobilops texasiana* (?), *Vallonia gracilicosta, Zonitoides arboreus*	20.0
3. Sand, fine, and silt, massive, darkly humic stained	1.0
2. Sand, fine, gravel and silt, massive to well bedded, gray to greenish gray; basal 1.5 feet predominantly gravel; upper 2.5 feet abundantly fossiliferous and yielded the following fossil snails: *Bulimulus dealbatus, Discus cronkhitei, Euconulus fulvus, Gastrocopta armifera* (?), *Gastrocopta tappaniana, Gyraulus labiatus* (?), *Gyraulus parvus, Gyraulus similaris, Hawaiia minuscula, Helicodiscus parallelus, Lymnaea caperata, Lymnaea dalli, Lymnaea palustris, Lymnaea parva, Lymnaea reflexa, Physa anatina, Pisidium* sp., *Pupilla muscorum, Pupoides albilabris, Quickella* sp., *Retinella electrina, Retinella indentata, Sphaerium* sp., *Stenotrema leai, Strobilops texasiana* (?), *Succinea avara* (?), *Succinea grosvenori, Vallonia gracilicosta, Vallonia parvula, Vertigo ovata diaboli* (?), *Zonitoides arboreus*	4.0
1. Gravel, sand, and some silt, bedded to cross-bedded, gravel and sand irregularly interbedded, gray tan to tan; gravels predominantly limestone with some crystalline rocks, range in diameter up to 6 inches. This unit rests unconformably on Triassic rocks	4.5
Total thickness of Tule formation measured	44.5

No. 15. Pleistocene deposits exposed on south side Spring Creek Canyon, 5 miles south and 3 miles west of Graham, Garza County, Texas (fig. 7) (1956).

	Thickness *(feet)*
Pleistocene	
"Cover sands"	
14. Sand, silty, massive, brick red, caliche in upper part	6.0
Tule formation	
13. Sand, massive, with nodular caliche, gray with pink mottling; contains fossil shells of *Succinea avara* and *Physa anatina*	5.0
12. Clay, silty, granular structure, olive gray; contains fossil shells of *Lymnaea reflexa*	1.0
11. Sand, silty, massive to blocky structure, pink to gray mottled	6.0
10. Silt and sand interbedded with sand, loosely cemented, gray to mottled gray and pink tan	7.0
9. Sand, medium to coarse, with some silt, irregularly cemented, gray to tan; contains the following fossil snails: *Discus cronkhitei, Hawaiia minuscula, Lymnaea* cf. *megasoma, L. palustris, Physa anatina, Physa* cf. *sayii, Pupilla muscorum, Pupoides albilabris, Succinea avara, S. grosvenori*	1.0
8. Silt, sandy, interbedded with sand, gray; contains fossil shells of *Succinea avara*	5.5
7. Silt, sand and marl, massive, weathers to granular to blocky structure, gray to greenish gray	11.0
6. Sand, fine, and silt, indistinctly bedded, rusty tan to gray; contains fossil shells of *Succinea avara*	2.0
5. Sand, with cobbles, massive to blocky, well cemented, rusty tan	1.0
4. Silt, sandy, massive to blocky, mottled purple gray to light gray above	4.5
3. Sand, silty, a few pebbles of caliche distributed throughout, massive, pink to pinkish gray	2.0
2. Gravels of caliche, sandstone, limestone and a few of crystalline rocks, massive, weakly cemented, pinkish tan	2.0
1. Sand, silty, massive, pebble zone in base, weakly cemented at top. Unconformable on Triassic sandstone	13.0
Total thickness measured	67.0

No. 16. Cenozoic deposits exposed on north side Spring Creek Canyon, 4 miles south and 2 miles west of Graham, Garza County, Texas (1956).

	Thickness *(feet)*
Pleistocene	
"Cover sands"	
9. Sand, silty, massive, red brown, a soil in top overlain by loose tan eolian sand	4.0
Tule formation	
8. Sand, silty, massive, mottled pink and gray, caliche irregularly distributed throughout and concentrated in upper part	20.0
7. Sand, silty, massive to blocky structure, gray, gradational at top to clayey silt with a concentration of nodular caliche, olive gray	25.0
6. Sand, massive, gray, contains lenses of platy caliche and fine gravel; in upper part grades to pinkish gray with weakly cemented zone at top; contains *Succinea avara*	23.0
5. Sand with streaks of fine gravel, indistinctly bedded, brick red	2.0
4. Sand, fine, and silt, loosely cemented, gray	7.0
3. Sand and silt with caliche pebbles throughout, contains thin lenses of well-sorted tan sand, pinkish gray. Unconformable on beds below	10.0
Pliocene	
Ogallala formation	
2. Sand, gravel and silt, irregularly interbedded, tan; gravels are predominantly of limestone and sandstone with some quartz, chert, and crystalline rocks	12.0
1. Gravel, coarse, sand and silt, grading upward into fine sand, silt and clay, pinkish tan. Base on Triassic sandstone	7.0
Total thickness measured	110.0

No. 17. Pleistocene deposits exposed in cut banks of tributary to Mustang Creek, 10.5 miles north and 1.7 miles west of Garden City, Glasscock County, Texas (fig. 9) (1956).

	Thickness *(feet)*
Pleistocene	
Late Wisconsinan terrace	
4. Sand and silt with streaks of gravel, reddish brown, indistinctly bedded, friable; contains a few shells of *Gyraulus parvus, Helicodiscus singleyanus, Succinea avara,* and fossil seeds of *Celtis occidentalis.* In low terrace unconformably against beds 1 and 2 below	7.0
Early Wisconsinan terrace	
3. Silt and sand, medium brown, weakly developed columnar structure	4.0
2. Sandy silt with a few thin streaks of gravel, pink tan; cemented throughout with $CaCO_3$ becoming more dense upward with a sharp contact at the top but gradational at bottom. Contains the same fossil snails as bed 1 but less abundant	3.0
1. Gravel, sand and silt, irregularly bedded, gravel predominantly of limestone and caliche with a few crystalline pebbles and occurs in localized lentils, pink tan to gray buff. Contains the following fossil snails: *Gastrocopta armifera, Gyraulus altissimus, Hawaiia minuscula, Helisoma trivolvis lentum, Lymnaea bulimoides, L. caperata, Pisidium* sp., *Pupilla muscorum, Pupoides albilabris, Succinea avara, S. grosvenori, Vallonia gracilicosta*	4.5
Total thickness measured	18.5

No. 18. Ogallala formation exposed in south wall of Wildhorse Creek valley 5.2 miles north of Coahoma, Howard County, Texas (1956).

	Thickness *(feet)*
Pliocene	
Ogallala formation	
9. Caliche with sand and silt, platy	3.0
8. Sand and silt, massive, irregularly cemented and contains caliche nodules throughout, tan to gray	12.0
7. Covered interval	3.5
6. Sand, fine to medium, massive, cemented throughout and contains scattered dense caliche masses, pinkish tan	5.0
5. Sand, medium to fine, light tan to gray, wavy cemented zones alternate with loose friable zones; abundant root tubules in friable zones. Contains fossil seeds of *Biorbia papillosa* and *Lithospermum* (?)	3.0

4. Sand, irregularly cemented in wavy bands, light gray with streaks of greenish gray to tan. Contains fossil seeds of *Berrichloa conica, Biorbia papillosa, Celtis willistoni, Panicum eliasi, Stipidium intermedium,* and well-preserved grass stems	2.5
3. Sand, fine to medium, with thin zones of coarse sand, loosely cemented, massive, pinkish tan	5.0
2. Sand, fine to medium with some silt and pebbles, cemented throughout, massive, gray to pinkish gray. An irregular zone more coarse textured and densely cemented at top	4.0
1. Sand, silty, with cobbles of quartzite, chert, and igneous rocks, massive to blocky structure; a white silt zone occurs at top. Ogallala rests on Triassic red and gray shale	1.0
Total thickness of Ogallala measured	39.0

No. 19. Ogallala formation exposed in road cuts 2¼ miles south of Howard-Borden County line and 0.4 mile west of Farm Road 669, Howard County, Texas (1956).

	Thickness *(feet)*
Pliocene	
Ogallala formation	
5. Caliche, sandy, dense, hard, nodular in lower part to platy above with pisolitic limestone layer, 2 feet thick, at top, gray	14.0
4. Sand, medium to fine, with pebbles of quartz and crystalline rocks, densely cemented	5.0
3. Sand, medium to fine, massive, densely cemented, weathers to rounded and cobbly surface, gray to pinkish gray; contains fossil seeds of *Celtis willistoni*	7.0
2. Sand, medium to fine, massive, cemented throughout, gray to pinkish gray; contains fossil seeds of *Berrichloa amphoralis, Biorbia papillosa, Stipidium intermedium*	3.0
1. Sand, medium to fine, massive, loosely cemented with $CaCO_3$, gray to pale pinkish gray; contains numerous casts of plant stems and roots and fossil seeds of *Berrichloa amphoralis, Biorbia papillosa,* and *Stipidium intermedium*	7.0
Total thickness measured	36.0

No. 20. Ogallala formation exposed along Acuff road, north side of Yellowhouse Canyon, 5 miles N of Slayton, Lubbock County, Texas (1955).

	Thickness *(feet)*
Pliocene	
Ogallala formation	
9. Sandy loam, dark gray to reddish brown, loose and friable	1.5
8. Caliche, massive becoming platy with crenulate laminae in upper part, light tan to ash gray	9.0
7. Sand, medium to fine, massive, rusty tan, weathers to columnar structure	15.0
6. Sand, medium to fine, loosely cemented throughout, rusty tan, massive, contains nodular caliche	15.0
5. Sand, medium to fine, massive, tan, irregularly cemented to form minor ledge	5.0
4. Sand, medium to fine, loose, massive, rusty tan; contains numerous small to large, irregular, elongate to branched concretions, with local cemented lenses; fossil seeds of *Panicum eliasi* Leonard occur 5 feet above base	30.0
3. Sand, fine to medium with some silt, massive, pale pinkish cream, loosely cemented throughout	8.5
2. Sand and gravel, interbedded; pebbles range to 2 inches in diameter and consist of crystalline rocks and Jurassic shale; partly covered	11.0
1. Sand, medium to fine, massive to indistinctly bedded, reddish tan (Below this zone a covered slope extends down to the flood plain.)	10.0
Total thickness of Ogallala measured	105.0

No. 21. Pleistocene deposits at N end of Tahoka Lake, Lynn County, Texas (fig. 9) (1955).

	Thickness (*feet*)
Pleistocene	
Tahoka clays	
5. Sandy loam, brown, contains cobbles of caliche	2.5
4. Clay silt and some fine sand, gray to pale olive gray; weathers to small angular grains commonly of coarse sand size; locally upper part contains shells of *Succinea avara* and *Hawaiia minuscula*	6.0
3. Marl, crumbly, light gray, interbedded irregularly with pale greenish gray silt and clay	4.0
2. Silt, clay and fine sand, blocky, pale olive gray; locally contains abundant selenite in bladed crystals	4.5
1. Sand, fine, and silt, irregularly bedded, rusty tan to gray; locally contains bladed selenite crystals. The base of this unit is at the level of the dry floor of Tahoka Lake at the north end	4.5
Total thickness of Pleistocene measured	21.0

No. 22. Ogallala formation exposed 200 yards W of S end of Buffalo Lake dam, Randall County, Texas (1955).

	Thickness (*feet*)
Pliocene	
Ogallala formation	
6. Caliche cap rock; contorted, platy, and fractured in upper and lower parts, dense in middle	17.0
5. Sand, fine, grading upward into sandy silt, tan to gray; contains stringers of $CaCO_3$ and irregular cementation at top; contains *Biorbia papillosa* Leonard	12.0
4. Sand, medium, tan, well sorted, generally loose with cemented zone at top; contains *Biorbia papillosa* Leonard	11.0
3. Sand, medium to fine, tan, well sorted, massive, loosely cemented in lower part with well-cemented zone at top; contains *Biorbia papillosa* Leonard	7.0
2. Sand, medium to coarse, massive, tan, loosely cemented in lower part with well-cemented zone at top; contains the following fossil seeds: *Berrichloa conica* Elias, *B. inflata* Elias, *Biorbia papillosa* Leonard, *Celtis willistoni* (Cockerell), *Stipidium intermedium* Elias	6.0
1. Sand, medium, massive, tan, loose with weakly cemented zone at top	15.0
(It is estimated that the covered interval below the base of the exposure contains approximately 25 feet of Ogallala resting on Triassic redbeds.)	
Total Ogallala measured	68.0

No. 23. Pleistocene deposits exposed on E side of Tule Creek, 9½ miles E of Tulia, Swisher County, Texas (fig. 7) (1955).

	Thickness (*feet*)
Pleistocene	
Tule formation (Kansan)	
5. Sand, fine, and silt, tan, some caliche disseminated throughout; upper part contains dense caliche in stringers and is pinkish tan in color	14.0
4. Sand, fine, and silt, with some clay, massive, gray to pale olive gray; contains some nodular caliche in upper part; contains the following fossil snails: *Aplexa hypnorum, Gastrocopta tappaniana, Gyraulus crista, Gyraulus labiatus, Helisoma trivolvis, Lymnaea bulimoides, Lymnaea caperata, Menetus pearlettei, Physa anatina, Pupoides albilabris, Succinea grosvenori*	10.0
3. Silt and clay with some fine sand, blocky structure, olive gray	1.0
2. Sand, fine to medium, with some silt and clay, massive, pale olive gray	2.0
Pliocene	
Ogallala formation	
1. Sand, fine, with some silt, gray, irregularly and densely cemented; weathers to nodular surface and forms ledge	8.0
Total thickness measured	35.0

No. 24. Pleistocene deposits, S side Tule Creek, 12 miles ESE of Tulia, Swisher County, Texas (fig. 9) (1955).

	Thickness *(feet)*
Pleistocene	
Terrace deposits (Early Wisconsinan)	
12. Gravel, coarse, and sand, in basal part grading upward into silty sand with thin lenses of fine gravel, gray to gray tan; gravels are predominantly caliche; the following fossil snails were collected from the lower part: *Discus cronkhitei, Gastrocopta armifera* (?), *Gastrocopta tappaniana, Helicodiscus parallelus, Pisidium* sp., *Pupilla muscorum, Pupoides albilabris, Quickella* sp., *Vallonia gracilicosta, Zonitoides arboreus.* This unit rests unconformably against beds 2 and 3 and locally rests on top of bed 1	12.0
Tule formation (Kansan)	
11. Sand, fine, silt and clay, permeated throughout with streaks and stringers of caliche	5.0
10. Sand, fine, silt and some clay, massive, pale reddish brown; contains stringers of caliche in upper part	5.0
9. Volcanic ash (Pearlette bed), interbedded with pale pinkish gray fine sand, silt and clay	1.0
8. Sand, fine, and silt, with a small amount of clay, massive, pinkish tan; contains large irregular masses of caliche in upper part	3.0
7. Silt and fine sand, pale reddish tan to pale pinkish gray; irregularly well cemented with caliche, some lenses are free of cement but contain caliche pebbles; contains *Succinea grosvenori*	9.0
6. Silt with some fine sand, pale olive to greenish gray; irregularly to densely cemented with caliche	5.0
5. Sand, fine, and silt, with some clay, pale olive gray; sheets of caliche in blocky pattern with dense caliche at top	5.0
4. Silt, densely cemented with caliche, thin to irregular platy structure, chalky-gray	8.0
3. Sand, fine, and silt, and fragments of caliche irregularly interstratified, gray to pale olive drab; platy to blocky appearance on surface	2.0
2. Caliche, soft, consisting of angular fragments of caliche, cemented with soft silty and sandy caliche, gray to cream white	12.0
Pliocene	
Ogallala formation	
1. Caliche, dense, hard, nodular uneven surface; forms distinct bench at edge of flood plain of Tule Creek	2.0
Total thickness measured	69.0

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Plates I–V

PLATE I

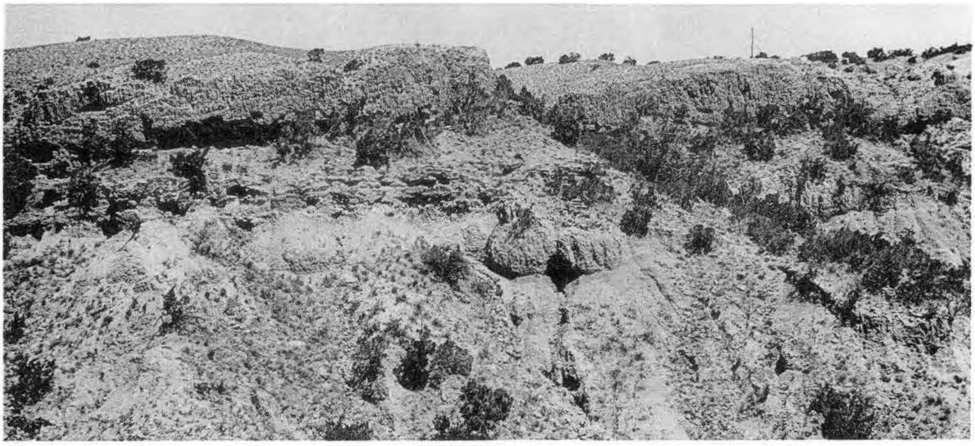
Ogallala formation in southern High Plains

A. View toward the southeast along the east scarp of High Plains, capped by Ogallala formation, Three and one-half miles southwest of Post, Garza County, Texas (1955).

B. Ogallala formation exposed in east scarp of High Plains, 3 miles west of Post, Garza County, Texas. Locality of measured section no. 13 (p. 46) and fossil seed collection (1955).

C. Uppermost Ogallala formation, unconformably overlain by "Cover sands," here locally called Judkins formation, exposed in caliche pit 11 miles east-northeast of Monahans, Ector County, Texas (p. 18). Note erosional-solutional contact at top of Ogallala (1956).

A



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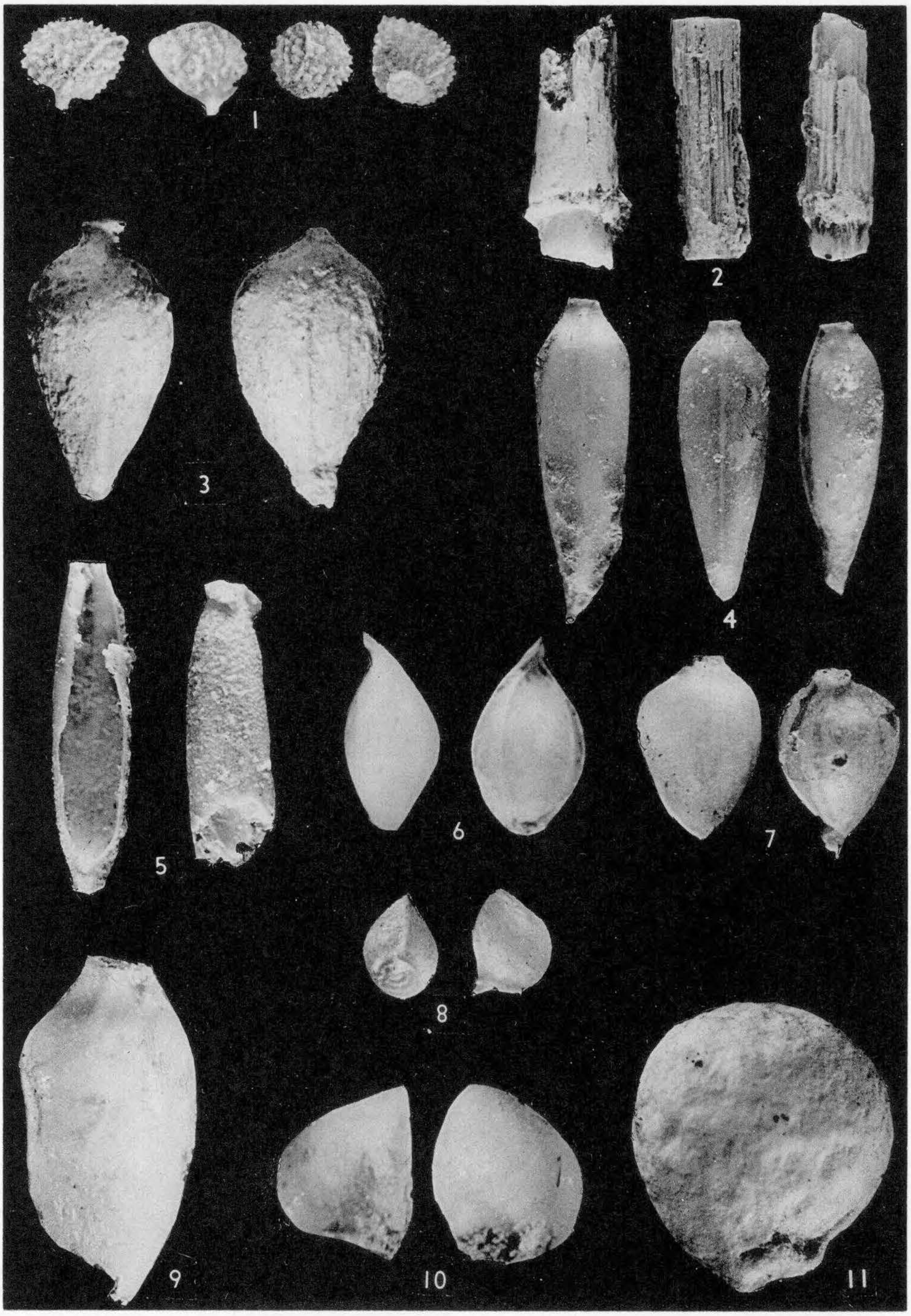
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PLATE II

Fossil seeds from the Ogallala of northwestern Texas

All figures enlarged approximately 9 times

FIGURES—

1. *Biorbia papillosa* Leonard, most characteristic fossil seed of the Ash Hollow floral zone in Ogallala deposits in the area between Howard and Randall counties, Texas. Different views of four examples.
2. Stems of unidentified grasses from Ash Hollow floral zone. Three examples, showing type of preservation.
3. *Berrichloa tuberculata* Elias, from Ash Hollow floral zone.
4. *Berrichloa* cf. *minuta* Elias, from Kimball floral zone, measured section no. 2, Briscoe County (p. 40). Lateral and ventral views of two specimens.
5. *Berrichloa conica* Elias, from Ash Hollow foral zone. Three examples showing variation in size.
6. *Stipidium commune* Elias, diagnostic of the Valentine floral zone, from measured section no. 10, Floyd County (p. 45). Two examples, both damaged.
7. *Panicum eliasi* Leonard from Ash Hollow floral zone. Lateral and ventral views of one example.
8. *Berrichloa amphoralis* Elias, from Ash Hollow floral zone. Different views of two examples.
9. *Berrichloa maxima* Elias, from Kimball floral zone, measured section no. 2, Briscoe County (p. 40).
10. *Prolithospermum johnstoni* Elias, from Kimball floral zone, measured section no. 2, Briscoe County (p. 40). Right and left lateral views of two examples.
11. *Celtis willistoni* (Cockerell) Berry. The hackberry occurs in all floral zones in the Ogallala formation.

Geographic and stratigraphic distribution of fossil seeds is shown on text figure 6, page 15.

PLATE III

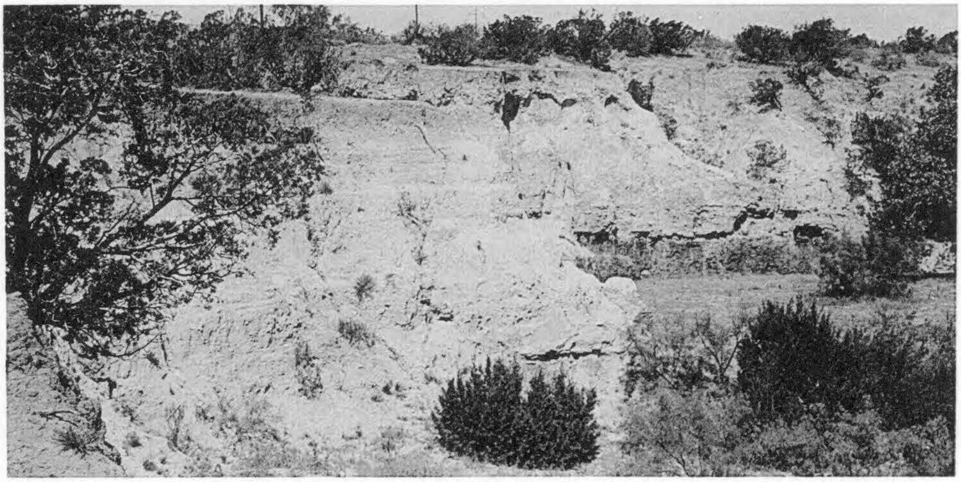
High Plains depression and Pleistocene deposits

A. Undrained High Plains depression after rains. Ten miles east-southeast of Tulia, Swisher County, Texas (July 1955).

B. Pleistocene Tule formation east of High Plains scarp, 2 miles west of Post, Garza County, Texas. Locality of measured section no. 14 (pp. 46–47) and collections of fossil snails (1955).

C. Fossiliferous Tule formation unconformably overlain by gravels of Illinoian age, exposed in cut along U. S. Highway 82 east of White River. These deposits underlie dissected high terrace near mouth of Blanco Canyon, Crosby County, Texas. Locality of measured section no. 8 (p. 44) (1955).

A



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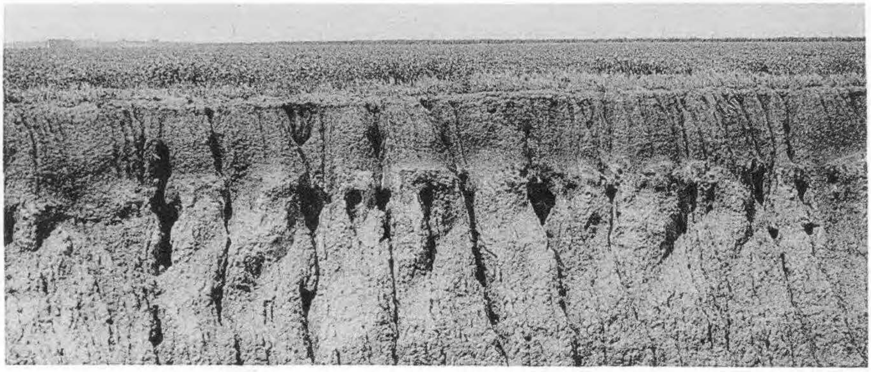

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PLATE IV

Soil profiles on Pleistocene deposits

A. Surface soil profile in "Cover sands" judged to have been in essentially continuous development since Illinoian time, exposed in highway barrow pit, 1 mile west of Trinity Chapel Church, Farm Road 146, 9 miles northeast of Tulia, Swisher County, Texas. Note prominent shoulder produced by zone of caliche accumulation in the soil profile (1955).

B. Surface soil profile in "Cover sands," judged to have been developing since Illinoian time, exposed in pit silo 7½ miles south of center of Crosbyton, Crosby County, Texas. Note well-developed structure and sharp upper limit of zone of caliche accumulation (1955).

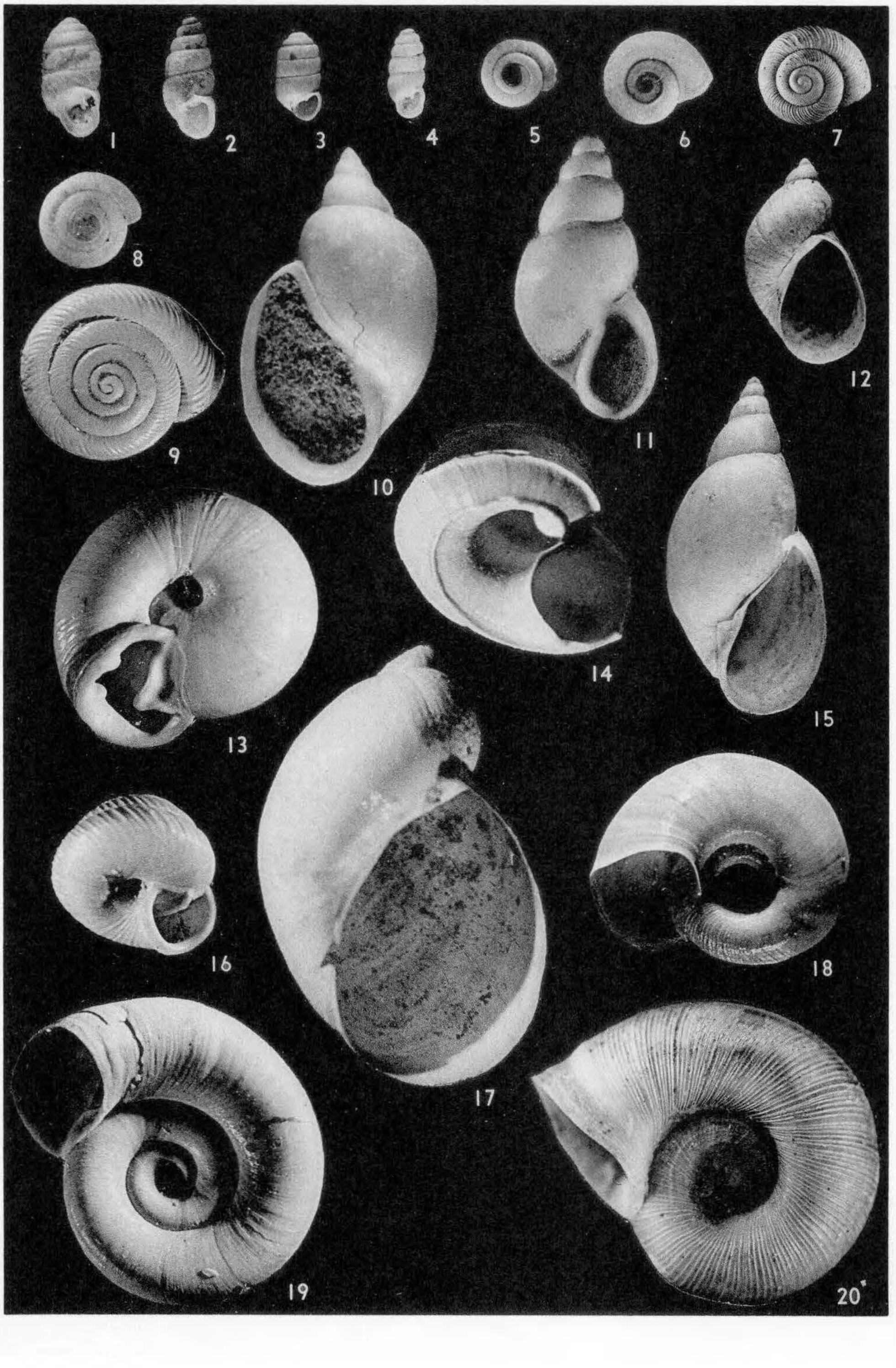
PLATE V

Typical Pleistocene fossil snails from western Texas

FIGURES—

1. *Gastrocopta proarmifera* Leonard, ×4-3/4.
2. *Pupoides albilabris* (Adams), ×4-3/4.
3. *Pupilla muscorum* (Linne), ×4-3/4.
4. *Gastrocopta cristata* (Pilsbry and Vanatta), ×4-3/4.
5. *Helicodiscus singleyanus* (Pilsbry), ×4-3/4.
6. *Gyraulus parvus* (Say), ×4-3/4.
7. *Discus cronkhitei* (Newcomb), ×4-3/4.
8. *Hawaiia minuscula* (Binney), ×4-3/4.
9. *Vallonia gracilicosta* Reinhardt, ×9.
10. *Physa anatina* Lea, ×4-3/4.
11. *Lymnaea parva* Lea, ×8.
12. *Succinea avara* Say, ×8.
13. *Polygyra texasiana* (Moricand), ×4-1/4.
14. *Valvata tricarinata* Say, ×8.
15. *Lymnaea caperata* Say, ×3.
16. *Strobilops sparsicosta* Baker, ×8.
17. *Succinea grosvenori* Lea, ×4-3/4.
18. *Menetus pearlettei* Leonard, ×7.
19. *Gyraulus labiatus* Leonard, ×7.
20. *Helisoma trivolvis* (Say), ×4-3/4.

Stratigraphic and geographic distribution of fossil mollusks is shown on text figures 7–10 inclusive.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