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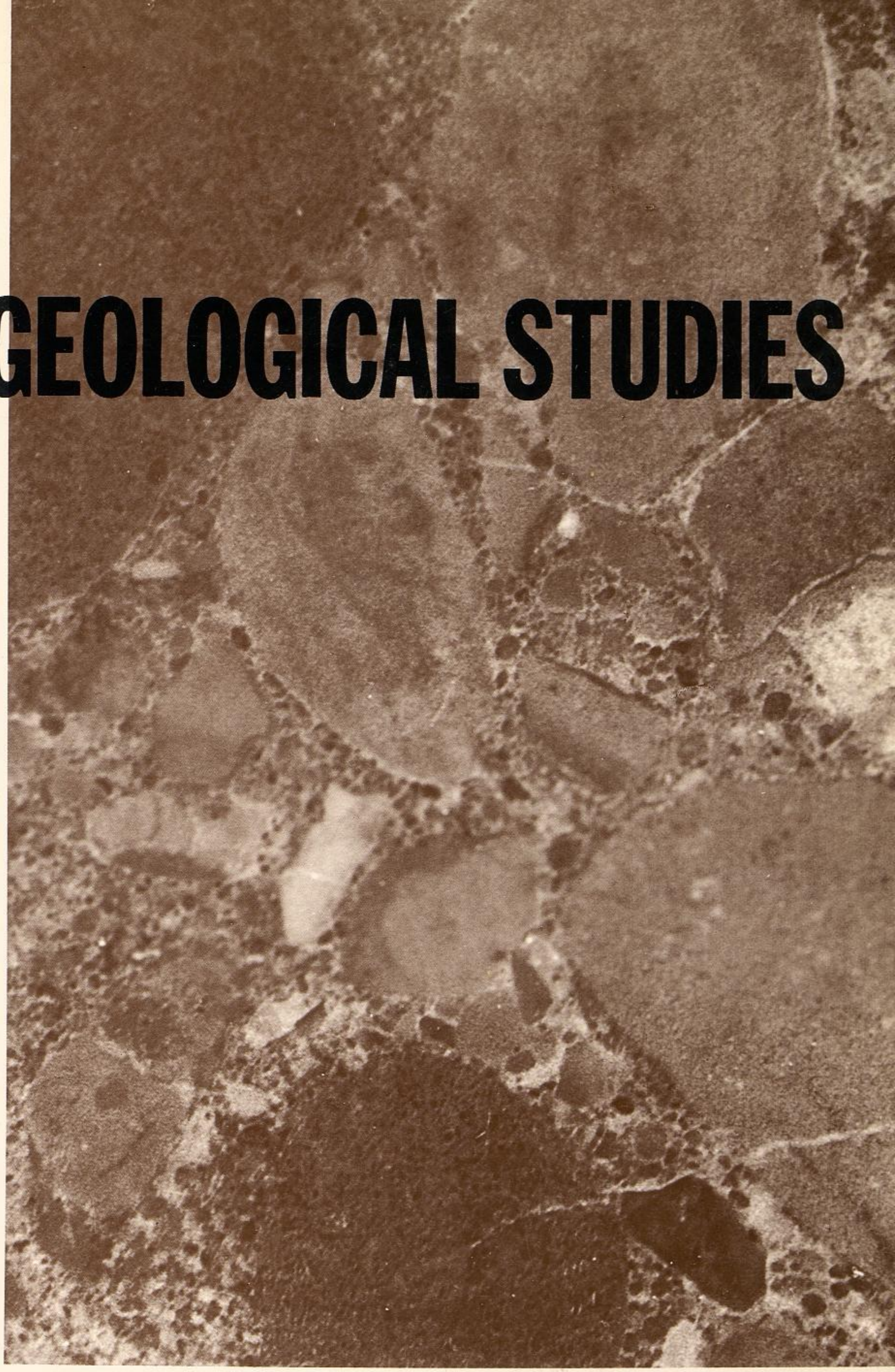

SPRING 1983

Bulletin No. 41

Stratigraphy and Environmental Significance of the Continental Triassic Rocks of Texas

TED GAWLOSKI

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

FRANK CARNEY, PH.D.
PROFESSOR OF GEOLOGY
BAYLOR UNIVERSITY
1929-1934

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The training of a geologist in a university covers but a few years; his education continues throughout his active life. The purposes of training geologists at Baylor University are to provide a sound basis of understanding and to foster a truly geological point of view, both of which are essential for continued professional growth. The staff considers geology to be unique among sciences since it is primarily a field science. All geologic research including that done in laboratories must be firmly supported by field observations. The student is encouraged to develop an inquiring objective attitude and to examine critically all geological concepts and principles. The development of a mature and professional attitude toward geology and geological research is a principal concern of the department.

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BAYLOR UNIVERSITY
Department of Geology
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Stratigraphy and Environmental Significance of the Continental Triassic Rocks of Texas

Ted Gawloski

ABSTRACT

The continental Triassic rocks of Texas are represented by four distinct but similar rock groups, which exist both in outcrop and in the subsurface and include: the Eagle Mills Formation (south-central and northeast Texas), Sycamore Formation (central Texas), Dockum Group (west Texas), and Bissett Formation (southwest Texas). They are clearly terrigenous in nature, derived principally from older Paleozoic sedimentary rocks.

The rock groups are composed in part or entirely of mudstone, siltstone, medium- to coarse-grained sandstone and pebble- to boulder-conglomerate (intrabasinal and extrabasinal). The sediments were deposited in alluvial fans, braided and meandering streams, lobate deltas, fan deltas, and lakes. The coarse sandstone and conglomerate are products of high-energy, short duration depositional events.

Sedimentation was greatly affected by alternating climatic conditions that produced changes in base level, water depth, lake area and the type of streams that flowed into the depositional basins. Character of the rock groups strongly suggests semi-arid to arid deposition typical of the low latitude desert regions of today. Thus, the rocks forming the Eagle Mills, Sycamore, Dockum, and Bissett Formations appear to be continental clastic products deposited during a major semi-arid to arid climatic episode, such as that of Late Triassic time.

INTRODUCTION*

PURPOSE

The continental Triassic rocks of Texas are represented by four distinct but similar rock groups: 1. the Eagle Mills Formation of northeast Texas, 2. the Sycamore Formation of central Texas, 3. the Dockum Group of west Texas, and 4. the Bissett Formation of southwest Texas (Table 1).

The Upper Triassic Eagle Mills Formation accumulated in an arcuate pattern bordering the eastern edge of the Ouachita Tectonic Belt from Falls and Robertson Counties in south-central Texas northeastward through Bowie County and eastward into Arkansas and Mississippi (Fig. 1). It is a subsurface unit, now buried beneath thousands of feet of Jurassic and Cretaceous sediments. The Eagle Mills formation represents the initial deposits of the Interior Gulf Coast Basin and consists of as much as 7000 ft of alternating sequences of coarse red sandstone, siltstone, and conglomerate deposited as bed-load to mixed-load streams on alluvial fans, which extended from the Ouachita Tectonic Belt southeastward into subsiding grabens.

The Sycamore Formation of central Texas is a highly localized, poorly sorted, coarse conglomerate consisting of pebbles and cobbles of hard limestone, dolomite, and chert in a matrix of coarse quartz sand. It is a distinctive unit in that it differs in composition and character from the underlying Paleozoic rocks and the overlying basal Cretaceous deposits. Rocks of the Sycamore Formation were deposited upon an erosional surface characterized by a series of valleys and divides that extend north, south,

*A thesis submitted in partial fulfillment of the M.S. degree in Geology, Baylor University, 1981.

Table 1. Nomenclature chart, upper Triassic rocks of Texas.

SOUTHWEST TEXAS	WEST TEXAS		CENTRAL TEXAS	EAST TEXAS
CRETACEOUS	TERTIARY (PLIOCENE)		CRETACEOUS	JURASSIC
?	DOCKUM GROUP	CHINLE FM.	?	EAGLE MILLS FORMATION
		TRUJILLO FM.	SYCAMORE FORMATION	
		TECOVAS FM.	?	
BISSETT FM.	?			
PERMIAN	PERMIAN		PALEOZOIC UNDIFFERENTIATED	PALEOZOIC UNDIFFERENTIATED

and east of the Llano Uplift. The Llano region served as the primary source area for the clastics of the Sycamore Formation. These clastics were probably laid down as a bed-load deposit in high gradient wadi stream channels or alluvial fans (Fig. 2).

The Dockum Group (Upper Triassic) was deposited in a fluvial-lacustrine basin, which formed in west Texas, eastern New Mexico, southeastern Colorado, and the far western portions of Kansas and Oklahoma. It is composed of up to 2000 ft of complexly interrelated terrigenous clastic facies ranging from mudstone to conglomerate (McGowen et al., 1979, p. 2) (Fig. 3). The sediments accumulated in: 1. alluvial fans, 2. valleys of braided and meandering streams, 3. lake basins, and 4. highly constructive lobate deltas. Within the Dockum Group several depositional cycles are recognized from the high and low stand of lake level within the basin. Principal sediment sources were the Ouachita-Marathon Tectonic Belt, Wichita Mountain System, the Diablo Platform, the Llano Uplift and the Sacramento Uplift (Fig. 4).

The Bissett Formation (Lower-Middle Triassic) is exposed in the Glass Mountains of southwest Texas (Fig. 5). The deposits consist of interbedded sandstones, limestone and chert conglomerates, reddish-brown mudstones and thin beds of limestone and dolomite (King, 1935, p. 1544). Physical and fossil evidence indicate a preDockum Triassic age for the Bissett Formation, which represents initial Triassic alluvial fan and fan-delta sedimentation immediately north of the Ouachita Tectonic Belt in southwest Texas.

The purpose of this study, therefore, is to describe the character, distribution, and environmental significance of the continental Triassic rocks of Texas. Each of these rock groups was deposited under similar environmental

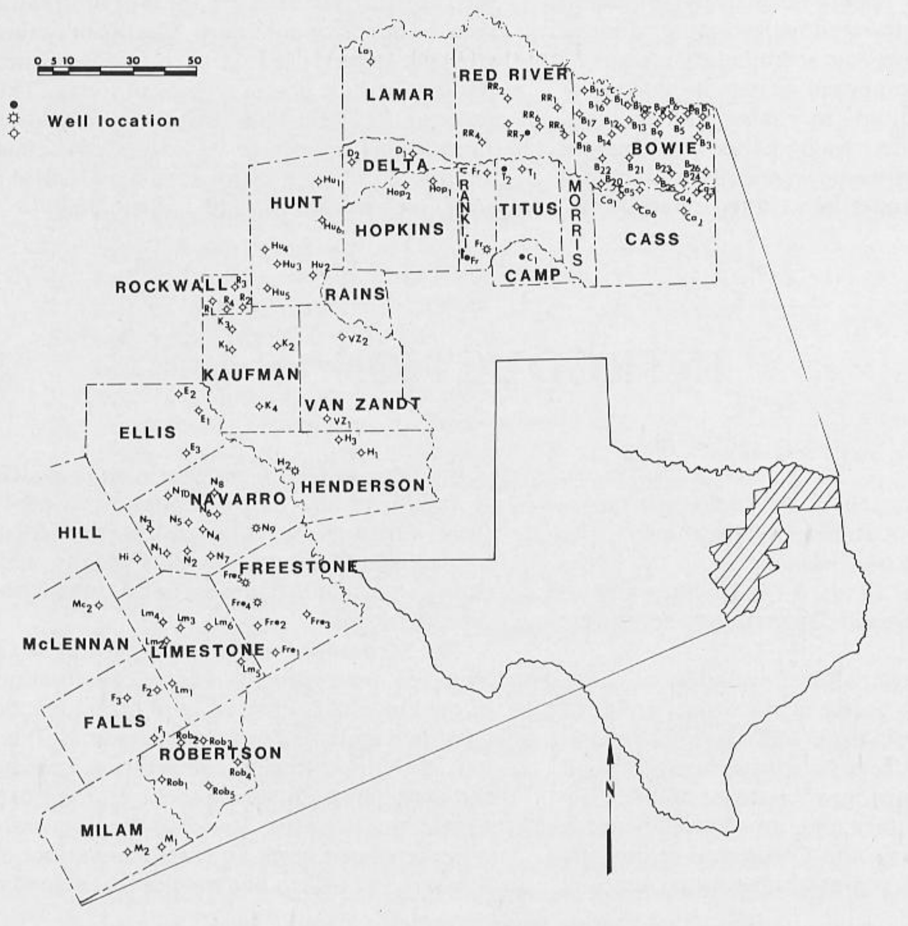


Fig. 1. Index map of northeast Texas showing location of wells that penetrate the Eagle Mills Formation.

conditions characteristic of semi-arid regions. All of the rock groups are largely terrigenous in origin, most derived from the same tectonic elements. It is, therefore, probable that a correlation exists between these rock types, and that the paleogeography of the Triassic of Texas can be determined.

LOCATION

The continental Triassic deposits of the study area occur, both in outcrop and in the subsurface, over large areas of northeast, central, and northwest Texas. For this investigation the area of study is subdivided into four separate regions: northeast, central, northwest, and southwest Texas.

Northeast Texas (Eagle Mills Formation)

This study area extends from south-central Texas northeastward to the Texas-Arkansas border. It includes all or parts of Bowie, Camp, Cass, Delta, Ellis, Falls, Franklin, Freestone, Hill, Hopkins, Hunt, Kaufman, Limestone, McLennan, Navarro, Red River, Robertson, and Rockwall Counties (Fig. 1). The trend of the Eagle Mills closely follows the eastern edge of the buried Ouachita Tectonic Belt.

Central Texas (Sycamore Formation)

The Sycamore Formation crops out in west-central Texas north and east of the Llano Uplift. Geographically, the area is located west-northwest of Austin, southwest of Dallas, and west of Waco, Texas. The study area includes all or parts of Blanco, Brown, Burnet, Comanche, Hays, Lampasas, Llano, McCulloch, Mason, Mills, San Saba and Travis Counties (Fig. 2) and lies within the physiographic regions of the Lampasas Cut Plain and the Western Cross Timbers (Fig. 6).

Northwest Texas (Dockum Group)

The Dockum Group was deposited in a broad shallow basin stretching across what is now the Panhandle region of Texas. This investigation is concerned chiefly with those Dockum rocks that crop out along the Caprock Escarpment in Armstrong, Borden, Briscoe, Crosby, Dawson, Deaf Smith, Dickens, Fisher, Floyd, Garza, Howard, Kent, Lynn, Lubbock, Martin, Mitchell, Motley, Nolan, Oldham, Potter, Randall, Scurry, Sterling, and Swisher Counties (Fig. 3). Most of the Triassic deposits of west Texas occur beneath younger deposits of the Llano Estacado (Fig. 6). Structurally the area lies within the boundaries of the Midland Basin, Matador Arch, and the Palo Duro Basin (Fig. 4).

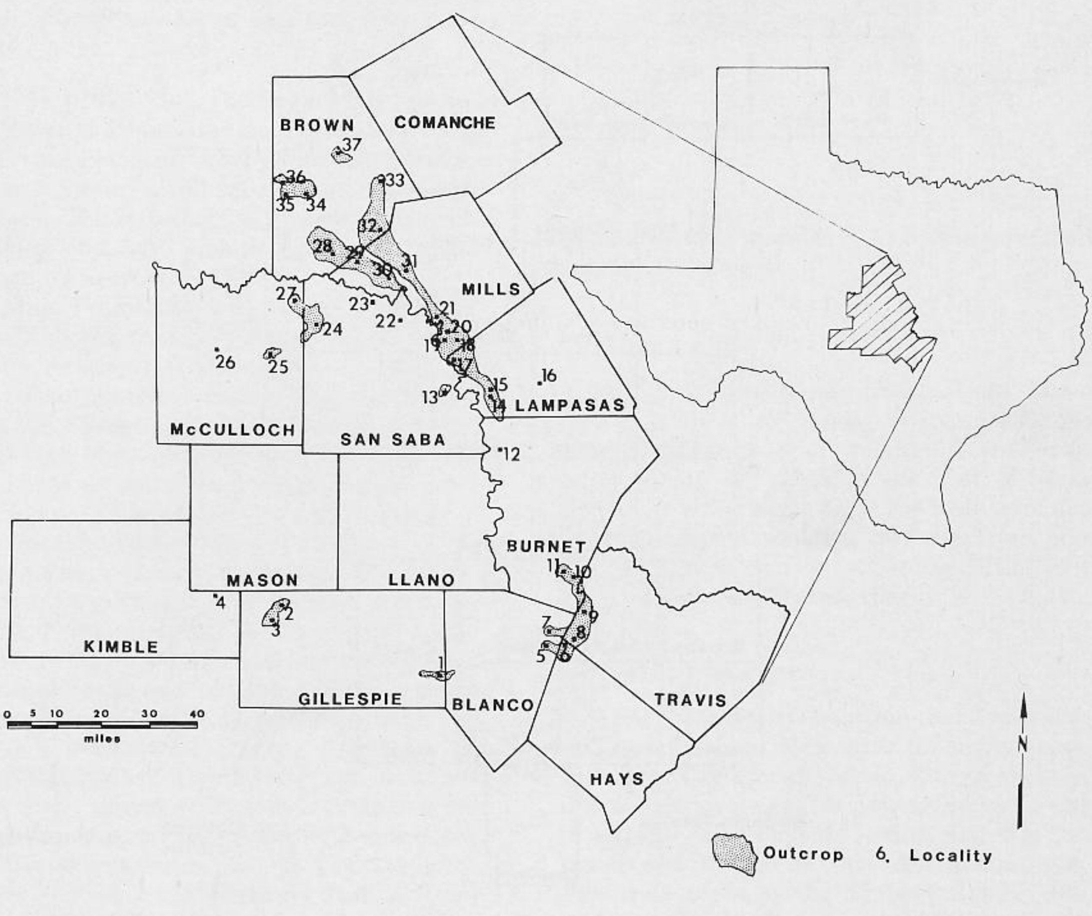


Fig. 2. Outcrop and locality map of Sycamore rocks, central Texas.

SOUTHWEST TEXAS (BISSETT FORMATION)

The Bissett Conglomerate crops out in the area of the Glass Mountains in northern Brewster and southern Pecos Counties of Texas. Structurally the area lies within the Marathon Uplift (Figs. 4, 5).

PROCEDURES

The methods of this investigation included: 1. a literature review, 2. field reconnaissance of selected Sycamore and Dockum outcrops, 3. microscopic examination of slabbed samples and cores, and 4. the analysis of northeast Texas logs of wells that penetrate the Eagle Mills or the underlying Paleozoic rocks. In addition, the rocks of the Eagle Mills were described from cores of the Humble, 1-Calfee Titus County, Texas. From this information, six structural cross sections were prepared to better illustrate the paleotectonic regime that existed during Eagle Mills deposition.

PREVIOUS WORKS

The continental Triassic rocks of Texas have, for the most part, been ignored by many authors, mainly because of their lack of significant deposits of economic value. However, some reports describe the stratigraphy and depositional history of these Triassic rocks groups. Most of the early works were concerned chiefly with the stratigraphic relationships and age of the deposits. More recent studies dealing with Triassic sediments describe their relationships with the initial opening of the Gulf of Mexico. Currently, there is a renewed interest in the Triassic deposits of Texas because of the discovery of uranium within the Dockum Group and the association of the Eagle Mills Formation with petroleum exploration in the Ouachita Tectonic Belt.

In the section that follows literature describing Triassic rocks of Texas is divided into five groups, one for each of the Triassic stratigraphic units and the final for works dealing with recent and ancient depositional models.

EAGLE MILLS FORMATION

Very little work has been done to date concerning the stratigraphy and environmental significance of the Eagle Mills Formation in Texas. There is some confusion in nomenclature of the various subsurface formations of the Gulf Coast region, most of which have no outcrop equivalents. This confusion is due chiefly to the use of such names as Permian or Trinity for formations of unknown

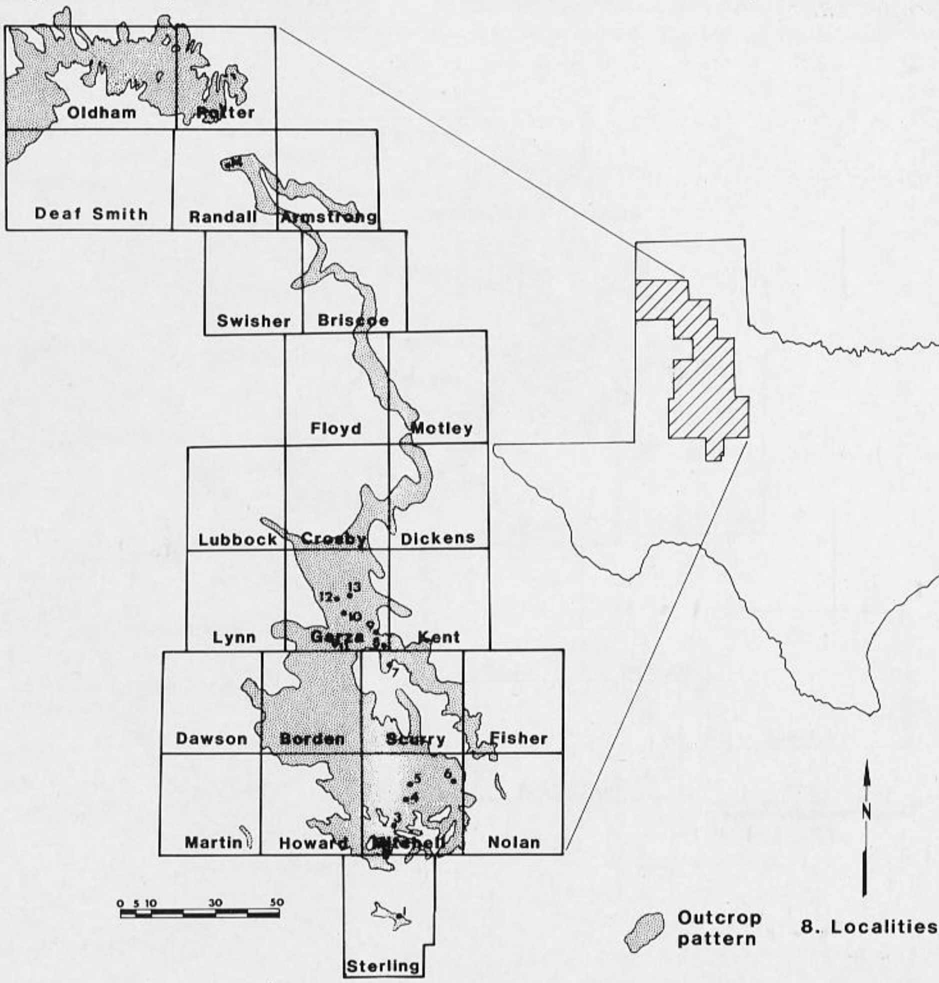


Fig. 3. Outcrop and locality map of Dockum rocks, west Texas.

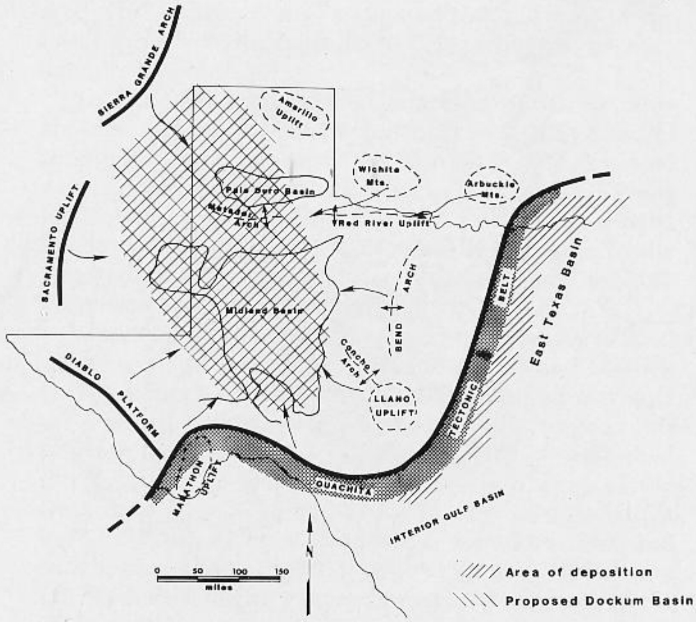


Fig. 4. Structural map of Texas showing major tectonic elements affecting deposition of Triassic rocks and suggested source area for Dockum sediments. *Adapted from* Kiatta, 1960, M.S. thesis, Texas Tech College, p. 52.

age (Shearer, 1938, p. 723-724). The Eagle Mills Formation has been classed as Pennsylvanian, Permian (Weeks, 1938; Hazzard et al., 1945; and Crosby, 1967), or Jurassic (Imlay, 1943 and Swain, 1949) on the basis of stratigraphic succession. This information, however, pre-dates the fossil evidence of a Late Triassic age for the Eagle Mills determined by Scott et al. (1961).

The Eagle Mills Formation was named by Shearer (1938) from wells drilled near the village of Eagle Mills, Calhoun County, Arkansas. He described the Eagle Mills Formation as consisting of red shale and sand overlying Pennsylvanian and Mississippian sediments and underlying the Smackover limestone. He suggested that the Eagle Mills red beds are early Mesozoic, probably Triassic or Jurassic in age (Shearer, 1938, p. 724). Hazzard et al. (1945) described the Eagle Mills Formation as a Permian red bed sequence overlying the Morehouse Formation and underlying the Werner conglomerate and anhydrite. Scott et al. (1961) described the nature, character, and thickness of the Eagle Mills Formation from wells in extreme northeast Texas and Arkansas. Furthermore, Scott recovered a fossil leaf impression from the Humble, 1-Royston well in Hempstead County, Arkansas. He determined this leaf to be of Late Triassic age. At about the same time, E. J. Crosby et al. (1961) described the stratigraphy, thickness, and paleotectonic implications of the Eagle Mills Formation in the Gulf Coast region.

Recent studies by Vail and Mitchum (1967), Rainwater, (1968), Vernon (1971), Walper and Rowett (1972),

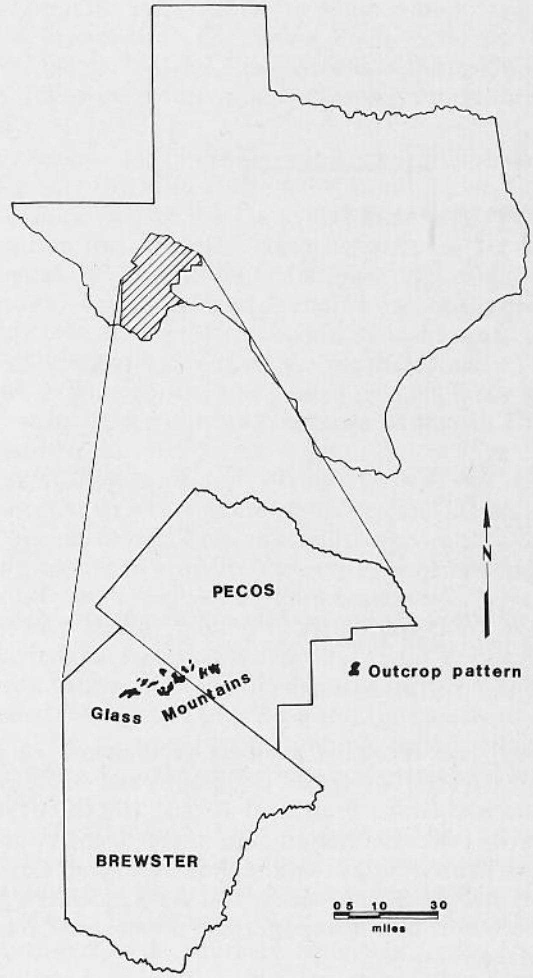


Fig. 5. Index map of southwest Texas showing the outcrop region of the Bissett Formation.

Woods and Addington (1973), Todd and Mitchum (1975), Burgess (1976), and Walper (1980) describe the nature and character of the Eagle Mills Formation and relate this to the origin of the Gulf of Mexico. They suggest that the Eagle Mills red beds were deposited in grabens and half grabens resulting from postorogenic normal faulting or from the initial rifting of the continents during Late Triassic time.

Sycamore Formation

While there is some question that Sycamore rocks are of Cretaceous age they were for many years included within the Cretaceous section. During those years basal Cretaceous strata in Travis and Burnet Counties were first described by Taff (1892) who referred to the conglomerates and sandstone that rest unconformably upon Paleozoic rocks as the "Trinity Sands" and included within these the Sycamore conglomerates. R. T. Hill

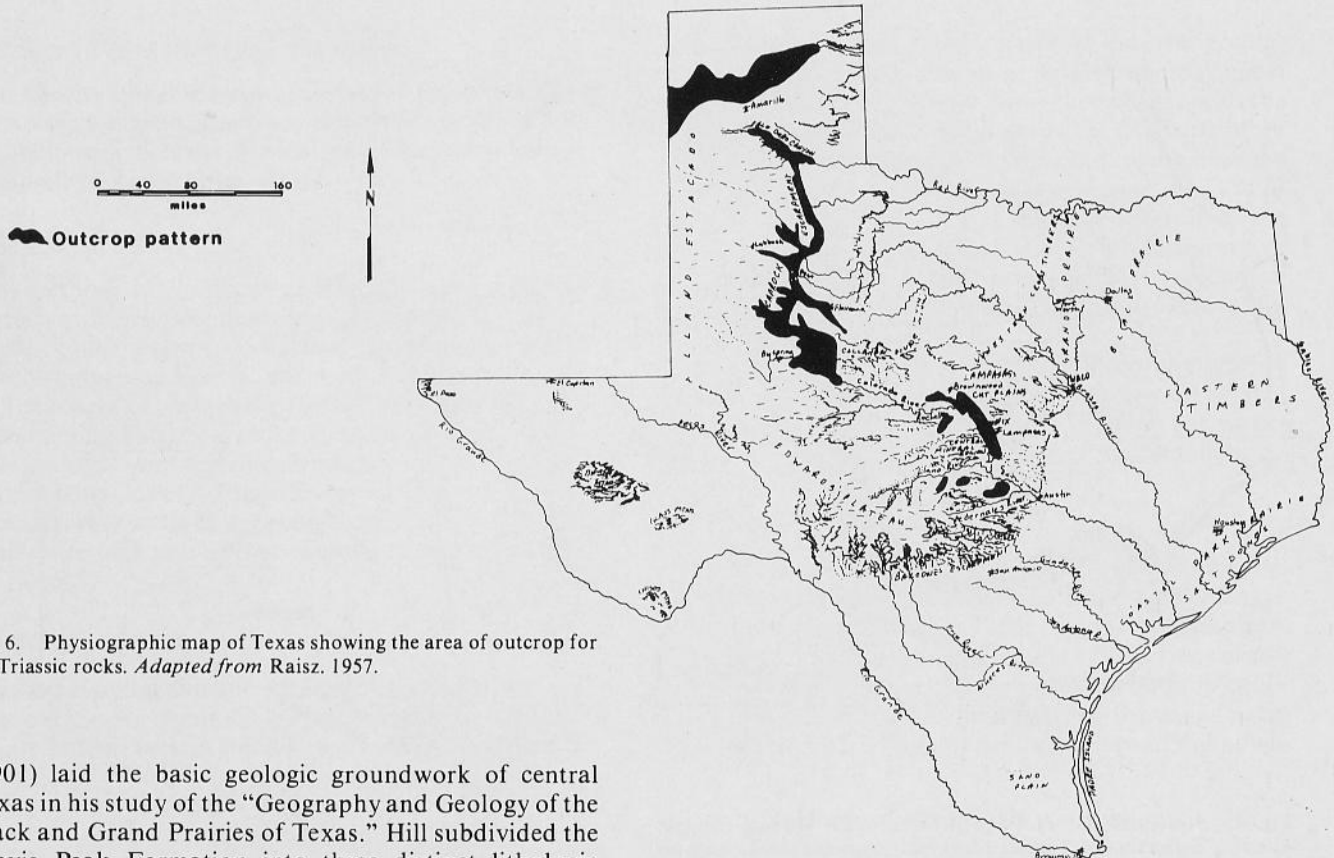


Fig. 6. Physiographic map of Texas showing the area of outcrop for the Triassic rocks. *Adapted from* Raisz. 1957.

(1901) laid the basic geologic groundwork of central Texas in his study of the "Geography and Geology of the Black and Grand Prairies of Texas." Hill subdivided the Travis Peak Formation into three distinct lithologic units, in ascending order the Sycamore sand, Cow Creek beds and the Hensell sands. This work includes a general description of the topography of the pre-Cretaceous surface.

The Travis Peak Formation in Travis, Blanco, and Hays Counties was described by Cuyler (1931). He provided detailed lithologic descriptions of the "basal" clastics, described the areal extent of the lower conglomerate (within study area), and described the regional unconformity at the top of the Sycamore conglomerate.

Bay in 1932 described certain Pennsylvanian conglomerates of central Texas that crop out in McCulloch County and may be correlative with the Sycamore Formation. He determined that stream direction during late Paleozoic time was westward away from the Ouachita disturbance.

In 1934, Sellards described the major structural elements of central Texas emphasizing the faulted rocks of the Llano Uplift. These structural elements described by Sellards are those referred to in this report.

Cretaceous conglomerates on the east side of the Llano Uplift region were described by Damon (1940). He divided the conglomerate into two distinct units: an upper marine marginal unit and a lower fluvial unit. Damon described the lower conglomerate as continental in character, deposited before the advance of the Cretaceous seas. He suggested that the lower conglomerate may be as old as Triassic.

In 1950, Plummer described Lower Pennsylvanian strata of the Llano area, which apparently were the chief contributors to the Sycamore conglomerate. Eardley (1951) summarized existing knowledge of the structural geology of the Texas foreland. His summary, which was compiled from a vast variety of literature, furnishes the basic tectonic framework referred to in this report. Later, in 1962, his summary was updated and revised.

Lozo and Stricklin (1956) suggested elevation of the Sycamore sandstone to formation rank. They also believed that the conglomerate was nonmarine in origin, possibly pre-Cretaceous in age.

Getzendaner (1956) also believed that the coarse conglomerates surrounding the Llano Uplift were older than Cretaceous, possibly Jurassic or Triassic in age. He was the first to differentiate the coarse terrigenous gravels of the Sycamore Formation from the coarse sand and conglomerate of the Lower Trinity Group. In a guidebook for the San Angelo Geological Society Getzendaner states:

> there are some reasons for believing that pre-Cretaceous rocks may outcrop locally, at present, in Central Texas. . . . Around the Central Mineral region and in some directions extending out for considerable distance is a deposit of coarse conglomeratic material that is not marginal, but piedmont and valley-flat fill, in part, dating back to the Jurassic and Triassic (Getzandaner, 1956, p. 77-78).

Boone (1968), in a study of the stratigraphy and depositional history of the basal Trinity sands between the Colorado and Brazos Rivers, included the Sycamore conglomerate as a continental facies of Travis Peak deposition.

Further studies on the stratigraphy and sedimentary history of the Sycamore Formation and initial Cretaceous deposits were presented by Dreyer (1971) and Young et al. (1972). Dreyer also suggested that portions of the basal conglomerate, considered Cretaceous in age, may actually be older.

An extensive study of the Cretaceous-pre-Cretaceous contact and the effect of paleoplain (pre-Sycamore) topography was completed by Bain in 1973. Additional work on the basal Cretaceous clastics of the central Texas region was completed by Dobbins (1974). He related Sycamore deposition to fault-controlled valleys in the Colorado River region and also suggested that the Sycamore was older than Cretaceous.

Recent studies on the Sycamore Formation in central Texas were presented by Ledbetter (1976) and Blalock (1976). Blalock stated that the Sycamore conglomerate is not a clearly defined stratigraphic unit, differing in composition from location to location. Ledbetter described the stratigraphy and depositional environment of the Sycamore Formation and divided it into three informal units: a lower conglomerate unit, a middle sand and caliche unit, and an upper conglomerate unit. Hazelwood (1977) discussed the paleogeomorphic evolution of the Wichita Paleoplain in the Colorado River region of central Texas and suggested a Jurassic age for the Sycamore conglomerate.

Whigham, in 1978, described the basal Cretaceous marginal marine deposits within the central Texas area. In this, however, she excluded the Sycamore conglomerate from her discussion of Cretaceous units.

Dockum Group

The first detailed studies on the Triassic deposits of the Southern High Plains were completed by Cummins in 1889 and 1890. In these reports, he described the Triassic exposures of northwest Texas and gave them the name "Dockum beds" after outcrops near Dockum, in Dickens County.

One year later, Drake (1891) in the first comprehensive report on the Triassic rocks of west Texas divided Cummins' "Dockum beds" into three units: a lower sandy clay bed, a middle unit of sandstone and conglomerate, and an upper bed of sandy clay. Also in 1891, E. D. Cope described the vertebrate remains found within the Dockum Group and confirmed the opinions of Cummins and Drake as to the Triassic age of the deposits (Green, 1954, p. 9).

In 1906 and 1907 Gould, in two reports on the geology and water resources of the Texas Panhandle, described the Dockum rocks of the Canadian River valley and Palo Duro Canyon regions. In these reports he described them as 150-300 ft of interbedded shales, sands, and conglomerates. In addition, Gould subdivided the Dockum Group into two formations: the lower shaly Tecovas Formation and an upper Trujillo Formation composed of massive ledges of cross-bedded sandstone and conglomerate interbedded with red shales.

Baker (1915) proposed that the coarse sandstone and conglomerates of the Dockum Group were derived chiefly from the ancestral Rocky Mountains or from the Wichita Mountains in Oklahoma. Eight years later, Patton (1923) described the Triassic rocks of Potter County, Texas, following the divisions previously established by Gould.

Another division of the Triassic System was presented by Hoots (1926) who studied the outcrop area in the southeastern part of the Llano Estacado as part of an exploration for salt and potash deposits for the U.S. Geological Survey. He defined a lower unit of red clay and gray cross-bedded sand overlain by an upper unit of red clay. He attempted to correlate his divisions with those of Drake and Gould, suggesting that Gould's Tecovas and Trujillo formations graded into his lower unit, and that his upper unit was the same as that of Drake (Hoots, 1926).

Adams (1929) in his study of the Triassic of west Texas described the structure, geomorphology, and lithology of the Dockum Group from subsurface and surface data. He defined several properties used to distinguish Triassic deposits from the underlying Permian deposits, which at first glance appear quite similar. In addition, Adams considered that the Triassic deposits of west Texas correlate with continental Triassic deposits farther west and suggested the name "Santa Rosa" for the basal sand and "Chinle" for the upper shale, both of which are formational names from the upper Triassic deposits of western New Mexico.

Roth (1932) stated that the source of the siliceous conglomerates of the Dockum Group was probably to the southwest in the area of the Glass Mountains. However, Sidwell (1943) suggested that the provenance lay to the northwest in the southern Sangre de Cristo Mountains.

The next study of the Triassic rocks of Texas was by Green in 1954. This is a detailed comprehensive analysis of the stratigraphy, paleontology, petrology, and sedimentology of the Dockum Group in northwest Texas. He modified the two formation division as established by Gould referring to the red beds that overlie the Trujillo sands in the southern part of the area as the Chinle Formation.

Recent studies dealing with the stratigraphy, petrology, and paleocurrent indicators for the Upper Triassic of west Texas were made by Kiatta in 1960 and Cazeau in 1962. From lithologic and sedimentary analyses of the sandstones, both authors agree that the Llano Uplift probably served as the immediate provenance area for the Dockum clastics.

Matthews (1969) in a geologic description of Palo Duro Canyon described each of the formations there exposed and the processes of weathering and erosion that formed the canyon. He examined and described outcrops along the eastern edge of the Caprock Escarpment in Borden and Garza Counties.

A paleocurrent analysis of the Upper Triassic sandstones of the Texas High Plains was completed by Cramer in 1973. He also suggested a probable southeastern source area for the Dockum clastics.

Walker (1978) described the geomorphic evolution of the southern High Plains, paying particular attention to the factors that controlled the deposition of the Ogallala Group. In this study he mentioned a pre-Ogallala landscape developed on Triassic rocks.

The most comprehensive study of the distribution and depositional framework of the Dockum Group in northwest Texas was completed by McGowen et al. in 1979. They described in detail the complex depositional facies, cyclic sedimentation, sediment dispersal patterns and occurrence of uranium in the Dockum sediments.

Bissett Formation

Work on the Bissett Formation was done almost exclusively by P. B. King and E. H. Sellards in the 1930's. They described the Bissett Formation as dominantly limestone and chert conglomerate with interbeds of red shale, sandstone, and some local limestone (caliche) and marl beds. Plant and vertebrate remains found within the sediments by King and Sellards seem to indicate an Early Triassic age for the Bissett Formation.

Depositional Models

In addition to those works dealing specifically with Triassic rocks in Texas there are a number of studies relating to depositional models applicable to the deposition of Triassic sediments. Blissenbach (1954) described the geology of alluvial fans in semi-arid regions with special emphasis on agents of alluvial fan deposition. Other studies dealing with the lithology and depositional processes of ancient and recent alluvial fans are those by Hooke (1967), McGowen and Groat (1971), and McGowen et al. (1978).

Butzer and Hansen (1968) in a study of the desert and rivers of Nubia (Egypt) provided models of wadi stream deposition. Descriptions of specific arid stream deposits similar in composition to the Sycamore Formation are included in this work. Glennie (1970) described desert sedimentary environments. In addition, much of the current literature on sedimentary environments and products was summarized by Reineck and Singh (1970) and Reading (1978).

Since pole positions are important to any paleoclimatological interpretation, a brief review of paleoclimatologic literature was undertaken. Robinson (1972) placed special consideration on the reconstruction of paleomagnetic data.

Finally, the literature on the formation, classification, and morphology of caliche is an enormous one. Of the works consulted in the progress of this investigation those most useful were by Rightmire (1967) and Reeves (1970) and (1976). These works included theories of origin, formation, morphology, and age of certain west Texas caliches. In 1976 Mikels presented an extensive review of the origin and significance of caliche, with emphasis on the caliches of central Texas. These caliche studies provided important information concerning the interpretation of Sycamore caliche deposits.

ACKNOWLEDGMENTS

Appreciation is extended to O. T. Hayward for suggesting the topic and for providing valuable assistance and guidance throughout the course of this study. Special thanks go to Walter Youngquist, Harold Beaver, and Robert Packard, members of my thesis committee, who critically reviewed this report. The field assistance and guidance of Joan Hancharik and Curtis Koger are gratefully acknowledged. Appreciation is also extended to my parents for financial assistance in typing and preparation of the thesis manuscript.

DESCRIPTIVE GEOLOGY

REGIONAL GEOLOGIC SETTING

The continental Triassic rocks of Texas consist of a complex clastic sequence composed of conglomerates, sandstones, siltstones and shales deposited by a variety of terrigenous depositional systems during a period of semi-aridity. They exist both in outcrop and in the subsurface across portions of northeast, central, southwest, and northwest Texas. Figure 4 illustrates the area of deposition for the Eagle Mills, Sycamore, Bissett and Dockum rock groups and associated tectonic features that affected their sedimentation.

REGIONAL STRUCTURAL ELEMENTS

The pre-Triassic surface was a continental erosional surface of moderate relief transecting a number of structural provinces. These include, from east to west the Interior Mesozoic Gulf Basin, the Ouachita Tectonic Belt, the Llano Uplift, the Bend Arch, the Concho Arch, the Wichita Mountain System and the Dockum Basin (Fig. 4).

Interior Mesozoic Gulf Basin

The Interior Mesozoic Gulf Basin formed during Late Triassic time probably as a result of the separation of the Afro-South American Plate from the North American Plate. The basin consisted of a discontinuous series of grabens and half grabens not unlike those of the Triassic basins of the northeastern United States. The faults closely follow the trend of the Ouachita Tectonic Belt from south-central Texas northeastward through northern Louisiana and southern Arkansas to the Florida panhandle (Fig. 7). These graben systems are probably

Fig. 7. Map of the Gulf Coast region showing the location of the Interior Mesozoic Basin and the Ouachita Tectonic Belt.

associated with the initial rifting of the continents during Late Triassic time.

Dockum Basin

The Dockum Basin is a broad shallow depression that underlies parts of Texas, New Mexico, Colorado, Kansas, and Oklahoma (Fig. 8). The location and geometry of the Dockum Basin probably reflect Paleozoic structural elements lying within an area roughly defined by the Midland Basin. It is bounded on the north by the Bravo Dome and Amarillo Uplift, which are structural elements probably originating during Late Mississippian time. To the south lie the Matador Arch and Central Basin Platform, which apparently exerted little influence on sedimentation (McGowen, et al., 1979, p. 2).

Concho Arch

The Concho Arch is a broad pronounced asymmetrical arch, which formed as a result of the Late Mississippian orogeny of the lands adjacent to the Ouachita Foldbelt (Eardley, 1951, p. 246) (Fig. 4). The Sycamore deposits appear to have been restricted on the west by topographic elements related to the Concho Arch. The uplift of the arch began during Pennsylvanian time; it was structurally and topographically high by Sycamore time, and may well have been a source for some Sycamore clastics (Blalock, 1976, p. 62).

Bend Arch

The Bend Arch is an elongate asymmetrical structural

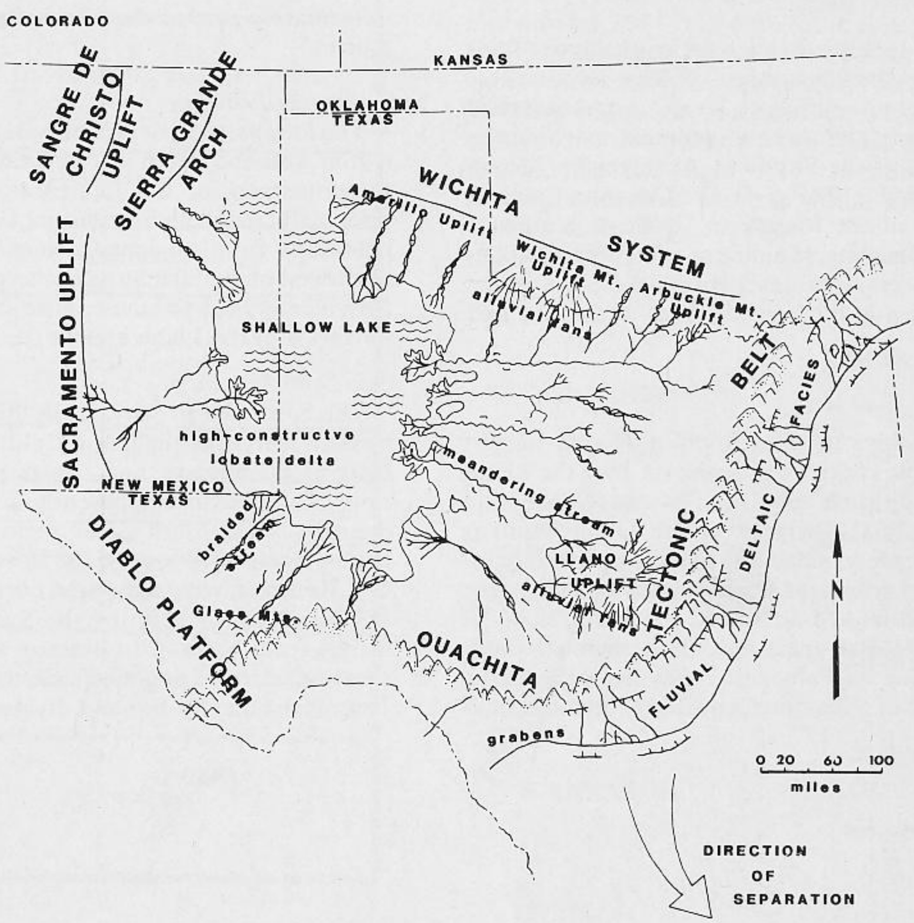


Fig. 8. Paleogeographic reconstruction of Texas during Late Triassic time showing major depositional systems and source areas for the Eagle Mills, Sycamore, Dockum, and Bissett rock groups. *Adapted from* McGowan et al., 1979, Texas Bureau of Economic Geology Rept. of Invest. 97, p. 6.

feature extending northward from the Llano Uplift to the Red River Uplift in north-central Texas (Fig. 4). The Bend Arch is believed to have undergone slight uplift and tilting to the west during Late Permian and Early Triassic time (Kiatta, 1960, p. 50).

Wichita Mountain System

The Wichita Mountain System of southwest Oklahoma and the Texas Panhandle is composed of three folded mountain chains. They are, from east to west, the Arbuckle, Wichita, and Amarillo Mountains (Fig. 4). The Arbuckle Mountains consist of a large complex anticline composed of a series of faulted subparallel folds trending northwest-southeast across southwestern Oklahoma. The Wichita Mountains consist of three en echelon anticlines with granitic cores flanked by Cambrian, Ordovician, Mississippian and Pennsylvanian sediments overlapped unconformably by Permian clastics (Eardley, 1951, p. 237). The Amarillo Mountains are a series of buried hills with Precambrian crystalline cores, which extend west-northwest across the Texas Panhandle. The crystalline core of the Amarillo Mountains is overlain by Pennsylvanian and Permian strata (Eardley, 1951, p. 238).

Ouachita Tectonic Belt

The Ouachita Tectonic Belt is a series of sinuous folds flanked on the north by thrust fault blocks. This tectonic belt extends from southwest Texas northeastward through Oklahoma and Arkansas almost reaching the buried extension of the Southern Appalachian Mountains (Beall, 1973, p. 110)(Fig. 4). The Ouachita Foldbelt is exposed only in the Marathon Uplift of southwest Texas and the Ouachita Mountains of southeast Oklahoma and southwest Arkansas; between these two points it is buried beneath thick sections of Mesozoic and Cenozoic rocks.

Llano Uplift

Local relationships in the Llano Uplift area suggest that late Paleozoic rocks were deposited over the Llano region and were uplifted, tilted, and eroded (Cheney and Goss, 1952, p. 2263). Bedrock of the Llano Uplift is composed of intensely folded and metamorphosed granites; gneisses and schists of Precambrian age and more gently folded and faulted limestone, shales and sands of early and middle Paleozoic age. This regional uplift caused the erosion of Paleozoic rocks from the Llano dome at the time of Sycamore deposition, because rocks of the Llano Uplift are clearly the primary source of the clastics for the Sycamore conglomerate. The diverse rock types and the areal distribution of the different formations of the Llano Uplift show a close lithologic correlation with the cobbles, pebbles, and sand of the Sycamore conglomerate. The region along the eastern border of the Llano Uplift may be divided into four distributive provinces (Damon, 1940, p. 59). These include the Round Mountain Province, Marble Falls Province, Lampasas Province, and San Saba Province.

Round Mountain Province

This province is in the southern part of the Llano region and was the provenance area for most of the Sycamore conglomerate in the Pedernales area. In this province the Ellenburger Group is most widely exposed though it was formerly covered by the Smithwick Formation.

Marble Falls Province

The Marble Falls Province lies west of the Colorado River area in the northern Llano region. This area includes outcrops of Ellenburger dolomite, Marble Falls Limestone, and Smithwick Shale, as well as igneous and metamorphic rocks of Cambrian and Precambrian age. These appear to have contributed chiefly to the region immediately east of the Llano Uplift in the vicinity of Austin.

Lampasas Province

The Lampasas Province includes the area of the Llano region west and southwest of Lampasas. The Sycamore conglomerates of the Lampasas region were derived principally from the Ellenburger Group with minor contributions from an igneous metamorphic area to the southwest of the Ellenburger outcrop belt. The Lampasas Province appears to have contributed chiefly to the rocks northeast of the Llano area in the region of Lampasas.

San Saba Province

The San Saba Province is in the northern and northwestern margin of the Llano Uplift and includes outcrop belts of Ellenburger and Upper Pennsylvanian formations. This province apparently furnished the Sycamore deposits of the Elliot Creek region (locality 20), which extend northward toward the Brownwood area (locality 37). However, within the area north of the Llano region the lithologic makeup of the Sycamore conglomerate differs from outcrop to outcrop suggesting that highly localized streams supplied sediments to areas separated from each other by drainage divides (Dreyer, 1971, p. 36).

DISTRIBUTION AND CHARACTER OF THE EAGLE MILLS FORMATION*

GEOLOGIC SETTING

The Eagle Mills Formation exists in discontinuous occurrence in the subsurface from south-central Texas northeastward across southern Arkansas and northern Louisiana into western Mississippi. Figure 1 shows the location of wells that penetrate the Eagle Mills rocks in Texas.

The eroded north edge of the Eagle Mills Formation follows the trend of the Ouachita Mountains across western Arkansas and eastern Oklahoma and the buried trend of the Ouachita structural belt in northeastern and south-central Texas. This trend represents the northernmost extent of the Interior Gulf Basin (Fig. 4).

TABLE 2. STRATIGRAPHIC COLUMN OF THE MESOZOIC ROCKS OF NORTHEAST TEXAS.

ERA	SYSTEM	SERIES	EUROPEAN	FORMATION / GROUP
MESOZOIC	JURASSIC	UPPER	PORTLANDIAN	COTTON VALLEY
			KIMMERIDGIAN	HAYNESVILLE
				BUCKNER
			OXFORDIAN	SMACKOVER
				NORPHLET
		MIDDLE	DOGGER	LOUANN
				WERNER
	TRIASSIC	UPPER	KUEPER	EAGLE MILLS
PALEOZOIC				PALEOZOIC

Stratigraphically, the Eagle Mills Formation unconformably overlies weathered Paleozoic sediments and is unconformably overlain by the Werner Formation, Louann salt, Norphlet formation, Smackover Formation, and at times the basal gravels of the Cotton Valley Group (Table 2).

THICKNESS

The Eagle Mills Formation is rarely penetrated to its base, and its thickness, therefore, is difficult to determine. Figure 9 shows the total thickness of the Eagle Mills Formation in southern Arkansas, northern Louisiana, western Mississippi, and northeast Texas. In Hempstead County, Arkansas the Humble, 1-Royston well penetrates almost 7000 ft of Eagle Mills rocks, presently the maximum known thickness of the formation (Fig.10).

Of all the well logs examined in Texas during this investigation only 43 penetrate the Eagle Mills, and of these only 12 were drilled through to underlying Paleozoic rocks. Thicknesses vary substantially from as little as 60-70 ft (Texas, 1-Solomon, Red River County) up to more than 1,360 + ft (Humble, 1-Calfee, Titus County).* In Texas the Eagle Mills shows no clear thickness trends except where it pinches out against Paleozoic rocks at the northern edge of the Interior Gulf Basin. Because of the erratic thickness pattern, many geologists believe that deposition of the Eagle Mills was controlled by normal faulting associated with the initial rifting of the Gulf Coastal Basin (Figs. 10, 11).

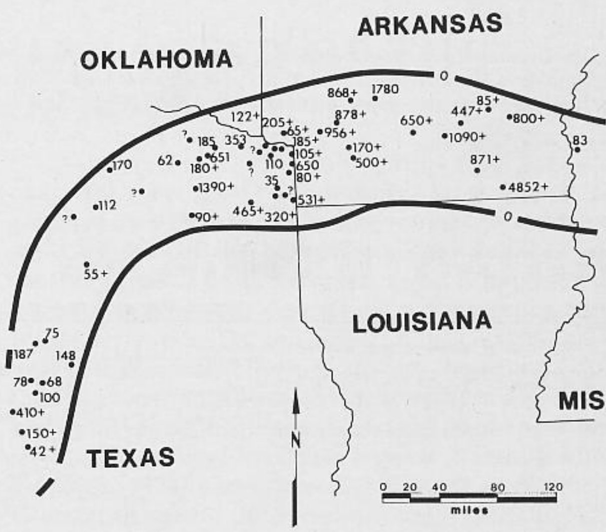


Fig. 9. Thickness, in feet, of the Eagle Mills Formation in northeastern Texas, southern Arkansas, northern Louisiana, and western Mississippi.

*Appendix 3, Core description of the Humble, 1-Calfee well, Titus County, Texas (3 p.), is available for costs from the Department of Geology, Baylor University —Editor.

LITHOLOGY

The Eagle Mills Formation of northeast Texas (Humble, 1-Calfee) consists of alternating layers of sandstone, siltstone, silty shale, and conglomerate (Figs. 12, 13).

The sandstone is commonly brick red, but in places is white or gray green in color. The texture ranges from fine to coarse grained (conglomeratic). The sand is commonly poorly sorted and argillaceous, becoming more calcareous and slightly chloritic toward the base of the formation (Fig. 12).

Siltstone in the Eagle Mills Formation is principally red to purplish red, argillaceous, and occasionally becomes finely micaceous in character. It is frequently mottled with areas of blue-green clay or shale probably indicating reducing conditions.

The shale is usually red to red brown in color but may be purplish red or gray green. It is silty, and at some horizons is mottled green by small clay clasts.

The conglomerate consists mostly of pebbles of round milky quartz and brick red, fine-grained orthoquartzite (up to 3 in diameter). The matrix is commonly fine to coarse grained argillaceous, slightly porous, red sandstone. Conglomeratic layers become progressively coarser downward (Fig. 13).

The principal lithology of the Eagle Mills in Arkansas is red silty shale, red clay shale, or mudstone with gray-green and red siltstone and sandstone. The sandstones, for the most part, are not porous and contain dolomitic, calcareous, or siliceous cement. Where siliceous cement predominates, the sands are represented by sedimentary

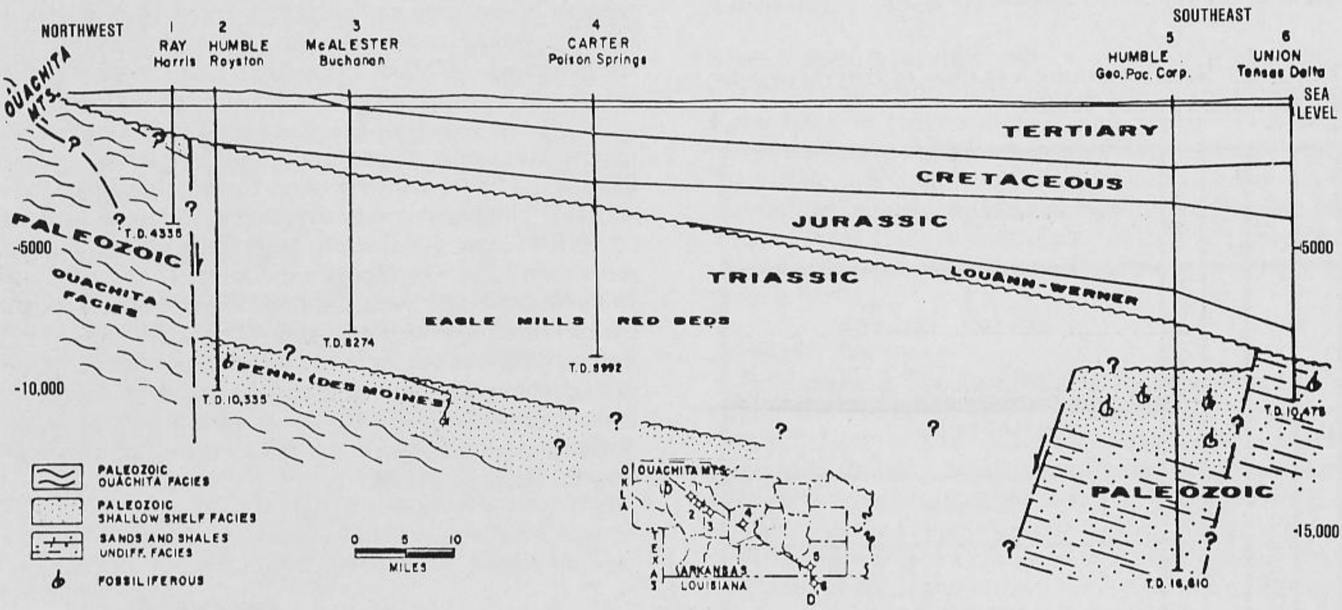


Fig. 10. Generalized northwest-southeast cross-section across southern Arkansas showing location of wells penetrating the Eagle Mills Formation. The Humble #1 Royston well (2) penetrates over 7000 ft of Eagle Mills red beds. Eagle Mills rocks were probably restricted to grabens along the front of the Ouachita Mountains. *From* Vernon, 1971, AAPG Mem. 15, v. 2, p. 975, used with permission.

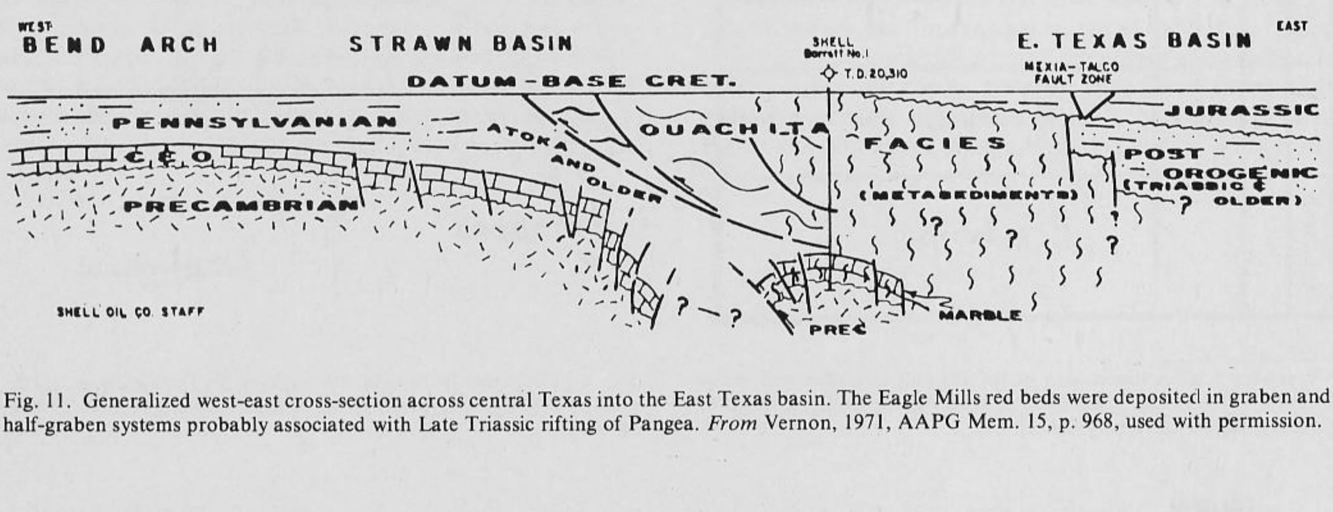


Fig. 11. Generalized west-east cross-section across central Texas into the East Texas basin. The Eagle Mills red beds were deposited in graben and half-graben systems probably associated with Late Triassic rifting of Pangea. *From* Vernon, 1971, AAPG Mem. 15, p. 968, used with permission.

quartzites. Limestone and dolomite, in the form of caliche-like blebs and inclusions or pebbles, are also present though not common. In some places thin conglomeratic beds a few inches thick occur in the shales, siltstones, and sandstones. Furthermore, there are minor traces of siderite, anhydrite, vein calcite, and dolomite in the Eagle Mills Formation of Arkansas (Scott, et al., 1961, p. 12).

The overlying Werner Formation represents the base of the Jurassic sequence in the Gulf Coast. It is composed of up to 50 ft of clear to gray crystalline anhydrite with occasional solution cavities (Fig. 14). In some wells a thin dense limestone layer and a conglomerate consisting of pebbles of white quartz, gray chert, and red and green igneous pebbles underlie the anhydrite (Fig. 15).

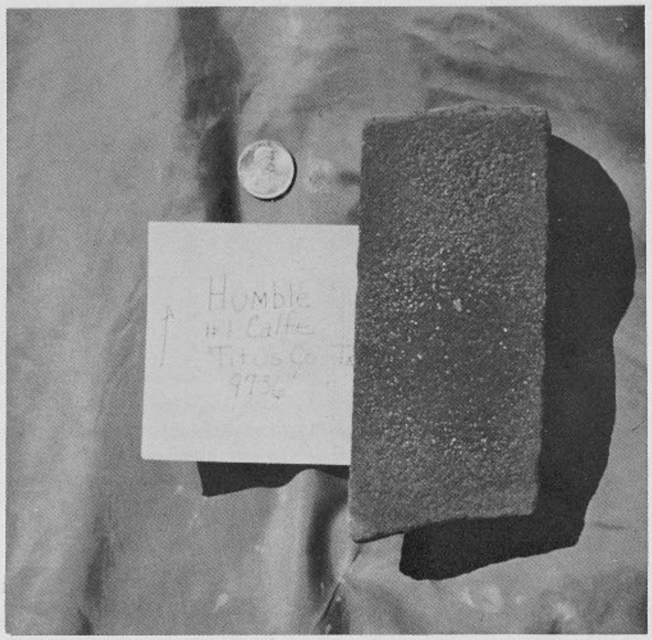


Fig. 12. Coarse-grained red sandstone from the Humble #1 Calfee core, Titus County, Texas.

Fig. 13. Section of Eagle Mills conglomerate from the Humble #1 Calfee well showing milky quartz and orthoquartzite pebbles in a red coarse-grained sandstone matrix.

DISTRIBUTION AND CHARACTER OF THE SYCAMORE FORMATION

INTRODUCTION

The Sycamore Formation of central Texas is a poorly sorted, coarse terrigenous conglomerate. It is a distinctive unit, differing greatly in composition and structure from underlying Paleozoic rocks and the overlying basal Cretaceous deposits. The Sycamore Formation is highly localized, cropping out radially along the northern, eastern and southern flanks of the Llano Uplift. It appears to have been derived primarily from the erosion of Paleozoic rocks of the Llano region. The character and distribution of Sycamore rocks was significantly affected by the tectonic history of the Llano region during the time of Sycamore deposition.

A major problem in interpreting Sycamore rocks is that the Sycamore conglomerate is not clearly defined as a stratigraphic unit, for it differs in composition and character from locality to locality. Most reports completed to date place the Sycamore Formation stratigraphically as part of the basal Cretaceous deposits in the central Texas region. However, as early as 1940, some doubt was expressed concerning a Cretaceous age for Sycamore rocks. Damon (1940, p. 86) stated that the lower conglomerate (Sycamore) was deposited prior to the advance of the Cretaceous sea, accumulation probably occurring soon after the Llano region was sufficiently elevated to undergo extensive erosion. Recent studies by Dobbins (1974) and others also suggest a possible pre-Cretaceous age for the Sycamore conglomerate. For the purpose of this investigation, therefore, the Sycamore conglomerate will be defined as the lowermost coarse terrigenous conglomerate deposit immediately beneath Cretaceous rocks unconformably overlying Paleozoic rocks and distributed in discontinuous outcrop from near

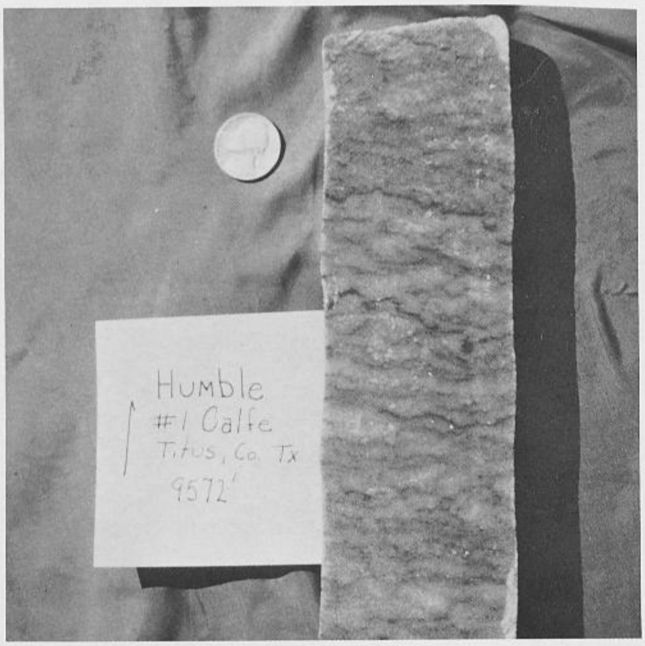


Fig. 14. Section of the Werner Formation showing clear-to-gray crystalline anhydrite with small solution cavities, Humble #1 Calfee core.

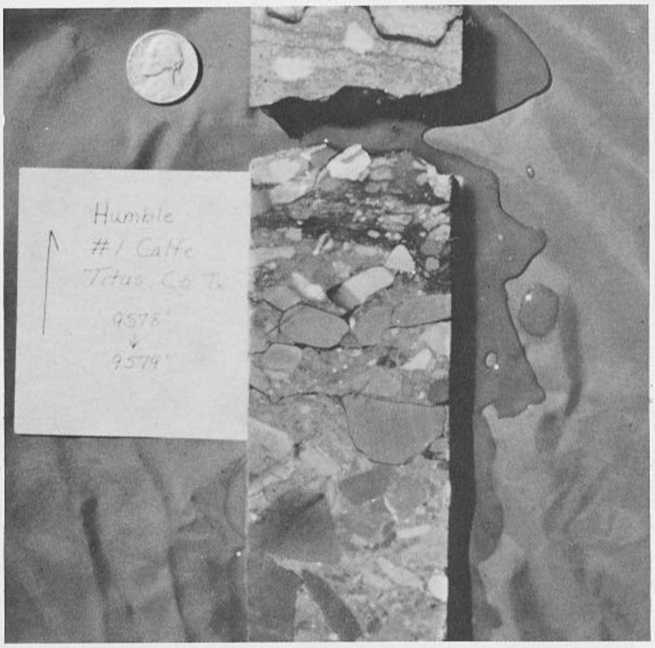


Fig. 15. Section of the Werner Formation directly above the contact with the Eagle Mills Formation. The conglomerate contains poorly sorted gravels of white quartz, green and gray chert, and some igneous fragments in a matrix of green-to-gray fine-grained sandstone. Directly above the conglomerate is a thin layer of dense fossiliferous limestone with stylolites.

Brownwood in Brown County southeast to the southern side of the Llano Uplift in Kimble County (Fig. 2).

REGIONAL GEOLOGIC SETTING

The Sycamore Formation is exposed in an outcrop belt that extends northwest to southeast around the northeast margin of the Llano Uplift (Blalock, 1976, p. 50) (Fig. 2). However, Sycamore outcrops south and southeast of the Llano Uplift in Gillespie and northern Blanco and Travis Counties suggest that Sycamore deposition was a product of radial drainage away from the Llano Uplift. The Sycamore conglomerate thins away from the Llano region in all directions strongly indicating that this region was the primary source area.

At locality 5 the Pedernales River and its small tributary streams have dissected the Sycamore conglomerate and underlying Paleozoic rocks revealing excellent sections. Here the conglomerate wedges out to the northwest between the rising Paleozoic floor and the nearly horizontal beds of the overlying Cretaceous sediments. The black limestone and shale of the basal Marble Falls Formation dip S 70° E at an angle of 12° (Fig. 16). In the Colorado region the old Paleozoic surface is almost a plane striking N 10° E and dipping gently eastward. The basal Sycamore conglomerate here continuously overlies the Paleozoic surface (Damon, 1940, p. 40).

The Sycamore conglomerate is absent at locality 12 where the Walnut Formation of the Fredericksburg Group overlies Paleozoic rocks of the Ellenburger Group. This was an area of positive relief upon which the Sycamore conglomerate was never deposited or on which it was deposited and from which it was later eroded prior to Fredericksburg deposition. The Sycamore conglomerate is present overlying Paleozoic beds just west of Lampasas (localities 14 and 15); from this point northwestward toward Brownwood, Sycamore rocks crop out along the Paleozoic/Cretaceous contact. In addition outliers of Sycamore rocks occur at localities 25, 26, and 27 in the vicinity of Rochelle, McCulloch County.

The Sycamore conglomerate occurs at an elevation of 960 ft in the area of Pedernales Falls, locality 5, at 1280 ft at Elliot Creek, locality 18, and about 1600 ft near Brownwood, Brown County. Since the cobbles of Sycamore rocks were clearly derived from Llano source areas, these elevations suggest that the region has been tilted south or southeastward since deposition of Sycamore conglomerate (Damon, 1940, p. 85).

STRATIGRAPHIC CONTACTS

The Sycamore conglomerate unconformably overlies rocks of Paleozoic age and is unconformably overlain by the more normal clastic deposits of the Travis Peak Formation, here considered the initial Cretaceous deposits of the central Texas region. These Travis Peak clastics consist of fluvial, deltaic, and marginal marine deposits and are probably rocks of the oldest Trinity Group in central Texas.

The Travis Peak Formation appears to represent a product of marine transgression across a gently subsiding land mass. As the waters deepened, the deposits changed from coarse to fine materials becoming more calcareous in the upper portion (Damon, 1940, p. 23).

The Travis Peak Formation of the Trinity Group can

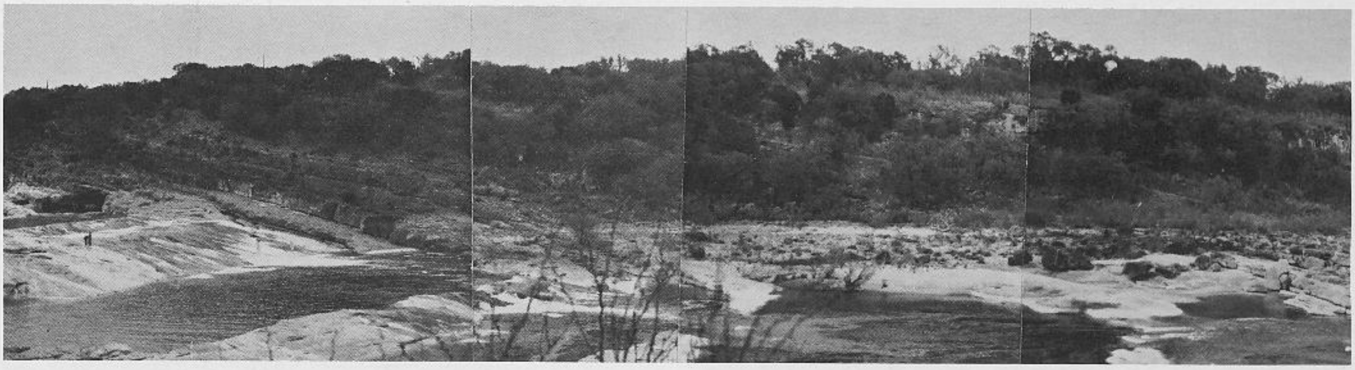


Fig. 16. Locality 5. 12 mi northeast of Johnson City at Pedernales Falls State Park, Blanco County. Here the Sycamore Formation rests unconformably on steeply dipping Pennsylvanian limestones and shales of the Marble Falls and Smithwick Formations. The conglomerate ranges from 0-100 ft in thickness where it wedges out between the overlying Cretaceous deposits and the underlying Pennsylvanian strata. The Sycamore here consists of numerous cobbles of hard Ellenburger dolomite and limestone with some pebbles of chert. The matrix, which is composed of coarse quartz sand and caliche, is badly weathered at the surface.

be divided into three major facies: a lower sand and conglomerate facies, a middle sand facies, and an upper silt and clay facies. The basal Travis Peak Formation is typically fine to coarse sands with interbedded silts and clays. The sands are commonly quartzose, well sorted and exhibit cross-bedding. Most of the sand is friable; however, ledges are occasionally formed as calcium carbonate cementation increases upward through the sequence (Whigham, 1978, p. 1). Localities 14 and 16 are examples of fluvial deposits of the Travis Peak-Twin Mountains Formation. The fluvial deposits are represented by an upward fining sequence grading from fine-grained quartz sand at the base to silt at the top. The lower facies consist of quartz sand and sandy conglomerate. The basal conglomerate is composed of well-rounded pebbles of quartz and chert increasing upward in abundance and size in a matrix of clean coarse-grained quartz sand (Fig. 17).

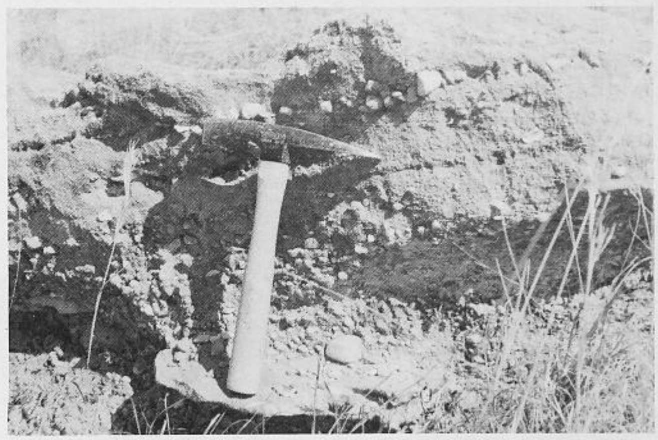


Fig. 17. Locality 14. Fluvial point-bar deposits of the Travis Peak Formation exposed at Lynch Creek, Lampasas County. These deposits consist of large-scale cross-bedded coarse-grained sandstone with pebbles of limestone and chert.

LITHOLOGY OF THE SYCAMORE CONGLOMERATE

The Sycamore conglomerate crops out radially around the Llano Uplift, but it is most widely exposed on the northern and eastern margins of the uplift where it occurs in a belt extending northwest from the northern Llano region (Blalock, 1976, p. 24). The Sycamore Formation is typically a poorly sorted coarse terrigenous unit consisting of a sequence of interbedded sandy, pebble-to-cobble conglomerate with thin sand drapes (Fig. 18). The cobbles consist largely of chert, dolomite, limestone and sandstone derived from exposures in the Llano region. Most of the conglomerate, ranging in size from sand to boulders, is derived from rocks of the Ordovican Ellenburger Group. Cobbles and pebbles of Sycamore conglomerate are well rounded, but sphericity decreases with increasing size (Dobbins, 1974, p. 29) (Fig. 19). In addition certain exposures of Sycamore conglomerate are composed of sand, pebbles, cobbles, and boulders derived from Marble Falls limestone of Pennsylvanian

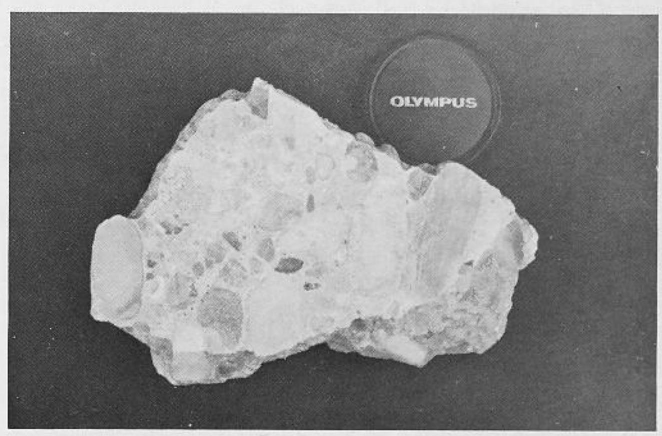


Fig. 18. Locality 19. Slabbed section of Sycamore conglomerate composed of pebbles and cobbles of dolomite and chert. Many of the chert pieces are highly polished suggesting that they may have been regolith cherts from a pre-Sycamore soil here incorporated into the Sycamore conglomerate.

Fig. 19. Locality 3. Slabbed sample of Sycamore conglomerate showing large rounded pebbles of dolomite and smaller pebbles of chert in a matrix of coarse quartz sand with caliche infilling. The sample is well cemented and many of the clasts contain calcite "halos."

Fig. 20. Locality 18. Sycamore conglomerate exposed at Elliot Creek consists of boulders, cobbles, and pebbles of dolomite, limestone, and chert derived primarily from the Ellenburger and Marble Falls rock groups of the Llano region. Arrow indicates a graded sequence of conglomerate representing waning stages of a single sediment influx.

age. Other outcrops of Sycamore rocks consist largely of boulders derived from the Pennsylvanian Strawn sandstone. In areas of good exposure Sycamore rocks typically consist of thick structureless beds of caliche-cemented conglomerate capped by thin sand drapes, which appear to represent cycles of sedimentation. The Sycamore rocks of the Elliot Creek and Pedernales Falls sections exhibit such sand drapes (Fig. 20). In areas of good exposures Sycamore conglomerate can be subdivided into an upper and lower unit.

The upper unit is characteristically a caliche zone and is present only where there is a complete section of Sycamore rocks. This zone varies in thickness from 2-10 ft (Fig. 21).

The basal Sycamore section is a poorly sorted, massive boulder to pebble conglomerate (Fig. 22).

Sycamore outcrops vary widely in particle size, matrix composition, and degree and character of cementation. Since grain size of a clastic deposit is the measure of the energy of the depositing agent, the maximum cobble size of the Sycamore conglomerate is significant to an interpretation of the depositional history. Total stream energy increases with an increase in discharge. Transportation of boulders, cobbles, and pebbles consumes energy causing a variation in grain size and thickness of the deposit. Generally there is a downcurrent decrease in grain size formed as a result of abrasion and progressive sorting (Mackin, 1948, p. 465-466). The Sycamore conglomerates, therefore, are almost classic indicators of sediment distribution from a localized source.

The thickness of the formation varies from outcrop to outcrop, generally decreasing away from the Llano region. Nearest the Llano region (locality 5) at Pedernales Falls, Sycamore conglomerates exceed 100 ft in thickness where they pinch out against the Paleozoic Smithwick and Marble Falls Formations below and the overlying Cretaceous deposits of the Travis Peak Formation above. In Lampasas County near Nix (localities 14 & 15), the Sycamore Formation is approximately 15 ft thick. In Brown County, at the northern margin of the outcrop area, Sycamore rocks are 4-5 ft thick and they continue to thin northward.

The matrix of Sycamore conglomerates consists of quartz sand grains and chert fragments often cemented in white to pink caliche (Fig. 19). The ratio of matrix to cobbles increases with transport distance away from the Llano source area, and at similar distances the dimensions of the maximum cobble size decrease. At locality 38, for example, the matrix consists almost exclusively of coarse quartz sand and small chert fragments; the cobbles are sparse and small, consisting almost entirely of chert. The Sycamore conglomerate is commonly cemented by calcite possibly derived both from the cobbles and from caliche, for it is most common where caliche cementation also exists.

OUTCROP REGIONS OF SYCAMORE CONGOLMERATES

The Sycamore conglomerate varies in composition and character from place to place. It is possible, therefore, to define for the Sycamore conglomerate areas of exposure in which composition and character are internally consistent but which differ from those of adjacent areas of Sycamore exposure. During this investigation seven areas characterized by internal consistency were identified. These include the Pedernales Falls, Sycamore Creek, Lampasas, Elliot Creek and Brownwood areas and possible areas of outcrop of Dockum rocks.

Pedernales Falls Area

In this area the conglomerate rests upon the steeply dipping limestones and shales of the Smithwick and Marble Falls Formations (Pennsylvanian). Here the Sycamore conglomerate consists of boulders and cobbles of limestone, dolomite, chert, and sandstone. Dolomite cobbles and pebbles, from Marble Falls and Ellenburger sources, form most of the conglomerate in this area. The matrix is primarily coarse brown quartz

Fig. 21. Locality 15. The upper caliche zone is exposed and forms a clear boundary between Sycamore rocks and more characteristic basal Cretaceous sediments. The boundary between the upper and lower Sycamore is found at the lower part of the picture.

Fig. 22. Locality 5. Weathered basal conglomerate exposed here at Pedernales Falls is composed almost entirely of dolomite cobbles and pebbles derived from the Ellenburger Group and Marble Falls Formation. The conglomerate at this locality is similar in lithology, composition, and structure, including sand drapes, to that found at Elliot Creek, Lampasas County.

sand with some indurated caliche, which contributes a light pink color. Sand drapes are also present within the conglomerate of this area (Fig. 22).

Sycamore Creek

The type locality of the Sycamore conglomerate is on Sycamore Creek, and this exposure is particularly significant to this investigation. Here a stream exposes the Smithwick shale, Sycamore conglomerate, and overlying basal Cretaceous clastics. The Sycamore Formation consists of a coarse basal conglomerate of several pre-Cretaceous rock types including the Ellenburger Group and Marble Falls Formation of the Llano area and grades upward to a mixture of sand pebbles, silt and clay (Young et al., 1972, p. 65).

Lampasas Area

The Lampasas area lies north and northeast of the Llano Uplift. The Sycamore conglomerate in this region is represented by the Nix locality (14, 15) 12 mi west of Lampasas. Here cobbles and pebbles of chert and dolomite are evident within an indurated caliche and sand matrix. The Sycamore Formation is overlain by more typical Travis Peak deposits of mixed-load fluvial streams and by shallow marine deposits of the upper Travis Peak Formation.

Elliot Creek

At Elliot Creek the Sycamore conglomerate consists of 25 ft of red-brown to brown pebble-to-cobble conglomerate alternating with thin layers of sand, which apparently represent waning stages of separate stream flows. The pebbles and cobbles consist of hard limestone, dolomite, and chert derived from the Ellenburger Group and Marble Falls Formation. The conglomerate at Elliot Creek is similar to the Sycamore conglomerates at Pedernales Falls (Fig. 20).

Brownwood Area

The Sycamore conglomerate in the Brownwood area consists primarily of small yellow, black and red chert in a coarse brown quartz sand matrix. Gravels are much finer and pebbles less numerous in the northern localities in Brown County, and limestone pebbles are noticeably absent northward from the Elliot Creek region to the Brownwood area.

DISTRIBUTION AND CHARACTER OF THE DOCKUM GROUP

INTRODUCTION

The Dockum Group of west Texas and New Mexico is a complex continental clastic sequence consisting of mudstone, siltstone, sandstone, and conglomerates. These terrigenous deposits accumulated in alluvial fans, braided and meandering streams, lobate deltas, and lakes.

GEOLOGIC SETTING

Rocks of the Dockum Group were deposited in a basin that underlies parts of Texas, New Mexico, Colorado, Kansas, and Oklahoma (Fig. 8). This study is concerned chiefly with those sediments that were deposited in the west Texas area.

The southern boundary of the Dockum Group approximately follows the east bank of the Pecos River downstream from the New Mexico-Texas border to eastern Reeves and northern Pecos Counties. From this point it extends northeast to Sterling County, includes much of Mitchell, Scurry, and Borden Counties, and continues northward along the Caprock Escarpment to the Canadian River valley (Adkins et al., 1932, p. 250-251) (Fig. 3). The Caprock Escarpment is an armored surface of massive caliche-cemented rock that underlies the Texas High Plains surface and serves as a protective covering for the underlying Dockum sediments (Fig. 6).

STRATIGRAPHIC CONTACTS

The Upper Triassic Dockum Group of west Texas unconformably overlies the red shales of the Upper Permian Quartermaster Group. Except for the sparse outcrops of the Bissett Formation in far southwest Texas there are no Lower or Middle Triassic deposits in the state. This contact between the Quartermaster and Dockum Groups represents a time gap of about 35 million years. However, the upper surface of the Permian rocks is generally smooth and regular, with little evidence of significant erosion prior to the deposition of the Triassic rocks (Gould, 1907, p. 21). In addition, though the retreat of the Permian sea was followed by erosion and local folding, the erosion was not extensive, because most

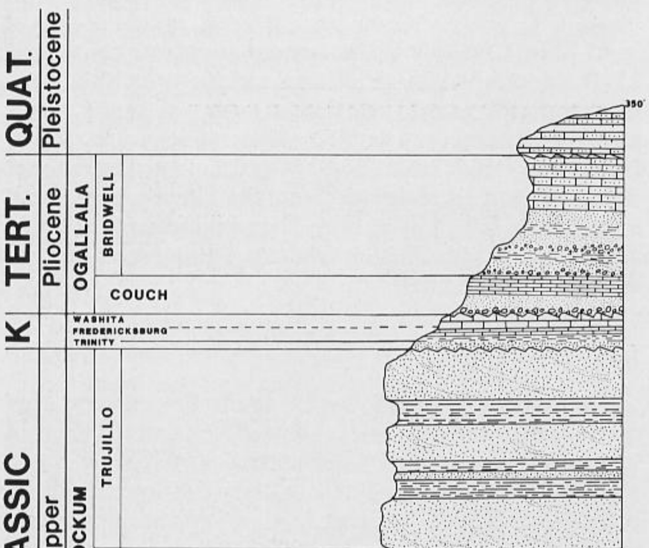


Fig. 23. Lithologic and stratigraphic relationships of the Upper Permian, Upper Triassic, Cretaceous, and Tertiary sediments of the Southern High Plains.

OGALLALA GROUP

BRIDWELL FORMATION
consists of well-sorted, reddish-brown, quartzose sand, silt and clay occasionally interlaminated with thin discontinuous channel gravels

COUCH FORMATION
composed primarily of unconsolidated, pinkish-gray, coarse-grained calcareous sand and gravel (from Walker, 1978 and Brand & Reeves, 1971)

WASHITA GROUP

PURGATOIRE FORMATION
upper—limey fine grained yellow to brown, fucoidal sandstone with bentonitic shale interbeds

lower—buff to brown, cross bedded, ripple marked sandstone with some fine-grained coarse sand and pebble layers (the Purgatoire Fm. is analogous to the Duck Creek and Kiamichi sections)

DUCK CREEK FORMATION
moderately yellow shale and thin light gray to yellowish brown limestone beds

KIAMICHI FORMATION
thinly laminated dark-gray to moderately yellowish-brown shale and scattered light gray limestone and yellowish sandstone lenses

FREDERICKSBURG GROUP

EDWARDS FORMATION
hard light-gray to grayish yellow thick bedded, fine to coarse-grained limestone with abundant rudist remains

COMANCHE PEAK LIMESTONE
light-gray to light-yellowish-gray argillaceous, fossiliferous limestone and thin light-gray shaly interbeds.

WALNUT FORMATION
light-gray to brown argillaceous sandstone, calcareous shale, and argillaceous limestone.

TRINITY GROUP

ANTLERS FORMATION
gray to purple loosely consolidated fine to coarse grained unfossiliferous quartz sandstone with scattered lenses of quartz gravel. Basal part contains clay and quartz pebbles derived from underlying Triassic beds

DOCKUM GROUP

CHINLE FORMATION
restricted to the southeastern portion of the High Plains and consists of thin shales and sandstone which are lithologically similar to the Tecovas and Trujillo Formations

TRUJILLO FORMATION
consists of several ledges of fine to medium grained, reddish-brown to gray, cross-bedded and massive sandstone and conglomerate separated by red, maroon, and gray shales

TECOVAS FORMATION
consists of a lower sequence of varigated sandy shales and a upper sequence of purplish-red and orange shale with thin layers of soft sandstone

QUARTERMASTER GROUP (FORMATION)
composed of primarily brick-red to vermillion shales interbedded with lenses of soft red sandstone, clays, and gray shales. The lower red shales contain a considerable amount of gypsum in the form of white to pink bands of satin spar

Fig. 24. Locality 5. Quartzitic, fine- to coarse-grained channel sand characteristic of the Dockum Group of west Texas.

Fig. 25. Locality 1. Red, silty shales of the lower Dockum Group exposed at Sterling City cemetery.

of the Permian structures that are reflected in Permian topography are also reflected in basal beds of the Triassic deposits.

Although there is good evidence for an unconformity between the Dockum and Quartermaster Groups, in many instances the boundary between them is difficult to determine and appears to be gradational in nature. There are, however, certain lithologic features characteristic of each of the groups. Table 3 illustrates some of the common lithologic differences between the Dockum and Quartermaster Groups in the west Texas area.

The Dockum Group is unconformably overlain by the Ogallala Group of Pliocene (Tertiary) age and to a lesser extent by Lower Cretaceous marine deposits chiefly south of lat. 33°N. In fact, in most areas of the Texas Panhandle there is no stratigraphic record of the Jurassic, Cretaceous, or lower Tertiary Periods, thus an unconformity representing 167 million years exists between the Triassic and Pliocene sections typical of the Caprock Escarpment. However, in some of synclines beneath the northern Llano Estacado the Upper Jurassic Morrison Formation may be present, associated with Cretaceous formations, above the Dockum deposits. Figure 23 shows the lithologic and stratigraphic character of the various stratigraphic units that are associated with rocks of the Dockum Group.

Table 3. Lithologic Differences Between the Upper Triassic Dockum Group and the Upper Permian Quartermaster Group.

DOCKUM GROUP (UPPER TRIASSIC)	QUARTERMASTER GROUP (UPPER PERMIAN)
1. Poor lithification of shales.	1. Good lithification of shales, compact and hard.
2. Color—maroon, yellow, light brown, magenta, and gray.	2. Color—vivid brick red.
3. Gypsum and anhydrite occur only in minor amounts and are generally not bedded.	3. Bedded anhydrite, gypsum and salt.
4. Abundance of mica and phosphate.	4. Little or no mica or phosphate.
5. Sandstones—generally heterogeneous in nature with extensive cross-bedding.	5. Sandstone—usually fine grained.
6. Conglomeratic beds, both intrabasinal and extrabasinal.	6. No substantial conglomeratic beds.
7. Reptilian bones and species of *Unio*.	7. No evidence of fossil bones or pelecypods.
8. Weathers easily forming dome-shaped masses.	8. Where exposed, weathers to form a typical badland topography.

LITHOLOGY OF DOCKUM ROCKS

The Upper Triassic Dockum Group of west Texas comprises a unique and complex red-bed sequence consisting of colorful sand, shale, and conglomerate.

The sands are commonly quartzitic, fine to coarse grained, poorly sorted, and range in color from white to red. Most of the sand is friable and is cemented by gray and red shale, silica, gypsum, and iron oxide (Adams, 1929, p. 1048) (Fig. 24).

The shales are commonly varigated, unlithified, micaceous, and silty (Fig. 25). Although most commonly red and maroon, the shales can also be gray, green, yellow or brown in color. Two types of conglomerate are present within the Dockum Basin. The first type of conglomerate consists of clasts commonly composed of mudstone, siltstone, sandstone and caliche derived from within the basin (McGowen et al., 1979, p. 10) (Fig. 26). The second type of conglomerate is composed of constituents derived from sources outside the depositional basin. These conglomerates are composed of clasts of chert, quartzite, vein quartz with some silicified wood fragments (Fig. 27).

Terminology applied to the Dockum Group of west Texas has undergone considerable evolution. Presently, however, the Dockum Group is divided into three formations, which can be traced for considerable distances. These are, from oldest to youngest the Tecovas, Trujillo, and Chinle Formations.

Tecovas Formation

The Tecovas Formation, named by Gould (1907, p. 21) for exposures on Tecovas Creek, Potter County, Texas, is present north of the Matador Arch where it can be

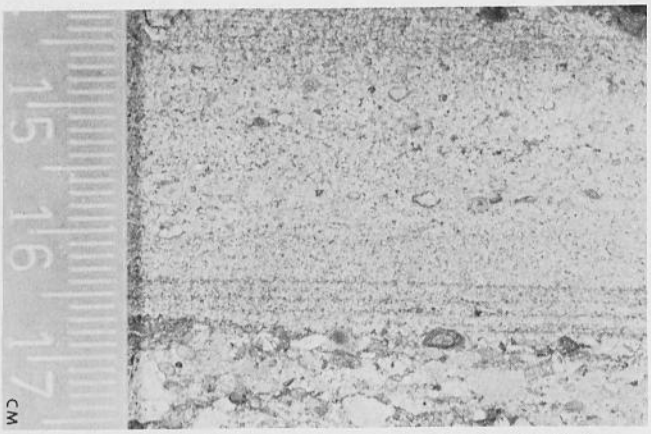


Fig. 26. Locality 8. Slabbed sample of a Dockum intrabasinal conglomerate composed of clasts of mudstone, siltstone, sandstone, and caliche (scale in cm).

Fig. 28. Locality 11. Outcrop of the Tecovas Formation, 17 mi south of Post, Garza County. At this locality the Tecovas consists of red siltstone interbedded with thin, fissile, light-gray to green sandstone and some coarse red sandstone.

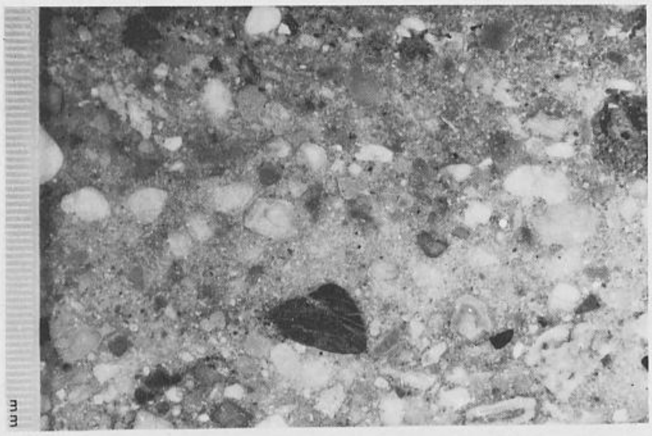


Fig. 27. Locality 6. Slabbed sample of a Dockum extrabasinal conglomerate composed of chert, quartzite, vein quartz and silicified wood fragments (scale in mm).

Fig. 29. Locality 4. Outcrop of Tecovas sandstone showing some of the dark-colored ironstone concretions that weather out of the sand at the surface.

divided into two members, a lower varigated sandy shale sequence and an upper dark-red or magenta shale sequence. However, Patton (1923, p. 51) and Green (1954, p. 17) have noted that because of the great variations in color the divisions of Gould can not be carried further south than the Palo Duro Canyon area. The varigated shales of the lower Tecovas lie directly upon the upper eroded surface of the Quartermaster Group, forming a vivid color contrast. The Tecovas Formation usually consists of sandy shales, typically calcareous, which are more or less cross-bedded and lenticular (Gould, 1907, p. 22) (Fig. 28). The color of the shale is due largely to the presence of iron, and many dark-colored clay-ironstone concretions weather out at the surface (Fig. 29). Interbedded with varigated shales are thin lenses of white, yellow, or light-brown friable soft sandstone. The sand is poorly cemented and weathers easily. Many of the outcrops exhibit sand-filled channels and intraformational conglomerates. The Tecovas attains its maximum thickness in an area roughly corresponding to the Palo Duro Basin and thins rapidly southward toward the Matador Arch (Kiatta, 1960, p. 12). The contact between the Tecovas Formation and the overlying massive sands of the Trujillo Formation is conformable.

Good outcrops of the Tecovas Formation occur in Mitchell County (localities 2, 3) where the Tecovas consists of red fine sandy silts and laminated sandstones. The muds and silts contain montmorillonite seams and small thin plates of sparry gypsum. The sand beds are lenticular and discontinuous, probably representing winnowing stages of stream deposition in a playa margin. Other good exposures of the Tecovas occur just north of Fluvanna (locality 6) and a few miles south and west of Post in Garza County (locality 8, 9) where the deposits consist chiefly of red mudstone and siltstone with gray-to-red, finely cross-bedded, graded sandstones (Fig. 30).

In the Palo Duro Canyon area the Tecovas Formation is about 200 ft thick and is composed of a lower lavender, gray, and white shale sequence; a middle bed of white friable sandstone; and an upper unit of orange shale, which underlies the more massive Trujillo sandstone (Matthews, 1969, p. 21). Figure 31 illustrates the geologic formations present within the canyon. The Tecovas shales form a relatively smooth slope readily distinguished from the gullied, steeper slopes of the Permian shales beneath them.

Fig. 30. Locality 7. Tecovas exposures near Post, Garza County, showing a finely cross-bedded graded sequence of loosely cemented pebble conglomerate and coarse quartz sand. The outcrop is friable and weathers easily.

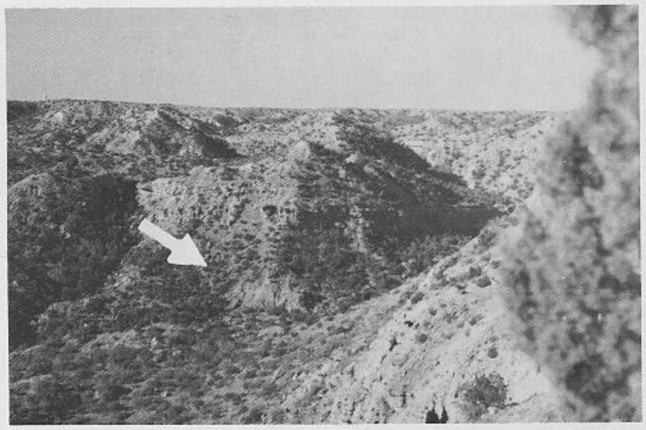


Fig. 31. Locality 14. Tecovas shales are well exposed in Palo Duro Canyon where they form a relatively smooth slope (arrow) below the more massive sandstone ledges of the Trujillo Formation.

Fig. 32. Locality 5. A massive sandstone channel some 50 yd wide and 15-20 ft deep is exposed at locality 5. The channel is composed almost entirely of medium- to fine-grained, massive sand and is in sharp contact with the underlying shale and sand beds.

Trujillo Formation

The Trujillo Formation, named by Gould (1907) for exposures along Trujillo Creek, Oldham County, Texas, consists principally of fine- to medium-grained cross-bedded sandstone, massive light-gray to reddish-brown sandstone, and thin lenticular quartzose conglomerate beds. The Trujillo consists of three to five well-defined ledges of massive, cross-bedded sandstone and conglomerate interbedded with red and gray shales and poorly consolidated cross-bedded sandstones (Gould, 1907, p. 26). He divided the Trujillo Formation into lower, middle, and upper units based upon the number of sandstone ledges. However, sand ledges often converge or die out making correlation difficult. The sandstones are highly cross-bedded and typically light gray to buff colored but may be light tan to yellowish brown where a large amount of iron oxide is present (Green, 1954, p. 29). The sands range from fine to medium grained and are locally conglomeratic. They are cemented by calcium carbonate, clay, iron oxide, and silica (Kiatta, 1960, p. 13).

Good outcrops of the Trujillo Formation may be seen along State Highway 163 in Mitchell County where they consist largely of massive, green to red lenticular channel-fill sands and conglomerates. Scour and fill structures as well as local cross-bedded pods are prevalent throughout the sections. At locality 5 a large filled channel some 50 yd wide and 15-20 ft deep is exposed, cutting the bedded sands below (Fig. 32). At the north end of the exposure the channels are oriented in a southeast-northwest direction. The outcrops also contain some highly friable sand and clay pebble conglomerates, many of which occupy the basal portion of the channels (Fig. 33). Figure 34 is an example of the festooned cross-bedding present within the channel fill at locality 5. Other good exposures of the Trujillo Formation may be seen along the eastern edge of the Caprock Escarpment near the town of Post in Garza County where the deposits are principally channel fill sands and conglomerates.

The Trujillo Formation of Palo Duro Canyon consists of prominent ledges of sandstone interbedded with red, maroon and gray shales (Matthews, 1969, p. 23) (Fig. 35). Triassic Peak in the northern part of Palo Duro Canyon State Park offers a unique exposure of the contacts between the Permian Quartermaster Group and the Tecovas and Trujillo Formations.

Analysis of cross-bedding of the Dockum sandstones was undertaken by Kiatta (1960), Cazeau (1962), and Cramer (1973), and they generally agree that paleocurrent patterns show a definite preferred orientation to the west-northwest. Figure 36 is a map and compass diagram showing the orientation of cross-beds in the Dockum sandstones. The mean cross-bed direction is N 61° W, indicating that the depositing streams flowed generally to the west-northwest.

In localities where good cross-bedding was evident, (localities 2, 5, 6, 8, 9) the principal directional component was also to the west-northwest. However, directional readings and sandstone percentage maps constructed from outcrop and subsurface data by McGowen et al. (1979) indicate that the basin was peripherally filled.

In many areas the upper Trujillo Formation shows

Fig. 33. Locality 5. Outcrop of the Trujillo Formation (?) showing characteristic scour and fill structure much of which contains a basal clay-pebble conglomerate.

evidence of extensive erosion prior to deposition of the Upper Tertiary Ogallala deposits. However, in the southeastern part of the Texas High Plains Chinle rocks overlie Trujillo sands beneath the Ogallala cover.

Chinle Formation

The Chinle deposits of west Texas differ from the Chinle rocks of western New Mexico and Arizona, and their stratigraphic continuity with the western deposits is not presently known. In west Texas, the formation consists mainly of greenish-gray and maroon sandy shales (Adams, 1929, p. 1052) with small conglomeratic and micaceous sandstone lenses. Overall, the clays and shales of the Chinle are of the same general rock type as the Tecovas and Trujillo Formations.

Fig. 34. Locality 12. Large sigmoidal foreset cross strata in the lower part of a distributary-filled channel.

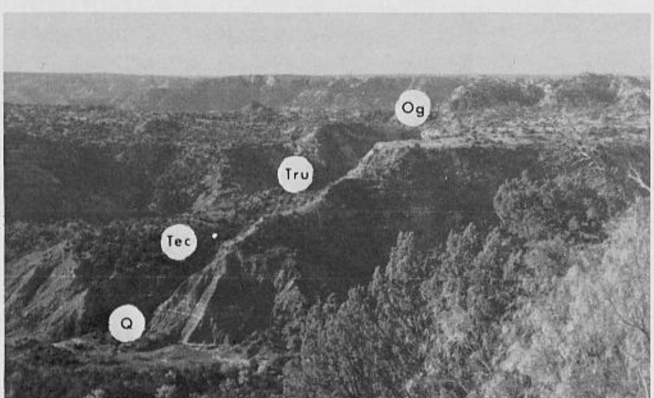


Fig. 35. Locality 14. View of north rim of Palo Duro Canyon illustrating the prominant sandstone ledges of the Trujillo Formation. The contacts between the Permian Quartermaster Group (Q), Tecovas Formation (Tec), Trujillo Formation (Tru), and Ogallala Group (Og) are easily distinguished in the canyon.

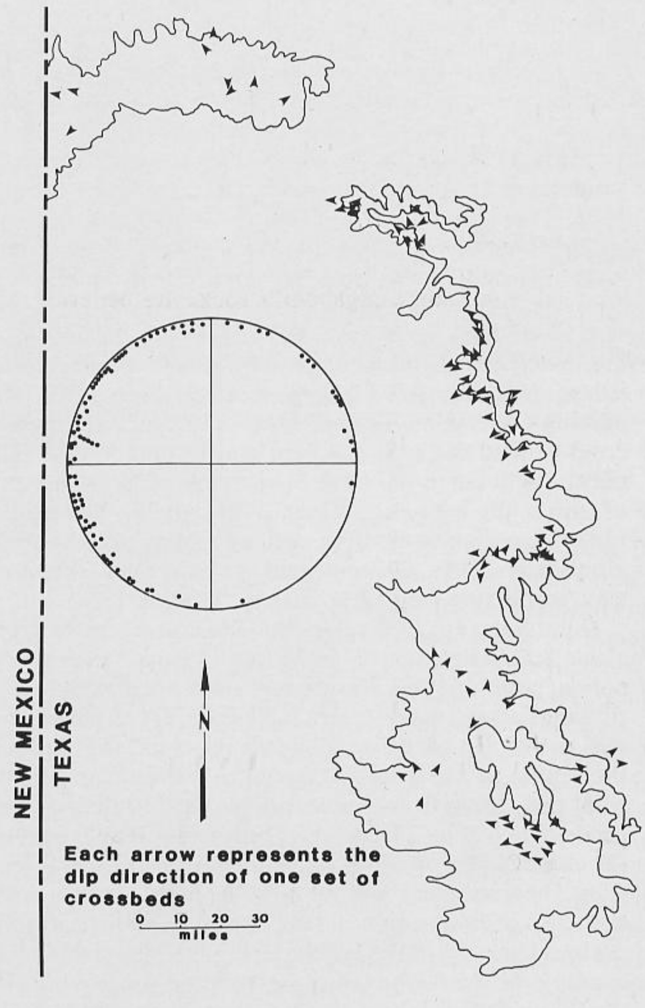


Fig. 36. Map showing orientation of cross-beds in the Dockum sandstone. The compass diagram shows the mean cross-bed direction to be N 61° W. *From* Kiatta, 1960, M.S. thesis, Texas Tech College, p. 22.

DISTRIBUTION AND CHARACTER OF THE BISSETT FORMATION

INTRODUCTION

The Bissett Formation is a terrigenous unit consisting largely of limestone and chert conglomerate, red shale, sandstone, and some local limestone and marl deposits (Sellards and Baker, 1934, p. 154). The formation crops out along the northwest margin of the Glass Mountains in southwest Texas varying in thickness from 10-500 ft (Fig. 5). It unconformably overlies Permian carbonates of the Capitan Formation and is unconformably overlain by Lower Cretaceous sandstones and limestones. Near Bissett Mountain (Type Locality) the formation is composed of a basal unit of red shale with some interbedded conglomerate and an upper cobble-to-boulder conglomeratic unit.

INTERPRETIVE GEOLOGY

The sedimentary history of the four areas of Triassic rocks, the Eagle Mills, Sycamore, Dockum, and Bissett outcrop areas is described individually in the section that follows. As the final part of this paper, the Triassic rock groups will be combined and their similarities in lithology and sedimentary history described.

SEDIMENTARY HISTORY OF THE EAGLE MILLS FORMATION

DEPOSITIONAL ENVIRONMENT

The Eagle Mills Formation represents the initial deposits of the subsiding Gulf Basin in Texas, Arkansas, and north Louisiana. Eagle Mills rocks are believed to have been deposited in deep troughs bounded by steep faults (Figs. 10, 11). The Eagle Mills sediments were land derived with no marine constituents. These sediments were predominantly alluvium with the coarser clastics representing probable alluvial fan and bed-load to mixed-load stream deposits derived from streams that flowed from the uplifted Ouachita Tectonic Belt. The mudstones, shales, and some of the siltstones are products of flood-plain deposition and include marshes, ephemeral lakes, streams, and shallow lakes. The presence of more sand in the lower portion of the formation and shale in the upper part is believed to be the result of (1) decrease in basin deepening tectonics, (2) lowering of the topography in the source areas, or (3) a trend toward increased aridity resulting in a more sporadic stream activity (Scott et al., 1961).

Figure 37 shows generalized lithofacies-environment maps for the Texas-Arkansas Gulf Coast region from Late Pennsylvanian to Early Cretaceous time. Figure 37A depicts the area prior to Eagle Mills deposition. It shows the Ouachita-Marathon trend with subsequent deposition both to the north and south. Figure 37B represents the region during deposition of the Eagle Mills Formation (Late Triassic). Eagle Mills sediments are continental in origin, derived principally from the eroding Ouachita Mountains to the north and west and deposited in grabens associated with the initial rifting of the North American Plate from the Afro-South American Plate. Paleoclimatic indicators for the Late Triassic point toward a period of aridity for the region. Aridity is indicated by the presence of the extensive red beds of the Eagle Mills Formation in the Gulf Coast region and in the Dockum Group in west Texas. Figure 37C shows further spreading of the plates with restricted marine influx into an extensive evaporite basin. The deposits of this episode constitute the Werner anhydrite and Louann salt of Early to Middle Jurassic age.

Figures 37D-F depict the Gulf Coast region from Middle Jurassic to Early Cretaceous time. This was a prolonged period of intermittent transgressions and regressions dominated by shallow marine carbonate and sand deposition. The sediments of these episodes, the Smackover Formation and the Cotton Valley Group, were deposited in an arcuate trend over a wide portion of south Texas. With continued subsidence, the area of sedimentation expanded. Both sedimentation and subsidence rates remained relatively equal through most of Jurassic and Cretaceous time resulting in the domination of shallow marine or deltaic deposits.

PALEOTECTONIC IMPLICATIONS OF ORIGIN

There are numerous theories pertaining to the origin and initial deposits of the Gulf Coast sedimentary basin. Early investigators concluded that the Gulf Basin did not exist prior to the Mesozoic Era. Branner (1897) and Willis (1907) believed that a large continental landmass, Llanoria, occupied much of the present basin area. Suess (1904) and Schuchert (1935) suggested that the Gulf Basin formed by collapse of a foreland. However, geologists now generally reject the concept of Llanoria, and presently two main schools of thought exist: (1) the Gulf Basin has existed since late Precambrian or early Paleo-

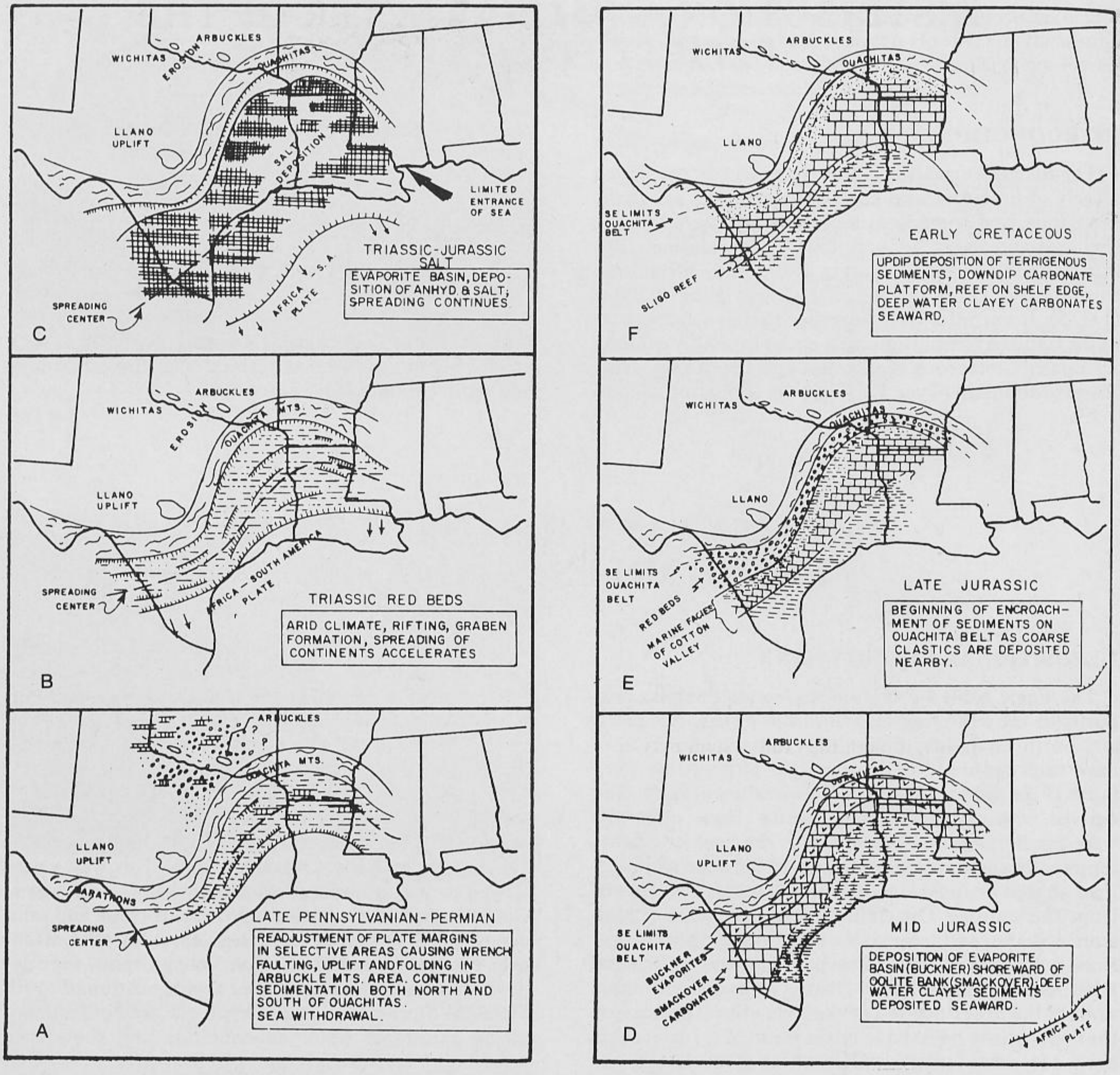


Fig. 37. Generalized lithofacies-environment maps showing Late Pennsylvanian to Early Cretaceous time. *From* Burgess, 1976, GCAGS Trans., v. 26, p. 138, used with permission.

zoic time, or (2) it was formed by Early Mesozoic sea-floor spreading in the Gulf, which created the Gulf of Mexico as a product of the general breakup of the old supercontinent Pangaea into continental blocks (Woods and Addington, 1973). Paine and Meyerhoff (1970), Shurbet and Cebull (1975), and others believe that the Gulf Basin has existed since the Precambrian (Fig. 38). Dietz and Holden (1970) explained the origin of the Gulf Basin in terms of plate tectonics, by relating it to the breakup of Pangaea at the end of Paleozoic time. Dickinson and Coney (1980) believed that the Gulf of Mexico did not exist at the end of Paleozoic time, and that the oceanic crust of the central Gulf of Mexico formed in Jurassic time as a result of rifting, which was probably initiated in Late Triassic time. Walper and Rowett (1972) and Walper (1980) proposed a modified version of the Bullard et al. (1965) fit for the reconstruction of Pangaea. This reconstruction, which is based on paleomagnetic data and the alignment of comparable orogenic belts (Fig. 39), rotates Gondwanaland clockwise about 23° and completely closes the Gulf of Mexico. According to Walper (1980), convergence of North America with Europe, Africa, and South America occurred during Late Paleozoic time. Late Triassic sea-floor spreading, which separated North and South America, created the Gulf and Caribbean basins.

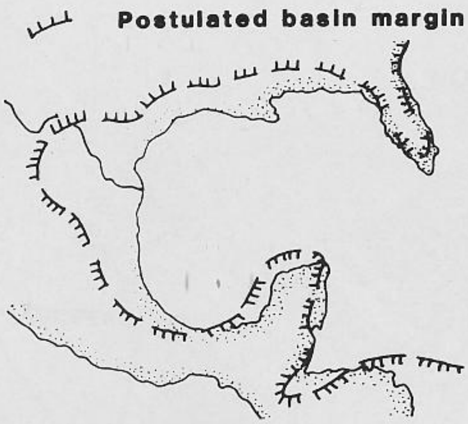


Fig. 38. Precambrian basin margin of the Gulf of Mexico as postulated by Paine and Meyerhoff. *Adapted from* Paine and Meyerhoff, 1970, GCAGS Trans., v. 20, p. 22, used with permission.

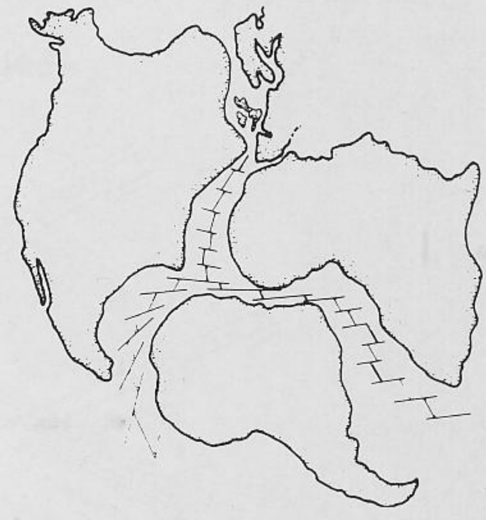


Fig. 39. Late Paleozoic/early Mesozoic sea-floor spreading of Pangaea, which separated North America from South America and Africa, creating the Gulf and Caribbean basins. *From* Walper and Rowett, 1972, GCAGS Trans., v. 22, p. 112, used with permission.

Others have interpreted the Gulf Basin as the result of north-south extension and left-lateral shear between North and South America as those continents separated from Africa.

The most widely accepted theory for the formation of the present Gulf Basin is that it was probably part of a continental landmass until Late Triassic time when widespread rifting split the North American Plate from the South American Plate (Fig. 40A). This rifting formed a complex system of grabens, the orientation of which was related to old structural trends in the Appalachian and Ouachita Mountains, though the fault system may also be independent of older structures outside the basin (Fig. 40B). According to this theory the entire graben system formed in Triassic time, but downfaulting ended first in the more northern grabens, progressively shifting southward as the basin subsided to the south. Locally derived sediments from the north and west, represented by the Eagle Mills Formation, were deposited in the grabens under arid conditions (Fig. 40C). In addition, igneous activity accompanied the downfaulting and formation of diabase dikes and sills are presently recognized in the Eagle Mills section (Rainwater, 1968). Dip sections drawn along the northern limit of the Gulf Basin illustrate the deposition associated with the complex block faulting (Plates I-III). The Eagle Mills, Werner, and Louann sediments were best developed in these buried graben systems. Cross sections A-A′ (Plate I) and CC′ (Plate II) indicate thick sections of Eagle Mills as do the Humble 1-Calfee, Shell 1-Koppers, and Anadarko 1-Bellieu wells. The sections also show the great thicknesses associated with the Interior Gulf Basin, the updip limits of which closely coincide with the subcrop of the Eagle Mills rocks.

The environment of deposition of Eagle Mills red beds was, for the most part, unfavorable for the generation and preservation of organic material. However, there may have been rift valley lakes where petroleum source material was deposited (Rainwater, 1968). Though no significant occurrence of hydrocarbons has been found in the Eagle Mills to date, recent drilling in northeastern Texas and northern Louisiana report non-commercial gas shows in the Eagle Mills section. The Hilliard No. 1 Pruitt, Marion County, Texas, found shows of gas in an Eagle Mills sequence that was over 1600 ft thick.

In Early or Middle Jurassic time an arm of the sea extended across the newly formed Gulf Basin (Fig. 40D). The Jurassic section is composed of evaporites (anhydrite and salt), carbonates, and clastics deposited in restricted marine, shallow-marine, deltaic, and continental environments (Fig. 37).

After deposition of the Eagle Mills Formation the breakup of Pangaea continued, with further separation of the Afro-South American Plate from North America. The grabens that formed in the early stages of continental rifting began to develop into a subsiding basin (Fig. 41). A topographic ridge developed along the retreating plate margin, which became an effective barrier to free circulation of sea water to the submerged area lying landward from it (Fig.42). This low lying area became the evaporite basin where the Werner anhydrite and Louann salt were deposited (Wood and Walper, 1974, p. 39).

The Eagle Mills Formation is an Upper Triassic continental red bed sequence resting unconformably upon weathered Paleozoic sediments. The age of the Eagle Mills Formation was not accurately determined until 1961 when Scott and others, identified plant macrofossils of Late Triassic age from cores in the Humble, 1-Royston well in southwest Arkansas. This age was later confirmed by radiometric dating of diabasic igneous rocks in the Eagle Mills section, which formed between 180 and 200 million years ago (Baldwin and Adams, 1971). Thus Eagle Mills Formation cannot be younger than the intrusions and most probably represents deposition during Late Triassic time. Upper Triassic palynmorphs were found in the Eagle Mills shales and silts in pre-Jurassic tests in Falls (Cockburn, 1-Buie) and Gonzales Counties,

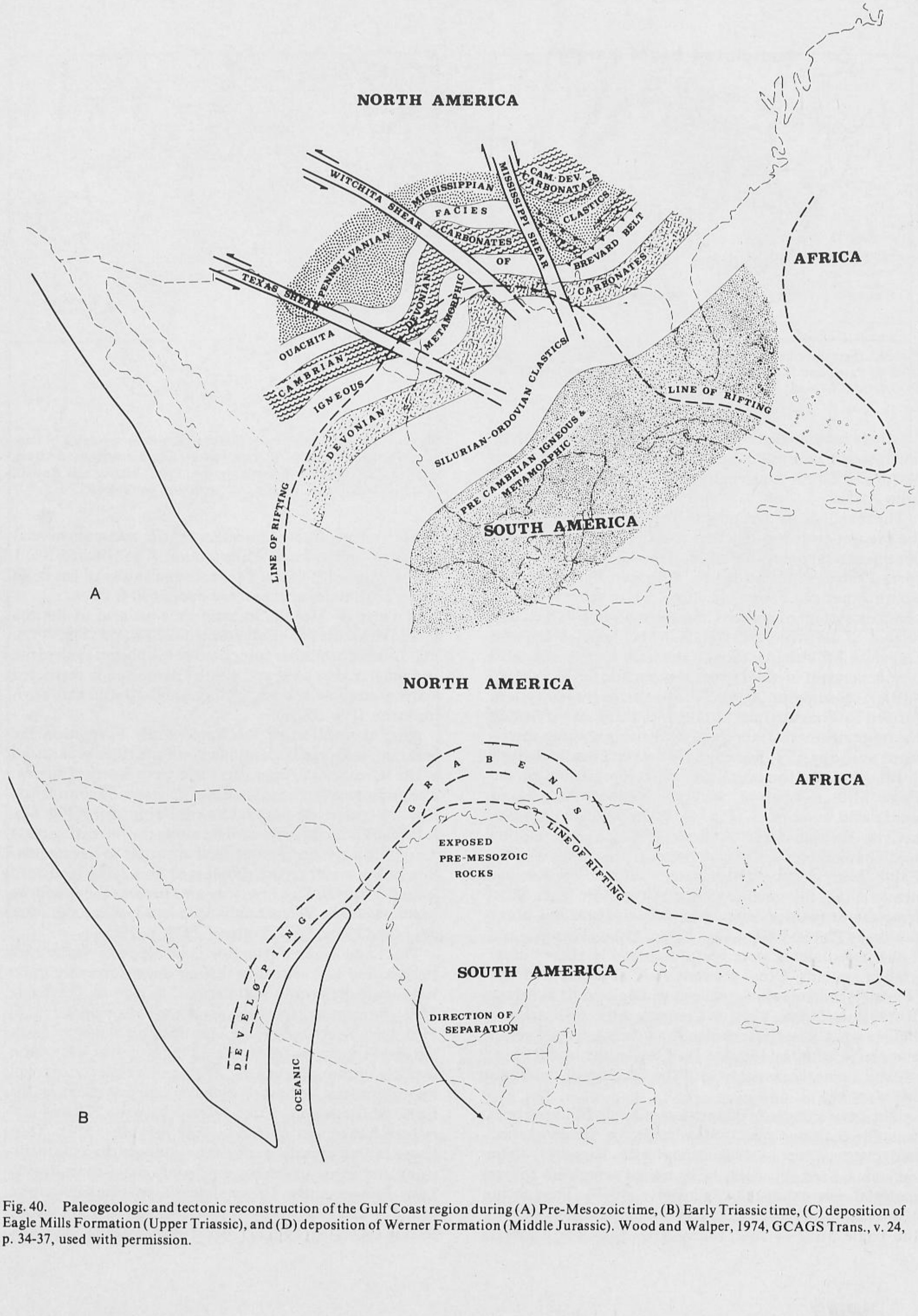
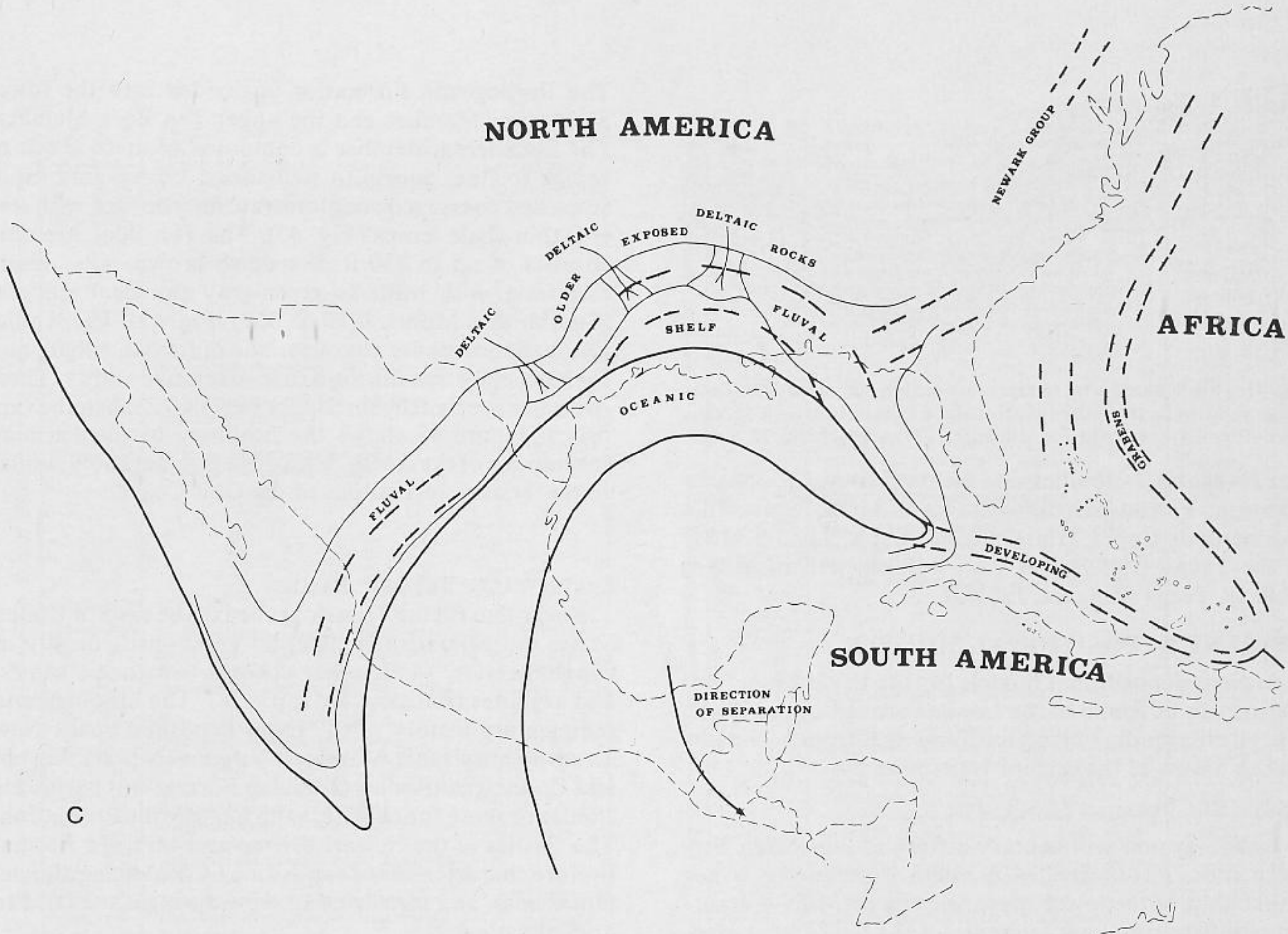


Fig. 40. Paleogeologic and tectonic reconstruction of the Gulf Coast region during (A) Pre-Mesozoic time, (B) Early Triassic time, (C) deposition of Eagle Mills Formation (Upper Triassic), and (D) deposition of Werner Formation (Middle Jurassic). Wood and Walper, 1974, GCAGS Trans., v. 24, p. 34-37, used with permission.


NORTH AMERICA
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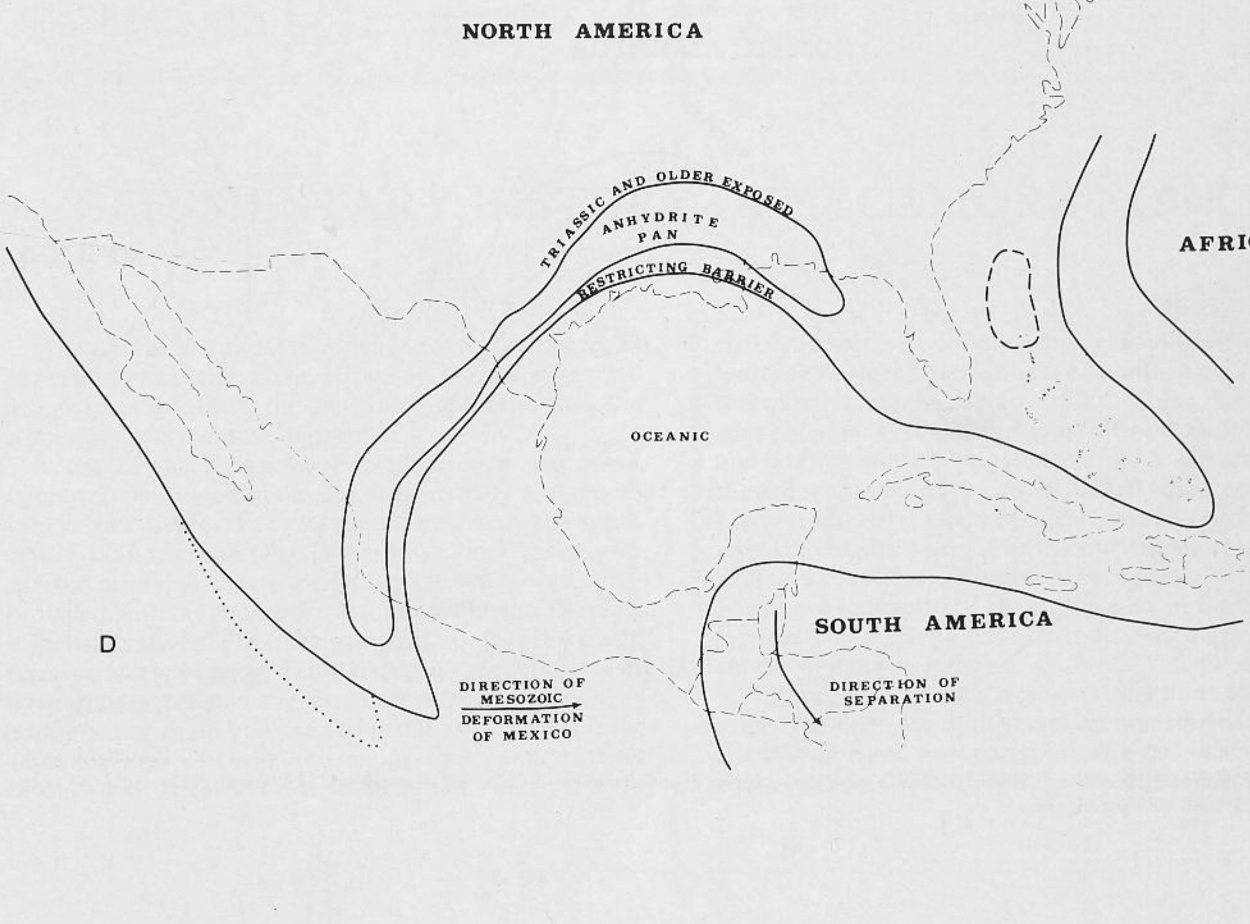
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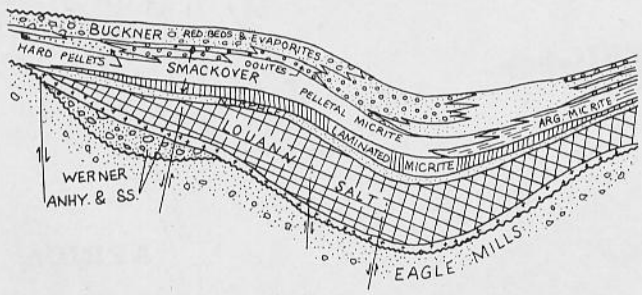

Fig. 41. Generalized west to east cross-section across the East Texas basin, showing formational units from Late Triassic to Middle Jurassic time. *Adapted from* Todd and Mitchum, 1977, AAPG Mem. 26, p. 151.

Texas (Mobil, 1-Bundick and Henry Kelsey, 1-Cook). In addition, Exxon palynologists have dated Eagle Mills sediments as Upper Triassic from cores at 9,685-9,975 ft in the Texas Gulf Sulfur Co., 1-Baker well in Milam County, Texas (Zingula, 1981).

ANCIENT DEPOSITIONAL MODELS

Ancient depositional models for the Eagle Mills Formation can be found in the Lower Permian of the North Sea (Rotliegende Formation) and the Upper Triassic graben basins of the eastern United States.

North Sea Permian Sequence

Lithology and sedimentary history of North Sea Permian rocks (Rotliegende-Zechstein Formations) is not unlike that of the lower Mesozoic (Eagle Mills-Werner-Louann) stratigraphic sequence of the Gulf Coast area. The Rotliegende Formation is divided into the lower Slochteren Member and the upper Ten Boer Member. The Slochteren Member is composed of up to 600 ft of coarse to fine, poorly to well-sorted brown-gray sandstone and coarse red conglomerate interbedded with several thin shale lenses (Fig. 43). The Ten Boer Member consists of up to 250 ft of reddish-brown, silty, sandy claystone, with white to green-gray anhydrite nodules (Stauble and Milius, 1970, p. 359) (Fig. 43). The Rotliegende sediments are characteristic of fluvial, eolian, and sabkha deposition during a time of relative aridity. These rocks are overlain by the Upper Permian Zechstein evaporites. Figure 43 shows the lithology of the Permian formations of the North Sea, which is remarkably similar to the Triassic formations of the Gulf Coast.

Eastern U.S. Triassic Basins

Rocks that fill the Triassic graben of the eastern United States are primarily continental and consist mostly of conglomerates, sandstones, arkoses, siltstones, shales, and argillites (Eardley, 1951, p. 128). The lithology and sedimentary history of the rocks deposited in the New Jersey-Pennsylvania-Maryland-Virginia (Newark Group) and Connecticut Valley (Meriden Formation) basins are similar to those found within the Eagle Mills Formation. The clastics of the Newark Group and Meriden Formation are characteristic of deposition by coalescing alluvial fan, fluvial, and lacustrine systems during a semiarid to arid climatic era.

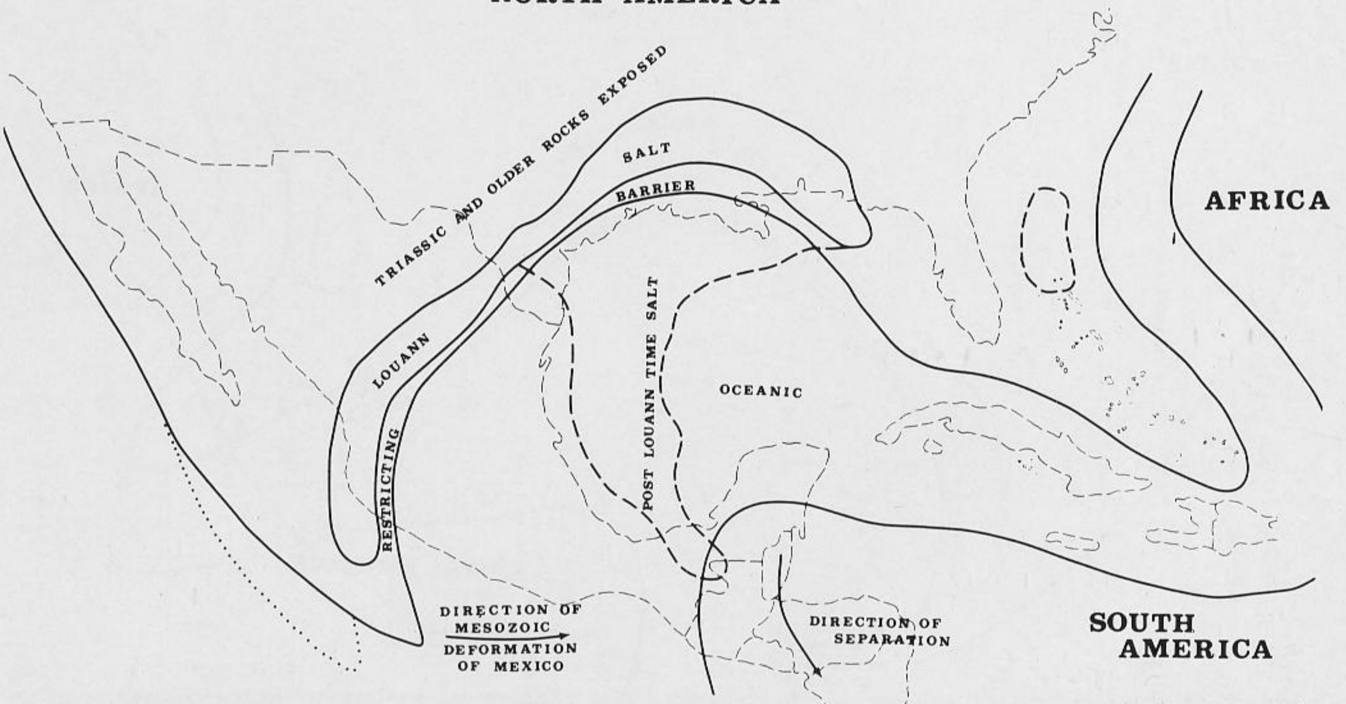

Fig. 42. Paleogeologic reconstruction of the Gulf Coast region during deposition of the Louann salt. *From* Wood and Walper, 1974, GCAGC Trans., v. 24, p. 39, used with permission.

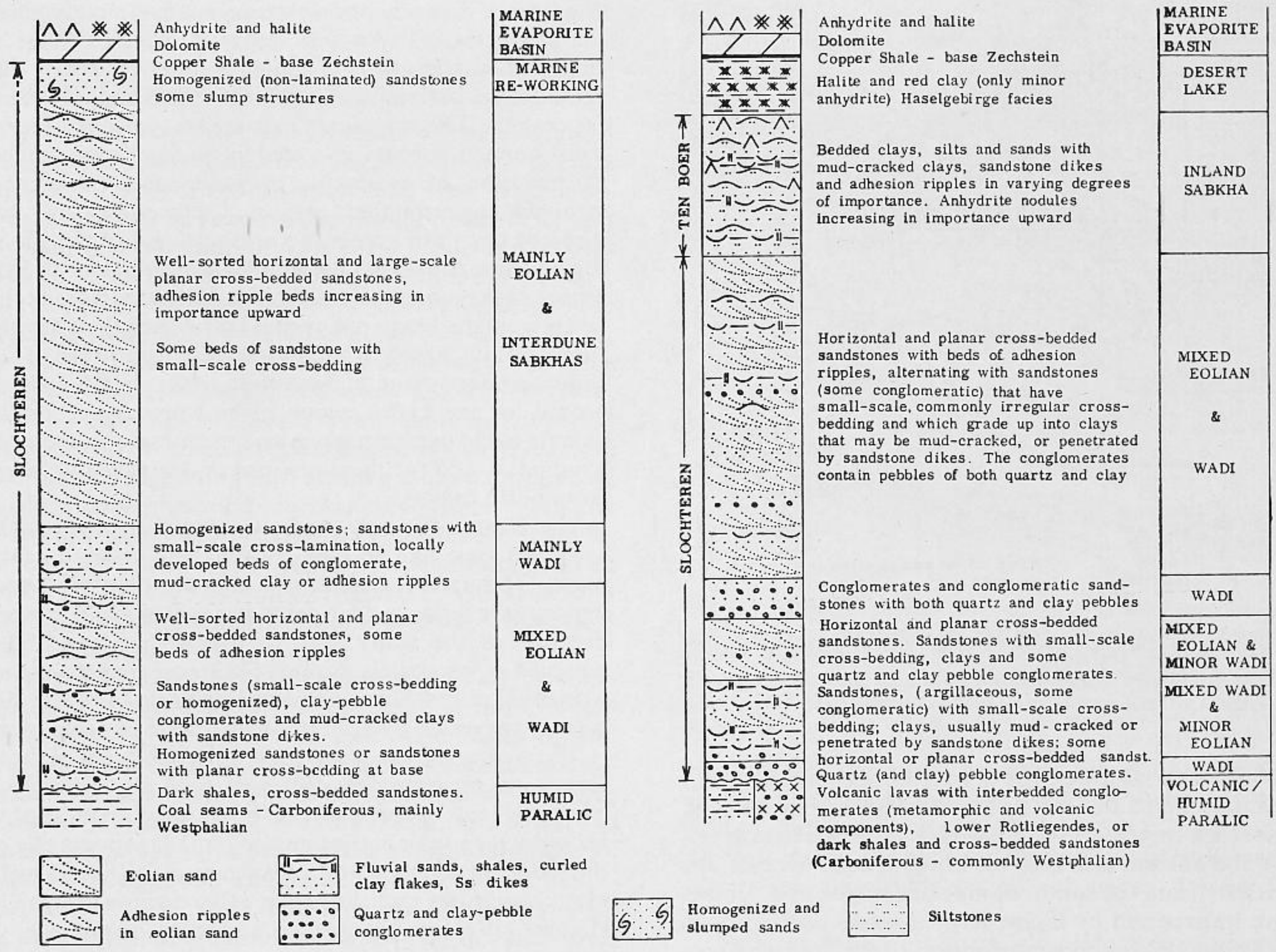

Fig. 43. Facies development of the upper Rotliegendes in northwest Europe. *After* Glennie, 1972, AAPG Bull. v. 56, no. 6, p. 1055. Used with permission.

SEDIMENTARY HISTORY OF SYCAMORE ROCKS

Much of the historical significance of Sycamore rocks has already been discussed. However, here an effort will be made to establish the sequence, processes and the continuity of Sycamore deposition.

Rocks of the Sycamore Formation were deposited upon an erosional surface characterized by a series of valleys and divides that extended north, east, and south of the Llano region (Fig. 44). Thus, the Llano Uplift exerted principal control on Sycamore deposition, for it provided both the source of water and sediments. While it is generally thought that the principal uplift of the Llano region occurred during Pennsylvanian time, evidence of Sycamore deposition suggests that this uplift may have continued or again become active in Early Triassic time. Thus the area of the Llano region underwent erosion throughout Triassic time. Distribution of Sycamore rocks appears to follow closely southwest-northeast trending Paleozoic fault blocks extending northward and eastward from the Llano Uplift. These fault trends roughly parallel the buried Ouachita Foldbelt (Fig. 44), and faulting may be related in age to that tectonic feature though it appears most closely related to the uplift of the Llano itself. After creation of these fault structures, erosion carved the shale-filled blocks into a sequence of subparallel valleys, which were then partially filled with Sycamore sediments. Thus the clastics of the Sycamore Formation appear to have been deposited upon an erosional surface consisting of fault valleys extending radially from the Llano region. Along these valleys, the gravels of the Sycamore conglomerate originated in the Llano region and were transported to their place of deposition (Damon, 1940, p. 88). On the divides that separated

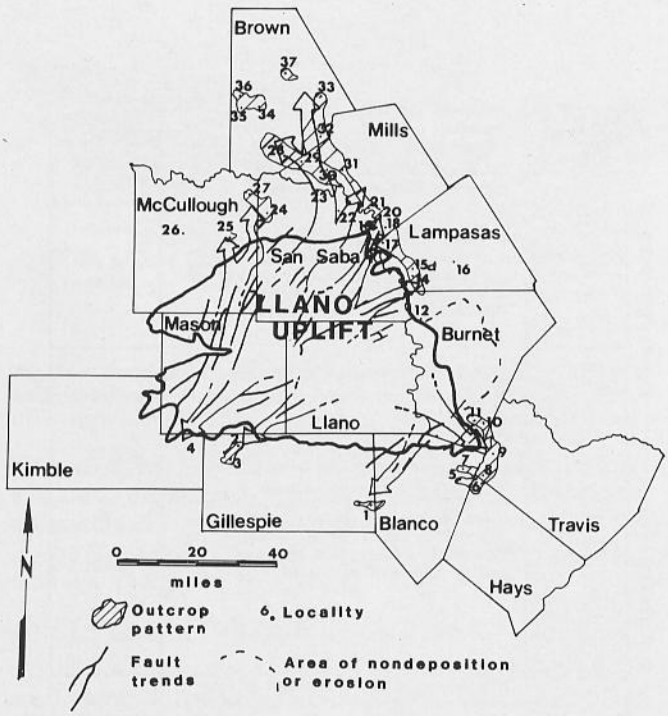

Fig. 44. Map of Llano Uplift region showing probable transport of Sycamore rocks along major fault valleys.

the valleys. Sycamore clastics were not deposited. When the Llano Uplift attained sufficient height during Triassic time, rock fragments were transported down stream valleys and alluvial fans into the lower area to the east, the northeast, and the south. Boulders, cobbles, and pebbles were transported by high-energy streams issuing from the Llano Uplift and were dumped in the proximal portions of alluvial fans as sieve deposits. Such deposits are characteristic of source areas composed primarily of coarse materials, much like that of the Llano region. Sieve deposits occur when water infiltrates debris lobes formed when the water can no longer transport material. As the water passes through the debris lobes, the fine material is carried off, leaving behind poorly sorted gravels and sandstone (Hooke, 1967, p. 454).

The climate at the time of Sycamore deposition appears to have been semiarid to arid, differing from the more humid climate suggested by the character of the overlying Cretaceous deposits, which are typically those of mixed-load streams together with clean marginal marine sands and shales. Alluvial fans are characterized by intermittent surge flow and give rise to structureless sedimentary blankets where the entire bed load is deposited simultaneously. In arid to semi-arid climates an increase in rainfall will increase sediment yield. In semiarid regions during Sycamore deposition, violent flood transport of Sycamore sediments apparently took place, though the flow was normal for transporting agents responsible for the development of wadi channels and wadi fans. Evidence for high stream velocities during Sycamore time is found in the dominance of plane bedding and low-angle cross-beds in the deposits. These bedding types require transitional and upper flow regime conditions. The semiarid to arid climate is suggested by the character of Sycamore deposits, which consist of thick structureless beds of conglomerate overlain by thin sand drapes indicative of individual torrential sedimentary events. The conglomerate consists typically of large well-rounded cobbles in a matrix of sand and caliche. Distribution of sediments in sedimentary structures strongly suggests that earliest Cretaceous flow was directed eastward across the northern end of the Llano region while lithology and sedimentary character of Sycamore rocks indicate that they are derived almost exclusively from the Llano region and that during their deposition the flow direction was principally northward. Thus following deposition of Sycamore rocks, sufficient time passed for the Llano region to be worn away, for the climate to change from warm arid to more tropical humid conditions, and for the directions of drainage to change from north to east.

Therefore, following deposition of Sycamore rocks sufficient time had to pass for all these events to take place. This fact also strongly suggests that Sycamore deposits are far older than the oldest typically Cretaceous deposits in the study area to which they have been assigned. Correlation of the Sycamore conglomerate with the Dockum Group, Bissett and Eagle Mills Formations is suggested by a common character of deposition.

The sedimentary history of the overlying Trinity Group as suggested by sediment type and formation geometry was a product of a complex relationship between such variables as physiography, topography of the sedimentary platform, subsidence rates, possible climatic variations and the influx of terrigenous sediment (Dreyer, 1971, p. 47). At the beginning of Cretaceous time the Llano Uplift had been worn down by erosion to such an elevation that it contributed little sediment to the earliest Cretaceous streams. Low-to-medium energy streams, which originated far west of the Llano Uplift, transported sands and pebbles and deposited them in fluvial sequences, including braided stream and point-bar deposits in which cross-bedding is emphasized by pebbles of chert and quartz (Whigham, 1978, p. 65) (Fig. 17). These streams ended in deltas on the east where they met the transgressing earliest Comanchean sea. As the sea continued to transgress eastward, the fluvial deltaic deposits were reworked and overlain by more marine shales and limestones of the Glen Rose Formation. The slow fluctuating advance of the sea continued throughout Fredericksburg time, and the Llano Uplift was finally covered during Edwards time (Upper Comanchean).

SUGGESTED DEPOSITIONAL MODELS FOR SYCAMORE SEDIMENTATION

Evidence suggests that the Sycamore conglomerates were deposited by alluvial fan and ephemeral (wadi) stream systems. The wadi type channel-fill deposits formed nearest the Llano Uplift, while the alluvial fan deposits formed in the distal portions. Therefore ancient and modern models for Sycamore deposition are those characteristic of semiarid climates, typically those of alluvial fans and ephemeral (wadi) streams.

Ancient Depositional Models

There are many ancient examples of coarse-grained terrigenous clastic facies interpreted as alluvial fan and ephemeral stream deposits. Some of these ancient sequences are: 1) the Precambrian Hazel Formation of west Texas, 2) the Cambrian Van Horn sandstone of west Texas, 3) the Devonian Old Red Sandstone of Norway, 4) the Permian Rotliegende of northwest Europe, 5) the Triassic Eagle Mills Formation in the Gulf Coast Basin, and 6) the Triassic Mount Toby Formation of northern Massachusetts (McGowen, Galloway, and Kreitler, 1978, p. 50). These ancient deposits are similar in rock type and structure to the conglomeratic deposits of the Sycamore Formation suggesting that all such deposits originated under similar climatic and tectonic conditions by swiftly flowing streams and alluvial fans. Two of these stratigraphic sequences, the Mount Toby conglomerate and the Van Horn sandstone, best typify terrigenous clastic facies and serve as useful ancient depositional models for Sycamore sedimentation.

The Van Horn sandstone was deposited by high-gradient, short-duration, high-energy streams, which transported gravel, sand and lesser amounts of silt and clay through steeply dissected canyons onto an alluvial plain (McGowen and Groat, 1971, p. 8). The Van Horn alluvial fan consists of proximal, mid, and distal fan facies (Fig. 45). The proximal fan consists mostly of well-rounded cobble and boulder conglomeratic deposits, similar to those of the Sycamore Formation. Both gravel and sand accumulated in the mid-fan area while the distal fan consists primarily of coarse to very coarse sand. These coarse conglomerates, which probably represent surge deposits, grade vertically and laterally into alternating conglomerate and thin sandstone beds. The sandstone developed as thin sheets overlying the conglomeratic beds, representing waning stages of current flow (McGowen, Galloway, and Kreitler, 1978, p. 52). Sandstone drapes similar to these are found in the Sycamore Formation at locality 25 (Elliot Creek). Although the Van Horn Formation has been classified as a "wet" alluvial fan (McGowen, Galloway, and Kreitler, 1978, p. 50), the sedimentary processes involved were not unlike those which deposited the Sycamore conglomerate.

The second ancient depositional model is the Mount Toby conglomerate of Triassic age, which crops out in northern Massachusetts where it is part of a continental sequence of fan conglomerate, fluvial sandstone, mudstone, and lake sediments occupying a fault valley flanked by higher areas of metamorphosed Paleozoic rock. The Mount Toby conglomerate consists of fine to coarse sandstone with tongues of poorly sorted pebble to boulder conglomerate. The conglomerates become coarser and thicker toward the higher source areas to the west. The regional paleogeography is one of coalescing alluvial fans spreading westward from a major border fault. The coarseness of the sediment of the Mount Toby conglomerate argues for swift, probably intermittent streams flowing down steep grades in what was probably a semi-arid to arid climate (Hand, 1969, p. 1311). The structure of the Mount Toby conglomerate is predominantly planar bedding characteristic of upper flow regime conditions.

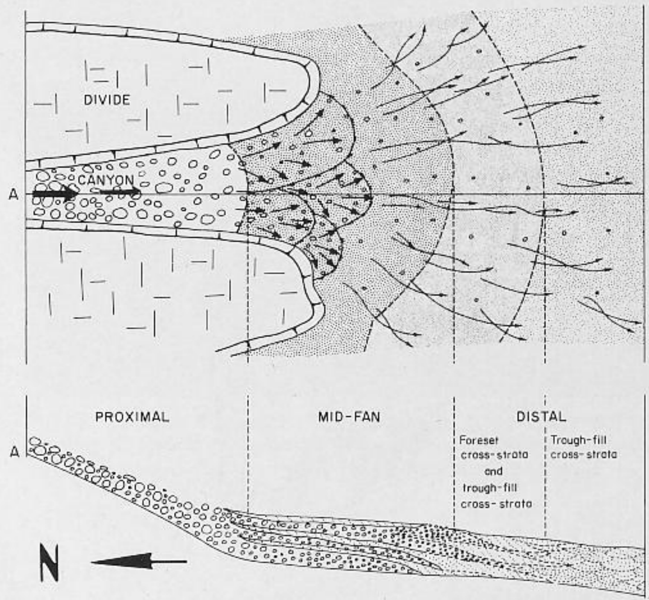

Fig. 45. Schematic plan and cross-section of the Van Horn alluvial fan system showing the general succession of stratification types from the coarse, massive gravels of the proximal fan facies to the trough and foreset cross-bedded sand of the distal fan facies. *From* McGowen and Groat, 1971, Texas Bureau of Economic Geology Rept. of Invest. 72, p. 8, 39.

Both the Mount Toby and Van Horn conglomerates are similar in composition and structure to the Sycamore conglomerate, and therefore deposition probably occurred under similar environmental and tectonic conditions.

Modern Depositional Models

Alluvial fan deposits tend to be poorly sorted coarse-grained sediments composed primarily of gravel cobblestones and boulders and are most common where coarse detrital material is most abundant (Reineck and Singh, 1970, p. 234). Alluvial fans are the product of sporadic, high energy, short duration depositional events (McGowen et al., 1978, p. 44). The Gorak Shep fan of the desert region of central California (Eureka Valley) is an example of an alluvial fan with sediments similar to those of the Sycamore Formation. Deposits of the Gorak Shep fan consist of pebble to cobble-sized gravel, with little or no fine material. The source area of the Gorak Shep fan is underlain by a thick section of resistant carbonate rocks, principally dolomite (Hooke, 1967, p. 455).

Deposition occurs mainly in sieve lobes, formed when water is unable to effect further transport (Hooke, 1967, p. 454). Figure 46 shows the distribution of the sieve deposits on the Gorak Shep fan. This distribution of sediment types may explain the diversity and discontinuous nature of Sycamore rocks from outcrop to outcrop.

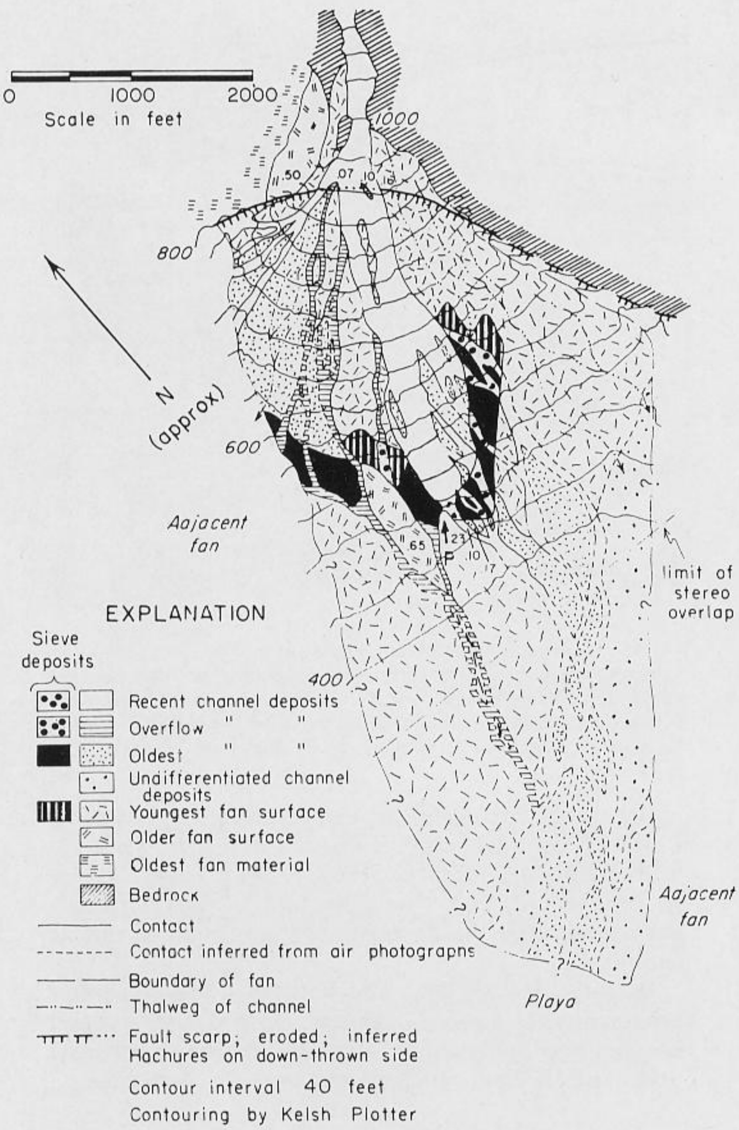

Fig. 46. Map of Gorak Shep alluvial fan, Eureka Valley region, southern California. Note the area of active sieve deposition. *From* Hooke, 1967, Journal of Geology, v. 75, no. 4, p. 442, used with permission.

A second possible modern model may be seen at the base of the Upper Pleistocene sequence in Nubia (Egypt) where the Wadi Or, a large Nubian tributary, enters the Nile on the east bank. The Wadi Or is usually a dry ravine except during rainy seasons. In hilly areas where occasional torrential rain falls, wadis become flooded and the flowing water can transport considerable amounts of sediments for short periods of time. Deposits within the wadi channels are mostly conglomeratic and fanglomeratic (Glennie, 1970, p. 29-34). Deposits found at the Wadi Or are coarse pebble to cobble-grade gravels of ferruginated sandstone, with a white to pink matrix of calcreted coarse sand (Butzer, 1968, p. 283).

Caliche, common in many wadi deposits, while not in itself an indicator of semiarid climates nevertheless is most common in semiarid to arid regions. Caliche, a calcareous formation of considerable thickness and volume, is found a few inches below the surface soil, upon the broad, dry gravelly plains, mesas and alluvial fans. While the processes of formation of caliche are not yet clearly understood, it occurs most commonly within the K horizon (horizon of carbonate accumulation) of the soil profile and is formed as a product of soil-water geochemistry. In a gravelly sequence of caliche development, the first stages are characterized by thin discontinuous pebble coatings ($CaCO_3$) and interpebble fillings. In the later stages there are many interpebble fillings, and eventually the plugging of the horizon with overlying horizontal $CaCO_3$ laminae (Rightmire, 1967, p. 5). The origin and climatic significance of caliche is a point of much debate upon which most authors agree in general but for which details are uncertain. The overall concensus is that caliche signifies a semiarid climate where average evaporation exceeds average precipitation (Mikels, 1976, p. 12). The existence of thick massive caliches is of considerable paleoenvironmental interest and, while some argument may exist concerning exact climatic implications, it is almost universally agreed that such caliches represent near-surface accumulations during prolonged areal exposure (Amsbury, 1967, p. 4; Dunham, 1972; Reeves, 1976, p. 5). Regardless of the mechanism of caliche formation, its common association with semiarid deposits makes the occurrence of widespread caliches both at the base and at the top of the Sycamore conglomerate strongly suggestive of semiarid land deposition. Amsbury (1967, p. 4) found evidence of ancient caliches in Lower Cretaceous and Sycamore rocks of central Texas. The caliches are best developed in the upper portions of depositional sequences, below unconformities. At the Nix Cemetery and Elliot Creek localities there are extensive caliche zones above the Sycamore conglomerate (Fig. 47) where caliche sections have asymmetrical profiles with sharp tops and gradational bases. Thus, the most acceptable modern models for Sycamore deposition are those typical of semiarid lands: wadi streams and alluvial fans. From this evidence it appears that clastics of the Sycamore Formation were deposited in stream valleys and fans extending from the mountain uplands of the Llano Uplift. Intermittent streams flowed from what may have been a pre-Sycamore pediment surface extending from the mountain toe northwestward to the basins of accumulation of the Dockum Group. Over this pediment surface Sycamore sediments were transported and deposited in shallow channels and fans separated by indistinct divides.

Following deposition of Sycamore sediments there appears to have been a reversal of the topography in many parts of the region. The valley fills armored by caliche-cemented Sycamore conglomerate were more resistant to erosion than the softer inter-stream divides. Thus the stream divides were worn away at a quicker rate leaving the once lower, valley-fill deposits as caps of small hills. Present day outcrops of the Sycamore conglomerate in Mills, McCulloch, and San Saba Counties occur on ridges and hills where the conglomerate forms a relatively smooth surface and a gently rolling topography (Fig. 48).

Fig. 47. Extensive caliche zone developed in the upper portions of the Sycamore conglomerate in Lampasas County.

Fig. 48. Locality 19. Overall view of the gently rolling topography and flat upland surfaces characteristic of the present day Sycamore Formation. Sycamore rocks are exposed in the roadcut on the right.

SEDIMENTARY HISTORY OF DOCKUM ROCKS

The Dockum Group is composed of a complex suite of continental clastic sediments deposited in a broad shallow fluvial-lacustrine basin extending across most of west Texas. The Dockum Group includes sediments that range through the entire sequence of continental clastic deposition from braided to meandering streams, alluvial fans, constructive lobate deltas, fan deltas and lakes (McGowen et al., 1979, p. 16).

The sedimentary history of the Dockum Group is extremely complex and interpretations pertaining to the depositional environments vary widely. Presently, there exist two contrasting environmental interpretations.

Kiatta (1960, p. 12) and Cazeau (1962, p. 81) believed that the poorly bedded clays and silts of the Tecovas Formation were essentially flood plain and meandering stream deposits whereas the overlying Trujillo sands and shales are characteristic of braided stream channel deposits.

On the other hand, McGowen and others (1979, p. 16) analyzed the sedimentary history of the Dockum Group in terms of genetic facies that compose depositional systems. They concluded that the Tecovas Formation is characteristic of ephemeral stream, fan-delta and lacustrine deposition (low-stand depositional systems) whereas the Trujillo Formation represents deposition by meandering stream and prograding lobate delta systems (high-stand depositional systems).

The method and interpretations established by McGowen and others (1979, p. 16) have proven to be of most use to this study and confirm field observations made of Dockum outcrops throughout the area of investigation.

TECOVAS FORMATION

The Tecovas Formation consists essentially of poorly bedded clays and silts with lenticular sandstone and conglomeratic lenses. The fine material accumulated in small ephemeral lakes. The lacustrine sediments are characteristic of a slow continuous form of sedimentation: an environment beneficial to the emplacement and preservation of fossil remains. Thus the Dockum Group contains faunal and floral assemblages representative of lacustrine deposits. The faunal assemblages and plant associations suggest an environment in which one or more streams emptied into lakes or ponds (Green, 1954, p. 92). Vertebrate fossil remains include bones and teeth of reptiles (mostly Phytosaurs) and amphibian (labyrinthodonts) as well as some fish scales and teeth. Invertebrate remains include those of the mollusk *Unio*, a fresh water bivalve, also characteristic of lake environments. Outcrops of laminated siltstone and fine sandstone of the Tecovas Formation exposed along the eastern edge of the Caprock Escarpment contain thin layers of light-green clay and sparry gypsum characteristic of lacustrine deposition. The presence of banded clay and some fine-grained limestone masses indicates deposition in quiet undisturbed waters (Green, 1954, p. 20). In addition, the muds and silts are interbedded with lenticular sands and conglomerates believed to have been associated with fan delta systems. These sand and conglomeratic lenses are probably indicative of the waxing and waning stages of stream deposition when stream channels became deeply incised then rapidly filled with detrital material.

TRUJILLO FORMATION

The Trujillo Formation consists predominantly of discontinous lenticular sandstones and intraformational conglomerates interbedded with red mudstone and siltstone. The sediments are characteristic of prograding delta and meandering fluvial systems. The sand and conglomerate lenses are highly variable in thickness and

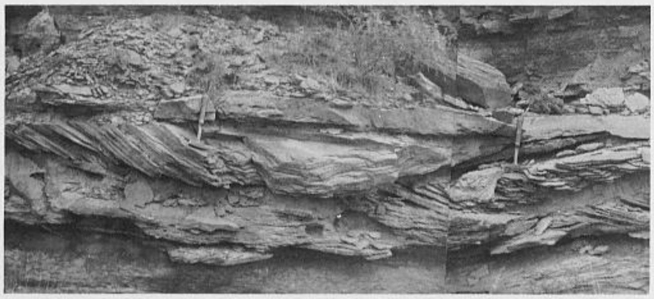

Fig. 49. Locality 5. Distributary channel-fill, dissected in lenticular cross-bedded sandstone pods.

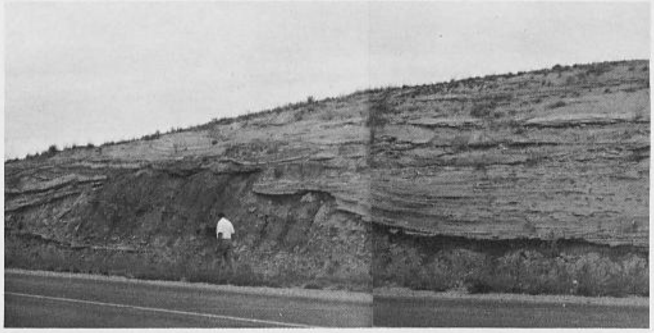

Fig. 50. Locality 5. Well developed cut-and-fill structure characteristic of fluvial Dockum sedimentation can be seen at Locality 5 where large channels of cross-bedded sand have cut into the surrounding mudstone and siltstone deposits.

horizontal extent, are commonly cross-bedded, and exhibit well developed cut-and-fill structures. Most of the outcrops reveal the lenticular nature, cross-bedding and scouring of the Trujillo sediments. Many of the filled channel deposits have clay- and sand-pebble conglomeratic lenses at their bases (Fig. 33), while other channels were dissected into lenticular crossbedded sandstone pods before being filled (Fig. 49). Characteristic Trujillo deposits are shown in Figure 50 (locality 5) where highly cross-bedded channel-fill sands have cut into red mud and siltstone layers.

DEPOSITIONAL SYSTEMS

The depositional environment for Dockum rocks can be analyzed in terms of depositional systems, under the influence of base-level oscillations (McGowen et al., 1979, p. 16). Dockum sedimentation was influenced greatly by rifting associated with the opening of the Gulf of Mexico, which probably caused 1) a change in climate, 2) subsidence of the Dockum Basin, and 3) an uplift in part of the Ouachita Tectonic Belt. McGowen and others (ibid.) noted that:

> with a slight increase in precipitation Permian sabkha environments were replaced by expanding lacustrine and fluvial-deltaic environments.

Late Triassic time in west Texas was characterized by alternating pluvial and arid conditions, which caused the lake area and depth to fluctuate. Lake level was highest and most stable during wet periods, when water depths reached about 30 ft.

High Stand Depositional Systems

The high-stand facies systems, characterized by meandering streams and high constructive lobate delta systems, developed when climatic conditions were more humid and lake areas and level were at their maximum (McGowen et al., 1979, p. 16) (Fig. 51A). The high-stand sediments are composed of a basal prograding, upward coarsening deltaic sequence of mudstone and sandstone overlain by an upward fining, meandering fluvial sequence of thick sandstone and conglomerate. Figure 26 shows a section of red mudstone and siltstone interbedded with thin sandstone layers overlain by more thickly bedded sandstone. This exposure is probably characteristic of lacustrine type deposition overlain by a prograding deltaic sequence. The thickly bedded sandstone developed at the top of the outcrop may represent a distributary channel fill. Large sigmoidal foreset cross-strata shown in Figure 34 are characteristic of the basal part of a distributary channel fill sequence.

Low Stand Depositional Systems

With a shift toward arid conditions, base level dropped, lake size decreased, and valleys were scoured. Local braided streams became the dominant type of fluvial system replacing most of the meandering streams (McGowen et al., 1979, p. 4). Low-stand deposits included lacustrine, fan delta, ephemeral streams, and interdeltaic mudflat systems (Fig. 51B). These are primarily the products of sporadic, high-intensity, short-duration depositional events (McGowen et al., 1979, p. 23). The fan deltas formed along the margins of ephemeral lakes and were fed by high-gradient headward-eroding braided streams. Many older Dockum deposits were scoured by these streams forming numerous valleys, which were then filled by a complex sequence of sediments ranging in texture from mudstone to cobble conglomerate (ibid., p. 31). These intrabasinal sediments were the major constituents of fan-delta depositional systems deposited in the delta-forset and delta-platform facies. The cross-stratified intrabasinal conglomerates and sandstones shown in Figure 33 (locality 5) probably represent sedimentation in a feeder channel for a small fan-delta system. The lake sediments probably accumulated by the settling of suspended particles and by bottom currents.

Sedimentation characteristic of both depositional systems can be seen at Palo Duro Canyon where fan-delta and lacustrine deposits of the Tecovas Formation (low stand) are overlain by prograding deltaic deposits characteristic of the Trujillo Formation (high stand) (Fig. 35). During drier periods, base level was lowered and many of the Trujillo deltaic sediments were removed by erosion to form valleys, which were later filled when base level rose because of accumulating fluvial, deltaic, and lacustrine deposition.

SEDIMENTARY HISTORY

Lower and Middle Triassic sediments are not recorded

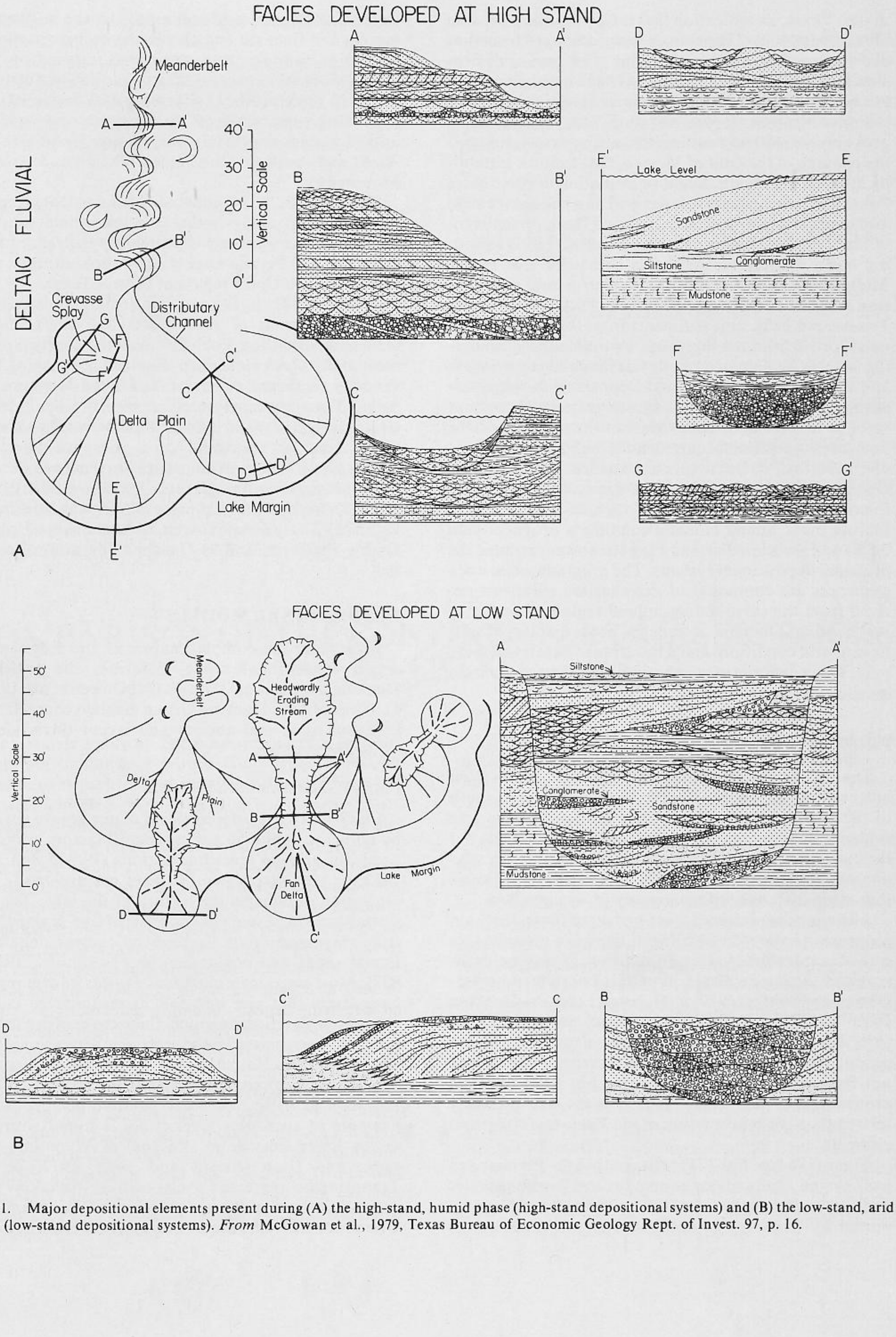

Fig. 51. Major depositional elements present during (A) the high-stand, humid phase (high-stand depositional systems) and (B) the low-stand, arid phase (low-stand depositional systems). *From* McGowan et al., 1979, Texas Bureau of Economic Geology Rept. of Invest. 97, p. 16.

in west Texas, an indication that this time period was one of relative stability. The climate was unchanged from that of Permian time, remaining for the most part arid. Erosion of Permian evaporites and red beds was widespread, but no significant deposition occurred within the area of this investigation. It was not until Late Triassic time, probably as a direct result of the rifting associated with the opening of the Gulf of Mexico, that tectonic instability affected the region. Slight rejuvenation of some older Paleozoic structural features as well as a change from an arid to more semiarid climate initiated Dockum sedimentation. These sediments were deposited in a gently subsiding basin roughly coinciding in area with that of the Midland Basin of Permian age. This structural rejuvenation resulted in increased erosion of Permian and older Triassic red beds, and sediments from this erosion were transported from the highlands by braided to meandering streams, which formed alluvial fans and constructive and destructive delta systems. Deposition during alternating pluvial and arid conditions existed throughout most of Late Triassic time. Most of the rainfall and the dominant vegetation occurred in the highlands to the east and southeast, decreasing in abundance westward (McGowen et al., 1979, p. 4). Lake area and water depth fluctuated with changes in climate and sedimentation. During more humid climatic conditions progadational deltas and associated meandering streams constituted the principal depositional systems. The progradational delta sequences are composed of extrabasinal sediments derived from the surrounding upland regions. Erosion of neighboring Dockum sediments accompanied a shift toward arid conditions and a lowering of base level (ibid., p. 1). These deposits of intrabasinal sediments range from mudstone to conglomerate.

PROVENANCE AREA

The Dockum sediments were derived chiefly from older sedimentary rocks lying to the east, west, and south of the basin (Fig. 4). Heavy mineral assemblages give evidence of metamorphic and igneous source rocks, but their contribution to the Dockum sediments was relatively minor (Kiatta, 1960, p. 49). This probably indicates that more than one sedimentary cycle was involved.

Although the preferred cross-bed direction in Dockum rocks was to the west-northwest, there is a considerable spread in calculated values. In addition, directional readings and sandstone dispersal patterns described by McGowen and others (1979, p. 4) indicate that the Dockum Basin was peripherally filled. Its seems probable, therefore, that the Dockum sediments were deposited by complex depositional systems, which derived their sediments not from a single localized source but from multiple provenance areas. These source areas are probably related to slight rejuvenation of old Paleozoic structural elements.

Green (1954, p. 170-171) believed that the Permian red beds served as the major source for the Dockum shales and clays. He suggested that the sediment was transported by westerly and southwesterly flowing streams depositing coarser sand and gravel on the northeastern margin and finer silt and clay in the deepest portions of the basin. Multiple provenance areas for the Upper Triassic sediments of west Texas were first postulated by Kiatta in 1960 (p. 50-51). He concluded that most of the depositing streams flowed to the north and west from upland regions in central Texas (Llano Uplift and Bend Arch) and southern Oklahoma (Wichita and Arbuckle Mountains).

Cazeau (1962, p. 74) concluded from paleocurrent and heavy mineral analysis that the immediate source of Dockum rocks was from a sedimentary terrain of Pennsylvanian and Permian age lying to the southeast, probably the Llano Uplift region of central Texas.

Cramer (1973, p. 26) assumed from grain size trends and the presence of vein quartz and chert that the Ouachita-Marathon Fold Belt was the source area for most of the Dockum Group. Figure 4 is a map of Texas showing suggested source areas for the Dockum sediments. The areas represented are mostly relict Paleozoic structural features and indicate that the basin was peripherally filled as the result of a complex mixture of sediments derived from numerous provenances. Included in the provenance areas are the: 1) Llano Uplift, 2) Bend Arch, 3) Wichita and Arbuckle Mountains, 4) Amarillo Uplift, 5) Sierra Grande Arch, 6) Sacramento Uplift, 7) Diablo Platform, and 8) Ouachita-Marathon Tectonic Belt.

DEPOSITIONAL MODELS

Because of the complex nature of the sediments no single depositional model describes the variety of Dockum depositional systems (McGowen et al., 1979, p. 4). However, the Dockum Group displays characteristics common to several ancient and recent fluvial-deltaic-lacustrine systems.

Fluvial-Lacustrine Systems

Fluvial-lacustrine depositional sequences are governed by numerous physical and biological factors best developed during lake level fluctuations (Picard and High, 1972, p. 115). Because most lakes are eventually filled regression dominates the history of the lake. The ideal fluvial-lacustrine sequence consists of fine-grained lacustrine clays and muds overlain by coarser deltaic and fluvial sands and conglomerates (Twenhofel, 1932, p. 827). Most large-scale closed lake systems form regional base levels that rise and fall in response to climatic changes. If significant enough, these changes can produce alternating transgressive and regressive depositional cycles similar to those found within the Dockum Group. A delicate balance exists between erosion and deposition in response to these base-level fluctuations. An ancient example of such base level cycles is found within the Green River Formation (Eocene) of Wyoming, Colorado, and Utah (Picard and High, 1972, p. 134). Transgressive-regressive cycles formed in shallow water areas as the base level and area of Lake Gosiute and Lake Uinta rose and fell. Alternating cycles of channel cutting and filling also occurred on the surrounding floodplain (Picard and High, 1972, p. 134).

Two possible modern depositional models for the Dockum Group are the Omo Delta in Ethiopia and Lake Eyre in Australia (McGowen et al., 1979, p. 47). The Omo Delta, a distributary delta along the shores of Lake Rudolph, is characterized by alternating transgressive and regressive cycles.

Lake Eyre in south Australia, a large shallow basin covering some 3000 mi² is rarely filled with water. Sediment supply is relatively low and the lake margin fluctuates over great distances (Reading, 1978, p. 61). Lake Eyre, like the Dockum Basin, is peripherally filled receiving sediment from more than one provenance.

SEDIMENTARY HISTORY OF THE BISSETT FORMATION

AGE DETERMINATION

Age of the Bissett conglomerate has been subject to much debate, having been classed variously as Upper Permian, Lower to Middle Triassic, and Lower Cretaceous. However, plant and vertebrate remains found within the Bissett Formation by P. B. King and E. H. Sellards strongly suggest a Triassic age. The fossils, studied by Case and Read (King, 1935, p. 1545), both flora and vertebrate species, are typically early Mesozoic types. Thus, the physical and paleontological evidence indicate an Early Triassic (pre-Dockum) age for the Bissett conglomerate (King, 1935, p. 1546).

DEPOSITIONAL ENVIRONMENT

The nature and character of Bissett rocks suggest deposition not unlike that of the Dockum Group and Eagle Mills Formation. The coarse limestone, dolomite, and chert gravels were probably derived from various nearby Permian formations and the Ouachita Tectonic Belt. Furthermore, McGowen and others (1979, p. 8) believed that the Bissett Formation records initial Triassic alluvial fan and fan-delta sedimentation immediately north of the Ouachita Foldbelt.

COMPARISON OF THE CONTINENTAL TRIASSIC ROCKS OF TEXAS

The Triassic rocks of Texas are represented by four distinct but similar rock groups. They are all primarily terrigenous in nature, and many are derived from the same tectonic elements. Therefore, a similarity exists between the lithological character and sedimentary history of these rock types, and a useful paleogeography of Texas during the Middle to Late Triassic Period can be constructed based upon the distribution of these deposits.

The lithologies of the Bissett Formation, Dockum Group, Eagle Mills Formation, and Sycamore conglomerate are much alike. They are clearly of nonmarine origin derived principally from older Paleozoic sedimentary rocks. The rock groups are composed in part or entirely of mudstone, siltstone, medium- to coarse-grained sandstone, and pebble-to-boulder conglomerate (intrabasinal and extrabasinal). Taking into account the diversity of the provenance areas, a unique interrelationship exists among lithologies of the formations. Table 4 lists the four rock groups and their associated characteristics. It illustrates the compatibility of the rock characteristics, particularly between those of the Bissett and Sycamore Formations and the Dockum Group and Eagle Mills Formation. Each of the rock units contains varying amounts of poorly sorted conglomerate and sandstone.

The conglomerates of the Bissett and Sycamore Formations both contain rounded pebbles and cobbles of limestone, dolomite and chert. They are typically homogenous masses with some interbedded sand layers representing waning stages of stream surges (Fig. 20).

Another comparison exists between the lithologies of the Dockum Group and Eagle Mills Formation (Table 4). They are both red-bed clastic sequences composed of interbedded layers of sandstone, siltstone, mudstone and conglomerate. The sandstones range from white to red in color and are locally highly cross-bedded, and in places finely micaceous. The silts and shales of the Eagle Mills Formation and Dockum Group are sometimes mottled with light green clay or mud inclusions indicative of reducing lake conditions.

All of the Triassic coarse sandstones and conglomerates are products of high energy short duration depositional events. The coarse detritus was transported when sporadic heavy rainfall, characteristic of semiarid to arid regions, fell in the surrounding upland regions. The cobble-to-boulder conglomerates of the Bissett and Sycamore Formations were deposited by high-gradient swiftly flowing streams on coalescing alluvial fan systems. These were highly localized deposits accumulating close to their respective source areas.

TABLE 4. THE FOUR TRIASSIC ROCK GROUPS OF TEXAS AND ASSOCIATED CHARACTERISTICS.
(All are Continental Red-bed Sequences Similar in Composition, Texture, and Color)

BISSETT FORMATION	DOCKUM GROUP	SYCAMORE FORMATION	EAGLE MILLS FORMATION
Sandstone red, yellow-brown, fine grained. **Shale** thinly bedded, reddish brown to maroon. **Conglomerate** rounded pebbles and cobbles of limestone and dolomite with minor amounts of quartz, quartzite, and chert in a calcareous sand matrix.	**Sandstone** red, yellow, white, fine to coarse grained, finely micaceous, quartzitic. **Shale** unlithified, variegated, micaceous. **Conglomerate** intrabasinal and extrabasinal; intrabasinal-clasts composed of mudstone, siltstone sandstone, and caliche; extrabasinal-clasts composed of chert, quartzite, and vein quartz with some silicified wood fragments in a red sand matrix.	**Conglomerate** poorly sorted, coarse limestone, dolomite, and chert pebbles, cobbles, and boulders in a coarse quartz sand and caliche matrix. caliche occurs as indurated zones both at the base and top of the formation.	**Sandstone** brick red, white, and green, fine to coarse grained. **Siltstone** red, argillaceous, finely micaceous, mottled by light green clay. **Conglomerate** pebbles and cobbles of quartz and orthoquartzite in a matrix of fine to coarse-grained argillaceous red sandstone. caliche inclusions minor amounts of siderite, anhydrite vein calcite, and dolomite.

In contrast, deposits of the Dockum Group and Eagle Mills Formation are arealy extensive accumulating in a variety of terrigenous clastic depositional environments. Both of these rock groups are composed of alternating alluvial fan, fluvial, deltaic, and lacustrine deposits, which reflect local climatic and tectonic fluctuations.

Figure 8 is a paleogeographic reconstruction of Texas during Triassic time illustrating the environments present during deposition of Triassic rocks. The Bissett Formation was deposited in alluvial fans and braided-to-meandering streams, which extended northward from the southern end of the Ouachita-Marathon Foldbelt. These are the earliest Triassic deposits in Texas. The Triassic deposits in eastern Texas of mudstones, siltstones, sandstones and conglomerates of the Eagle Mills Formation were derived from the northern extent of the Ouachita Tectonic Belt. Erratic thickness patterns and geophysical data suggest that the Eagle Mills Formation was deposited in subsiding grabens formed as extensional features associated with the initial opening of the Gulf Coast during Late Triassic time adjacent to the Ouachita Foldbelt. The sediments were transported by southeastward flowing streams and deposited in alluvial fans originating from the Ouachita Mountains.

The Sycamore Formation was a similar localized conglomeratic deposit surrounding the Llano Uplift of central Texas. These poorly sorted conglomerates were deposited by high-gradient streams, which formed alluvial fans adjacent to the Llano region. There is a pronounced decrease in size away from the Llano Uplift indicating that it was the principal source area for Sycamore deposits.

The Dockum Group is a complex sequence of continental clastic sediments deposited in an inland fluvial-lacustrine basin encompassing much of west Texas. The thinned edge of the Dockum red beds may have reached almost to the Llano region in central Texas before being eroded back to its present position during the Jurassic and Cretaceous Periods (Barnes et al., 1972, p. 41). The Dockum Basin was filled by streams entering around its margins, and thus the sediments reflect a variety of provenance areas (Fig. 4). Some of the chert and quartz found in some of the extrabasinal conglomerates may have been derived from the Llano Uplift region (Roth, 1961, p. 51). Dockum sediments were deposited in alluvial fans, channels of braided-to-meandering streams, on prograding lobate deltas, on fan deltas, and in lacustrine systems. Sedimentation was greatly affected by alternating climatic conditions, which produced changes in base level, water depth, and areas of lakes and in the character of streams that flowed into the basin (McGowen et al., 1979, p. 46). The low-stand deposits are products of sporadic, high-energy, short-duration depositional events similar to those that formed the Sycamore and Bissett Formations. The alternating fluvial deltaic, and lacustrine sequences of the Dockum Group are not unlike those found within the Eagle Mills Formation and were probably deposited in similar depositional environmentals.

The character and distribution of the continental Triassic rocks of Texas were directly influenced by the climatic regime existing during deposition. The character of these formations strongly suggests semiarid deposition typical of the low latitude desert regions of today. During Triassic time arid climates dominated a broad region of the global landmass, as is indicated by paleogeography and paleoclimatology. This arid region included the Tri-

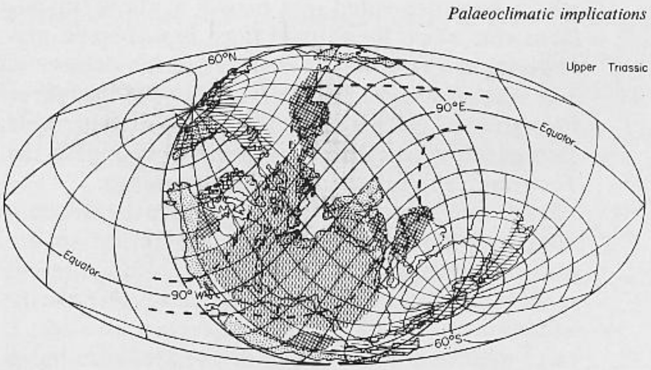

Fig. 52. Sketch of probable course of the Intertropical Convergence Zone for July and January and major precipitation climatic regions in the Triassic Period. Vertical dashed lines indicate region with year-round dry climate. *From* Robinson, 1973, Implications of continental drift to the Earth Sciences, p. 466, Academic Press, used with permission.

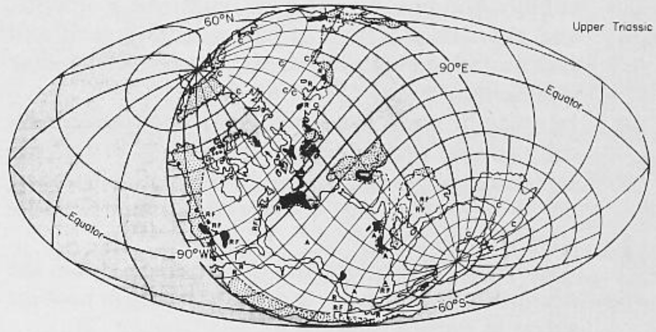

Fig. 53. Distribution of certain Upper Triassic climate-sensitive sedimentary rocks. Arrows show wind direction obtained from aeolianites, evaportites in black. A = aeolian, C = coals, D = deltaic, F = fluviatile, L = lacustrine, R = red beds. *From* Robinson, 1973, Implications of continental drift to the Earth Sciences, p. 467, Academic Press, used with permission.

assic depositional area of Texas. Because of the northward deflection of the Intertropical Convergence Zone (ITC) (Fig. 52) the Trade Winds travelled over the landmass, bringing a dry semiarid climate to the region of Triassic deposition (Robinson, 1973, p. 464-467). In Figure 53 the distribution of Upper Triassic evaporites, aeolian sands and red beds has been plotted. The semiarid to arid type deposits occur in the intertropic latitudes of the western and central portion of the landmass where dry conditions are suggested. Thus, Sycamore, Eagle Mills, Dockum, and Bissett rocks appear to be products of deposition during a single major arid to semiarid climatic episode, such as that of Late Triassic time. These deposits are most closely related, not in terms of stratigraphic continuity but in terms of the mechanics of their origin: continental clastic sediments derived primarily from older sedimentary rocks during a period of semiaridity.

CONCLUSIONS

1. Four Upper Triassic rock units exist in Texas: 1) Eagle Mills Formation, 2) Sycamore Formation, 3) Dockum Group, and 4) Bissett Formation.
2. The Triassic rocks occur both in outcrop and in the subsurface encompassing large portions of northeast, central, and northwest Texas.
3. The pre-Triassic surface was a continental erosional surface of moderate relief transecting a number of structural provinces.
4. The Eagle Mills Formation exists in discontinuous occurrence in the subsurface from south Texas northeastward across southern Arkansas and northern Louisiana into western Mississippi.
5. The eroded north edge of the Eagle Mills Formation follows the southern boundary of the Ouachita Tectonic Belt and represents the initial deposits of the Interior Gulf Basin.
6. Eagle Mills deposition was controlled by normal faulting associated with the initial rifting of the Gulf Coast.
7. The Eagle Mills Formation is composed of interbedded layers of sandstone, siltstone, shale and conglomerate.
8. Eagle Mills sediments are predominantly alluvium with the coarser clastics representing alluvial fan deposits derived from streams that flowed from the Ouachita Tectonic Belt.
9. Mudstones and siltstones of the Eagle Mills Formation are products of floodplain deposition, which includes marshes, ephemeral lakes, and meandering streams.
10. The environment of deposition during Eagle Mills time was unfavorable for the generation and preservation of organic material. However, there may have been rift valley lakes where petroleum source material was deposited.
11. The Late Triassic age for the Eagle Mills Formation was based on the identification of Upper Triassic palynmorphs and plant macrofossils as well as radiometric dating of diabasic igneous rocks in the Eagle Mills section.
12. The Sycamore conglomerate is the lowermost coarse terrigenous conglomeratic deposit immediately beneath Cretaceous rocks unconformably overlying Paleozoic rocks and distributed in discontinuous outcrop along the northern, eastern, and southern flanks of the Llano Uplift.
13. The Sycamore Formation is composed of pebbles,

cobbles and boulders of hard limestone, dolomite, and chert in a matrix of coarse quartz sand and caliche derived primarily from erosion of Paleozoic sedimentary rocks of the Llano region.

14. In areas of good exposure, Sycamore rocks typically consist of thin structureless beds of caliche-cemented conglomerate capped by thin sand drapes, which represent the waning stages of separate stream flows.
15. Evidence of Sycamore deposition suggests that the Llano Uplift may have continued or again become active in Early Triassic time.
16. Distribution of Sycamore rocks follows closely southwest-to-northeast trending Paleozoic fault blocks extending north and east of the Llano Uplift.
17. When the Llano Uplift attained sufficient height during Triassic time, rock fragments were transported by high-energy streams and dumped in the proximal portions of alluvial fans as sieve deposits.
18. Distribution of sediments and sedimentary structures strongly suggests that earliest Cretaceous flow was directed eastward across the northern end of the Llano region while lithology and sedimentary character of Sycamore rocks indicate that they are derived from the Llano region and that during their deposition flow direction was principally northward.
19. Regardless of the mechanism of caliche formation, its common association with semiarid deposits makes the occurrence of widespread caliches both at the base and at the top of the Sycamore Formation strongly suggestive of semiarid land deposition.
20. The Dockum Group of west Texas is a complex red-bed sequence consisting of interbedded mudstones, siltstones, sandstones, and conglomerates, which were deposited in a broad, shallow fluvial-lacustrine basin by alluvial fans, braided and meandering streams, lobate deltas, and fan deltas.
21. The Dockum Group is presently divided into three formations, which can be traced for considerable distances and include, from oldest to youngest, the Tecovas, Trujillo, and Chinle Formations.
22. Paleocurrent patterns from cross-beds in the Dockum sandstones show a preferred orientation to the west-northwest indicating that the depositing streams east of the basin flowed generally to the west-northwest.
23. Lake area and water depth of the Dockum basin fluctuated with changes in climate and sedimentation. When climatic conditions were more humid and lake level and areas were at their maximum, prograding deltas and associated meandering streams constituted the principal depositional systems. With a shift toward more arid conditions base level and lake size decreased and valleys were scoured. Local braided streams and fan deltas became the dominant type of depositional system.
24. The Bissett Formation is a terrigenous unit composed primarily of limestone and chert conglomerate, red shale and sandstone, which crop out along the northwest margin of the Glass Mountains.
25. The coarse limestone, dolomite and chert gravels of the Bissett Formation were deposited in alluvial fans and fan deltas by streams following northward from the Ouachita Fold Belt.
26. The nature and character of the Triassic rock units strongly suggest semiarid to arid deposition typical of the low latitude desert regions of today.

APPENDIX*

LOCALITIES

1. Outcrop of Dockum rocks just west of Sterling City cemetery on State Highway 163, Sterling County, Texas.
2. Dockum rocks exposed along State Highway 163, 24 mi† north of Sterling City, Mitchell County, Texas.
3. Roadcut on State Highway 163 at east end of Beals Mountain, 14 mi south of Sterling City, Mitchell County, Texas.
4. Outcrop of Dockum rocks just north of Camp Creek on State Highway 163, 11 mi south of Colorado City, Mitchell County, Texas.
5. Dockum rocks exposed in a roadcut along State Highway 163, 7 mi south of Colorado City, Mitchell County, Texas.

6a. Triassic Dockum conglomerate found at the intersection of two unpaved farm roads just north of Interstate Highway 20, city limit, Loraine, Texas (Mitchell County).

6b. Stream cut just off Interstate Highway 20 Loraine, Texas (Mitchell County).

7. Outcrop of Dockum Group along the Caprock Escarpment about 2 mi north of Fluvanna, Scurry County, Texas.
8. Railroad cut exposed along U.S. Highway 84, 3 mi south of Justiceburg, Garza County, Texas.
9. Dockum rocks exposed along U.S. Highway 84, 2 mi north of Justiceburg, Garza County, Texas.
10. Triassic Dockum Group exposed along U.S. Highway 84, approximately 3 mi south of Post, Garza County, Texas.
11. Triassic Dockum Group, 17 mi south of Post on Farm Road 669.
12. Outcrop of Dockum rocks exposed along Highway 38, 1 mi west of Post, Garza County, Texas.
13. Dockum rocks exposed along the Caprock Escarpment on State Highway 207 just north of Courthouse Mountain, approximately 2 mi north of Post, Garza County, Texas.
14. Outcrop of Permian (Quartermaster Group), Triassic (Dockum Group), and Tertiary (Ogallala Group) rocks exposed at Palo Duro Canyon State Park, 12 mi east of Canyon, Randall County, Texas.
5. Sycamore Formation exposed above the steeply dipping Paleozoic rocks, Pedernales Falls area, Blanco County.
6. Outcrop of Sycamore on the Pedernales River northern Hays County.
7. Sycamore Formation exposed at Cypress Creek, Blanco County.
8. Sycamore conglomerate exposed at Hammett's Crossing, Pedernales River, Travis County.

*Thesis Appendix I, measured sections and described localities Dockum Group, Sycamore Formation (77 p.), is available from the Department of Geology, Baylor University, for reproduction costs. —Editor

†1 mi = 1.609 km

‡1 yd = 0.9144 m

9. Section of Sycamore conglomerate exposed at Cox's Crossing, Pedernales River, Travis County.
10. Sycamore Formation exposed at Hickory Creek, Burnet County.
11. Travis Peak-Sycamore Formation exposed at Sycamore Creek, 10 mi east of Marble Falls, Burnet County.
12. Exposure of Paleozoic rock, Walnut Clay, and Comanche Peak Limestone 12.1 mi west of Lampasas on Farm Road 1478, Lampasas County.
13. Sycamore conglomerate exposed in roadcut (Bend Locality), 3 mi southwest of Bend on State Highway 501, San Saba County.
14. Basal Cretaceous and Sycamore contact 0.25 mi south of Nix, on country road at Lynch Creek, Lampasas County.
15. Sycamore conglomerate exposed in stream cut at Nix Cemetery, just west of Nix, Lampasas County, Texas.
16. Exposure of Travis Peak Formation 7 mi east of Lampasas at the intersection of Farm Road 580 and Lucy Creek, Lampasas County.
17. Sycamore conglomerate in contact with Paleozoic rocks 6.7 mi west of Lometa on Texas Highway 190 (Dobbins, 1974, p. 110).
18. Massive Sycamore conglomerate outcrop exposed at Elliot Creek, Mills County (lat.31° 18′ N. long.98°31′W.) 1000 yd‡ south of old Lometa Highway (Boone, 1968, p. 61).
19. Sycamore-Strawn outcrop exposed in roadcut 3 mi west of Elliot Creek locality on unmarked county road, Mills County (1 mi east of the Colorado River. Base of Sycamore rocks).
20. Sycamore-Strawn contact exposed on a hill 12 mi northeast of San Saba on unmarked county road (1.5 mi north of Locality 10) Mills County.
21. Mills County. In road cut of county road. Section about 1 mi west of intersection of two county roads. Begins about half way down hillside and continues west to crest of hill. Contact elevation 1,320 ft.
22. Sycamore conglomerate on Farm Road 500, 9.3 mi north of San Saba, San Saba County.
23. Sycamore conglomerate found atop ridge on Farm Road 500, 16.3 mi north of San Saba, San Saba County.
24. Basal Cretaceous clastics and Sycamore conglomerate of Farm Road 2997 about 0.5 mi on dirt road approximately 1.5 mi from Wilbarger Peak, San Saba County.
25. Massive outcrop of Rochelle Conglomerate 1 mi north on Farm Road 2822 with intersection of State Highway 190, 5 mi northeast of Rochelle, McCulloch County.
26. Rochelle Conglomerate and Paleozoic sandstone exposed at a roadcut 4 mi east of Rochelle on State Highway 190, McCulloch County.
27. Sycamore and Cretaceous outcrop 2 mi east of Rochelle on State Highway 190, McCulloch County.
28. Rochelle Conglomerate exposed in a small hill at Soldiers Waterhole (historical monument) 2 mi east of New Sweden on unmarked county road, McCulloch County.
29. Massive caliche section resting on Paleozoic sands along unmarked county road 4 mi from intersection with U.S. Highway 283 (approximately 22 mi northwest of Brady), McCulloch County.
30. Sycamore conglomerate scattered about Paleozoic sandstone along Farm Road 502, 4 mi west of Mercury.
31. Brown County. Series of two road cuts on Farm Road 845 south of Brownwood, approximately 2 mi north of Brown-Mills County line. Sycamore Formation overlying Pennsylvanian shale.
32. Sycamore Sand exposed southwest of road, 5.3 airline mi north-northeast of Ebony Cemetery, Mills County.
33. Sycamore-Strawn outcrop exposed on hilltop (roadcut) 7.6 mi southwest of Mullin on Texas Highway 573, Mills County.
34. Sycamore Conglomerate exposed in roadcut 5.3 mi southwest of Mullin, on State Highway 573, Mills County.
35. Brown County. Road cut on county road immediately north of the Brown-Mills County line, approximately 6 mi south of Zephyr. Sycamore Formation overlying Pennsylvanian shale.
36. Paleozoic and Sycamore contact, 0.8 mi from Jones Chapel on Highway 67-377, Brown County.
37. Cretaceous-Pennsylvanian contact, on county road at intersection with a second county road, 9 airline mi west of Brownwood, Brown County.
38. Paleozoic and Sycamore contact on Farm Road 586, 3 mi southwest of Bangs at the Ford Holt home, Brown County.
39. Sycamore Formation exposed on hilltop 5 mi northwest of Bangs, Brown County.
40. Sycamore conglomerate along Park Road P-15, 0.25 mi south of its intersection with Highway 2559, north of Lake Brownwood, Brown County.

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