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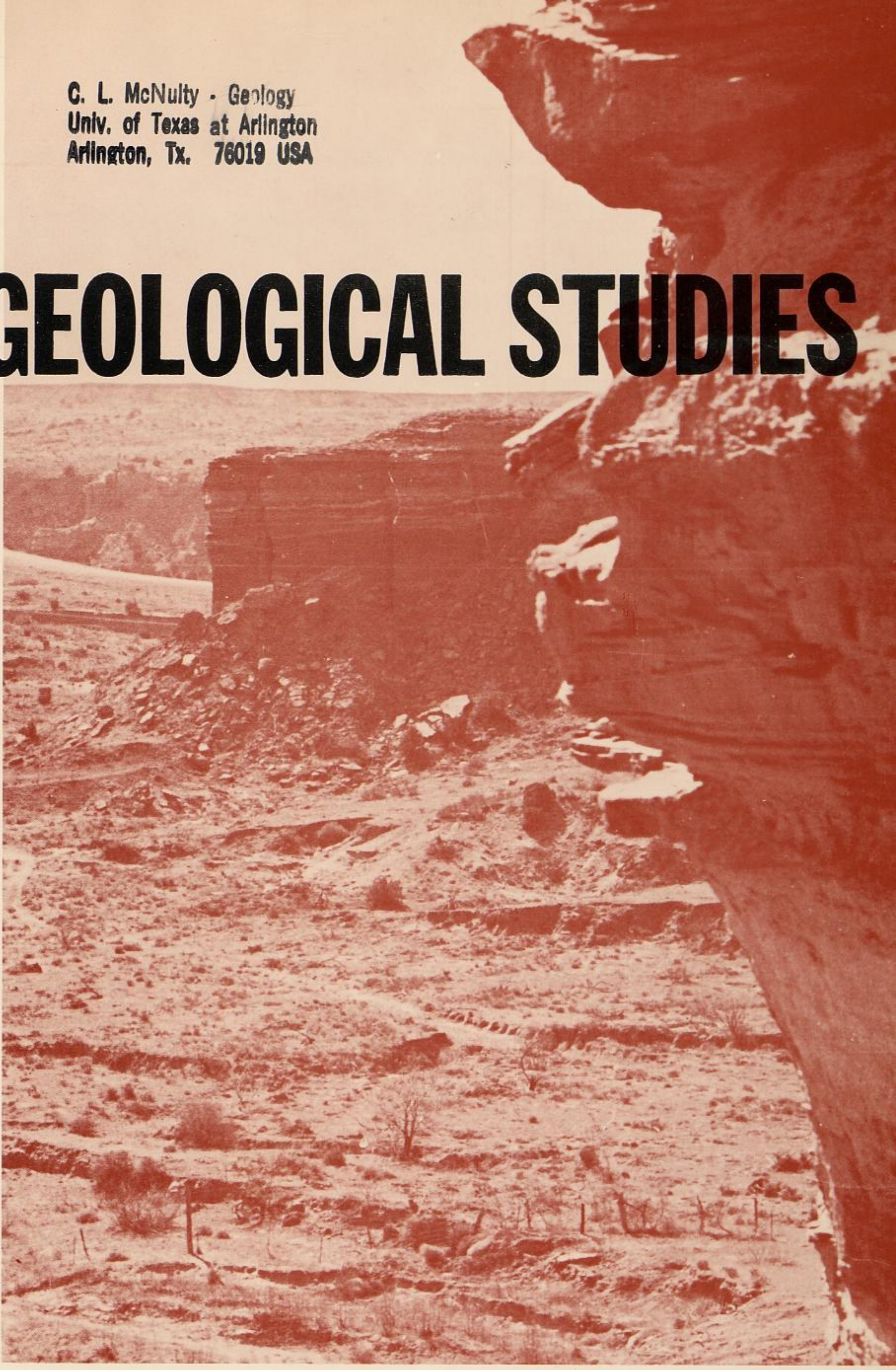

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BAYLOR UNIVERSITY - WACO, TEXAS

Geomorphic Evolution of the Southern High Plains

JIMMY R. WALKER

"Creative thinking is more important than elaborate equipment--"

Frank Carney, Ph.D.
Professor of Geology
Baylor University
1929-1934

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Department of Geology
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Geomorphic Evolution of the Southern High Plains

Jimmy R. Walker

ABSTRACT

The Southern High Plains (or Llano Estacado) of Texas and New Mexico forms the southernmost extension of the Great Plains physiographic province, covering an area of approximately 30,000 square miles.

The history of the Southern High Plains is intimately related to that of major central Texas rivers, all of which originate either at the eastern or western margins of the Southern High Plains. There were four events in Southern High Plains history of major interest to central Texas drainage: (1) the period before Southern High Plains deposition, when eastward drainage was just starting and during which time drainage was first established in central Texas; (2) the period of Southern High Plains deposition when both water and sediment from the Southern High Plains exited through central Texas streams; (3) a period of Southern High Plains scarp retreat and canyon cutting when water and sediment of Southern High Plains origin flowed through central Texas streams; and (4) the present, when the Southern High Plains is essentially isolated from central Texas drainage.

The initiation of Southern High Plains drainage history began with the Cretaceous uplift of the Southern Rocky Mountains of New Mexico and Colorado, resulting in both the retreat of the Cretaceous seas and the development of southeast-flowing streams across the now exposed surface of Cretaceous rocks. By the end of the Oligocene epoch, these streams had completed their downcutting cycle and were re-entrenched into valleys floored in Paleozoic rocks.

Following this cycle of erosion, the streams began depositing their fluvial debris (in late Miocene time), and by the end of Pliocene time they had completely filled the valleys and migrated across the highest of the divides which once separated the valleys. The High Plains reached its maximum areal extent by the end of Pliocene time, extending eastward and southeastward approximately 175 miles from the present eastern escarpment.

Pleistocene time witnessed the return of moist conditions and subsequently the westward retreat of the eastern escarpment to the Southern High Plains. Also, during the Pleistocene epoch, both the Pecos and Canadian Rivers were entrenched across the Southern High Plains, delivering to central Texas rivers the product of that erosion. Since late Pleistocene time, the drainage of central Texas has remained essentially as it is today, modified only by minor episodes of alluviation and dissection.

INTRODUCTION*

PURPOSE

There have been many studies of the Southern High Plains of Texas and New Mexico (see Previous Works), but for the most part these studies have concentrated on geological problems internal to the High Plains. For example, most geological investigations of the Southern High Plains have dealt with the stratigraphy of local deposits, correlation of local or regional stratigraphic units with units farther north, and stratigraphic chronology. However, recent studies of central and southwest Texas drainage (Lewand, 1969; Byrd, 1971; Thomas, 1972; Epps, 1973; Roberson, 1973; Belcher, 1975) have shown close correlation between such drainage evolution and High Plains history. Drainage ancestral to the present central Texas rivers apparently originated to the west of the Southern High Plains and throughout much of their history flowed across, through, and on the Southern High Plains. Sediments from the High Plains provenance areas and sediments from episodes of alluviation now

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*A thesis submitted in partial fulfillment of the M.S. degree in Geology, Baylor University, 1977.

form terraces and alluvial platforms along central Texas streams.

While much of the High Plains evolution may be of marginal interest to central Texas drainage history, there are a number of critical points in the evolution of the Southern High Plains which are of particular significance to central Texas drainage. Water which delivered initial Ogallala deposits to the Southern High Plains also exited through central Texas streams transporting an abundance of distinctive fluvial clastics. Later a phase of valley cutting and scarp retreat yielded additional water and sediment to the central Texas region. Most recently, the Southern High Plains is largely isolated from central Texas drainage, with resultant changes in stream regime. Thus, almost every major aspect of Southern High Plains history ties directly or indirectly with the evolution of central Texas drainage. Therefore, the purpose of this study "The Geomorphic Evolution of the Southern High Plains" centers largely on the influence that this history had on central Texas rivers.

LOCATION

The Great Plains physiographic province of the United States extends from southern Canada southward to the Edwards Plateau of southwest Texas, occupying the western margin of the stable interior of the United States.

The Southern High Plains of Texas and New Mexico forms the southernmost extension of this province, occupying an area of approximately 30,000 square miles (Fig. 1), bounded on the north by the Canadian River, on the west by the Mescalero escarpment and Pecos River, on the east by the prominent "Caprock" escarpment, and on the south by an almost imperceptible gradation into the Cretaceous Edwards Plateau. Local outliers of the Southern High Plains occur both east and west of the present Southern High Plains surface.

Geologically, the Southern High Plains consists of late Cenozoic deposits of fluvial, lacustrine, and aeolian origin which rests unconformably on a surface of considerable relief carved in Mesozoic and Cenozoic rocks (Frye and Leonard, 1957b, p. 2).

METHOD

It was necessary to consider the entire Southern High Plains during the course of this investigation, thus it was physically impossible to measure, collect, or visit all important outcrops. The initial phase required an extensive literature review which pinpointed a number of critical sections which were measured, described, and sampled. The sand and gravel samples were analyzed for properties indicative of provenance. Topographic maps were utilized to establish mean surface gradients, playa lake density, and other significant factors. For these investigations, a number of interpretive maps were compiled to emphasize aspects important to central Texas drainage, original High Plains extent, mechanisms and rate of caprock retreat, and significance of playa lake distribution. Field work occupied approximately 3 months in the summer and fall of 1975 and early 1976.

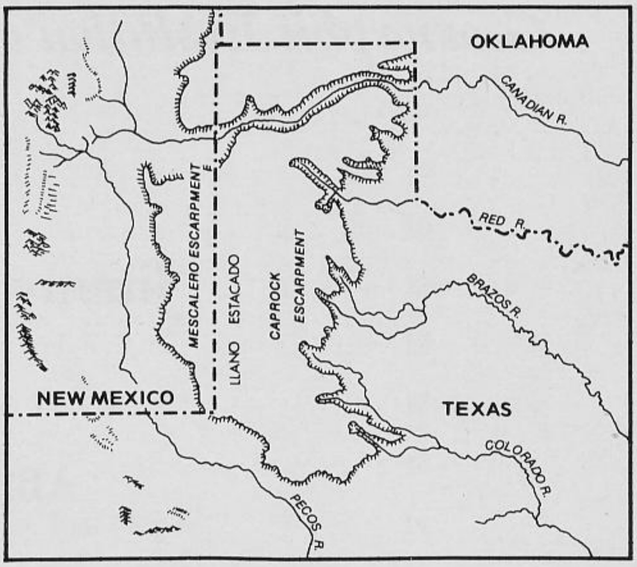

Fig. 1. Index map of area of investigation—The Southern High Plains.

PREVIOUS WORKS

Previous works significant to this study can be divided into three categories. First, are those works dealing directly with the geology of the Southern High Plains; second, are those dealing with the evolution of central Texas drainage; and third, are papers of more general nature dealing with geomorphic processes, fluvial mechanics, sedimentary models, and other aspects of geology essential to the interpretation of High Plains geomorphic evolution.

In the first category (those publications dealing directly with the geology of the Southern High Plains) there are a vast number. However, listed below are the ones most directly useful in the present study. The previous works mentioned here are only a part of the number consulted for the completion of this study, but they represent a chronological sequence of works leading to present-day interpretations of Southern High Plains evolution.

Geology of the Southern High Plains (Early descriptive accounts, evolutionary ideas, playa lake basin development and caliche development)

The studies here summarized are listed in chronological order, without regard to subject interest. While this leads to a rather haphazard appearance, it preserves the chronology, and since later works depend upon earlier efforts, this is thought to be the correct approach.

Earliest accounts of the Southern High Plains or Llano Estacado were related by explorers and pioneers who crossed the plains to explore and settle the West. However, theirs were not scientific descriptions, but merely comments in passing, and thus contributed little to the understanding of the evolution of the Southern High Plains.

One of the first scientific investigations of the High Plains region was that of Captain R. B. Marcy, who in 1840 led a group of settlers up the Canadian River and later led an expedition up the Brazos and Big Wichita Rivers to the Llano Estacado (Marcy, 1845).

In 1852, following his trip up the Brazos and Big

Wichita Rivers, Captain Marcy was again commissioned by the U.S. Government to explore the country bordering the headwaters of the Red River. Traveling with Marcy, Dr. G. G. Shumard described the physiography of the High Plain and measured certain sections of Triassic and Tertiary rocks along Palo Duro Canyon (Marcy, 1852).

In 1891, Cummins first dated the caprock of the Ogallala as Tertiary in age and recognized that it overlay rocks of Cretaceous, Triassic, and Jurassic (?) age. In 1893, Cummins, accompanied by vertebrate paleontologist E. D. Cope, explored the High Plains escarpment and acquired an extensive vertebrate collection with which the Tertiary age of the High Plains was firmly established. Relying largely upon fossils, Cummins and Cope named and established the ages of the Tule, Blanco, Seymour, Goodnight, and Loup-Fork beds (Cummins, 1893, p. 192-210).

The Ogallala Formation was named by Darton in 1898 for the type area near Ogallala, Nebraska. He also correlated it with the Mortar beds of the Southern Great Plains (Darton, 1898, p. 734) and by implication suggested that it was perhaps the most widely exposed formation in North America.

In 1899, Gidley described the Panhandle beds of the Llano Estacado as the fine clay deposits above Mesozoic strata and below recent surface sands. He renamed the Loup-Fork beds of Cummins, calling them the Clarendon beds (Gidley, 1903).

Whereas the early works were almost entirely descriptive, W. D. Johnson (1901, p. 611) first considered the origin of the High Plains stating:

> . . . But the present surface grade of the plain is not that of the original tilting. The surface has gone through a series of transformations. These have been accomplished by the eastward flowing streams from the mountains. In the first stage the mountain streams, traversing the plains, cut their smooth structural slope and produced a topography of parallel broad valleys and ridges. In the second stage they ceased to cut, depositing instead, and refilling the valleys they had excavated, even burying the intervening ridges, to a smooth upper surface . . .

This was followed by a first mention of a possible eastward extension of the Southern High Plains by Gould (1906), who suggested that the High Plains surface, from Nebraska to Texas, at one time extended several tens of miles eastward from the present margins. Later, C. L. Baker (1915, p. 29) summarized the history of the High Plains Cenozoic deposits by stating:

> . . . The early Cretaceous period was a time of erosion in which canyons were cut into the pre-Ogallala surface and late Cenozoic was a period of deposition in which pre-Ogallala valleys were filled by eastbound sediments . . .

This essentially modern view has been little changed since that time.

Within the framework established by these earlier workers, succeeding efforts recognized smaller stratigraphic units and detailed aspects of High Plains Formation.

Patton (1923, p. 78) named the Potter Formation which crops out along the Canadian River in Potter County, Texas, as the basal High Plains gravels just above the Triassic Dockum Formation. He also named and described the Coetas Formation which lies just above the Potter Formation, but below the surface silts and marls, thus establishing the stratigraphic framework for the northernmost portion of the Southern High Plains.

Following this the Hemphill beds of Hemphill County, Texas, were first described by Reed and Longnecker (1932) who in 1928 had assigned them to lowermost Pliocene age.

In 1929, in a work closely related in interest to the present investigation, Russell discussed the evolution of drainage on the western Great Plains, and considered four possible origins: (1) influence of prevailing surface slope, (2) differential erosion of weak and resistant strata along strike, (3) effect of structural deformation, and (4) depositional and erosional action by wind. He believed that all four possibilities may have been significant influences upon stream evolution, but believed that only structural deformation and wind action should have had marked effects (Russell, 1929, p. 251).

In a work which refined the 1928 efforts of Reed and Longnecker (1932), Matthews and Stirton (1930, p. 336) investigated the Pliocene *Equidae* of High Plains and, based upon their findings, dated the Hemphill Formation as pre-Blancan but post-Clarendon in age.

Based upon the prevailing opinion of that time, Plummer (1933) suggested that the High Plains were formed by the coalescense of broad alluvial fans which spread eastward from the Southern Rocky Mountains of New Mexico and Colorado, and presented a small diagrammatic map to show how the plains evolved. However, this interpretation was based on little more information than had been available to Johnson (1901), Gould (1906), or Baker (1915).

The most conspicuous local features of the Southern High Plains are the many playa basins which dot its surface. L T. Patton (1935, p. 451) first investigated these lakes classifying them as (1) those due to solution, (2) those due to surface erosion, and (3) "alkali sinks" which developed in the valley floors.

In an earlier effort to utilize all of the scanty paleontologic information in Ogallala sediments, Lugn (1938, p. 223-226) divided the Ogallala Formation into the Valentine, Ash Hollow, Sidney, and Kimball beds on the basis of fossil seeds and vertebrates, in effect, presenting the modern stratigraphic subdivision of the Ogallala.

W. A. Price (1940, p. 1939), following Patton (1935), also noted the numerous playa lakes dotting the Southern High Plains and attributed their formation to a single cause, dissolution of the underlying caliche. Origin of High Plains caliche was explained by Price (ibid.) as the end product in the formation on well-drained, well-developed soils by the process of "soil lime" accumulation.

The upper boundary of the Ogallala was further localized by Elias (1942, p. 133) who defined the top of the Ogallala on the basis of the occurrence of an "algal limestone" which he thought to have been formed in widespread lakes by the algae *Chlorellopsis bradleyi Elias.*

Frye (1946, p. 80) stated that the original Northern High Plains surface, at the end of Pliocene time, extended southeastward across most of Kansas, and has since been reduced in area by erosion, chiefly by scarp retreat. Since the Southern High Plains is of similar aspect he concluded that it might also have had a similar history.

While essentially all workers since Cummins have considered the High Plains deposits to be clearly divided between Ogallala and later deposits, and while the upper boundary of the Ogallala has been put at the Pliocene-Pleistocene boundary, this bounday has not always been clear. Flint (1948, p. 545) suggested that without dramatic climatic changes between Pliocene and Pleistocene time, no division would occur in High Plains stratigraphy, and thus Ogallala-Post Ogallala stratigraphic divisions were also markers of major climatic change.

Almost all workers in High Plains geology are impressed with the great area of existing deposits, and the once greater area covered by original deposition. In keeping with this interest Schultz and Stout (1948, p. 558) suggested that the original High Plains surface covered most of the southwestern section of Nebraska, western Kansas, and the panhandles of Oklahoma and Texas, an interpretation which now appears conservative.

In more recent years, the correct stratigraphic sequence and classification of High Plains deposits has occupied the interest of a number of workers. Elias (1948, p. 609), in a study of High Plains Pleistocene deposits, concluded that the Blancan beds should be classified as post-Ogallala because of their localized nature, and stratigraphic dissimilarity with the Ogallala.

G. L Evans (1948, p. 618) discussed the origin and formations of the Pleistocene Blanco beds, emphasizing that Blanco beds were lacustrine in origin and that their formation was both preceded and succeeded by more arid climates.

With passage of time, workers on High Plains geomorphology have tended to "push" the original eastern margin farther and farther to the east and south.

Bretz and Horberg (1949, p. 484) determined through gravel collections and westward High Plains mean gradient maps that the High Plains surface at one time extended southward across the Pecos River at least to the Texas-New Mexico border. Southwestward Bretz and Horberg (ibid.) also believed that the Ogallala at one time covered the Guadalupe Mountains which then were lower than the westward extension of the High Plains surface, and which have since been elevated.

Of the minor features of the High Plains surface, none have received more attention, and none have proven more enigmatic than the playa lake basins. Judson (1950, p. 272) theorized that basins of the Llano Estacado were not formed by collapse or by differential subsidence in Tertiary rocks, but by a combination of leaching and wind deflation which occurred throughout the Pleistocene Epoch.

The major break between Ogallala and later deposits was largely climate controlled. Climatic conditions at the beginning of Pleistocene time became increasingly moist (Frye and Leonard, 1957b) as indicated by deep stream entrenchment, coarse textured deposits, and resurgence of a number of gastropod types. Later Frye and Leonard (1957a) conducted a regional study of Tertiary and Quaternary sediments of the eastern escarpment of the Southern High Plains, correlating Cenozoic deposits of the Southern High Plains to those of the Northern Great Plains. Following this Swineford, Leonard, and Frye (1958, p. 114) examined the caliche capping the Southern High Plains surface. The caliche was considered not of an algal origin as postulated earlier by Elias (1942) but the product of soil-forming processes on the uppermost sand of the Ogallala, and involved a radically different climatic history than that proposed by Elias (1942).

Much of the more recent information on High Plains deposition has come about through investigations of ground-water supplies through analysis of well logs and cuttings from the thousands of wells on the High Plains. Buried topography beneath the Ogallala Formation was mapped by Cronin (1969) in a study of High Plains aquifer depletion rates, and, largely as a result of his study, we have some idea of the details of pre-High Plains drainways.

Pleistocene climates of the High Plains have been of interest because not only are they well documented by deposits and fossils, but they had influence in earliest human settlement. Wendorf (1961) conducted an investigation of High Plains Pleistocene paleoecology, which indicated that each of the four major periods of glacial advance and retreat were accompanied by alternating periods of wet and dry conditions on the Southern High Plains. Each climate period was represented by specific fossil indicators.

In a study of possible ground-water recharge potential, test drilling of small playa lakes on the Southern High Plains was conducted by John Havens (1961), who suggested that alignment of the playas occurred along ancient drainages. Test drilling revealed no collapse of the Ogallala and no signs of solution of salt or gypsum.

The source of High Plains deposits has long been a subject of great interest, principally because of the great volume of material involved. Lotspeich and Coover (1962, p. 16) determined that soil parent material on the Southern High Plains was derived from the Pecos valley during Pleistocene time and transported by northeast-trending winds.

A recurring theme in High Plains studies is the origin of playa lake basins. Reeves (1966) in the most comprehensive study of the basins to date, investigated several hundred High Plains playas and suggested that there were a number of causes for lake formation, including: (1) breeching along Pleistocene pluvial streams, (2) solution, (3) leaching, and (4) wind deflation. Of these, he indicated that wind deflation played the major role.

Slaughter (1967) investigating Cenozoic vertebrates of the Southern High Plains theorized that post-Pliocene climatic changes resulted in the extinction of several Southern High Plains vertebrate species.

Overall views of the Southern High Plains are rare in literature and of recent date. Reeves (1970a) completed the first truly comprehensive structural, stratigraphic, and geomorphic study of the Southern High Plains.

Because of the wide distribution of Ogallala type gravels and sediments, sediment sources are a constant question in the literature. Petrographic studies of gravels in central Texas by Lewand (1969, p. 23) and Menzer and Slaughter (1971, p. 217) suggest an origin in the Manzano and Sangre de Cristo Mountains of northeastern New Mexico, and indicate that the Southern High Plains once extended to the Dallas, Texas, area.

The age ranges of various High Plains deposits have been based on far firmer footing in recent years. A late Miocene age for oldest Ogallala is indicated by vertebrate remains collected from more than a dozen eastern escarpment localities. However, Frye (1971) indicated that the scarce vertebrate remains are of little value for regional correlation and that fossil pollen and seeds are useless for age determination but are invaluable regional correlation markers.

Studies of High Plains Drainage Systems

Since the purpose of the present investigation is to relate High Plains evolution to the evolution of central Texas drainage, the works in this category are particularly important. They are few in number and in all of these the aspect of High Plains evolution was a minor element.

Sand and gravel composition has been a major key in provenance studies of High Plains deposits and Texas river sediments. Heavy mineral analysis by Mathis (1944) on terraces of the Colorado River, Texas, indicated such studies could be useful for correlating other river terraces.

Much later, in a series of related river studies, gravel provenance was a major consideration. Byrd (1971, p. 30) believed the Uvalde gravels of central Texas represent lags from terraces constructed from the detritus of the westward retreat of the High Plains escarpment which was delivered to central Texas by ancestors to modern streams. Thomas (1972, p. 28) suggested that the Pecos River was extended northward by headward erosion thoughout Pleistocene time. As erosion progressed, the lengthening Pecos successively pirated the headwaters of southeastward-flowing streams, finally capturing the ancient Portales River near Fort Sumner, New Mexico. However, Reeves (personal communication, 1977) has found no evidence of eastward-flowing streams on the southwestern part of the Southern High Plains.

In a study of the geomorphic evolution of the Rio Grande, Belcher (1975, p. 50) concluded that the ancestral Rio Grande probably joined the Pecos River in northern New Mexico and crossed the Southern High Plains, possibly through the Portales valley, during the later Miocene and Pliocene Periods. During this time it may have been a contributor to central Texas streams and was diverted later by tectonics to its present course.

General Geomorphic Studies

Each of the earlier river studies has emphasized the apparent great age of central Texas drainage and all have suggested that the present pattern has existed since pre-Ogallala time. Geomorphic processes play an essential role in the evolution of an enormous, complex feature such as the Southern High Plains. Summary literature on general geomorphic processes, fluvial mechanics, and sedimentary models was therefore consulted in order to interpret the evolution of the Southern High Plains. References most useful in this study include those by Schumm (1968), Blatt, Middleton, and Murray (1972), and Reineck and Singh (1973).

Heavy Minerals (Laboratory Procedures)

A final category of previous works deals with laboratory procedures required to carry out heavy mineral analyses of High Plains sands and the identification of heavy minerals. Those most useful to this study include those by Milner (1926), Twenhofel and Tyler (1941), and Fessenden (1959).

ACKNOWLEDGMENTS

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THE HIGH PLAINS

PHYSIOGRAPHY

In its very monotony, the High Plains is perhaps the most impressive physiographic region on this continent. Almost a uniform and featureless plain, its isolation discouraged settlement until the earliest years of this century. The initial effect on the observer was perhaps best described by Marcy in 1852 (p. 127) as follows:

> . . . One of the most prominent features which strikes the eye of the beholder on an examination of this section, is the very remarkable uniformity of its surface, and the almost total absence of those abrupt and rugged primitive mountain ranges which in many other parts of our country offer such formidable obstacles to the passage of railways. But few mountains are seen throughout this region and those few are so little elevated that they present but trifling obstructions when compared with many that are found in the eastern states. This section is, however, traversed throughout nearly its whole length, by the lofty plateau of the "Llano Estacado," which, as will be observed on the map, stretches out from the 32nd to the 36th parallel of latitude, and in places two hundred miles without a tree or running stream throughout its entire surface, and presents, in my judgment an impassable barrier to a wagon road; and am fully impressed with the belief that a route crossing this desert anywhere between the 33rd parallel of latitude and its northern limits will never be selected for a Pacific railway, or indeed, a road of any description.

Later, Gould (1906, p. 8) described the High Plains in a more analytical study as follows:

> The surface of the High Plains is generally flat, with nothing to break the severe monotony. The drainage for the most part is wholly undeveloped. There is no run-off, and the rainfall either evaporates directly, sinks into the soil, or collects in buffalo wallows and broad, shallow depressions locally known as "playa lakes," from which it can escape only by seepage or evaporation. Here and there on this flat upland is a draw or incipient stream channel in which after a heavy rain the water collects and runs off. If traced for any considerable distance, these immature drainage ways will usually be found to end in a playa lake.

While land use on the Southern High Plains has changed since that time from ranching to intensive farming, the appearance today is little different from that described by the original observers.

Fig. 2. The eastern escarpment of the Southern High Plains near Matador, Texas. The horizon exemplifies the flat nature of the entire High Plains surface. In the foreground, the headwaters of an eastward draining marginal draw may be seen, the result of a breached playa basin.

In summary, the Southern High Plains is virtually a planar surface with an 8- to 10-foot gradient to the southeast (Fig. 2). Within the Southern High Plains proper, the only common form of surface relief is in the form of playa lake basins of which approximately 37,000 have been identified (Schweison, 1965, p. 1). Playa lake basins range in size from a few tens of feet to several miles in diameter and from a foot to over 100 feet deep (Brown, 1956, p. 7; Wendorf, 1961, p. 14; Reeves, 1966, p. 269). Such basins are most abundant above ancient pre-Ogallala drainage ways and are greater in number to the east than to the west.

Whereas topographic maps frequently show drainage originating on the High Plains surface, it is in effect a noncontributing area, with a runoff of only 0.25 inch per year, absorbing essentially all the rain that falls upon its surface. Stream erosion of the Southern High Plains has had little effect on the High Plains surface. Along the margins of the High Plains however, erosion has created conspicuous escarpments since the end of Pliocene time. On the eastern margin the headwaters of the Red, Colorado, and Brazos Rivers have formed the prominent "Caprock" escarpment. Erosion has caused retreat of the escarpment several tens of miles westward in certain areas. The Pecos (Thomas, 1972) and Canadian (Roberson, 1973) Rivers flow in canyons which breached the High Plains surface probably in late Pleistocene time. They thereby isolated the Southern High Plains from the Northern High Plains and thus from the mountains of New Mexico and Colorado which originally supplied sediments and water to the area (Kottlowski, Cooley, and Rhue, 1965, p. 290; Reeves, 1970a, p. 100; Leonard, Frye, and Glass, 1975, p. 16; Leonard and Frye, 1974, p. 12).

Native vegetation of the Southern High Plains includes a variety of plains grasses and a few woody shrubs. Prevalent native grasses and shrubs include buffalo grass (*Buchloe dactyloides*), gramma grass (*Chrysothamnus supp.*), yucca (*Yucca glauca*), and mesquite (*Prosopis juliflora*) (which normally grows only along the margins of the escarpment). There are few trees native to the Southern High Plains, most of which are confined either to the escarpment or to stream channels. These include plains cottonwood (*Popolus sargentii*), juniper (*Juniper monosperma*), and a few oak (*Quercus spp.*) (Wendorf, 1961, p. 17).

GEOLOGY

The geology of the Southern High Plains is best described in terms of (1) bed rock beneath the High Plains sediments, (2) the High Plains deposits themselves, and (3) post-High Plains sediments, now found marginal to the High Plains.

Strata beneath High Plains sediments consist of Permian through Cretaceous formations. Post-Cretaceous erosion formed a valley-and-divide topography with several hundred feet of relief prior to Ogallala deposition (Brand, 1953, p. 19; Frye and Leonard, 1965, p. 206; and Cronin, 1969, p. 6) (Table 1).

Permian strata, belonging to the Quartermaster and Blain Formations, crop out along the northern and eastern margins of the High Plains (Localities 1, 3, 4, 10, 12, 16, and 78; Fig. 3) as evenly bedded red sand and siltstone, interlaminated with thin discontinuous gypsum beds.

Correlation of late Cenozoic deposits of the Northern Great Plains and Southern High Plains.

		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)		SOUTHERN HIGH PLAINS OF TEXAS and NEW MEXICO
PLEISTOCENE		Recent	Almenan		(Alluvium; dune sand)	Sanborn formation	(Alluvium; dune sand)		(Alluvium and dune sand)
	Wisconsinian	Late Wisc.			Bignell loess (sand and gravel)		Bignell m. (sand and gr.)		Late Wisconsinian terrace deposits; minor upland depression fills; dune sand
		Bradyan			*Brady soil*		*Brady soil*		
		Early Wisc.	Scandian		Peorian loess Todd Valley fm.		Peoria m. (sand and gr.)		Tahoka fm.; Early Wisconsinan terrace deposits; "Cover sands" (locally)
		Sangamonian			*Sangamon soil*		*Sangamon soil*		*Sangamon soil*
		Illinoian			Loveland loess Crete sd. and gr.		Loveland m. Crete m.		"Cover sands" (major part), local terrace deposits
		Yarmouthian			*Yarmouth soil*		*Yarmouth soil*		*Yarmouth soil*
		Kansan			Sappa fm. (incl. Pearlette v. ash) Grand Island fm.	Meade	Sappa fm. (incl. Pearlette v. ash) Grand Island fm.		Tule fm. (including Pearlette volcanic ash)
		Aftonian			*Afton soil*		*Afton soil*		*Afton soil*
		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)
					Ash Hollow fm.		Ash Hollow m.		(Ash Hollow floral zone)
		? ?							
		Miocene			Valentine fm.		Valentine m.		(Valentine floral zone)

After Frye and Leonard, 1957a.

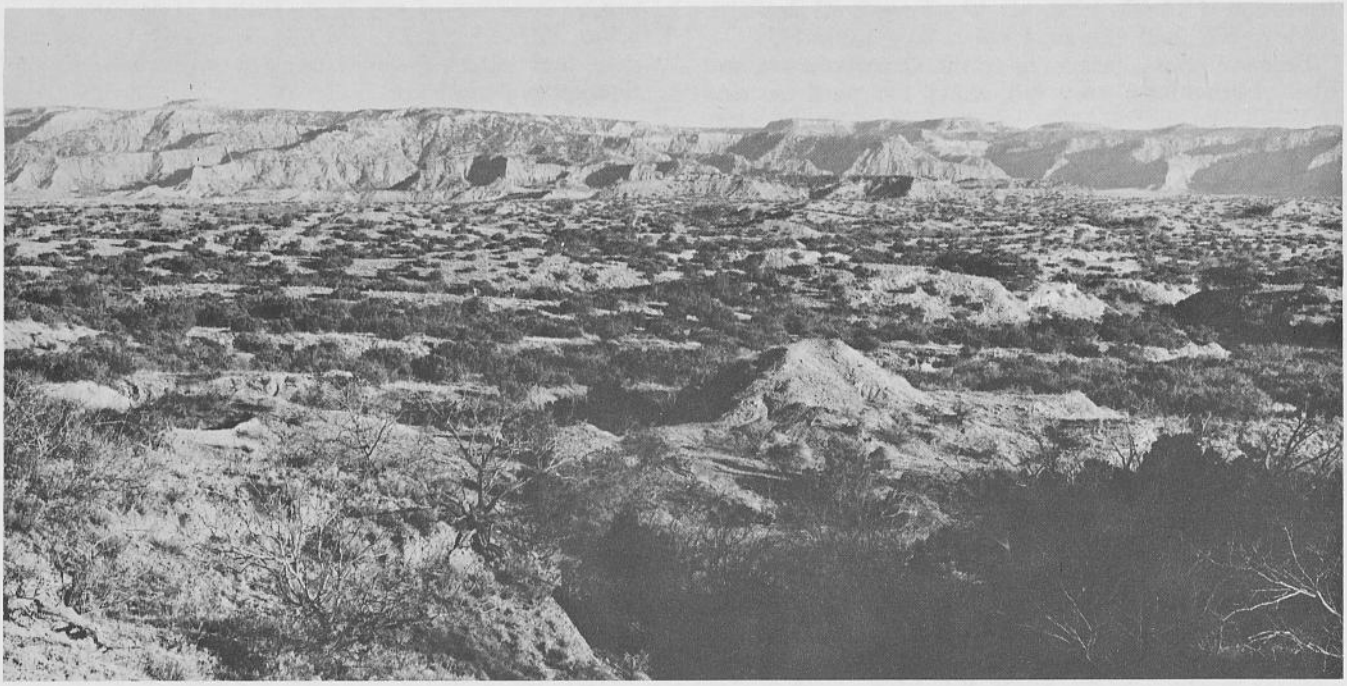

Fig. 3 (Locality 11) The eastern escarpment of the Southern High Plains in Caprock Canyons State Park, Briscoe County, Texas. The surface of the foreground is dissected in red Permian sand. The bluffs in the background form the caprock escarpment. The light colored band along the skyline is the Pliocene Ogallala Formation.

The Triassic Dockum Group (Locality 8, Fig. 4) underlies the entire Southern High Plains and is best exposed along the northern and eastern escarpment of the Llano Estacado (Brand, 1953, p. 7). On outcrop, the Dockum Group consists of red to brown continental sandstone, siltstone, and siliceous conglomerate.

Jurassic rocks are not present beneath the Southern High Plains but sporadically crop out in northern Quay County, New Mexico (Cronin, 1969, p. 3). The Jurassic section, where present, consists of continental sandstone, siltstone, claystone, and siliceous conglomerate.

Cretaceous strata cap the highest of the pre-Ogallala divides and form the floors for shallower pre-Ogallala valleys (Brand, 1953, p. 19). The formation of deeper canyons removed the Cretaceous beds so that the Ogallala section rests on Triassic, Jurassic, and Permian strata. The Cretaceous rocks are composed of fossiliferous marine limestone and claystone (Localities 20, 25, 72, 73, 93, and 105; Fig. 5) deposited upon an eroded surface of Triassic, Jurassic, and Permian strata. Thus, Cretaceous rocks at one time essentially blanketed the entire area now covered by High Plains deposits (Frye and Leonard, 1965, p. 205). Cretaceous

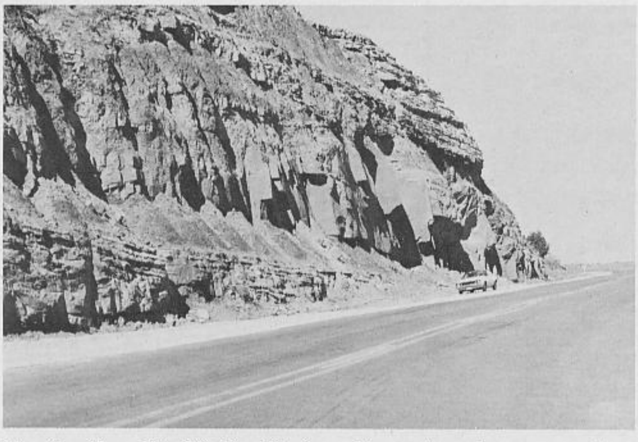

Fig. 4. (Locality 8) The Dockum Formation, here exposed on the eastern escarpment of the Southern High Plains twelve and one-half miles east of Silverton, Texas, consists of unevenly bedded red, white, and maroon sands, silts, and gravels. The overlying Ogallala Formation is not visible in the photograph.

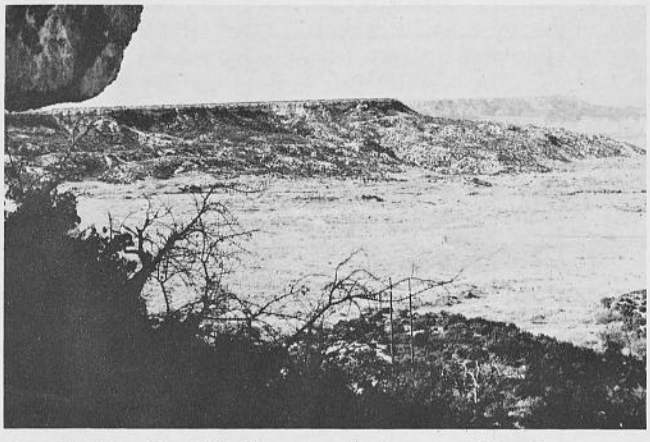

Fig. 5. (Locality 72) View north from a high Cretaceous-capped remnant, just south of Post, Texas. In the foreground, Edwards Limestone, overlain by a thin Ogallala caliche, is underlain by the less resistant Comanche Peak Formation. The valley in the middleground is developed in the Dockum Formation.

rocks underlying the High plains surface belong to the Trinity, Fredericksburg, and Wachita groups (Brand, 1953, p. 8) and dip to the southeast at 7 to 8 feet per mile (ibid.). This gradient closely conforms to the present configuration of the High Plains surface (Fig. 6) and probably contributed substantially to the present High Plains gradient (Frye, 1971, p. 5). It is this surface that forms the unconformity which underlies the Tertiary deposits of the Southern High Plains.

Initial deposits of the Ogallala Formation which immediately overlie this surface of unconformity consist of sands and gravels representing valley fills (Localities 3, 8-12, 26, 34, 75, and 126). Basal gravels consist predominantly of quartzite, but also include varying percentages of petrified wood, basalt, granite, schist, syenite, rhyolite, reworked limestone, fossil *Gryphaea*, and sandstone. The most complex suites and largest cobbles are found on the northwesternmost corner of the Southern High Plains (Locality 26). Both size and petrologic diversities diminish to the southeast (Localities 8, 9, 12, and 75). The basal Ogallala gravels, derived largely from the Southern Rocky Mountains (Localities 12, 21, 26, and 23), appear to have been deposited by bedload streams during periods of major flooding.

The age of these initial deposits is uncertain, although the earliest Ogallala gravels are normally considered to be of late Miocene age (Gidley, 1903, p. 632; Frye and Leonard, 1959, p. 27; Stirton, 1936, p. 165) or early Pliocene age (Lugn, 1938, p. 227). These dates are based on fossil vertebrate finds along the eastern caprock escarpment (basal Ogallala of the western escarpment is naturally older than that of the eastern escarpment, but has not been exposed for investigation). However, the local occurrence of significant assemblages of fossil vertebrates reduces their usefulness in field stratigraphy and makes exact dating of earliest Ogallala gravels, as well as correlation to the Ogallala gravels of the Northern High Plains, somewhat difficult and of doubtful validity. Because of this, the age of the oldest Ogallala gravels in various areas is not exactly known, thus the oldest Ogallala sediments in various areas may represent various ages.

Following the initial valley-filling phase of coarse clastic deposition, late Ogallala deposits ultimately filled the valleys and spread across the highest divides to create an essentially uniform eastward-sloping surface of alluviation.

These later deposits, above the gravels, consist predominantly of pinkish-grey, fine-to-medium green sands, silts, and clays with occasional gravel stringers (Localities 1, 2, 8-11). Except for the uppermost caliche layer, there is limited continuity of distinctive lithologic units, and there is little vertical change in lithologic character. None of the sections measured during the field investigations of this study showed distinct lateral diversity along the escarpment faces. The only noticeable changes occurred across pre-Ogallala valleys (Localities 1, 9, 12, 21-23, 26, and 123) where the base of the Ogallala Formation was dominated by course siliceous sands and gravels, or across playa lakes, which had been filled by Pleistocene sediments and later dissected by the retreating caprock escarpment (Localities 5, 6, 14). This monotonous lithology of the upper Ogallala sections suggests a random mixture of channel and overbank deposits of anastomosing streams.

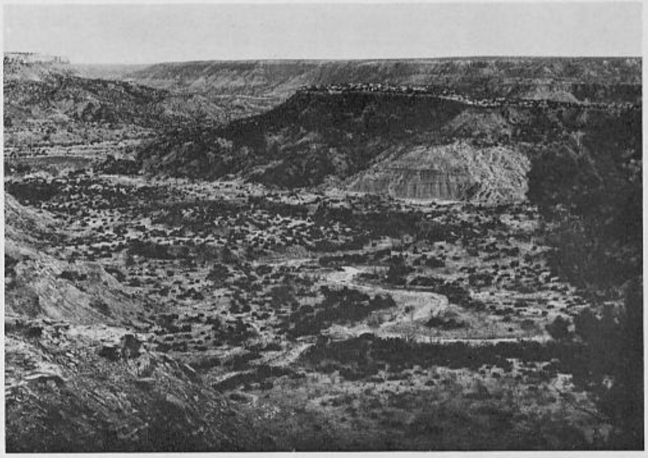

Fig. 6. (Locality 1, looking east) Palo Duro Canyon is formed by the headwaters of the Red River. The mesa to the left, below the High Plains surface represents the base of the Ogallala Formation at this location. It is covered by coarse Ogallala gravels.

NOMENCLATURE

Though rocks of Ogallala age in the High Plains are covered by a thin mantle of aeolian silt and sand, the Ogallala rocks constitute perhaps the most widely exposed rock stratigraphic unit in the United States, extending from South Dakota to the southern border of New Mexico and Texas (Leonard and Frye, 1974, p. 8).

The Ogallala Formation was first named by Darton (1898, p. 734) for the town of Ogallala, Nebraska. In the type area of the Northern Great Plains, lithologically individual units of the Ogallala Formation are indistinguishable, although the basal section normally contains a higher percentage of gravel than the younger units. For this reason, the Ogallala Formation is subdivided into four distinct floral members of similar lithology. These include the Valentine, Ash Hollow, Sidney, and Kimball Members (Frye, 1971, p. 10) and are divided on the basis of fossil seed and pollen associations (Elias, 1942, p. 10; Frye and Leonard, 1964, p. 12; Frye and Leonard, 1965, p. 206; Leonard and Frye, 1974, p. 8).

The Valentine Member represents initial late Miocene Ogallala deposition and is distinguished by the fossil grass *Stipidium commune* and hackberry *Celtis willistone* (Elias, 1942, p. 138; Frye and Leonard, 1964, p. 12; Frye, 1971, p. 11). Although the age of the basal Ogallala Formation cannot be determined by dating these fossil seeds, they are extremely useful in correlating the Ogallala over a wide area and in distinguishing one floral unit from another.

Ash Hollow sediments can be distinguished from the underlying Valentine Member by the presence of the nutlets *Biorbia paillosa*, several species of the spear grass *Stipidium berrichloa*, and the berry *Celtis willistone* and from the overlying Kimball member by its lack of the nutlets *Prolithospermum johnstoni* and *Berrichloa maxima* (Frye and Leonard, 1964, p. 12).

The uppermost member of the Ogallala Formation is the Kimball. This section, together with the Sidney gravels, represents the final stage of Ogallala deposition in the area. These units, which undoubtedly represent the culmination of the dry Pliocene history, are identified by the pisolitic limestone (caliche) which caps the surface of the entire High Plains. Correlation of the Kimball and Southern High Plains equivalents (other than by the occurrence of the caliche caprock) is determined by the presence of the fossil seeds: *Prolithospermum johnstoni, Berrichloa maxima,* and *B. minuta* (Frye and Leonard, 1959, p. 26).

The fossil plants of the Ogallala Formation on the Southern High Plains represent a typical mixed prairie flora probably dominated by grasses. In contrast with the relative abundance of Pliocene flora in the Ogallala Formation of the Northern High Plains, the Ogallala of the Southern High Plains is sparse, probably reflecting a less humid climate and lower water table than those which prevailed during the deposition of the Ogallala of the Northern Great Plains (Frye and Leonard, 1957a, p. 16).

In the Southern High Plains where the floral zones become less distinct, they are divided into two groups, (1) the Couch (Evans, 1948, p. 617), which represents initial Ogallala deposition in pre-existing channels (equivalent to the Valentine member), and (2) the Bridwell, which represents final filling of those pre-Ogallala channels and the coalescing of streams across the flat plains of alluviation.

The Couch Group is massively bedded, consisting of well-sorted sand and siliceous gravel. It may be cemented by calcium carbonate (Localities 13, 21, 28) but locally may be cemented by silica (Localities 1 and 3). Calcareous nodules occur locally. The sand, containing approximately 5% heavy minerals, is fine grained, ranging in shape from sub-angular to subrounded. Gravels (consisting largely of quartzite) range in size from a maximum of 2 feet in diameter on the north and northwest (Localities 21, 23, 26, 34, and 123) to 3 inches and smaller on the east and southeast (Localities 8-12, 19, 75, and 126).

The Couch Group is not present everywhere beneath the Southern High Plains but where it is found (in the deep pre-Ogallala valleys) it ranges in thickness from 10 to 25 feet (Localities 12, 22, 23, 24, 26, and 126) with a maximum total thickness of 125 feet in the type area (Evans, 1949, p. 6).

Although the boundary between the Couch and Bridwell Groups is not everywhere clearly defined, the Bridwell Group can be recognized by its lack of cobble-sized gravel, that is characteristic of the basal Couch Group. The Bridwell consists predominantly of unconsolidated sand, silts, and clay. Gravel in the Bridwell is not uncommon, but unlike the Couch, is finer and limited in thickness and distribution. Thickness of the formation reaches a maximum of 155 feet at the type section in Crosby County, but it is normally much thinner. The Bridwell is equivalent to the Ash Hollow, Sidney, and Kimball floral members of the Northern Great Plains (Brand, 1953, p. 18; Frye and Leonard, 1964, p. 12; Frye, 1971, p. 12).

Ogallala deposition terminated with culmination of extended, increasingly dry conditions. The end result of this long dry period was the formation of the Ogallala climax soil, caliche (Fig. 7), which now caps almost the entire High Plains surface and forms the boundary between Pliocene and Pleistocene Formations (Elias, 1942, p. 146; Reeves, 1970b, p. 359).

Fig. 7. (Locality 124) View north into the Canadian River valley 1 mile south of the Quay County line, New Mexico, and 11 miles west of the Deaf Smith County line, Texas. The Ogallala Formation here is approximately 150 feet thick and is topped by a thick, very hard caliche layer which here forms the over-hanging ledge at the top of the sloping Ogallala Formation.

There were numerous episodes of caliche formation throughout Pleistocene time, which are represented by thin layers of caliche (Localities 8 and 24), but the uppermost massive caliche (Bridwell) is the most prominent and in places is still in the process of formation. It is even now represented by different stages of development; the lowermost caliche is typical of old age, overlain by mature caliche, and capped by the still active undeveloped, youthful stage (Reeves, 1970b, p. 357).

Formation of the caprock caliche was earlier believed to be the result of algal processes (Elias, 1942, p. 146) but more recently has been attributed to soil-forming processes in the Cca horizon following removal of the A and B horizon of the original soil (Brown, 1956, p. 11; Swineford, Leonard, and Frye, 1958, p. 114; Hawley and Gile, 1966; Reeves, 1970a, p. 29; Reeves, 1970b, p. 354). The Ogallala caprock caliche is the only lithologic unit of the Ogallala Formation which can be used as a regional stratigraphic marker on the Southern High Plains.

The brecciated nature of the caprock caliche suggests that it has gone through a long period of fracturing and recementation caused by alternating arid and moist periods during Pleistocene time (Reeves, 1970a, p. 33).

The beginning of Pleistocene time (Nebraskan) began with increasingly moist conditions (Evans and Meade, 1944, p. 492; Anderson and Kirkland, 1960, p. 5). Nebraskan deposits of the Southern High Plains were termed Blanco by Cummins (1891, p. 431), after the type section near Mount Blanco in Lubbock County, and represent initial Pleistocene deposition on the Southern High Plains (Fig. 8). Blanco beds (Locality 14) consist predominantly of white to light grey bentonitic clay, sand, caliche, gravel, and local diatomaceous beds. Formation of the Blanco beds resulted from the filling of post-Ogallala lake basins (Evans and Meade, 1944, p. 492; Reeves, 1970a, p. 50). Gravel found in the bottom of early Pleistocene lake basins was apparently deposited by eastward-trending streams flowing across the High Plains before development of the Pecos valley.

Nebraskan time was followed by a period of aridity in which the Aftonian soil was formed (Frye and Leonard, 1957a, p. 8). Overlying the Aftonian soil is the Tule Formation of Kansan age which was first described by Cummins in 1893 (p. 199). The type locality for the Tule Formation is along Tule Canyon in Swisher County (Fig. 9; Localities 5 and 6). Tule sediments, like those of the Blanco, are fine-grained lacustrine deposits (Cummins, 1893, p. 199; Evans and Meade, 1944, p. 494; Reeves, 1963, p. 325) which formed during the wettest of the four major Pleistocene pluvial periods. Correlation of the Tule Formation is based upon vertebrate fossils and upon the presence and position of lenticular deposits of Pearlette volcanic ash (Evans and Meade, 1944, p. 494; Frye and Leonard, 1957a, p. 22; Reeves, 1963, p. 327; Reeves, 1970a, p. 55).

Kansan time was followed by a period of arid conditions and the formation of the Yarmouth soil (Frye and Leonard, 1957a, p. 27; 1965, p. 206).

Illinoian deposits of the Southern High Plains are represented by cover sands and as minor terrace deposits in major re-entrant canyons (Frye and Leonard, 1957a, p. 28). The Illinoian period was characterized by very dry conditions, accounting for the accumulation of the Blackwater Draw Formation (Reeves, 1976, p. 217) and the lack of fluvial deposits. The Blackwater Draw Formation is overlain by the Sangamon soil (Reeves, 1976, p. 219).

Wisconsin lacustrine deposits of the Southern High Plains reflect the humid conditions of late Pleistocene time and have been termed the Double Lakes Formation (Reeves, 1976); they are overlain by the Tahoka Formation (Evans and Meade, 1944). Other Wisconsin deposits are represented in the lowest terrace deposits of the upper tributaries of the Brazos, Colorado, and Red Rivers. Also, across the northern part of the Southern High Plains is a very late Wisconsinian loessic mantle deposited by strong prevailing southwesterly winds postdating deposition of the Tahoka Clay (Reeves, personal communication, 1977).

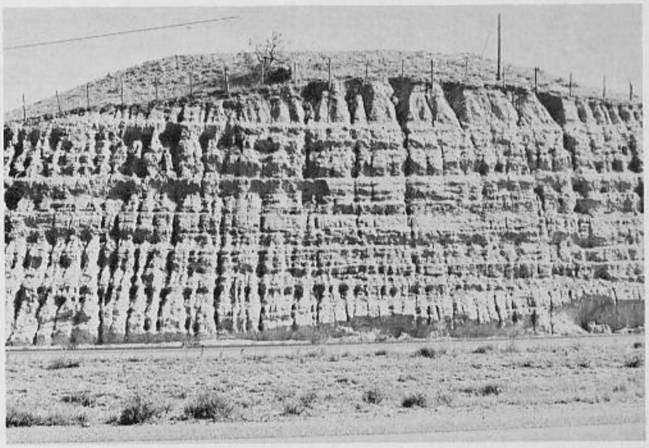

Fig. 8. (Locality 14) The Blanco (Nebraskan beds) Formation here is just south of Mount Blanco in Lubbock County, Texas. Note the even bedded nature of the lake deposits. Along the margin of the Blanco Lake deposits are sediments of reworked caliche and quartzite which were washed into the lake from the Ogallala surface prior to the time of capture of southeast-flowing High Plains streams by the Pecos River.

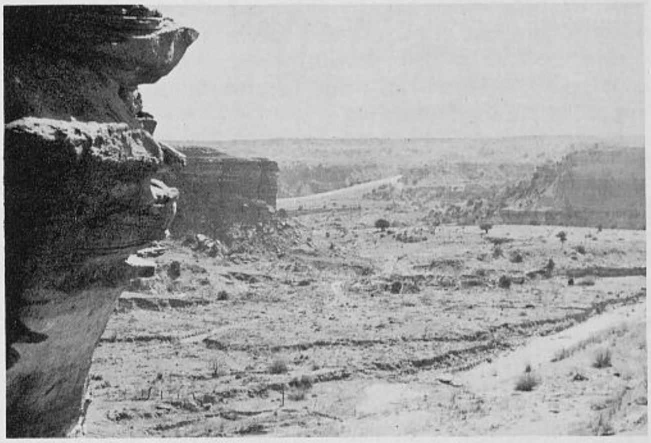

Fig. 9. (Locality 76) The Tule Formation (Kansan) is exposed in Tule Canyon, Swisher County, Texas. Here the Tule consists of lake sediments apparently deposited in basins in the Ogallala Formation. In places the Tule Formation rests unconformably on the Triassic Dockum Formation.

At the present time the High Plains surface is undergoing erosion principally through the action of wind and the infilling of playa lakes through erosion, primarily from plowed fields.

SOILS

Soils of the Southern High Plains belong to the Chernozem and Chesnut major soil groups, whereas the Amarillo Silty Clay is the dominant High Plains soil type (Brown, 1956, p. 3).

All of the High Plains soils formed during interglacial periods at the expense of middle Pleistocene cover sands (Lotspeich and Coover, 1962, p. 9). Present soils, particularly in the southern part of the Southern High Plains, veneer Kansan and Nebraskan deposits and are Yarmouthian and particularly Illinoian age (idem). However, in the northern part of the Southern High Plains the Pullman soil has formed on late (post-Tahoka) loessic debris during the last 14,000 years (Reeves, 1976, p. 218).

CLIMATE

The Ogallala and later deposits of the Southern High Plains reflect the influence of varying climates on stream regimes. While climates and processes of the past were at times greatly different from those of the present, present climate and processes form a basis of comparison. For this reason, present climate is first considered, followed by an interpretation of climatic indicators of earlier times.

Present Climate

Climate across the High Plains of Texas and New Mexico varies little from place to place. It tends to be semiarid with annual precipitation ranging from 16 inches on the west to 20 inches on the east (U. S. Dept. Commerce, 1968, p. 43). Most of this precipitation comes in the form of rain during the early spring months. Winter precipitation averages one-fifth the moisture characteristic of spring and summer (Brown, 1956, p. 2). Average lake evaporation rates range from 60 to 70 inches per year (U. S. Dept. Commerce, 1968, p. 43).

Daytime temperatures for the area range from an average of 90°F in the summer to 35°F in the winter (idem). Winds average from 12 to 16 miles per hour trending from the southwest (Brown, 1956, p. 3).

Past Climate

Earlier climates of the Southern High Plains must be interpreted from various climatic indicators. These include fossil seeds and pollen, sedimentary structures indicative of specific stream regimes, and fossil soils and caliche, indicative of certain climatic origins.

Initial Ogallala deposition was probably characterized by a prairie environment of moderate rainfall not greatly different from that of today. Soils were probably drained over a relatively low water table. This implication is derived from the knowledge of the geological requirements of the closest known living relatives of the fossil Ogallala seeds.

The oxidized iron compounds found with Ogallala sediments of the Southern High Plains, the floral assemblages, the relative paucity of fossil seeds, and complete lack of gastropods indicate that the remainder of the Ogallala of the Southern High Plains formed under a semi-arid climate (Frye and Leonard, 1957a, p. 16).

The low annual precipitation and sparse vegetal cover which persisted on the High Plains throughout its major period of formation controlled the depositional rates and evolutionary development of the High Plains. The lack of ground cover resulted in increased runoff and subsequently hastened erosional processes on the Southern High Plains.

Climates of the Pleistocene epoch varied widely from semi-arid to humid, but the dominant effect of those changes was the destruction of the Southern High Plains through canyon cutting and scarp retreat, both of which delivered great quantities of water and sediment to areas marginal to the High Plains and to central Texas streams. The principal period of High Plains destruction and central Texas alluviation appears to have been earliest Pleistocene, and the principal product of that action in central Texas was terrace formation.

EVOLUTION OF THE SOUTHERN HIGH PLAINS

There are four episodes in the history of the geomorphic evolution of the High Plains that are most significant to the development of central Texas drainage. They include: (1) the initial conditions prior to Ogallala sedimentation, (2) earliest Ogallala deposition, (3) later Ogallala deposition, and (4) episodes of major canyon cutting and scarp retreat.

INITIAL CONDITIONS

With the beginning of the Laramide revolution of the Southern Rocky Mountains, the Cretaceous seas which had covered the American Southwest began their long regression. Contemporaneous with this marine regression, drainage from the newly uplifted Southern Rocky Mountains resulted in the development of a network of southeasterly flowing streams which carved canyons in the newly exposed subareal surface (Brand, 1953; p. 19; Fig. 10).

These were the ancestors of Texas streams: the Brazos (Epps, 1973), the Leon (Lewand, 1969), the Canadian (Roberson, 1973), the Red, and the Colorado Rivers, and were the initial contributors of fluvial deposits to the upper Gulf Coast. These deposits were not only received from the Rocky Mountains but also from the landscape now buried beneath the Southern High Plains. All of these sediments had to be transported through Texas by way of the ancestral Brazos, Leon, Canadian, Red, and Colorado Rivers, and, therefore, the same type of sediments deposited at the base of the Ogallala Formation were also transported through Texas, possibly to the upper Gulf Coast.

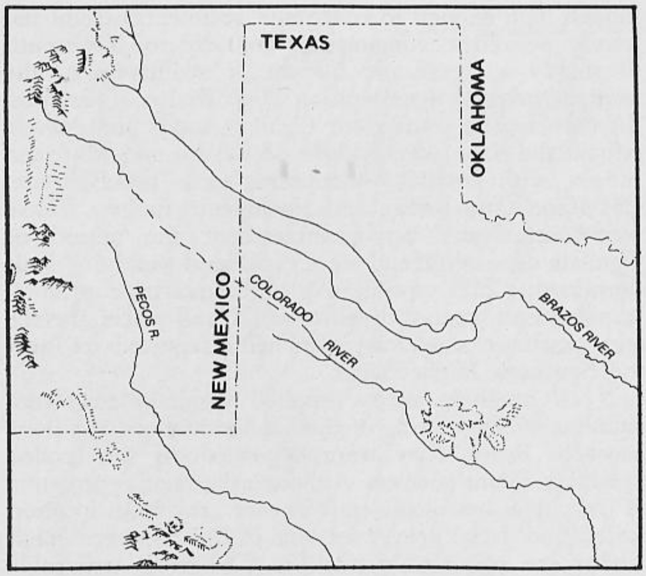

Fig. 10. Miocene drainage. Southern High Plains drainage prior to capture of the Brazos and Colorado Rivers.

Also, as a result of initial Rocky Mountain uplift, there was increased availability of water to streams, and a vast variety of distinctive rocks. Principal gravels included metamorphic and igneous rocks, with some sedimentary types. Quartzite and varying types of granite, gneiss, schist, and limestone became available to central Texas streams. These rock types form the most common constituents of the Couch Group, and likewise are seen as lag gravel occurring along the high divides extending several tens of miles both to the east and west of the present High Plains boundaries.

Tectonism, which initiated both the retreat of Cretaceous seas and the earliest episode of canyon cutting, probably resulted from the San Luis uplift, the domal uplift of the San Juan Mountains of southern Colorado and the uplift of the adjacent Sangre de Cristo and Brazos ranges (Atwood and Mather, 1932, p. 15; Baltz, 1965, p. 2041). At the same time the Los Pinos, Manzano (Stark and Dapples, 1946, p. 1164), San Andres, Nacimiento, and Sacramento Mountains (Kelly, 1955, p. 103) were being elevated to the south.

During middle Oligocene time following the formation of San Luis Valley (Baltz, 1965, p. 2041), activity ceased in the San Luis uplift. During this same period, the northern Sangre de Cristo and Wet Mountains underwent thrusting, folding, and normal faulting (Johnson, 1959). While the San Juan Mountains built up a high volcanic plateau (Atwood and Mather, 1932, p. 18) following middle Oligocene time and before middle Miocene time, the Sangre de Cristo Mountains were rejuvenated.

The second doming of the San Juan Mountains began during late Pliocene time while the Sandia, Manzano, and Los Pinos Mountains were also being rejuvenated (Stark and Dapples, 1946, p. 1164), and the Jemez volcanic area underwent intense volcanism (Ross, Smith, and Bailey, 1961, p. 139).

During early Pleistocene times, the Sangre de Cristo Range was again rejuvenated (Cabot, 1938, p. 104), possibly blocking eastward drainage to the High Plains from the San Juan Mountains.

This sequence of tectonic events suggests that throughout the time of pre-Ogallala valleys, and until the time the Pecos River pirated the last major eastward-flowing High Plains stream (Portales River), the Southern Rocky Mountains were structurally unstable, and that they provided a number of possible source areas for sediments of the Southern High Plains and central Texas streams.

EARLIEST OGALLALA DEPOSITION

Stream erosion of the pre-High Plains surface continued from the beginning of the Laramide revolution (Late Cretaceous Period) through middle Miocene time (Frye and Leonard, 1959, p. 27). During this period the Southwest, including the area of the Southern High Plains, became progressively more arid (Leonard and Frye, 1974, p. 10). This change to a more arid climate is indicated by changes in sediment type, sedimentary structures and sediment distribution, and by variation in floral types, thus accounting for the change from erosion to alluviation of the pre-High Plains valleys. However, the abundance, magnitude, and composition of coarse bedload deposits, together with their abundance in lowest Ogallala sediments, are also indicative of Tertiary uplift of the Southern Rocky Mountains, suggesting that a combination of mountain building and climatic variation accounted for initial deposition of coarse clastic materials by southeastward-flowing bedload streams.

The pre-Ogallala channels extended through central Texas as drainage ways ancestral to present drainage. Thus, while alluviation was occurring in the area of the Southern High Plains, the pre-Ogallala channels in central Texas transported the finer detritus which was not temporarily empounded in the western Ogallala deposits.

Basal Ogallala sediments consist dominantly of unconsolidated coarse sand and gravels (Figs. 11 and 12). Gravel constitutes perhaps 50% of the basal deposits and is largely confined to ancient valleys in the erosional surface upon which the Ogallala Formation was deposited. Basal Ogallala gravels range in size from a maximum boulder size of 30 inches in

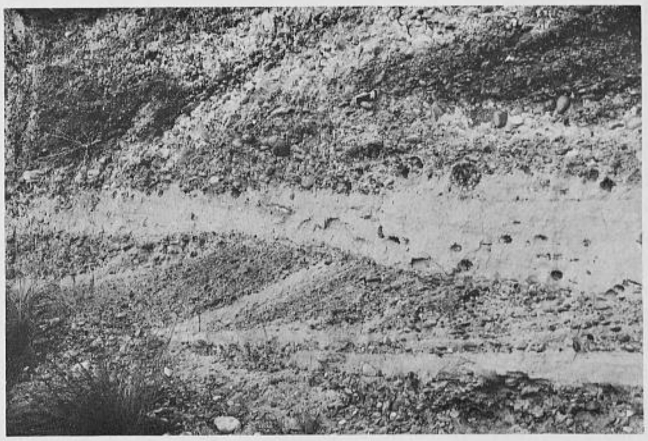

Fig. 11. (Locality 12) This is a basal Ogallala gravel section exposed on the eastern escarpment of the Southern High Plains 12 miles west of Matador, Texas. The maximum cobble diameter is approximately 6 inches and the sample consists of 80% quartzite, 10% gneiss, 5% rhyolite, and 5% granite. Gravels were deposited principally by torrential flow.

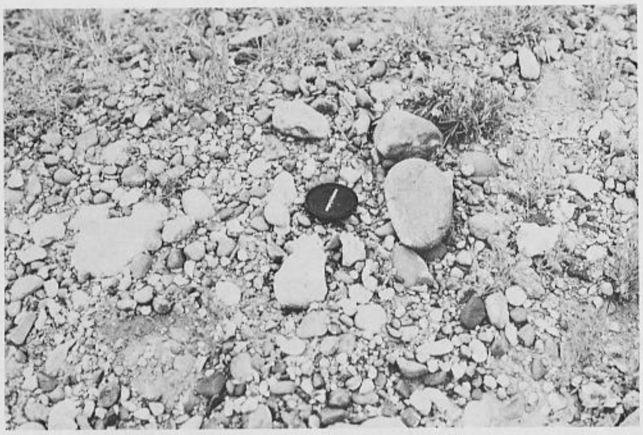

Fig. 12. (Locality 2) Ogallala gravels capping the mesas of Palo Duro Canyon. Here, gravel occurs as lag accumulation, remaining from local erosions of Ogallala deposits.

diameter on the northwest (Localities 20 and 21) to 3 inches and less on the east (Localities 8, 11, 12, 14, and 15), becoming better rounded because of long transport. The comparison of petrologic diversity, size diversity, size distribution, and mean surface gradient (Fig. 13) strongly suggests that the provenance area for basal Ogallala gravels (as well as subsequent Ogallala deposits) lies somewhere in the Southern Rocky Mountains, northwest of the present Southern High Plains.

Although it is not possible to accurately pinpoint the exact provenance areas from which earliest Ogallala sediments were derived, the general source can be determined. Lewand in 1969 (p. 23) and Menzer and Slaughter in 1971 (p. 219), from limited petrographic analysis, suggested that Ogallala gravel originated in the Sangre de Cristo and Manzano Mountains of New Mexico. However, Thomas (1972, p. 23) believed these ranges incapable of supplying the quantity of rocks of proper types required to form the Ogallala sediments. Other ranges of the Southern Rocky Mountains, petrologically capable of supplying Ogallala type sands and gravels, include the Ladrone, Los Pinos, San Pedro, and Nacimiento Mountains of New Mexico as well as the San Juan Mountains of southern Colorado. All of these ranges correlate well with slope vectors of the Southern High Plains (Fig. 13), and all are petrologically acceptable as possible source areas for Ogallala sands and gravels. Other highlands that lie in this same general area and correlate with slope vectors include Glorieta Mesa, the Pedernal Hills, and possibly the Gallinas and Jicarilla Mountains, though they do not provide adequate sources for the amount of Ogallala gravels. In addition, the projected surface of present High Plains gradients indicates either that both the Pedernal Hills and Glorieta Mesa were below the Ogallala surface, or that this steeper gradient is a product of post-Ogallala uplift. It was suggested by Bretz and Horberg (1949, p. 486) (based upon Ogallala-type gravels found in Guadalupe caves) that Ogallala gravels once covered the Pedernal Hills, Glorieta Mesa, and all but the highest portions of the Sacramento and Guadalupe Mountains. The Gallinas, Jicarilla, Sacramento, and Guadalupe Mountains, though high enough to contribute sediments, are of the wrong petrologic composition and are too far south to supply a significant amount of sediments to the northern part of the Southern High Plains. Therefore, the most logical sources for Ogallala sands and gravels remain the San Juan, Sangre de Cristo, and Manzano ranges, with possible contribution from the Ladrone, Los Pinos, San Pedro, and Nacimiento ranges. These were tectonically active throughout the period of Ogallala deposition, and were capable of supplying both the quantity and type of sediment (quartzite, granite, jasper, basalt, gneiss, rhyolite, schist, and scoria gravels, and quartzose sand, clay, and silt) required to form the Southern High Plains.

If all of these areas supplied Ogallala sediments simultaneously, mixing of their individual contributions occurred before they were deposited on the eroded pre-High Plains surface. Although the relative amounts of individual petrologic constituents vary from location to location, basal gravel sections of the Southern High Plains are remarkably similar. The most noticeable change in Ogallala gravel composition is a decrease in less stable rock types from the northwest to the southeast, a direction parallel to the mean gradient vectors (Fig. 13).

LATER OGALLALA DEPOSITION

Above the basal gravels (Couch), the Bridwell Group consists largely of well-sorted quartzose sand and silt, occasionally interlaminated with thin discontinuous channel gravels. Sands and silts are by far the dominant constituent of the Bridwell Group, representing approximately 90% of the total volume.

Like the Couch Group, the younger Bridwell sediments appear to have been the product of aggrading streams which filled the southeast-trending valleys existing in the pre-Ogallala surface. The massive, poorly bedded nature of the Bridwell sands and silts and the thin discontinuous channel gravel deposits suggest that deposition was again the product of sedimentation in anastomozing streams. Caliche stringers found locally in the Bridwell Group (Locality 24) indicate that Bridwell deposition was not everywhere constant; caliche apparently formed between active channels. The presence of caliche within the deposits of the Bridwell suggests that except for occasional flooding, the region was arid.

By late Bridwell time, the valleys which had earlier controlled Ogallala deposition had been filled. Streams meandered across an alluvial surface, depositing very fine sediment over an enormous area. Beyond the margins of the growing High Plains, these same streams transported sediments along well established drainage ways (Trinity, Brazos, and Colorado Rivers) to the upper Gulf Coast of Texas. During this period, alluvial flood plains were formed along major streams throughout central Texas.

The gradient of the late Ogallala surface was essentially the gradient of the present Southern High Plains as is indicated by the uniform slope across the High Plains from west to east. Since the area of the Southern High Plains is very large, post depositional tectonic modification of the High Plains surface gradient should influence one area more than another. There-

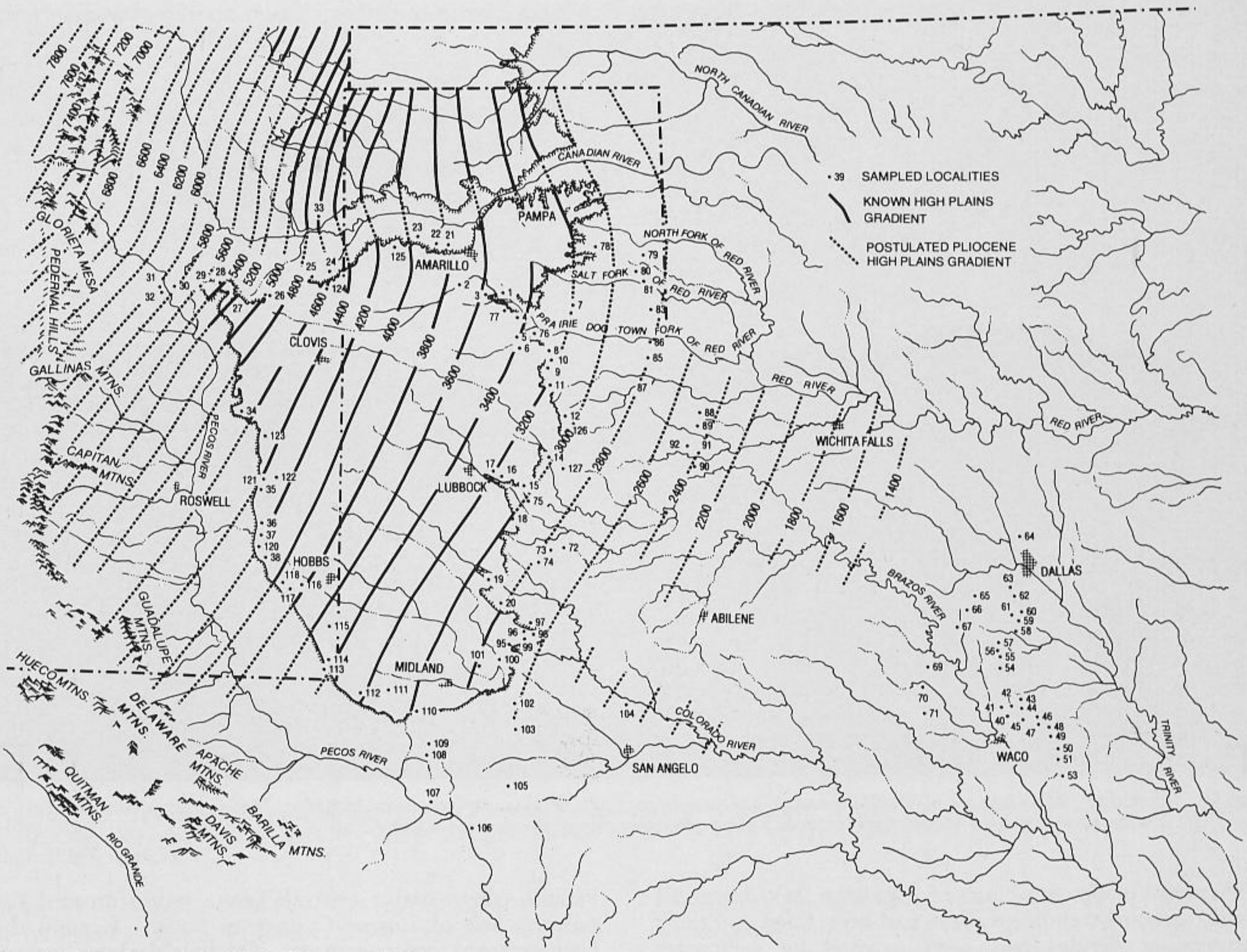

Fig. 13. Mean gradient, High Plains surface.

fore, had tectonics played a significant part, surface gradients of the High Plains should vary from place to place. A mean gradient map (Fig. 13) constructed by contour smoothing over the Southern High Plains surface shows only two areas of significant gradient variation: (1) Locality 34, 18 miles northwest of Elida, New Mexico, atop San Juan Mesa, and (2) Locality 124, one mile north of Kenna, New Mexico. Each of these localities appears to have been elevated since latest Ogallala deposition. Otherwise, the present surface of the High Plains appears to have the same configuration today as it did at the end of Ogallala time. For this reason, orthogonals to the present mean gradient probably indicate the direction of sediment transport from primary provenance areas.

Younger sands of the Ogallala Formation are composed of about 90% quartz and less than 10% heavy minerals. A study of the heavy mineral composition and distribution suggests that all Ogallala sands have approximately the same mineralogic composition. This uniformity suggests a single major source for most Ogallala deposits, again in the northwest in the vicinity of southwest Colorado and north-central New Mexico.

The minerals which constitute the major portion of the heavy mineral suites of Ogallala sands include: anatase, epidote, hornblende, rutile, magnetite, hematite, garnet, leucoxene, zircon, ilminite, biotite, muscovite, and tourmaline. Although the abundance and relative proportions of heavy minerals fluctuate from locality to locality, the degree of variation is slight, suggesting that one provenance area supplied all clastics, and that this provenance area did not change significantly with time. Had there been different source areas for the many drainage networks which crossed the pre-High Plains surface, the lowermost deposits should exhibit noticeably different suites of heavy minerals from younger deposits. As the valleys filled and the rivers meandered across the high divides, the mineral suites from various provenance areas should mix, resulting in a more common heavy mineral suite for the uppermost Ogallala deposits. This sequence is not indicated, because almost identical heavy mineral suites occur in essentially all Ogallala sections.

Ogallala sediments become finer upward from the basal gravels. Additionally, the most consistent caliche of the High Plains is at the top of the Ogallala Formation. These facts combine to suggest that climatic conditions were becoming increasingly more arid during Ogallala deposition and that stream gradients were lessening toward the end of Ogallala time (early

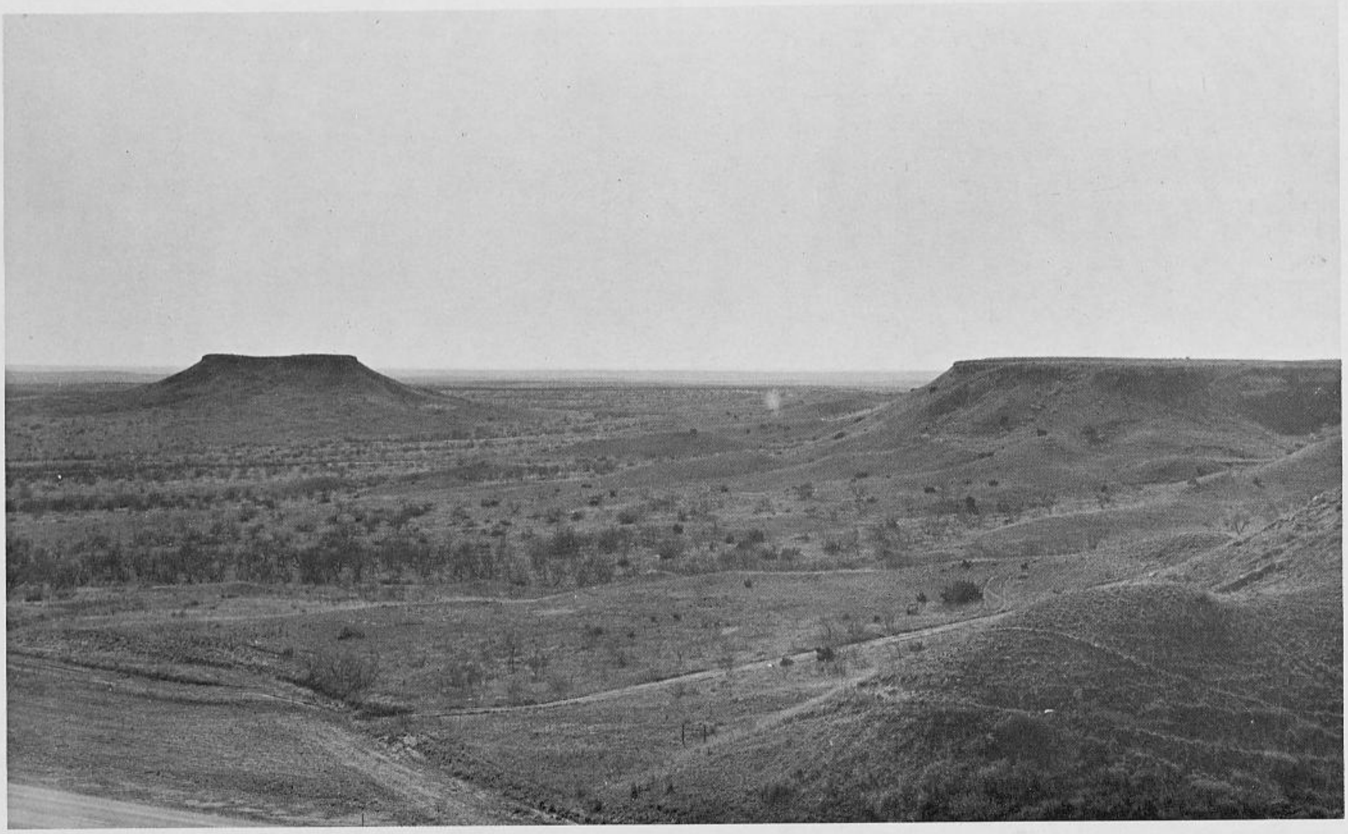

Fig. 14. (Locality 127) Outliers of Ogallala east of the Southern High Plains surface near Matador, Texas, mark the position of the High Plains surface which at one time extended some distance east of the present position.

Pleistocene). By the close of Ogallala deposition, all southeastward-trending valleys had been filled and their intervening divides had been covered by sediments deposited by those streams, which now wandered without restriction across the great alluvial plain of the High Plains surface. It was at this time (early Pleistocene) that the High Plains had reached its maximum areal extent, extending both east and west of the present High Plains surface.

In earlier investigations in which the evolution of the High Plains was of peripheral interest, Byrd (1971, p. 22) and Menzer and Slaughter (1971, p. 220) postulated that the original Southern High Plains surface extended eastward from the present caprock escarpment to the vicinity of Dallas, Texas. These interpretations were based upon projected gradients of the High Plains surface and on the abundance and petrology of gravels found in the Dallas area.

As part of the current investigation, a more detailed mean gradient map (Fig. 13) of the High Plains surface was constructed, and surface gradients were projected eastward and westward from the High Plains margins in an effort to determine the approximate original extent of the High Plains surface. This map, together with the petrology of gravels on the divides between the Brazos and Trinity Rivers, suggests that the original High Plains surface extended westward to a point along the rivers just east of a line joining Wichita Falls and Abilene, Texas. However, coarse sediments derived from the High Plains provenance areas apparently extended as alluvial fills along extended valleys where major central Texas rivers crossed the outcrop belt of Lower Cretaceous rocks. Beyond the Comanchean outcrop area, Ogallala-derived gravel spread widely across the gentle topography of Gulfian outcrop areas.

West of the present Mescalero escarpment, Ogallala deposits extended across the Pecos Valley to a provenance area in northern New Mexico and southern Colorado. Ogallala deposits at one time may have extended west of the Pedernal Hills and north of Glorieta Mesa (Thomas, 1972, p. 24). Bretz and Horberg (1949, p. 487) believed that Ogallala deposits covered all but the highest portions of the Sacramento and Guadalupe Ranges and extended southward and southwestward of the Pecos River as far as the Texas border (idem).

Eastward projections of the existing High Plains surface, a gradient of 8 to 10 feet per mile, show that this surface coincides with the tops of isolated High Plains outliers (Fig. 14). The projected surface eventually intersects older topographic highs which rise significantly above the projected surface (Fig. 15) and farther east intersects alluvial flood plains. This line of juncture with existing topography marks the probable maximum eastward extent of the High Plains surface.

Gravels collected in McLennan, Limestone, and Falls Counties (Localities 39-53) show that along present Brazos drainage Ogallala-type gravels occur along the highest interstream divides. Northward in Ellis, Dallas, Rockwall, Hill, Johnson, and Bosque

Fig. 15. The Cretaceous Callahan Divide, south of Abilene, Texas, existed at the time of Ogallala deposition and acted as a barrier against the eastward flow of Ogallala sediments. The surface of the Callahan Divide stands several tens of feet above the projected High Plains surface.

Counties (Localities 54-71) gravel is rare and is petrologically quite different from gravels collected from known Ogallala deposits (Fig. 16, Locality 20).

Topographic highs which marked the limits of Ogallala deposition include the Callahan Divide of Callahan and Taylor Counties and high areas of Young County along stream divides. Through these elevated regions, tongues of alluvial sand and gravel apparently extended eastward for many miles. These pathways include Panther Valley (Frye, 1971, p. 8), the Colorado River valley (Byrd, 1971, p. 29), and the Clear Fork of the Brazos River (Lewand, 1969, p. 21). Within these entrenched valleys, streams which drained the Ogallala uplands were confined, and therefore sediments derived from Ogallala sources were also confined to the valleys. Beyond the eastern mouths of these valleys, where streams transected less resistant Upper Cretaceous deposits, they again meandered, depositing Uvalde and possibly Goliad sands and gravels of east-central Texas as a veneer across the Gulfian countryside. Flowing south out of the Southern High Plains, the Pleistocene Pecos River produced the same effect by removing Ogallala fill from the Pecos Valley and redistributing it to the south (Byrd, 1971, p. 29).

PLAYA LAKE BASINS

Following deposition of the Ogallala Formation in latest Pliocene time (Judson, 1950, p. 269; Reeves, 1970a, p. 108), thousands of lake basins formed on the plains surface. The mechanism of formation of these lake basins has long been a subject of controversy. They have been attributed to buffalo wallows (Johnson, 1901, p. 702), wind deflation (Gilbert, 1895, p. 49; Evans and Meade, 1944, p. 486), solution of underlying salt and gypsum deposits (Johnson, 1901, p. 703), and caliche karst (Price, 1940, p. 1939).

Although each of these theories may explain the formation of individual lakes, it seems unlikely that in a region of such geological uniformity as the Southern High Plains, such an enormous abundance of lake basins of similar aspect should owe their origin to more than one major cause.

While at first glance, playa lake basins may appear of little importance to central Texas drainage history, this is not necessarily so. If formed by solution, these lakes at one time constituted a principal Ogallala aquifer recharge mechanism and were the principal contributors to base flow of central streams. If formed by deflation, they contributed nothing to central Texas drainage, but do indicate a radically different climatic regime.

In an effort to determine controls on their distribution, the abundance of lake basins per 7½ minute quadrangle of High Plains surface was determined by actual count on 1:250,000 scale topographic sheets. This count (Fig. 17) indicates that the highest density of lake basins occurs along buried pre-Ogallala valleys, and on the eastern margin of the High Plains surface. The significance of this relationship is not entirely clear, although it may suggest that the depressions are most abundant where rainfall is greatest (on the eastern margin on the Southern High Plains) and/or where the Ogallala sections (including caliche) are the thickest (the filled valleys).

During latest Ogallala deposition, rainfall may have varied over wide ranges, but the regional distribution should have been similar to that of today; that is, most abundant on the east, least abundant on the west. Thus, the distribution of the lake basins is suggestive of origin as caliche-solution features. Had they been formed by deflation, they should have been most abundant to the west where rainfall was least abundant. Likewise the correlation between lake basin distribution and the ancient drainways is difficult to explain unless there is also a correlation between the thickness of soluble sediments (caliche) and the abundance of lake basins. However, the present configuration of the basins is seldom suggestive of solution, and the basins (if of solution origin) probably have been widely modified by subsequent aeolian and fluvial action. Their continued existence, however, suggests that the process which formed them is still active, though perhaps active at a much reduced rate. The time of origin of the playas is not certain. If of solution origin, they probably began as a result of significant climatic change toward a more humid period.

This interpretation of solution origin for most playa basins is not widely shared by other High Plains workers. Extensive studies by Reeves (oral communication) suggest to him that the probable origin for a great number of playa basins is wind deflation. To the northeast, as playa density becomes greater, soil becomes finer grained; this is due to distribution by prevailing winds from the southwest. Unlike the hard pan surface of the southwestern Southern High Plains where essentially all topsoil has been removed, the surface to the northeast is covered by thick, fine sediments which are highly susceptible to wind deflation. A number of playa basins examined by Reeves lack caliche bases, as might be expected in solution-originated playa basins. This also indicates deflation formation.

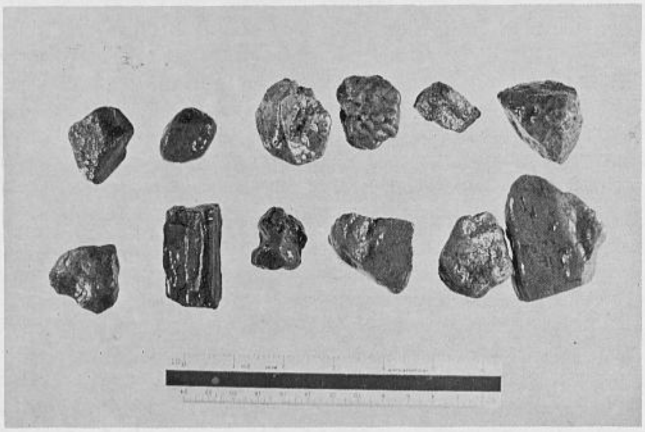

Fig. 16. (Locality 128) Gravels from high divides between the Trinity and Brazos Rivers in Dallas County, Texas. These are all quartzitic, but are petrologically unlike both the Ogallala gravels from the High Plains and the Seymour gravels found on the high divides to the south. Presence of these gravels, and the lack of true Ogallala gravels, suggests that these had a source different than the Southern High Plains Ogallala gravels and that the Ogallala Formation never extended into the Dallas area.

In so far as the present study is concerned, the origin of playa lake basins remains an unresolved problem. While there is a strong tendency to defer to more experienced workers, the significance of playa basin origin is so important to central Texas drainage history that it is here considered an open question, yet to be answered.

At the beginning of the Pleistocene period, conditions again became moist (Frye and Leonard, 1957a, p. 21; Anderson and Kirkland, 1960, p. 5; Reeves, 1970a, p. 47), and rivers which once crossed the Southern High Plains surface again meandered widely, creating broad flat alluvial plains. As a result of increased runoff at this time, there were possibly several large streams transecting the Southern High Plains. The main stream, flowing through the now buried Portales Valley (Thomas, 1972, p. 25), initially formed the headwaters of the Brazos River of central Texas. Earlier studies by Epps (1973, p. 33), confirmed by the presence of Ogallala-type gravels in the Brazos terraces of central Texas (Localities 41-53), suggest that the early Brazos River was related to the development of the Southern High Plains (Fig. 18).

Biological evidence in the form of fish populations suggests that the Colorado River was at one time connected to the Pecos River system. *Etheostoma lepidum,* a common darter, which is found east of the Southern High Plains is likewise found in an isolated middle section of the Pecos River from Roswell, New Mexico, to the Black River area near Carlsbad, New Mexico. This isolated population of fish possibly indicates a junction where Pecos River drainage captured the older southeast-flowing Colorado River (Echelle, 1976, oral communication).

EPISODES OF CANYON CUTTING AND MAJOR SCARP RETREAT

Canyon cutting and scarp retreat are discussed together because the processes which encouraged one likewise encouraged the other.

Aided by continuing moist conditions the Pecos Valley was quickly exhumed, possibly due to headward erosion along a less resistant filled channel through which an even older Pecos River had flowed (Bretz and Horberg, 1949, p. 489) delivering Ogallala sediments. During late Pliocene time the headwaters of the Pecos River were in Pecos and Reeves Counties, Texas, and by earliest Pleistocene time had advanced to a position just south of the De Baca-Chaves County line in New Mexico (Leonard and Frye, 1974, p. 12). Throughout the remainder of Pleistocene time, the Pecos River, aided by development of a structural trough along the present Pecos Valley (idem), extended headward. The Pecos River finally achieved its present configuration during late Kansan or early Wisconsin time with the beheading of the Portales River just north of Santa Rosa, New Mexico (Leonard, Frye and Glass, 1975, p. 12). Dating of the erosional history of the Pleistocene Pecos interpreted by Leonard and Frye (1974) and Leonard, Frye and Glass (1975) on the basis of radiocarbon dates (principally of Pleistocene mollusks found in high terraces of the modern Pecos

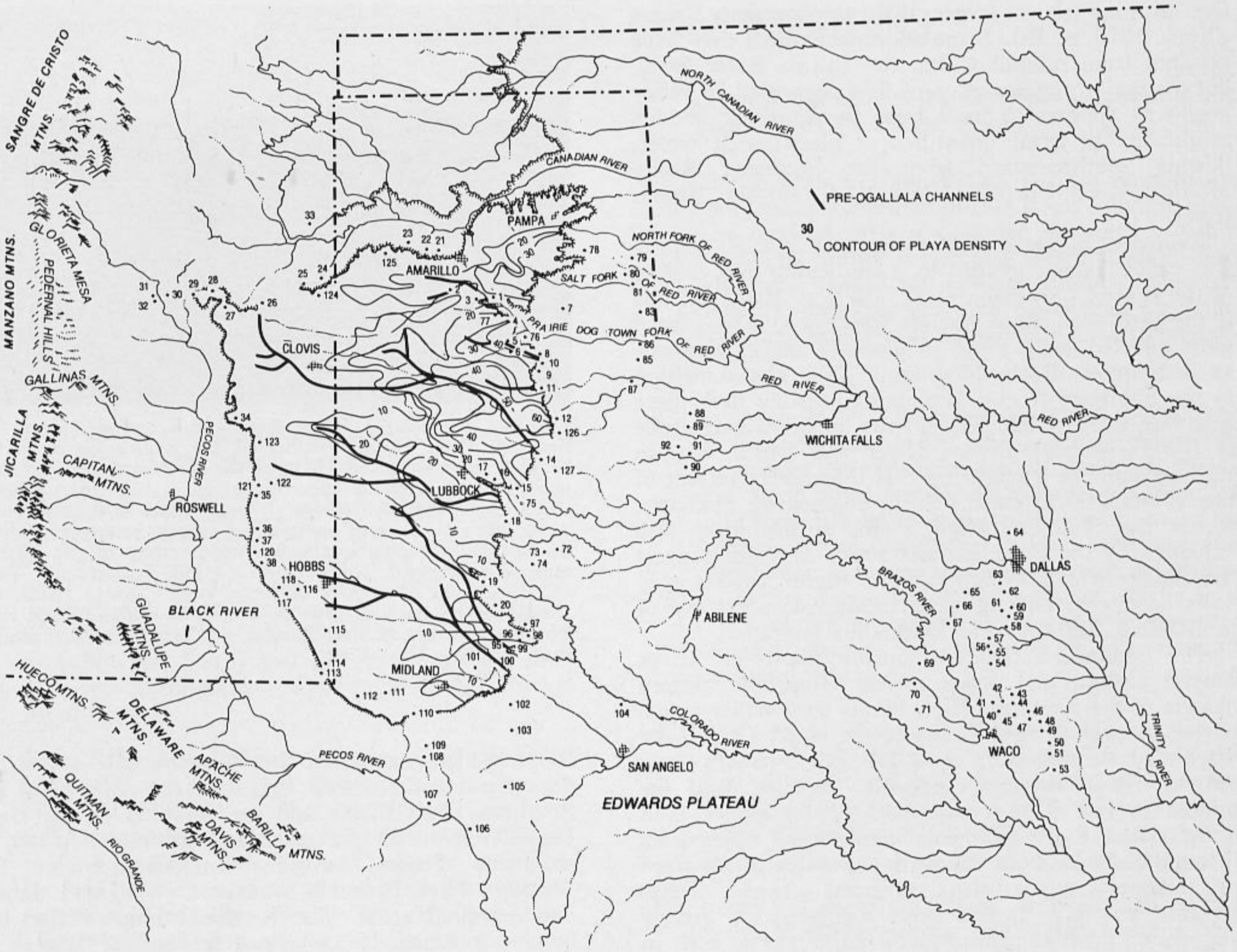

Fig. 17. Playa density and pre-Ogallala drainage.

River) suggests that headward migration of the Pecos was swift due to the fact that it was channeling through a valley filled with unconsolidated early Ogallala sand and gravel.

The Canadian River, apparently penecontemporaneous with development of the Pecos River, extended headward across the Southern High Plains, possibly (like the Pecos) following the route of a valley filled during earliest Ogallala time. The Canadian River achieved its present configuration during late Pleistocene time with the capture of the northernmost tributary of the Pecos River approximately 32 miles northwest of Tucumcari, New Mexico, at the site of the Conchas Reservoir (Roberson, 1973, p. 136). It was during this same period of the dissection of the Southern High Plains by the Canadian and the Pecos Rivers that the eastern escarpment was rapidly eroded westward.

Retreat of the caprock escarpment was rapid, for the present position is approximately 175 miles west of the inferred original eastern margin. Based on present erosional rates, the caprock escarpment presently retreats westward at approximately 2.1 x 10^{-3} feet per year (U. S. Dept. Commerce, 1968). Had this rate occurred throughout Pleistocene time (approximately 1.5 m.y.) the maximum distance of caprock retreat would have been about ⅔ mile. Thus, in order for the escarpment to have reached its present position since erosion began in early Pleistocene time (Fig. 13), the erosional rates must have averaged approximately 1⅔ feet per year. Additionally, scarp retreat, may have been a great deal faster than the approximate 1 foot per year during much of post-Ogallala history, but at other times the scarps were essentially stable.

There are at least two factors which may shed light on the unusually rapid scarp retreat: (1) Because Ogallala deposits near the eastern margin of the ancestral High Plains were probably much thinner than those of the present caprock escarpment, retreat of the Ogallala escarpment should have been much more rapid as the escarpment was less pronounced and the amount of sediment to be transported much less. (2) Catastrophic Pleistocene glacial melts in the Southern Rocky Mountains possibly resulted in a release of a vast amount of water, which poured across the Southern High Plains into central Texas. This possibility is suggested by Brazos terraces which were formed by a river five to nine times larger than the present Brazos (Epps, 1973, p. 39). Some additional runoff may have resulted from rainfall within the Brazos River basin, but the major augmentation of flow suggested by valley geometry appears to have been the result of sudden availability of great quantities of glacial melt water, flowing southeastward from the Southern Rocky Mountains via Portales Valley and into the Brazos River.

Evidence suggests that Pleistocene glacial melting was rapid enough to lead to a freshening and cooling of the oceans (Emiliani, et al., 1975, p. 1087). If this is the case, then those glaciers which would have been most affected were those in glacially marginal areas, as the Southern Rocky Mountains. Thus, glacial melting in the Southern Rocky Mountains possibly took place at a rate which might explain the apparant magnitude of the Pleistocene Brazos River and which may in turn account for a major part of the sudden retreat of the caprock escarpment. Such augmented discharge across the Southern High Plains surface may also explain why the Canadian and Pecos canyons transect the Southern High Plains. Thus these canyons may have been cut, not by slow headward migration of headwaters, but by rapid knickpoint migration.

The sediments removed during Canadian River canyon cutting and scarp retreat along the eastern margin of the Southern High Plains were either transported through central Texas to the upper Gulf Coast or ponded somewhere in central Texas. Terraces along central Texas streams represent "storage" and the middle to late Tertiary deposits of the upper Gulf Coast reflect those sediments which were transported through central Texas. Likewise the water which acted as transport agent also traversed central Texas streams, possibly, as has been suggested, as greatly augmented flow, coinciding with major glacial melt in the Southern Rocky Mountains. This in turn led to the formation of minor alluvial valleys, remnants of which are preserved as terraces along the Brazos River. Rainfall in the area of the Brazos basin apparently did not increase to such extent as to account for the indicated river size, because minor tributaries of the Brazos such as the Bosque River would indicate a similar history, yet they do not.

PRESENT CONDITIONS

Present conditions on the Southern High Plains began with the beheading of the Portales Valley by the Pecos River and the completion of the Canadian River canyon, thus marking the eastern and northern margins of the Southern High Plains and the isolation of the High Plains from further external contributions of water or sediment. Present erosional modification of the Southern High Plains is by export (wind and water) into marginal areas. The Southern High Plains has become increasingly arid since the end of Wisconsin time (Frye and Leonard, 1968, p. 530), leading to decreased stream erosion and increased wind erosion. Because of reduced ground cover, this change in erosional agents has undoubtedly increased surface erosion but has reduced the rate of caprock retreat far below that which occurred throughout Pleistocene time. With the exception of the Canadian and Pecos Rivers, none of the present streams head beyond the western margin of the Southern High Plains. All originate on the eastern margin, even though well-developed channels show that the Southern High Plains was in the past an important contributing area to central Texas drainage.

Fig. 18. The Brazos River flows south and east from the Southern High Plains. History of the Brazos began in late Tertiary time with the uplift of the Southern Rocky Mountains. It first acted as an erosional agent, carving southeast-trending pre-Ogallala valleys. It later acted as an alluviating agent filling those same valleys. It now, again acts as an erosional agent resulting in the westward retreat of the existing caprock escarpment. Note the hills in the background. These are the Double Mountains of Stone Wall County, Texas, and are capped by quartzite gravels. This is an outlier of the High Plains and is situated far east of the present eastern margin of the Southern High Plains.

SUMMARY AND CONCLUSIONS

1. The evolution of the Southern High Plains has been closely related to the evolution of central Texas drainage. The same drainage networks that created the Southern High Plains likewise initiated the drainage history of present central Texas streams.

2. Initiation of the development of the Southern High Plains of Texas and New Mexico began with the Cretaceous uplift of the Southern Rocky Mountains. This series of tectonic events resulted in increased southeasterly runoff which in turn carved a ridge-valley topography into the pre-High Plains surface. These same streams were the ancestors to the central Texas streams.

3. This new availability of water from a new provenance area resulted, in turn, in an increase of a vast variety of distinctive rock types. Lithologic characteristics of these initial deposits coupled with High Plains mean gradients indicate that the sources for initial Ogallala sediments were probably the San Juan, Sangre de Cristo, and Manzano Mountains of the Southern Rocky Mountains.

4. Initial deposition of coarse basal Ogallala sediments (Couch) resulted from a combination of mountain building in the provenance area and sedimentation of basal Ogallala deposits. Climatic variation during late Tertiary time is indicated by fossil evidence along the eastern escarpment, suggesting deposition during late Miocene time. However, sediments closer to the source area on the west were deposited first and are undoubtedly older than those on the east.

5. Late in Ogallala deposition, pre-Ogallala channels had been filled, and a smooth surface had formed across the High Plains area. Streams which meandered across the surface exited through central Texas via well established drainage ways to the Gulf of Mexico. These streams were the ancestors to present day eastward-flowing Texas rivers.

6. Latest Ogallala sediments (Bridwell) consist primarily of fine-grained sand. This is composed of approximately 90% quartz and 10% heavy minerals. The degree of variation in heavy mineral suites is negligible from place to place and vertically across the Southern High Plains. This does not point to a specific source area, but does indicate that all Ogallala sediments had the same source area, and that the source area was not changed throughout the development phase of the Southern High Plains.

7. The Southern High Plains surface reached its maximum areal extent during latest Pliocene time. The original surface extended eastward possibly as far as a line connecting Wichita Falls and Abilene, Texas. Late Tertiary streams, however, extended past this line, and distributed Ogallala-type sand and gravel across the Gulfian countryside.

8. Approximately 37,000 playa basins dot the surface of the Southern High Plains. Playa density is greater on the eastern margin of the High Plains and along filled pre-Ogallala valleys. Origin of the playas has been attributed to deflation and to solution of the underlying caliche. However, the distribution of playas also suggests solution origin, caused by dissolution and collapse of caliche as a result of higher rainfall in the area where pre-Ogallala channels are filled with thick sections of sand and caliche.

9. The Brazos River was at one time connected to the upper tributaries of the Pecos River via the now filled Portales Valley which crosses the Southern High Plains. Distinctive fish populations of the Colorado and Pecos Rivers indicate that at one time these rivers communicated as well.

10. Retreat of the High Plains surface began during early Pleistocene time with the western and northern boundaries defined by headward erosion of the Pecos and Canadian Rivers. On the east, the escarpment retreated at a much greater rate than is indicated by present erosional figures. Glacial melting in the Southern Rocky Mountains possibly contributed greatly to the rapid scarp retreat and to the increase in central Texas stream activity.

11. Present conditions began with the beheading of the Pecos River, completion of headward migration of the Canadian River, and a marked decrease in rate of retreat of the eastern escarpment of the Southern High Plains. Erosion on the surface is now confined to wind action, with little stream runoff. Erosional rates are minor, changing the surface little and causing negligible retreat of the escarpment. Those sediments removed from the Southern High Plains by runoff are carried southeastward and deposited by central Texas streams.

APPENDIX

REFERENCE LOCALITIES

Because the purpose of this study was to determine the gross characteristics and history of the Southern High Plains, correlation of individual units was not attempted. Correlations cited within this report are those derived largely from the literature. However, wherever possible, samples were taken in the field from the lower, middle, and upper beds at each section to determine whether there were significant changes in provenance during Ogallala deposition.*

Locality 1 (34°45′N, 101°40′W)
85-foot Ogallala section at head of Palo Duro State Park. Outcrop consists of a 2-foot gravel section at the base overlain by well-sorted sands and silts.

Locality 2 (34°59′N, 101°56′W)
Road quarry pit approximately 1 mile north of Canyon, Texas, on Interstate 87. Pit did not cut through the base of the Ogallala and consisted of well-sorted sands and silts.

Locality 3 (34°44′N, 101°39′W)
Mesa on the south side of Palo Duro State Park approximately 100 feet below the High Plains surface. Surface veneered with Ogallala gravels.

Locality 4 (34°46′N, 101°39′W)
Mesa on the north side of Palo Duro State Park approximately 100 feet below the High Plains surface. Ogallala gravels absent from the mesa surface.

Locality 5 (34°32′N, 101°28′W)
McKenzie Reservoir site on Tule Canyon, 8½ miles northwest of Silverton, Texas, on State Road 207. Surface veneered with Ogallala gravels as well as abundant petrified wood.

Locality 6 (34°36′N, 101°26′W)
Tule formation along Tule Canyon, 8 miles northwest of Silverton, Texas, on State Road 207. Outcrop consists of interbedded sand, silt, and Pearlette ash, overlying Triassic Dockum sands.

Locality 7 (34°51′N, 100°54′W)
Ogallala lag gravels 3 miles south of Clarendon, Texas, on State Road 70. Surface is mostly sand covered by fine Ogallala gravel.

Locality 8 (34°29′N, 101°06′W)
80-foot Ogallala section 12½ miles east of Silverton, Texas, on State Highway 256. Section consists of a consolidated basal gravel overlain by evenly bedded sand and silt. The section is capped by a massive section of sandy caliche.

Locality 9 (34°26′N, 101°06′W)
100-foot Ogallala section 13 miles east of Silverton on Holmes Creek. Section consists of a loose basal gravel overlain by sand, silt and a massive caliche cap.

Locality 10 (34°23′N, 101°06′W)
80-foot Ogallala section on State Highway 86, 12 miles east of Silverton, Texas. Section consists of fine sands and silts overlain by thick caprock caliche. There is no basal gravel.

Locality 11 (34°15′N, 101°12′W)
100-foot Ogallala section 12 miles southeast of Silverton, Texas, on State Highway 86. Section consists of loose basal gravel overlain by poorly consolidated sands and silts capped by a massive sandy caliche.

Locality 12 (33°59′N, 101°02′W)
Burleson Ranch section approximately 12 miles west of Matador, Texas, on U.S. Highway 70. Section consists of 35 feet of crossbedded Ogallala sands and coarse gravels.

Locality 13 (33°56′N, 101°20′W)
10 miles south of Floydada, Texas, on Texas Highway 62, along the head waters of White River. Section consists of 70 feet of sand and silt overlain by a thick sandy caliche. No gravel is present at the base.

Locality 14 (33°40′N, 101°13′W)
5 miles east of Crosbyton, Texas, on Texas Highway 82 on White River. Blanco Formation here in the form of Pleistocene lake deposits.

Locality 15 (33°35′N, 101°15′W)
20 miles north of Post, Texas, on Texas Highway 207. Ogallala section consists of fine sands and silts capped by a sandy caliche layer. Gravel was not exposed at the base.

Locality 16 (33°33′N, 101°33′W)
5½ miles south of Robertson, Texas, on County Road, continuation of Farm Road 378. Ogallala Formation consists of evenly bedded sand and silt capped by a massive caliche layer.

Locality 17 (33°30′N, 101°38′W)
5 miles north of Slaton, Texas, on Farm Road 400. Ogallala exposed along wall of the Double Mountain Fork of the Brazos River valley. Formation consists of sand and silt capped by sandy caliche.

Locality 18 (33°13′N, 101°40′W)
5 miles west of Post, Texas, on U.S. Highway 380. Ogallala Formation exposed along Caprock escarpment consists of fine-grained sand and silt. No gravel is exposed at the base.

Locality 19 (32°30′N, 101°35′W)
10 miles north of Vealmoor, Texas, on Farm Road 1054. Basal Ogallala gravels exposed here in Pleistocene terrace deposit.

Locality 20 (32°13′N, 101°32′W)
1 mile south of Big Spring, Texas, on U.S. 87. Cretaceous remnant above the top of the Ogallala Formation. There are no lag gravels atop the high Cretaceous mesa.

Locality 21 (35°15′N, 102°04′W)
4½ miles north of Bushland, Texas on Texas Highway 2381. Ogallala outcrop on the south side of the Canadian River valley exhibits a 10-foot bed of gravel. Some cobbles measure 18 inches in diameter. The thick gravel is overlain by 75 feet of clean sand. The section is capped by a 12-foot layer of sandy caliche.

Locality 22 (35°12′N, 102°08′W)
Portland Cement Plant located 2 miles north of Bushland, Texas, on a dirt road. Basal Ogallala gravels veneer a portion of the lower slopes but are not found in bedding position. Sands above the gravels are evenly bedded and capped by a massive layer of sandy caliche.

Locality 23 (35°23′N, 102°15′W)
Amarillo Gravel Works is located 14 miles north of Vega, Texas, on U.S. Highway 385. Basal Ogallala gravels are highly crossbedded and interbedded with lenses of clean sand.

Locality 24 (34°54′N, 103°06′W)
Quay-Curry County line is 9 miles north of Bellview, New Mexico, on New Mexico Highway 93. 95-foot Ogallala section consists of fine sand and silt interbedded with stringers on caliche. Gravel is not present at the base.

Locality 25 (34°59′N, 103°21′W)
8 miles south of San Jon, New Mexico, on New Mexico Highway 39. 20-foot Ogallala section consists of sand and silt overlain by thin caliche bed. Gravel is not present at the base.

Locality 26 (34°50′N, 103°44′W)
¼ mile north of Ragland, New Mexico. Gravel pit exposes massive beds of unconsolidated gravels and interbedded stringers of sand. Gravel lithology is very diverse with cobbles measuring up to 2 feet in diameter.

Locality 27 (34°54′N, 104°04′W)
Escarpment southeast of Ima, New Mexico, 9 miles north and 4 miles east of the common corner of Guadalupe, DeBaca, and Quay County, New Mexico. 30-foot Ogallala section resting upon Triassic sandstone consists of evenly bedded sand and silt. It is capped by approximately 8 feet of indurated sandy caliche.

Locality 28 (34°55′N, 104°10′W)
10 miles west of Ima, New Mexico, on New Mexico Highway 156. Ogallala section consists of fine-grained sand underlain by the Triassic Dockum Formation.

Locality 29 (34°58′N, 104°14′W)
15 miles east of Santa Rosa, New Mexico, on U.S. 66. Section consists of basal unconsolidated gravel overlain by approximately 10 feet of clean sand. The section probably represents a Pleistocene terrace deposit.

Locality 30 (34°58′N, 104°14′W)
3 miles east of Santa Rosa, New Mexico, on Interstate 66. Pleistocene terrace deposit.

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*Copies of this heavy mineral and cobble analysis can be obtained from the Department of Geology, Baylor University, for reproduction costs.

Locality 31 (34°55'N, 104°42'W)
1 mile west of Santa Rosa, New Mexico, on Interstate 40. Pleistocene terrace gravel capped by a thin layer of caliche. Gravel probably derived from an older Ogallala deposit.

Locality 32 (34°53'N, 104°38'W)
2 miles south of Santa Rosa, New Mexico, on New Mexico Highway 91. A very low exposure of Ogallala adjacent to the Pecos Valley. No gravel present.

Locality 33 (35°33'N, 103°13'W)
17 miles northeast of Logan, New Mexico, on U.S. 54. Pleistocene terrace deposit consisting of Ogallala lag gravels including reworked caliche.

Locality 34 (34°04'N, 103°58'W)
May Ranch, 18 miles northwest of Elida, New Mexico, atop San Juan Mesa. 20-foot outcrop of Ogallala composed almost entirely of sand with occasional gravel cobbles. The top is capped by a thick caliche layer.

Locality 35 (33°18'N, 103°48'W)
28 miles north of Maljamar, New Mexico, on New Mexico Highway 172. 170+ feet of clean Ogallala sand. The section is capped by a thick caliche layer but the bottom is not exposed.

Locality 36 (33°14'N, 103°48'W)
24 miles north of Maljamar, New Mexico, on New Mexico Highway 172. 175 feet of clean Ogallala sand and silt. The top is capped by a thick caliche zone, but the bottom is not exposed.

Locality 37 (32°52'N, 103°50'W)
2 miles southwest of Maljamar, New Mexico, on U.S. Highway 82. Pleistocene blow sands cover most of the area underlain by Ogallala sands.

Locality 38 (32°51'N, 103°46'W)
½ mile north of Maljamar, New Mexico, on New Mexico Highway 31. Ogallala section consists of 20 feet of cemented sand overlain by about 2 feet of caliche.

The following 32 Localities (39 to 71) are spot checks of central Texas upland surfaces which were investigated to determine original areal distribution of Ogallala-derived gravels. Sites which show no lag are as significant as those which do, for they suggest that Uvalde gravel was highly localized over the Gulfian outcrop area.

Locality 39 (31°43'N, 97°03'W)
Plowed field 3 miles south of Tours, Texas, on Farm Road 308, Gravels scattered across the field are much like Ogallala gravels of the High Plains and are probably lag gravels.

Locality 40 (31°45'N, 97°03'W)
Plowed cotton field ½ mile south of Tours, Texas, on Farm Road 2311. Small amount of lag pea-sized gravel consisting of quartzite, chert and limestone.

Locality 41 (31°47'N, 97°05'W)
Plowed field 2½ miles north of Tours, Texas, on Farm Road 2311. Lag gravels consist of quartzite, chert, limestone, and some jasper.

Locality 42 (31°51'N, 97°03'W)
Field 2 miles north of Cottonwood, Texas, on a county road south of Abbott. Lag gravels consist of several types of chert along with some quartzites.

Locality 43 (31°48'N, 96°56'W)
1 mile south of Penelope, Texas, on Farm Road 339. Field contains small amount of chert and yellow quartzite.

Locality 44 (31°47'N, 96°53'W)
4 miles north of Mount Calm, Texas, on Texas Highway 31. Plowed field exhibits small amount of purple, yellow, and white quartzite along with some jasper.

Locality 45 (31°43'N, 96°52'W)
6 miles north of Mount Calm, Texas, on Texas Highway 31. Grassy pasture covered by small quartzite pebbles. Mostly black and purple.

Locality 46 (31°39'N, 96°48'W)
3 miles north of Prairie Hill, Texas, on Farm Road 339. Plowed field contains small amount of pebble-sized yellow quartzite along with some petrified wood fragments.

Locality 47 (31°41'N, 96°44'W)
1 mile south of Mustang, Texas, on County Road. Pebbles of purple and black quartzite along with petrified wood fragments cover the surface.

Locality 48 (31°38'N, 96°43'W)
1 mile south of the junction of Texas Highway 84 and Farm Road 1245. Quartzite pebbles scattered across the surface, mostly purple quartzite.

Locality 49 (31°36'N, 96°43'W)
1½ miles east of Kirk Community on Farm Road 1224. Localized quartzite gravels scattered across the plowed field. Quartzite is mostly yellow but some is purple.

Locality 50 (31°31'N, 96°34'W)
10 miles west of Groesbeck, Texas, on Farm Road 2489. The only gravel occurring here is along the road and was probably hauled in as road material.

Locality 51 (31°35'N, 96°42'W)
East side of Coit Oil Field 2 miles south of Farm Road 147. Plowed field is completely barren of any gravel.

Locality 52 (31°23'N, 96°41'W)
Gunter Cemetery 2 miles northeast of Coit, Texas, on County Road. Plowed field is free from gravels.

Locality 53 (31°18'N, 96°36'W)
4 miles south of Kosse, Texas, on Texas Highway 14. Quartzitic gravels absent from plowed field. Localized limestone gravels present.

Locality 54 (32°07'N, 97°04'W)
1 mile north of Love View, Texas, on County Road. Plowed field covered with limestone cobbles. No quartzitic material present.

Locality 55 (32°05'N, 97°03'W)
2 miles northeast of Interstate 35 and west on Farm Road 2959. Plowed field covered by angular limestone cobbles. Probably plowed up in the same field. No quartzitic material present.

Locality 56 (32°08'N, 97°04'W)
3 miles east and 2 miles south of Itasca, Texas, on Farm Road 934. Short grass pasture contains scattered limestone fragments.

Locality 57 (32°13'N, 97°05'W)
3 miles south of File Valley, Texas, on Texas Highway 66. Quartzitic gravels absent.

Locality 58 (32°17'N, 97°01'W)
3 miles south of Maypearl, Texas, on Texas Highway 66. Plowed field does not contain quartzitic gravels.

Locality 59 (32°21'N, 96°57'W)
3 miles south of Oak Branch, Texas, on country road. No gravels present.

Locality 60 (32°24'N, 97°00'W)
1 mile east and 2 miles south of Mountain Peak Road between Mountain Peak and Leguizamon, Texas. Plowed field covered by angular limestone fragments but quartzitic material absent.

Locality 61 (32°28'N, 96°59'W)
3 miles south of Midlothian, Texas, on Texas Highway 663. Limestone fragments present in plowed field but quartzitic gravels absent.

Locality 62 (32°34'N, 96°58'W)
1 mile south of Cedar Hill, Texas, on U.S. Highway 67. Plowed field covered by angular limestone fragments. No quartzitic material present.

Locality 63 (32°39'N, 96°57'W)
1 mile north of Duncanville, Texas, on U.S. Highway 67. Plowed field is barren of gravels.

Locality 64 (33°10'N, 96°46'W)
3 miles north of Lolaville, Texas, on Texas Highway 289. Plowed field completely free from gravels of any type.

Locality 65 (32°32'N, 97°17'W)
3 miles west of Burleson, Texas, on Texas Highway 174. Short grass pasture contains no quartzitic gravels.

Locality 66 (32°27'N, 97°24'W)
4 miles north of Joshua, Texas, on Texas Highway 174. No gravel exposed in plowed field.

Locality 67 (32°20'N, 97°28'W)
10 miles west of Cleburne, Texas, on Texas Highway 67. Outcrop of Cretaceous gryphaea. No gravels at the outcrop or on surrounding highlands.

Locality 68 (32°12'N, 97°45'W)
6 miles south of Glen Rose, Texas, on Texas Highway 144. Plowed field contains numerous angular limestone cobbles, but no quartzitic materials.

Locality 69 (32°03'N, 97°41'W)
3 miles south of Walnut Springs, Texas, on Texas Highway 144. Plowed field contains no gravels.

Locality 70 (31°56'N, 97°39'W)
1 mile west of Meridian, Texas, on Texas Highway 6. Limestone outcrops at the surface and in some places covered by thin soil. No gravel present.

Locality 71 (31°47'N, 97°33'W)
3 miles north of Clifton, Texas, on Texas Highway 6. Plowed field contains few limestone fragments but no quartzitic

material.

Locality 72 (32°57'N, 101°07'W)
Sherrod Lease Well No. 8 is 15 miles south of Post, Texas, on the Edwards outlier containing numerous fossils. No sign of Ogallala remnants were found adjacent to or atop the outlier.

Locality 73 (32°56'N, 101°09'W)
Farm Road 1269, 3 miles south of the junction of 1269 and U.S. Highway 84. Good exposure of Edwards Limestone overlying Comanche Peak Limestone. The section is capped by a 5-foot caliche layer which is probably Pleistocene in age.

Locality 74 (32°53'N, 101°16'W)
8 miles west of Fluvanna, Texas, beyond the junction of Farm Road 612 and 2350. 20-foot Ogallala section is capped by a thin layer of caliche. There are also a few pebbles located at the base of the section.

Locality 75 (33°19'N, 101°22'W)
3 miles north of Post, Texas, on Texas Highway 207. Pleistocene terrace deposit on the north side of the Double Mountain Fork of the Brazos River. Gravel in the terrace is definitely reworked Ogallala.

Locality 76 (34°32'N, 101°26'W)
Tule Canyon is approximately 8½ miles northwest of Silverton, Texas, on Texas Highway 207. Collected Tule silts and Pearlette ash on the north side of the canyon can be found approximately 1 mile north of Locality 6.

Locality 77 (34°47'N, 101°25'W)
Ogallala Formation is overlying Triassic Dockum sands 30 miles north of Silverton, Texas, on Texas Highway 207. Ogallala consists of loose gravel scattered at the base covered by approximately 60 feet of clean sand. The formation here is capped by a massive caliche lag.

Locality 78 (35°14'N, 100°28'W)
13 miles east of McLean, Texas, on Texas Highway 66. A thin section of Ogallala is exposed consisting entirely of clean sand. There is no gravel at the base.

Locality 79 (35°09'N, 100°15'W)
5 miles south of Shamrock, Texas, on U.S. Highway 83 on the north bank of Elm Creek. Reworked Ogallala sands and gravels were collected from a Pleistocene terrace of Elm Creek.

Locality 80 (35°04'N, 100°17'W)
Samnorwood Triangulation Station 3 miles west of Samnorwood, Texas, on Farm Road 1547. Gypsum quarry probably Permian in age. No Ogallala sands or gravels were found.

Locality 81 (34°55'N, 100°13'W)
9 miles north of Wellington, Texas, on State Highway 83. 2 miles north of the Salt Fork of the Red River. Plowed sandy cotton field contains no quartzitic gravels. The surface is probably Pleistocene blow sands.

Locality 82 (34°54'N, 100°13'W)
North bank of the Salt Fork of the Red River and 3 miles north of Wellington, Texas, on State Highway 83. Terrace of the Salt Fork contains abundant quartzose gravels which were probably derived from Ogallala outwash.

Locality 83 (34°48'N, 100°12'W)
5 miles south of Wellington, Texas, on State Highway 83. Seymour gravels cover the surface along the road and in adjacent fields.

Locality 84 (34°37'N, 100°13'W)
7 miles south of Loco, Texas, on U.S. Highway 83. Seymour gravels present in gravel pit.

Locality 85 (34°27'N, 100°13'W)
3 miles north of Childress, Texas, on U.S. Highway 83, Gravel pit exposes 20-foot sections of Pleistocene terrace gravels which were derived from the Ogallala retreat.

Locality 86 (34°33'N, 100°12'W)
9 miles north of Childress, Texas, on U.S. Highway 83. The Red River exposes a thick section of Pleistocene terrace sand. There is no gravel exposed.

Locality 87 (34°15'N, 100°17'W)
14 miles south of Childress, Texas, on U.S. Highway 83. Gravel along roadside is probably Ogallala lag gravel but has been stock-piled from nearby sources.

Locality 88 (33°52'N, 99°46'W)
1 mile south of the Pease River on U.S. Highway 83. This is probably the second terrace of the middle Pease River. Gravels were collected along the road and in a road construction gravel pit.

Locality 89 (33°50'N, 99°46'W)
3 miles north of the North Wichita River on Texas Highway 283. Road cut exhibits approximately 50 feet of Seymour sands and gravels. Gravels here are much like Ogallala gravels of the Southern High Plains.

Locality 90 (34°36'N. 99°47'W)
½ mile north of Benjamin, Texas, on Texas Highway 283. Seymour gravels veneer the surface of the fields on either side of the road.

Locality 91 (33°42'N, 99°46'W)
½ mile south of the South Wichita River on Texas Highway 283. Seymour gravels veneer the surface on both sides of the highway.

Locality 92 (33°39'N, 99°47'W)
5 miles north of Benjamin, Texas, on Texas Highway 283. Seymour gravels veneer the surface of the plowed fields on either side of the highway.

Locality 93 (34°06'N, 101°19'W)
Edwards high exposed by road quarry pit. The Cretaceous high represents one of the remnant highs which underlies much of the Southern High Plains.

Locality 94 (35°05'N, 101°52'W)
1½ miles south of Amarillo, Texas, on Farm Road 1541 on Palo Duro Creek. Ogallala sand and silt collected from the upper Ogallala section. The section is capped by a thick caliche horizon.

Locality 95 (32°14'N, 101°32'W)
1 mile west of Big Spring, Texas, on Interstate 20. Clean Ogallala sand along with basal gravel which contains much reworked Cretaceous material.

Locality 96 (32°19'N, 101°27'W)
Wild Horse Creek Road cut 12 miles northeast of Big Spring, Texas, on Texas Highway 350. Questionable Ogallala deposits, probably reworked basal Cretaceous sand.

Locality 97 (32°23'N, 101°00'W)
Morgan Creek Road cut 15 miles northeast of Big Spring, Texas, on Texas Highway 350. 60-foot Ogallala section immediately overlies Triassic standstone. There is no gravel at the base of the Ogallala.

Locality 98 (32°21'N, 101°22'W)
8 miles north of Coahoma, Texas, on Farm Road 820. Caliche, but no Ogallala sands or gravels are exposed in shallow road cut.

Locality 99 (32°28'N, 101°21'W)
5 miles north of Coahoma, Texas, on Farm Road 820. Sand and basal Ogallala gravels collected from 50-foot Ogallala section exposed in road cut. Section is capped by thin caliche layer.

Locality 100 (32°15'N, 101°43'W)
3 miles west of Big Spring, Texas, on Interstate 20. Pleistocene Lake Lomax. Road cut covered by gypsum evaporite crystals.

Locality 101 (32°08'N, 101°45'W)
3 miles east of Stanton, Texas, on Interstate 20. Uncompleted railroad cut exposes 30 feet of massive indurated Ogallala silt and sand. Some reworked pea-sized gravel is found at the base.

Locality 102 (31°50'N, 101°23'W)
3 miles south of Garden City, Texas, on Farm Road 33. Edwards outlier protrudes about the projected High Plains surface. It is capped by a massive caliche layer.

Locality 103 (31°45'N, 101°27'W)
17 miles south of Garden City, Texas, on Farm Road 33. Loess soils cover the surface of the plains. Loess probably filled in the final valleys after deposition of the Ogallala, creating the final flat-topped surface.

Locality 104 (31°53'N, 100°30'W)
Colorado River terrace 1 mile west of Robert Lee, Texas, on Texas Highway 158. Terrace material composed mostly of locally derived limestone pebbles along with some Ogallala-type gravels.

Locality 105 (31°16'N, 102°01'W)
11 miles north of Rankin, Texas, on Texas Highway 349. Road cut exposes caliche-capped Cretaceous limestone outlier.

Locality 106 (30°55'N, 101°54'W)
Pecos River 1 mile south of Iraan, Texas, on Texas Highway 349. Terrace deposit here on the Pecos River composed entirely of limestone fragments.

Locality 107 (31°02'N, 102°13'W)
Pecos River 9 miles southeast of McCamey, Texas, on Farm Road 305. Surface is covered by overbank material, but no gravels are present.

Locality 108 (31°24'N, 102°22'W)
7 miles east of Crane, Texas, on Texas Highway 329.

Ogallala sand capped by a thin layer of sandy caliche. Sand is mostly loose except for scattered cemented patches.

Locality 109 (31°35′N, 102°20′W)
Escarpment on U.S. Highway 385, in Crane County, 13 miles north of Crane on Farm Road 1601. Cretaceous limestone remnant. No sand or caliche present.

Locality 110 (31°48′N, 102°21′W)
1 mile south of Odessa, Texas, on U.S. Highway 385. Garbage dump exposes 15-foot section of clean Ogallala sand which is capped by approximately 2 feet of sandy pisolitic caliche.

Locality 111 (31°55′N, 102°43′W)
25 miles east of Kermit, Texas, on Texas Highway 302. Road construction pit exposes about 20 feet of clean Ogallala sand. Ogallala sands rest directly upon Cretaceous limestone.

Locality 112 (31°54′N, 102°47′W)
17 miles east of Kermit, Texas, on Texas Highway 302. Escarpment here is formed by Cretaceous limestone. No Ogallala sand or gravel is present.

Locality 113 (32°07′N, 103°12′W)
Road cut in Jal, New Mexico. Road cut exposes a thin band of orthoquartzite which forms the base of the Ogallala Formation here. It is overlain by approximately 5 feet of sand and a thin caliche cap.

Locality 114 (32°07′N, 103°10′W)
1 mile east of Jal, New Mexico, on New Mexico Highway 128. Road quarry pit filled with gravel. Mostly limestone pebbles combined with some typical quartzitic Ogallala gravels.

Locality 115 (32°32′N, 103°09′W)
21 miles south of Hobbs, New Mexico, on New Mexico Highway 18. Excavation on road side exposes approximately 20 feet of Ogallala sand covered by about 10 feet of red sandy Pleistocene soil.

Locality 116 (32°42′N, 103°22′W)
15 miles west of Hobbs, New Mexico, on New Mexico Highway 8. Approximately 10 feet of sandy caliche exposed in road cut. The bottom of the caliche zone is not exposed.

Locality 117 (32°42′N, 103°29′W)
18 miles west of Hobbs, New Mexico, on New Mexico Highway 529. Road cut exposes approximately 10 feet of sandy caliche underlain by a thin band of brown orthoquartzite.

Locality 118 (32°42′N, 103°32′W)
24 miles west of Hobbs, New Mexico, on New Mexico Highway 529. 8-foot road quarry exposes a section of white sandy caliche. The surface here is almost barren of soil and is covered by Pleistocene and Recent blow sands.

Locality 119 (32°50′N, 103°33′W)
3 miles south of Maljamar, New Mexico, on New Mexico Highway 529, below the Mescalero Ridge. The surface here is completely covered by blow sands. No outcrops are visible.

Locality 120 (33°03′N, 103°52′W)
4 miles west of the junction of New Mexico Highways 31 and 172. 90-foot Ogallala section. The section is composed almost entirely of well-sorted, loosely cemented sand capped by an 8-foot caliche zone which forms the prominent Mescalero escarpment.

Locality 121 (33°24′N, 103°42′W)
2 miles west of Caprock, New Mexico, at the junction of U.S. 380 and New Mexico Highway 172. Mescalero escarpment here is defined by a 35-foot section of loosely cemented sand capped by 15 feet of white sandy caliche.

Locality 122 (33°26′N, 103°40′W)
7 miles north of Caprock Baptist Church, Caprock, New Mexico. Sand quarry exposes approximately 15 feet of loose Ogallala sand.

Locality 123 (33°52′N, 103°46′W)
1 mile northeast of Kenna, New Mexico, on U.S. 70. Road cut exposes 5-foot section of Ogallala gravels. Gravels are coarse and vary widely in composition. This is an area in which the Ogallala Formation was warped following its deposition.

Locality 124 (34°58′N, 103°07′W)
1 mile south of the Quay County line, New Mexico, and 11 miles west of the Deaf Smith County line, Texas. Canadian River escarpment here exposes approximately 100 feet of Ogallala sand which is overlain by a 3-foot caliche horizon.

Locality 125 (35°15′N, 102°42′W)
6 miles west of Adrian, Texas, on U.S. 66. Road cut exposes approximately 70 feet of clean Ogallala sand capped by caliche. No gravel is present at the base.

Locality 126 (33°58′N, 101°01′W)
Gravel pit 12 miles east of Floydada, Texas, on U.S. 62. Gravel pit exposes approximately 20 feet of Ogallala sand and gravels. This gravel was probably deposited by the same channel responsible for the deposits at Locality 12.

Locality 127 (33°41′N, 101°05′W)
15 miles east of Crosbyton, Texas, on U.S. 82 and adjacent to Haystack Mountain in the Dockum Creek valley. Ogallala sands are exposed here in a road cut which cuts through the Caprock escarpment. Approximately 60 feet of sand are exposed, capped by a thin section of sandy caliche.

Locality 128 (32°46′N, 96°14′W)
3 miles north of Terrell, Texas, on Texas Highway 34. Plowed wheat field contains few quartzite cobbles, all of which are different from typical Ogallala gravel.

Locality 129 (32°48′N, 96°16′W)
2 miles north of Poetry, Texas, on country road. Gravel is exposed along the roadside but is absent from the fields adjacent to the road.

Locality 130 (32°49′N, 96°17′W)
4 miles north of Poetry, Texas, on country road. Plowed field contains several pebbles of quartzose material. The gravel is unique to this area and quite different from the Ogallala gravels.

Locality 131 (32°50′N, 96°20′W)
2 miles south of Blackland, Texas, on Farm Road 35. Plowed field veneered with quartzite, petrified wood and limestone pebbles. Quartzite definitely unlike Ogallala gravels but is similar to other quartzite gravels found in this area. They were probably all derived from a source farther north than the main body of Ogallala material.

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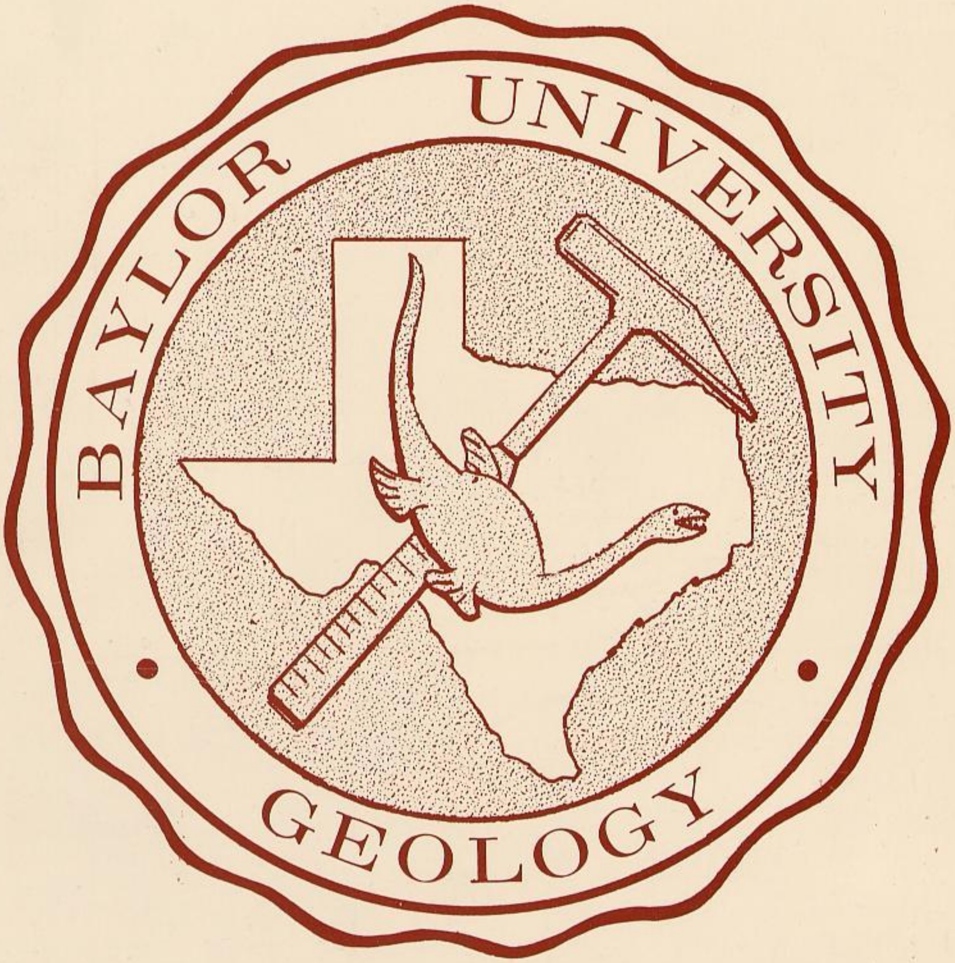
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