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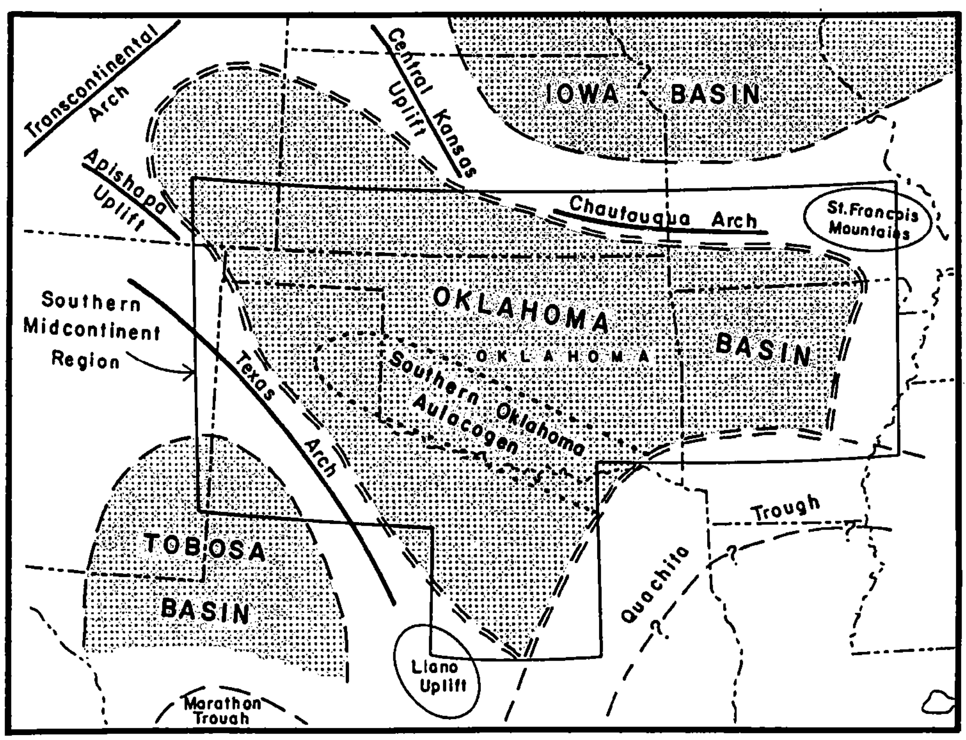
Geology of the Southern Midcontinent

Kenneth S. Johnson and others



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GEOLOGY OF THE SOUTHERN MIDCONTINENT

by

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Charles J. Mankin, *Director*
The University of Oklahoma
Norman, Oklahoma
1989

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FOREWORD

This Special Publication is reprinted from one of the volumes prepared for the Decade of North American Geology (DNAG) Project that marks the Centennial of the Geological Society of America (GSA). It is a reprint of: Johnson, K. S., and others, 1988, Southern Midcontinent region, *in* Sloss, L. L. (ed.), *Sedimentary cover--North American craton; U.S.*: Boulder, Colorado, Geological Society of America, The Geology of North America, v. D-2, Chapter 12, p. 307-359. We herein express appreciation to GSA for permission to reprint this report. The entire volume D-2 deals with the Phanerozoic sedimentary cover on the U.S. portion of the North American craton. Various chapters in D-2 discuss regions ranging from the Rocky Mountains to the Appalachian basin, and from the U.S.-Canadian border to the front of the Ouachita-Marathon orogenic belt. Volume D-2, and other volumes prepared under the DNAG Project, are available from the Geological Society of America, Inc., 3300 Penrose Place, P.O. Box 9140, Boulder, Colorado 80301.

Following is the complete table of contents for volume D-2: **Chapter 1. Introduction,** by L. L. Sloss. **Chapter 2. Geophysical aspects of the craton: U.S.,** by William J. Hinze and Lawrence W. Braile. **Chapter 3. Tectonic evolution of the craton in Phanerozoic time,** by L. L. Sloss. **Chapter 4. Triassic and older stratigraphy; southern Rocky Mountains and Colorado Plateau,** by D. L. Baars. **Chapter 5. A synthesis of the Jurassic system in the southern Rocky Mountain region,** by Fred Peterson. **Chapter 6. Cretaceous rocks of the Western Interior basin,** by C. M. Molenaar and D. D. Rice. **Chapter 7. Phanerozoic stratigraphy of the northern Rocky Mountain region,** by J. A. Peterson. **Chapter 8. Basins of the Rocky Mountain region,** by D. L. Baars, B. L. Bartleson, C. E. Chapin, B. F. Curtis, R. H. De Voto, J. R. Everett, R. C. Johnson, C. M. Molenaar, F. Peterson, C. J. Schenk, J. D. Love, I. S. Merin, P. R. Rose, R. T. Ryder, N. B. Waechter, and L. A. Woodward. **Chapter 9. Geology of the Williston basin (United States portion),** by Lee C. Gerhard and Sidney B. Anderson. **Chapter 10. Phanerozoic history of the central midcontinent, United States,** by Bill J. Bunker, Brian J. Witzke, W. Lynn Watney, and Greg A. Ludvigson. **Chapter 11. The Permian basin region,** by H. N. Frenzel, R. R. Bloomer, R. B. Cline, J. M. Cys, J. E. Galley, W. R. Gibson, J. M. Hills, W. E. King, W. R. Seager, F. E. Kottlowski, S. Thompson III, G. C. Luff, B. T. Pearson, and D. C. Van Siclen. **Chapter 12. Southern Midcontinent region,** by Kenneth S. Johnson, Thomas W. Amsden, Rodger E. Denison, Shirley P. Dutton, Arthur G. Goldstein, Bailey Rascoe, Jr., Patrick K. Sutherland, and Diana Morton Thompson. **Chapter 13. Michigan basin,** by James H. Fisher, Michael W. Barratt, John B. Droste, and Robert H. Shaver. **Chapter 14. Illinois basin region,** by Charles Collinson, Michael L. Sargent, and James R. Jennings. **Chapter 15. The Appalachian basin,** by Robert C. Milici and Wallace de Witt, Jr. **Chapter 16. The Black Warrior basin,** by William A. Thomas. **Chapter 17. Conclusions,** by L. L. Sloss. **Index.**

KENNETH S. JOHNSON
Project Coordinator and Editor

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Chapter 12

Geology of the Southern Midcontinent

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INTRODUCTION

Kenneth S. Johnson

The Southern Midcontinent is a complex region characterized by great thicknesses of sediments preserved in a series of major depositional and structural basins separated by orogenic uplifts created mainly during Pennsylvanian time (Plate 5-A). Sedimentary rocks of every geologic system from Precambrian through the Quaternary are preserved within the region, and their diverse lithologies include limestones, dolomites, sandstones, shales, conglomerates, red beds, and evaporites. The strata are a mixture of marine and nonmarine deposits, and generally (except for the red bed–evaporite sequences), they are richly fossiliferous and are well suited to biostratigraphic correlation and interpretation of depositional environments.

Dominant lithologies in most basins of the region are, in ascending order, as follows: a thin transgressive sandstone of Late Cambrian age that covered the basement-rock complex of intrusives, extrusives, and metasediments; overlain by a thick sequence of Late Cambrian through Late Mississippian (Meramecian) carbonates, with minor amounts of sandstone and shale; followed by a thick sequence of terrigenous clastics, with some carbonates, deposited from Late Mississippian (Chesterian) through Early Permian (Wolfcampian) time; then a thick series of red beds and evaporites were deposited during the remainder of the Permian; overlain, in the west only, by Triassic and Jurassic terrestrial red beds; then Cretaceous marine deposits in the south and west; and finally a mantle of Tertiary alluvial-fan, aeolian, and lacustrine sediments in the west.

Owing to the great thickness of strata in most basins of the region, and the many surface and subsurface stratigraphic studies that have been conducted, a plethora of stratigraphic names have been proposed and used in the Southern Midcontinent. The correlation charts and stratigraphic nomenclature used in this chapter are based primarily upon the recently completed COSUNA charts released by the American Association of Petroleum Geologists. The lithology and thickness of selected units are discussed throughout this chapter, and they are summarized in a series of maps (Plates 5 and 6). The thickness and lithology maps show the present distribution and thickness of each mapped unit (not the restored distribution and thickness), and they show the dominant lithology (i.e., mostly limestone, or mostly shale) present in each unit, unless otherwise noted in the explanation.

The Southern Midcontinent contains one of the greatest thicknesses of sedimentary rocks preserved in North America, with as much as 12,000 m of strata in the deep Anadarko Basin. Other major accumulations of sediments are in the Ardmore Basin (about 9,000 m), the southern part of the Arkoma Basin

Johnson, K. S., Amsden, T. W., Denison, R. E., Dutton, S. P., Goldstein, A. G., Rascoe, B., Jr., Sutherland, P. K., and Thompson, D. M., 1988, Southern Midcontinent region, *in* Sloss, L. L., ed., Sedimentary Cover—North American Craton; U.S.: Boulder, Colorado, Geological Society of America, The Geology of North America, v. D-2.

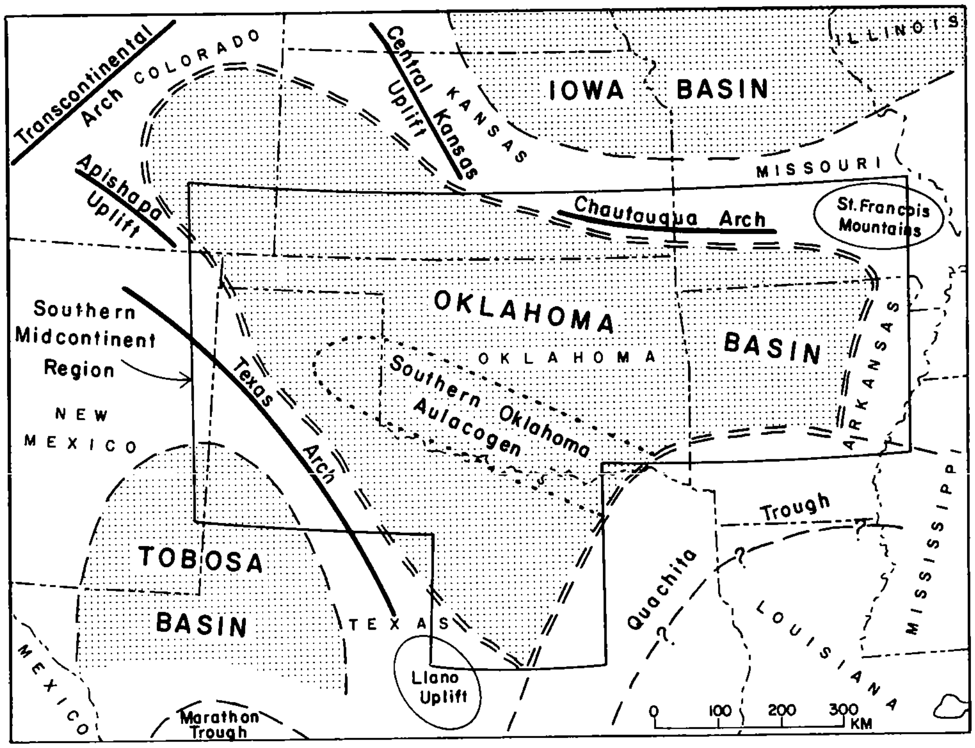


Figure 1. Map of southwestern United States showing outline of Southern Midcontinent region, as discussed in this chapter, and approximate boundary of the Oklahoma Basin and other major features that existed in parts of early and middle Paleozoic time.

(about 8,000 m), the Marietta Basin (about 8,000 m), and the Palo Duro, Dalhart, Hardeman, and Fort Worth Basins (each of which contains 3,000 to 4,000 m). These thick sedimentary packages accumulated along the southern margin of the North American Craton during Paleozoic episodes of subsidence of the Anadarko, Ardmore, and Marietta Basins, and of the foredeep areas north and west of the Ouachita Trough. The west-northwest–trending trough comprising the Anadarko, Ardmore, and Marietta Basins, and the associated uplifts, has been referred to as the Southern Oklahoma Geosyncline (Ham and others, 1964; Ham and Wilson, 1967) or the Southern Oklahoma Aulacogen (Gilbert, 1983; Brewer and others, 1983; see Fig. 1).

The Phanerozoic history of the Southern Midcontinent is characterized by three major periods or phases of tectonics and sedimentation: early and late phases of broad subsidence and epeirogenic movements were interrupted by a middle phase of sharp orogenic uplift and deep subsidence. The early epeirogenic phase is represented by Late Cambrian through Mississippian marine sediments deposited in a broad epicontinental sea, herein called the Oklahoma Basin, that extended across almost all parts of the Southern Midcontinent (Fig. 1). The Oklahoma Basin was a shelf-like area that received a sequence of remarkably thick and extensive marine carbonates interbedded with thinner marine shales and sandstones. These strata are readily correlated though-out the basin. The sediments thicken into protobasins (Anadarko, Ardmore, and others) accentuated later during Pennsylvanian orogenies, and they also were deposited upon and across the present-day major uplifts, from which they were subsequently stripped during Pennsylvanian uplift and erosion. Whereas the Southern Oklahoma Aulacogen was the depocenter for the Oklahoma Basin, the entire basin covered a much greater area: the basin extended from the Ouachita trough on the southeast to a series of broad arches on the north and west that were intermittently uplifted epeirogenically in early and middle Paleozoic time. Adler and others (1971) used the term Oklahoma Basin in referring to the Anadarko Basin and Hugoton Embayment areas during early and middle Paleozoic time, but the use in the current report is for a much larger area.

The middle phase of Phanerozoic development centered on orogenic activity during the Pennsylvanian Period. The broad, shallow-marine Oklahoma Basin was divided by sharply uplifted crustal blocks into a series of well-defined marine basins. The Ouachita trough was destroyed by uplift and northwesterly thrusting of the Ouachita Fold Belt (Plate 5-A). Orogenic activity was limited to folding, faulting, and uplift, and was not accompanied by igneous or metamorphic activity. Sedimentation in the rapidly subsiding basins was dominated by coarse and fine clastics shed from the nearby uplifts, although platform conditions persisted in some of the broad shelf areas away from the uplifts.

The final Phanerozoic phase, from the Permian Period until the present time, consisted of infilling of the basins in the west, and a return to epeirogenic movements. Western basins were filled with Permian red beds and evaporites, and subsequently with Triassic and Jurassic alluvial-deltaic and lacustrine red beds. The last marine incursion occurred when shallow Cretaceous seas spread over the south and west parts of the region. Regional eastward tilting of the Southern Midcontinent during uplift of the Rocky Mountains in Late Cretaceous and Early Tertiary time established the dominant east-flowing river systems, which deposited Late Tertiary alluvial, aeolian, and lacustrine sediments in the west, and Quaternary terraces and alluvial deposits throughout the region.

Owing to the major tectonic and sedimentologic changes that occurred in Pennsylvanian time, the remainder of this chapter is organized in three sections. (1) Pre-Pennsylvanian depositional environments and patterns of sedimentation were laterally persistent across most of the Oklahoma Basin, and thus each of the major pre-Pennsylvanian sedimentary units is discussed for the entire region in the first section. (2) Because Pennsylvanian orogenies subdivided the Southern Midcontinent into a number of major basins and uplifts, each with a somewhat different evolutionary history, the Pennsylvanian and Permian sedimentary rocks are discussed separately for each major basin (and surrounding uplifts) in the second section. (3) The third section contains a discussion of post-Permian rocks and sediments for the entire Southern Midcontinent region, inasmuch as after Permian time the separate major basins ceased having any significant effect upon sedimentation patterns.

The vast size of the Southern Midcontinent, and the complex history of its many basins and uplifts, required the cooperative efforts of eight authors, and each is credited for his/her individual contribution.

PRE-PENNSYLVANIAN ROCKS

REGIONAL STRATIGRAPHIC FRAMEWORK

Kenneth S. Johnson

Pre-Pennsylvanian strata of the Southern Midcontinent are mainly shallow-marine carbonates (limestone and dolomite), interbedded with several sandstone and shale units. These strata are remarkably widespread and laterally persistent throughout most parts of the Oklahoma Basin, reflecting the stability of this part of the craton and the importance of epeirogenic movements during early and middle Paleozoic time. Early studies of the pre-Pennsylvanian units were focused on outcrops in the widely separated Ozark Uplift, Arbuckle and Wichita Mountains, and Llano Uplift areas (Plate 5-A), and thus a different nomenclature for each area was established and ingrained before equivalency of the rock units could be fully established.

In most parts of the Oklahoma Basin, particularly the eastern, central, and southern parts, there is a basal, transgressive sand of late Middle to early Late Cambrian age, variously called the Reagan, Lamott, or Hickory Sandstone. This is overlain by a thick Cambro-Ordovician carbonate section, called the Ellenberger and Moore Hollow Groups in Texas, the Arbuckle Group in Oklahoma and Kansas, and by a series of formation names in Missouri and Arkansas.

The Middle Ordovician Simpson Group and equivalent strata in the eastern part of the region consists of widespread quartzose sandstones and carbonates. The sandstones, named the "Wilcox" sands in many oil fields of Oklahoma, are partly equivalent to the St. Peter Sandstone that extends northward across much of the midwestern United States. The overlying Viola Group carbonates, Sylvan Shale, and Hunton Group (and equivalent) carbonates, ranging in age from Late Ordovician to Middle Devonian, reflect continued shallow-marine shelf deposition in most parts of the region. Several widespread disconformities are due to epeirogenic uplifts.

Lateral persistence of a uniform lithology is best represented by the Upper Devonian–Lower Mississippian organic-rich black shales that stretch across the eastern, central, and southwestern United States. Named the Chattanooga Shale for exposures in Tennessee and the Woodford Shale for exposures in the Arbuckle Mountains, this unit overlies one of the most widespread unconformities of the Southern Midcontinent. Carbonates, cherty carbonates, and some shales typify the remaining Mississippian strata that overlie the Woodford-Chattanooga Shale in the region.

PRECAMBRIAN THROUGH MIDDLE CAMBRIAN

Rodger E. Denison

There are three substantial outcrops of basement rocks in the Southern Midcontinent: the St. Francois Mountains in southeast Missouri and the Wichita and Arbuckle Mountains in southern Oklahoma (Plate 5-B). In addition, several small outcrops of granite are exposed in northeast Oklahoma near the town of Spavinaw. In most of the area the basement is buried beneath Paleozoic cover at depths generally less than 3,000 m. The exceptions are in the Arkoma, Ardmore, and Anadarko Basins where the sedimentary cover is as much as 12,000 m. A large number of wells drilled in search of oil, gas, and other minerals have penetrated the basement in all but the deepest basins.

Detailed petrographic study of samples from these drill holes, together with geochronologic studies on both outcrop and subsurface samples, has led to a reasonably clear understanding of the basement upon which the Paleozoic rocks were deposited. Flawn (1956) in Texas provided the first successful regional study of the buried basement. Later work by Ham and others (1964) in southern Oklahoma, Muehlberger and others (1967) over the entire area, Kisvarsanyi (1979) in Missouri, Bickford and others (1981) in Kansas and Missouri, Denison (1981) in northeast Oklahoma, Denison (1984) in northern Arkansas, and Tweto (1983) in southeast Colorado have provided most of the data on which our understanding is based. A more complete summary of the basement is in Denison and others (1984).

The Precambrian basement in the Southern Midcontinent is characterized by granitic igneous rocks extruded or emplaced at shallow depths (Plate 5-B). Large areas are covered by rhyolites associated with comagmatic epizonal granites. Low-rank metasedimentary rocks account for only a small part of the basement surface, but analysis of deep seismic profiles (Brewer and others, 1981) suggests a possible Precambrian basin in southwest Oklahoma containing as much as 10 km of relatively undisturbed layered rocks. There is little direct evidence to indicate the extent of this basin, but seismic data show similar Precambrian reflections in parts of the Texas Panhandle where most of the basement surface is covered by rhyolites (Budnik, 1984). Massive granitic and metagranitic rocks make up most of the area between the rhyolite fields. Basaltic rocks are common as dikes and sills but are volumetrically not important. Much of the area shown in Texas is believed to be underlain by rocks related to those exposed in the Llano Uplift.

The ages of these Precambrian rocks range from about 1,400 to 1,600 Ma in Kansas and Missouri to near 1,000 Ma in Texas. Neither age nor compositional boundaries of these Precambrian rocks appears to have had a substantial effect on Paleozoic history. In contrast, the two much younger linear basins that strike into the stable interior had a profound influence on later history.

Virtually every aspect of later Paleozoic sedimentary thickness and structural style and direction is strongly influenced by a zone of weakness developed in southern Oklahoma during Cambrian time (Ham and others, 1964; Ham, 1969; Denison, 1982). Rocks emplaced at this time include Early and Middle Cambrian granites, rhyolites, gabbros, and basalts that extend across southern Oklahoma and into the Texas Panhandle: they were emplaced into and upon a sequence of sedimentary rocks referred to as the Tillman Metasedimentary Group. The sequence of Cambrian igneous events in southern Oklahoma is closely constrained and well documented, and this area contains the only suite of crystalline Cambrian basement rocks in the entire central interior of the United States and Canada.

Knowledge of the early history of the present Mississippi Embayment is based almost entirely on geophysical evidence and a few deep drill holes. Howe and Thompson (1984) have summarized the results of recent drilling as well as an interpretation of reflection seismic profiles and a summary of previous work. Only one well is known to have reached crystalline basement in the embayment (Denison, 1984). The well penetrated about 490 m of red arkose before bottoming in a granitic gneiss. The age of the red arkose may be Cambrian. The faults bounding the inferred arkosic basin have been the focus of later Cretaceous intrusions as well as a modern zone of seismicity.

Outside the area of Early and Middle Cambrian igneous activity in southern Oklahoma and the Texas Panhandle, there is no geologic record for the substantial time interval after the final crystallization or metamorphism of the Precambrian basement and before the Cambrian marine transgression. There was extensive erosion to expose rocks that were formed, in some cases, at considerable depth. The surface on which the Cambrian seas transgressed was generally of low relief (about 100 m), supported by a heterogeneous suite of mostly granitic igneous rocks swept clean of any significant debris.

MIDDLE CAMBRIAN THROUGH EARLY ORDOVICIAN

Rodger E. Denison

In Middle and Late Cambrian time seas transgressed to the north and west across the Southern Midcontinent onto what was to become the stable interior of the United States (Plate 5-C). The basement surface was of modest to locally rugged relief composed of largely granitic rocks ranging in age from about 1,600 Ma to 525 Ma. A time-transgressive basal sandstone was deposited except on topographic highs. This sand grades into an overlying succession of shallow-water carbonates deposited more or less continuously until the end of Early Ordovician time. These rocks are well exposed in central Texas, southern Oklahoma, and the St. Francois Mountains and Ozark Uplift of Missouri and Arkansas (Fig. 2) and have been penetrated in all but the deepest basins by numerous drill holes. In the subsurface, virtually any basal sandstone, regardless of age, has been designated with one or another of the basal Cambrian names.

In Oklahoma, the basal sandstone, called the Reagan, is overlain by a bioclastic limestone, the Honey Creek. These two units form the Timbered Hills Group. This is overlain by the Arbuckle Group, which is divided into six limestone units. Two secondary dolomites, formed at the expense of the primary limestones, have also been named (Fig. 2). The lower units are more distinctive lithologically than the upper units, which are identifiable only on the basis of stratigraphic position and fauna. Most of the southern Oklahoma information has been taken from Ham (1969) and work in Donovan (1986).

There are exceptional exposures of Arbuckle Group rocks in the Wichita and western Arbuckle Mountains. The thick, lime-mud–dominated succession of peritidal limestones was deposited on a vast carbonate platform that covered much of the Cratonic interior during the Late Cambrian and Early Ordovician. Although there is only a small, rather disseminated terrigenous

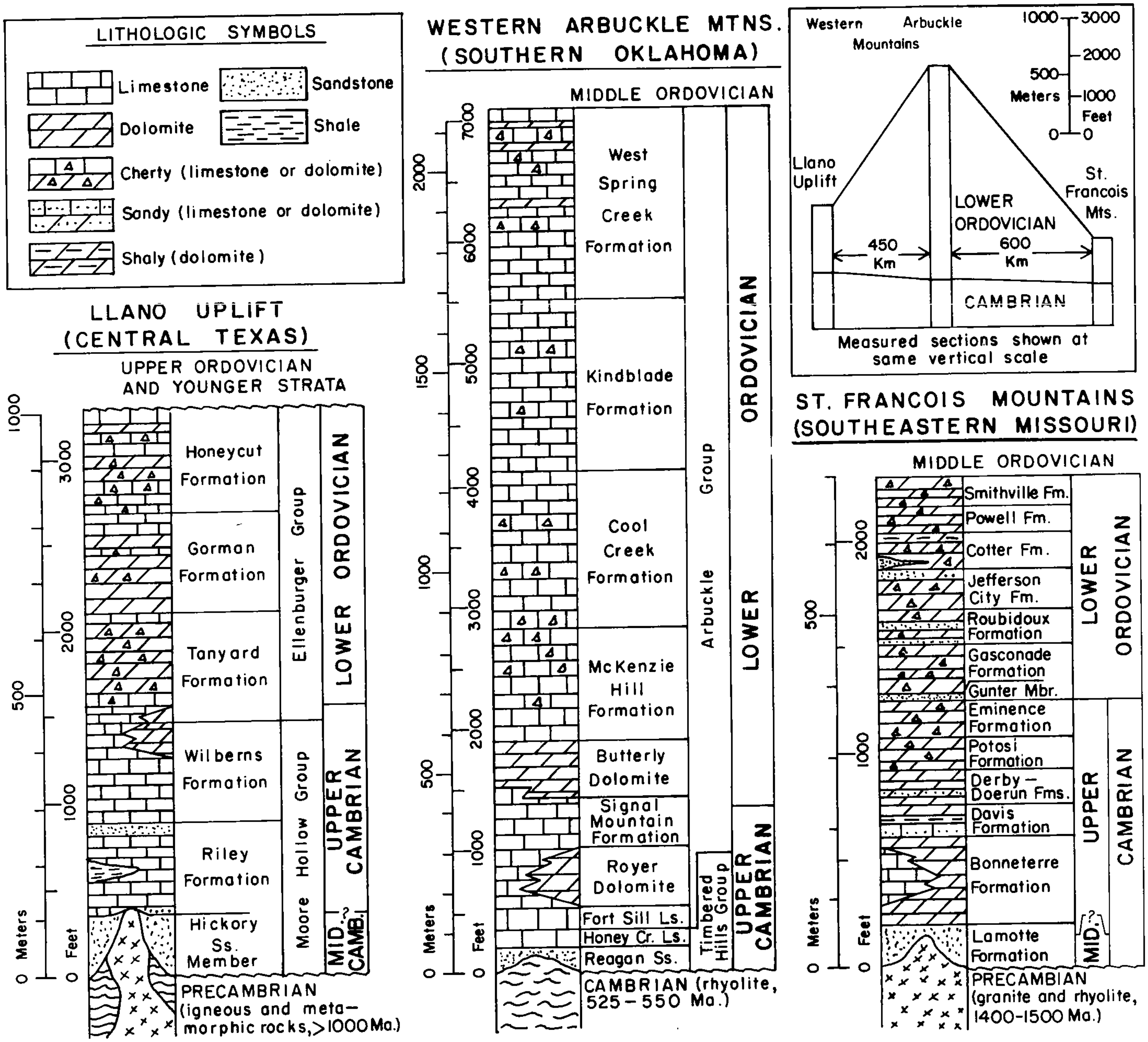


Figure 2. Subdivisions and comparison of lithology (not to scale) of Cambrian and Early Ordovician strata from the principal outcrop areas. The composite St. Francois Mountain section is taken from Hayes and Knight (1961) and Martin and others (1961). The Arbuckle Mountains section in Oklahoma was measured near what is now I-35 by Ham (1969). Age and lithologies in the Llano region are taken from Cloud and Barnes (1948) and Barnes and Bell (1977). Assignment of ages in Oklahoma from Stitt (1977) and Derby (1973) and in Missouri from Kurtz and others (1975) and Ross and others (1982).

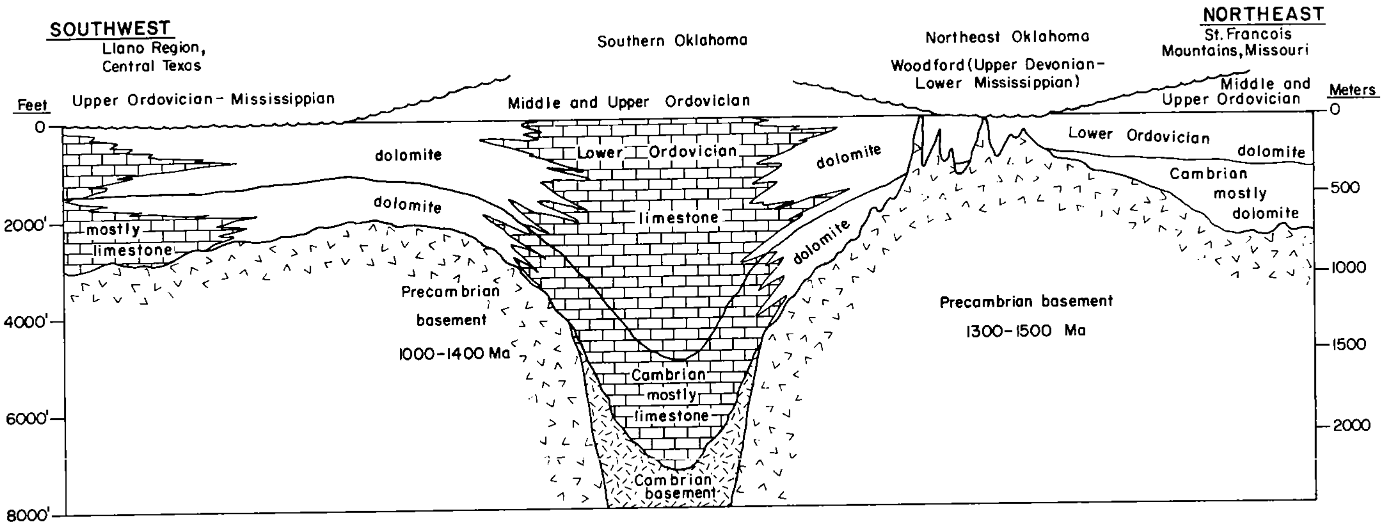


Figure 3. Schematic cross section through the Southern Midcontinent showing restored thickness of Middle Cambrian–Lower Ordovician strata and the generalized distribution of limestone and dolomite (also see Gatewood, 1970).

component in the carbonates, some of the thin sandy zones are remarkably persistent (Ragland and Donovan, 1985a).

The Arbuckle Group is composed almost entirely of limestone and is thickest (more than 2,100 m) in the Southern Oklahoma Aulacogen where the basement rocks are Cambrian in age (Fig. 3). In the eastern Arbuckle Mountains, where the basement is massive Precambrian (about 1,400 Ma) granitic rocks, the Arbuckle is mostly dolomite, contains moderate amounts of quartz sand, and is only about 1,200 m thick. Anhydrite is known from drill holes into the Arbuckle Group in some of the Oklahoma basins (Latham, 1970). Bedded evaporites are not found on the outcrop, but their original presence in outcropping rocks is suggested by collapse features and small anhydrite relicts in chert (Ragland and Donovan, 1985b).

Nearly 1,000 m of Cambrian and Early Ordovician sedimentary rocks are exposed in the Llano Uplift of central Texas. The Middle Cambrian seas transgressed over a surface with as much as 250 m of relief to deposit the basal Hickory Sandstone Member of the Riley Formation (Fig. 2) of the Moore Hollow Group. The younger Cambrian units of the Moore Hollow Group are composed dominantly of peritidal and shallow subtidal carbonate rocks with some significant terrigenous influxes (Barnes and Bell, 1977). Bell and Barnes (in Barnes and others, 1972) have provided a summary of Cambrian sedimentation and nomenclature. The Ordovician Ellenburger rocks are mostly limestone and dolomite with locally abundant chert. Cloud and Barnes (1948) describe the Ellenburger as lime-mud–dominated, shallow-water limestones with extensive dolomite replacement.

In Missouri and northern Arkansas, there are no inclusive terms for rocks equivalent to the Arbuckle and Timbered Hills Groups, but the gross lithologies of the formations (Fig. 2) are quite similar (Hayes and Knight, 1961; Martin and others, 1961). The outcrop pattern is in broad rings around the Precambrian of the St. Francois Mountains. Thickness of the 12 formations composing this time interval must be measured in separate areas. The original thickness of rocks deposited during the Cambrian and Early Ordovician at a given locality is difficult to estimate but is probably in the range of 600 to 900 m. Most of the sequence is dolomite, with lesser amounts of limestone, shale, and sandstone, and locally abundant secondary silica. The environment of deposition, based upon original and relict textures in the carbonates, appears to have been shallow water (Kurtz and others, 1975). The terrigenous content is greater here than in southern Oklahoma.

In the Arkansas part of the Mississippi Embayment, a few wells that have not been carefully studied have penetrated what has been interpreted as the complete, or nearly complete, Cambrian–Lower Ordovician sequence. The section here, if properly correlated, has a drilled thickness in excess of 2,900 m and a composite thickness of nearly 6,400 m, of which 5,000 m is thought to be Cambrian by Howe and Thompson (1984; because of the uncertainty, these data are not shown on Plate 5-C). Howe and Thompson (1984) show much of the Cambrian section to be composed of dark shales and sands, suggesting deeper water than on the adjacent platform.

Correlation between areas of outcropping units is based largely on shelly faunas. In the subsurface this is possible only under fortuitous circumstances where specimens are recovered in cores. In the Ozark region, correlations are made on the basis of the comparison of insoluble residues of outcropping units with those found in the subsurface (e.g., McCracken, 1955). In other areas the correlation is on the uncertain basis of lithology. On the outcrop, where the rocks are best known, the Cambrian–Lower Ordovician stratigraphic section seems to be thickest and most complete. In northeast Oklahoma, where the topography of the basement was most rugged, the older units are apparently missing by nondeposition, indicating this area was a gentle arch during the Late Cambrian (Fig. 3). The basement topography was so rugged here that some of the hills were not covered until the Middle Ordovician (Tarr, 1955).

The Cambrian and Early Ordovician carbonates were deposited over the Southern Midcontinent as part of a vast shallow-water platform that stretched from New York to New Mexico (best shown in Cook and Bally, 1975). The impressive stability of the continental interior following the basal Paleozoic transgression is unmatched during later geologic history. The present thickness of Late Cambrian–Early Ordovician strata (Plate 5-C) is due to the original deposition, modified in some areas by one or more periods of erosion. The earliest erosion period affected the Llano region in pre-Devonian time, the first of seven cited by Cloud and Barnes (1948). Barnes (in Barnes and others, 1959) and Barnes and Bell (1977) also synthesized the regional distribution and thickness of various divisions of the Ellenburger and Moore Hollow Groups in the subsurface of Texas. The pre-Woodford (Late Devonian–Early Mississippian) regional unconformity had a profound influence on the distribution of older rocks in the area, as shown by Tarr and others (1965) in Oklahoma. Deformation in the late Paleozoic caused differential uplift and erosion in Oklahoma and the Texas panhandle to expose basement over large areas. The Cambro-Ordovician rocks have been exposed locally to erosion during several periods from the Pennsylvanian to the present.

MIDDLE ORDOVICIAN THROUGH EARLIEST MISSISSIPPIAN

Thomas W. Amsden

The depositional environment throughout the Oklahoma Basin appears to have been reasonably constant during Middle Ordovician through Early Mississippian time, with shallow carbonate seas supporting rich benthic faunas periodically interrupted by injections of fine to moderately coarse clastics derived from an eastern source. Most of the major lithostratigraphic divisions can be recognized throughout the basin, indicating only moderate lateral variation in sedimentation and paleoenvironment. Deposition was interrupted by two major epeirogenic uplifts, a pre–middle Early Devonian (pre–Frisco-Sallisaw) and a pre–Late Devonian (pre–Woodford-Chattanooga). Both represent broad upwarpings with the maximum uplift on the flanks of the Oklahoma Basin where truncation of the underlying strata was greatest. These uplifts (Figs. 4 and 5) represent large, elongate tectonic features that followed the northwest-southeast structural grain developed in the Precambrian. Little if any folding and faulting accompanied these uplifts, and regional compressive forces were minimal during early and middle Paleozoic time.

In all probability, Middle Ordovician through earliest Mississippian strata were deposited throughout most of the Oklahoma Basin, but their present distribution results from the two episodes of Devonian truncation and, in the case of Woodford-Chattanooga distribution, from post-Woodford truncation. Late Ordovician through Early Mississippian strata are preserved in a small area on the Llano Uplift (just south of the area labeled Llano Uplift on Plate 5-A), and these strata are described briefly at the end of this portion of the chapter.

Middle Ordovician to Lower Mississippian strata in the Oklahoma Basin comprise five major stratigraphic units: Simpson Group, Viola Group, Sylvan-Cason Shale, Hunton Group, and Woodford-Chattanooga Shale (Fig. 4). The Viola and Hunton Groups represent mainly shallow-water carbonate sedimentation interrupted by the Simpson, Sylvan-Cason, and Woodford-Chattanooga depositional episodes when substantial quantities of terrigenous detritus were introduced into the depositional basin. The regional distribution of this detritus indicates it was derived mainly from an eastern source.

This depositional sequence was locally interrupted by numerous diastems and unconformities (Amsden, 1960; Amsden and Sweet, 1983). Two unconformities can be traced over most of this region, and these involve truncation of major proportions. These are the pre–Frisco-Sallisaw (pre–middle Early Devonian) unconformity, during which time strata as old as Late Ordovician were deleted (Fig. 5A), and the pre–Woodford-Chattanooga (pre–Late Devonian) unconformity, which truncated strata as old as the Early Ordovician (Fig. 5B; Jordan, 1965; Amsden, 1975, 1980).

The Simpson Group of Middle Ordovician age includes substantial quantities of sand, silt, and clay-size terrigenous detritus, including well-rounded quartz grains representing multiple-generation sands. This detritus is interspersed with varying amounts of carbonate, especially in the upper part (Bromide), which includes shelly benthic faunas of impressive diversity. Latest Simpson intertidal birdseye limestones occupy most of the western Arkoma Basin (Amsden and Sweet, 1983). Terrigenous detritus, including some graptolitic shale, is present in the lower part of the Viola Group; however, this decreases upward and the strata grade into clean-washed skeletal limestones (Welling Formation = "Fernvale" Formation). The Viola and Simpson Groups are primarily shallow-water sediments with the skeletal limestones representing clean-washed substrate and low turbidity. The combined thickness of both these groups is greatest in southern Oklahoma, where they reach a thickness in excess of 750 m (Plate 5-D). Undoubtedly, deepening of the water occurred from time to time, but the primary factor influencing the paleoenvironment appears to have been the periodic influx of terrigenous sediments, which at times engulfed the substrate.

The Sylvan Shale in the region from western Arkansas into central Oklahoma is a gray shale, noncalcareous in the lower part, becoming increasingly dolomitic in the upper part.

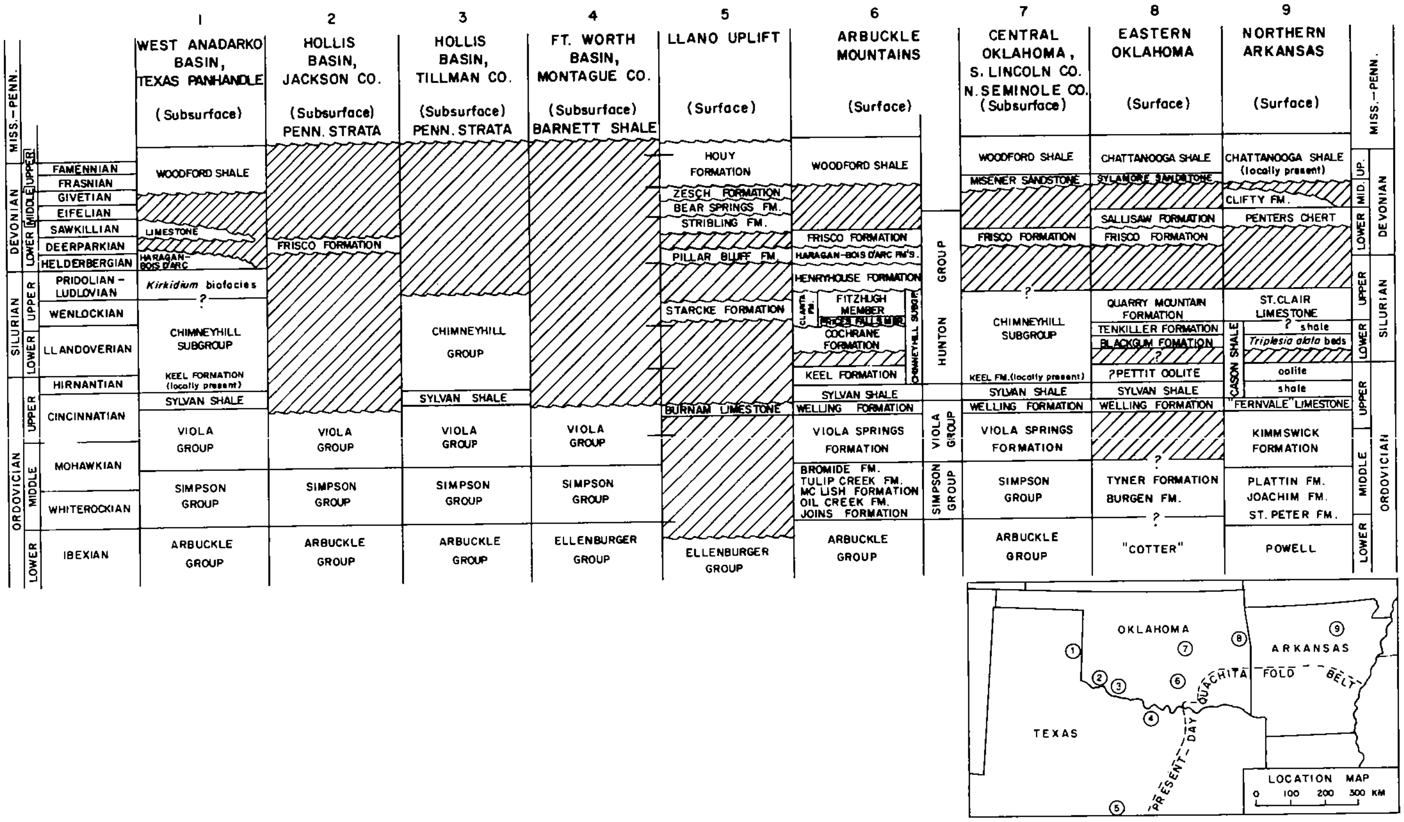


Figure 4. Correlation chart for Ordovician, Silurian, and Devonian strata in the Texas Panhandle, Oklahoma, north Texas, and northern Arkansas. From Amsden (1980) and unpublished data, Amsden and Sweet (1983) and Bozovitch (1963).

Throughout this area the Sylvan includes graptolites and chitinozoans, but no shelly benthic fauna. In western Arkansas it grades into the lower part of the Cason Shale (Fig. 4), which contains much silt-size detritus. In the western part of Oklahoma and the Texas panhandle, the Sylvan Shale becomes increasingly calcareous and locally grades into argillaceous skeletal carbonate (Plate 5-E). The absence of benthic shelly faunas over most of the Sylvan area has commonly been attributed to deep and/or cold water, but the condition can be reasonably explained by assuming that the influx of fine detritus was rapid enough to prevent colonization of the sea floor by benthic organisms. This explanation is in accord with the presence of benthic shelly faunas in the western part of the Sylvan sea, in a region well removed from the source of the terrigenous material. The Sylvan is truncated by erosion around the margins of the Oklahoma Basin and along the Wichita-Amarillo Uplift, but the remaining Sylvan thickens toward the south-central part of the basin where it is in excess of 100 m (Plate 5-E).

The base of the Hunton Group is the Late Ordovician (Hirnantian) Keel oolite, which is a part of an oolitic facies distributed over a wide area in eastern North America, and which represents a shoaling of the water probably related to the eustatic lowering of sea level during North African glaciation. The Keel is overlain by the generally clean-washed skeletal limestones of the Chimneyhill Group. Some silt and clay-size detritus was introduced during Chimneyhill time, but this was largely restricted to the southeastern areas bordering the Ouachita Province (Plate 5-F). The volume of detritus increased sharply in the Late Silurian (Henryhouse) and Early Devonian (Haragan-Bois d'Arc), extending much farther west into the Anadarko Basin. Late Ordovician (Keel), Silurian (Chimneyhill, Henryhouse), and Early Devonian (Haragan–Bois d'Arc) strata in the northern and western part of this region are moderately to heavily dolomitized (Plates 5-F and 5-G), and are a part of the North American Silurian dolomite province, which occupied the continental interior (Amsden, 1975, 1980; Berry and Boucot, 1970). Following deposition of Helderbergian-age strata, the entire area was uplifted and eroded. When deposition resumed, the flood of detritus had ceased, and the Frisco Formation (Deerparkian) is everywhere a clean-washed, low-magnesium limestone.

Latest Early Devonian (Sawkillian) strata are represented by cherts and cherty limestones (Penters and Sallisaw) in the east, grading into clean-washed skeletal limestones in the west (Plate 5-G). The only Middle Devonian strata presently recognized in

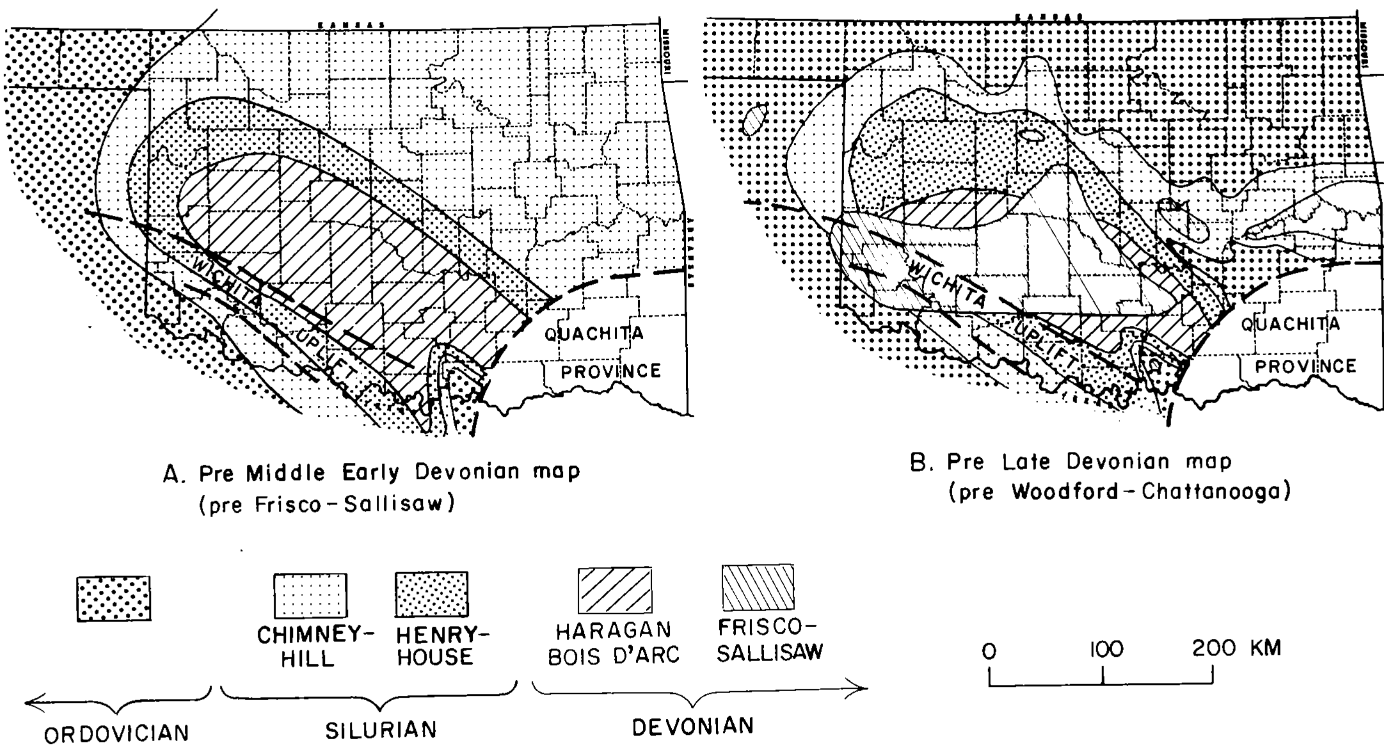


Figure 5. Paleogeologic maps showing inferred distribution of strata in the Oklahoma Basin following two major epeirogenic uplifts. Map A shows pre-middle Early Devonian strata (pre-Frisco-Sallisaw Subcrop map); map B shows pre-Late Devonian strata (pre-Woodford-Chattanooga subcrop map). After Amsden (1980, Figs. 18, 23).

this region are the Clifty Sandstone present in a small area in northwestern Arkansas, and locally the Misener Sandstone in north-central Oklahoma.

Following Early Devonian sedimentation, the area was uplifted and exposed to erosion (Fig. 5B), during which time extensive dissolution and channeling occurred. In late Middle Devonian to early Late Devonian time the Woodford-Chattanooga sea advanced from the east, burying the old erosion surface under a blanket of dark-gray to black, fine silt and clay. Where the advancing sea encountered weathered clastic debris on the underlying eroded surface, this material was incorporated into the basal sediments (Sylamore-Misener Formations). Conditions on the sea floor during deposition inhibited almost all benthic organisms, probably the result of anaerobic conditions and/or a high rate of siltation. Woodford-Chattanooga sediments covered most of the Oklahoma Basin (Plate 5-H).

A sparse representation of middle Paleozoic strata is present in the Llano Uplift region centering around Marble Falls, Burnet County, central Texas. These strata are preserved mainly as infilling or collapse sediments in joints and caves located in Early Ordovician strata of this region. Most formations are represented by very thin sequences of carbonate or cherty carbonate strata whose relationships are not well understood. The stratigraphic units recognized by Seddon (1970) are herein represented in Figure 4. The Burnam Limestone has a conodont fauna of Late Ordovician age. The Starcke (Silurian) and Pillar Bluff (Early Devonian) have a brachiopod and conodont fauna, enabling correlation with equivalent units to the north. The Stribling, Bear Springs, and Zesch Formations consist of sandy and/or cherty limestones that yield brachiopods and conodonts, mainly of Middle Devonian age (Barnes and others, 1947; Seddon, 1970). The Houy Formation comprises several lithologies whose stratigraphic relations are uncertain, but conodont studies indicate a late Middle Devonian to earliest Mississippian age (Seddon, 1970; Kier and others, 1979).

MISSISSIPPIAN SYSTEM

Kenneth S. Johnson

During the Mississippian Period, broad epeirogenic movements continued throughout the Southern Midcontinent. Deposition of shallow-marine limestones and shales was predominant, and in the middle of Mississippian time, cherty limestone deposi-

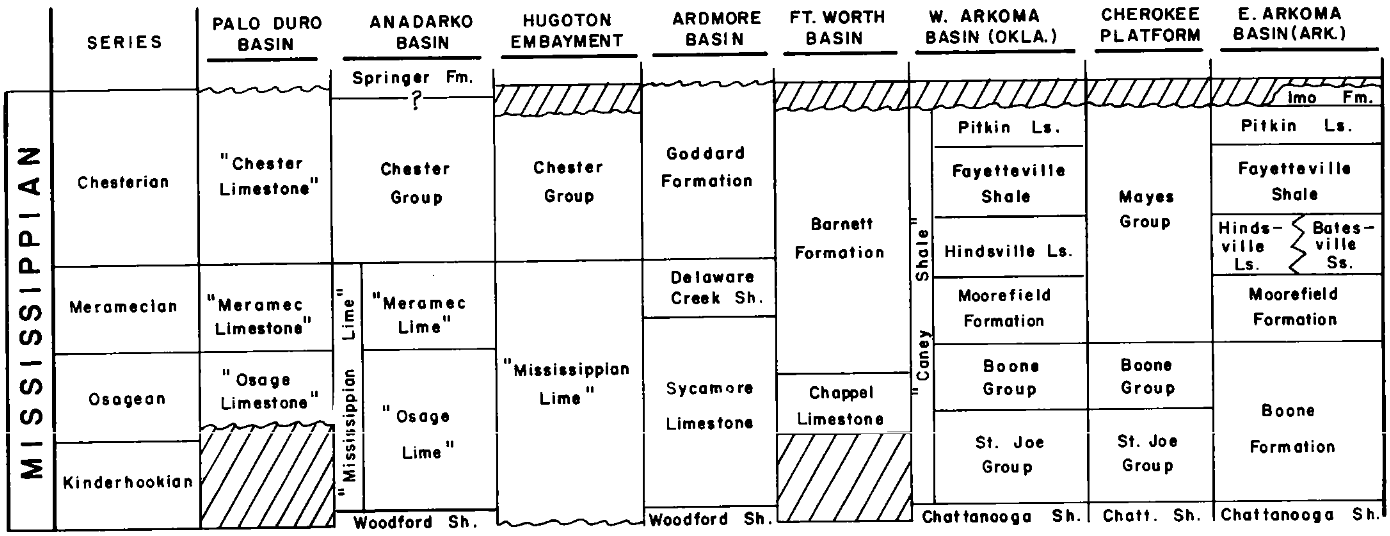


Figure 6. Correlation of Mississippian stratigraphic units in the Southern Midcontinent, based upon COSUNA charts (Hills and Kottlowski, 1983; Mankin, 1987).

tion was widespread. Major tectonic features that influenced Mississippian sedimentation include the Oklahoma Basin, the Texas Arch, and the Ozark Uplift; most other regions of the Southern Midcontinent were low-energy shelves or platforms. Correlation of Mississippian stratigraphic units in various parts of the Southern Midcontinent is shown in Figure 6. Principal sources of data on the Mississippian System are by Craig and others (1979), Glick (1979), Frezon and Jordan (1979), Mapel and others (1979), Goebel and Stewart (1979), Ebanks and others (1979), Thompson (1979), Haley and others (1979), Fay and others (1979), Kier and others (1979), and Sable (1979).

Although most of the Woodford-Chattanooga Shale is Late Devonian in age, Mississippian conodonts occur in the top few meters at several localities (Frezon and Jordan, 1979). Commonly, however, the base of the lowest Mississippian (Kinderhookian Series) is placed arbitrarily at the top of the Woodford-Chattanooga Shale. This easily recognized rock-stratigraphic boundary is more indicative of paleotectonic change than is the time-stratigraphic boundary within the upper part of the Woodford-Chattanooga Shale (Frezon and Jordan, 1979).

After withdrawal of the euxinic seas in which the organic-rich black shales of the Woodford-Chattanooga were deposited, the region was inundated in Kinderhookian time (Plate 5-I) by shallow, well-oxygenated, marine waters that originally covered all areas except the Texas Arch and the Llano Uplift. The limestone-shale sequence is less than 30 m thick in the northeast, is typically 15 to 60 m thick in the northwest, and was largely removed from the central and southern parts of Oklahoma by post-Kinderhookian erosion. Sandstone and fine-grained clastics in the northern Texas panhandle are marginal marine deposits on the north flank of the Texas Arch, which itself was inundated by the sea shortly after Kinderhookian time.

The Osagean sea occupied most of the continental interior, and sedimentation in the Southern Midcontinent occurred in aerated, warm, shallow seas that were stirred by currents or waves that gently affected the sea floor. Limestone and cherty limestone were the dominant sediments (Plate 5-J). A rich marine fauna, principally crinoids, flourished in the Osagean sea. The region was affected only by slight epeirogenic movements during the Osagean Epoch. Gentle subsidence or uplift of 100 m or less was enough to cause large areas to be submerged by, or emergent from, the shallow sea. With subsidence of the Texas Arch and Llano Uplift area, marine carbonates were deposited across parts of these provinces. Much of the Osagean rock now present in the Llano Uplift area is preserved as collapse blocks in sinkholes that formed during Meramecian uplift and erosion.

Chert, which occurs in most Osagean rocks, is a replacement of carbonate by silica. Chert generally comprises 10 to 30 percent of the units denoted as cherty limestone or cherty shale on Plates 5-J and 5-K. Principal outcropping cherty beds are in the Boone Formation (or Group) on the flanks of the Ozark Uplift in Arkansas, Missouri, and Oklahoma. The chert locally occurs as interbeds with limestone, as sheetlike masses, and as small- to moderate-sized nodules. Replacement by chert ranges from early diagenetic to postlithification of host limestones, but the source of silica (hydrothermal sources, or spicules from siliceous sponges, or other sources) is uncertain (Giles, 1935; McKnight and Fisher, 1970; Sable, 1979).

Terrigenous clastic sediments are present in many of the Osagean units in the region, but they occur mainly as disseminated clays and silts, and only locally as discrete shales. Carbonates grade southward into shale toward the Ouachita Trough in Arkansas. In the eastern part of the present Arkoma Basin, a tongue of silt and clay extends north-south, reflecting deposition along the seaward extension of a stream system that headed far to the north (Glick, 1979).

The maximum thickness of Osagean strata is in the western part of the Oklahoma Basin where 225 m of cherty limestone is preserved (Plate 5-J). In most other areas, Osagean strata typically range from 50 to 100 m thick. Thickness variations result mainly from post-Osagean erosion. Epeirogenic uplift during Meramecian time caused erosion of Osagean strata deposited in central and southern Oklahoma, and uplift during Meramecian and early Chesterian time caused denudation of Osagean strata in the present Forth Worth Basin area. Removal of Osagean strata along the Wichita-Amarillo Uplift and the Matador Arch resulted mainly from tectonic movements during Pennsylvanian time.

Meramecian marine environments in the Southern Midcontinent resembled those of the Osagean Epoch. Shallow, well-aerated, warm seas were widespread and favored deposition of fossiliferous (commonly crinoidal) and oolitic limestones with some interbeds of claystone, shale, and siltstone (Plate 5-K). Most of the region was a carbonate shelf, and chert formation, similar to the Osagean occurrences, was largely restricted to the northern half of Oklahoma and northwestern Arkansas. The presence of oolitic limestone in many parts of Arkansas, Oklahoma, and Texas indicates that the shallow sea bottom was more agitated by wave and current action during the Meramecian than at other times during the Mississiippian.

In the Arkoma Basin area the Meramecian carbonates grade southward into calcareous shales deposited in and adjacent to the Ouachita Trough. These fine-grained clastics were carried into northeastern Arkansas by streams, and also were transported across the Ouachita Trough from eastern and southeastern sources (Glick, 1979). According to Frezon and Jordan (1979), a depression extended to the west and northwest of the Ouachita Trough across a shoal area into the Oklahoma Basin. The shoal area, which apparently was in the vicinity of the future Arbuckle Mountains, was a high-energy environment where fine-grained clastics were winnowed and transported westward to a low-energy environment in the central part of what would become the Anadarko Basin (Plate 5-K).

There was little or no tectonic activity in the Southern Midcontinent during the Meramecian Epoch. Epeirogenic movements in mid-Meramecian time raised the Ozark region slightly above sea-level, and in late-Meramecian time the Fort Worth Basin area was elevated (Mapel and others, 1979), causing erosion of Meramecian and much of the Osagean strata.

Thickness variations in the Meramecian result mainly from post-Meramecian erosion. In most areas the thickness now ranges from 50 to 150 m; the maximum preserved thickness is nearly 400 m in the western part of the Anadarko Basin. In this area, sedimentation probably was continuous from Meramecian into Chesterian time. Small areas where Meramecian strata are missing—over the Matador Arch, in southern and central Oklahoma, and along the Nemaha Uplift in northern Oklahoma and southern Kansas—result from post-Mississippian tectonic uplift and erosion.

Chesterian seas covered all parts of the Southern Midcontinent, although epeirogenic movements and eustatic changes of sea level caused intermittent emergence of many areas. In much of the region the Chesterian sequence consists of shale with some limestone and marginal sandstones in the lower part, and limestone with some shales in the upper part (Plate 5-L). These strata were deposited in normal marine waters, although the shales were generally laid down in somewhat deeper and more turbid waters than were the limestones.

The Ouachita Trough became an increasingly important factor affecting sedimentation in parts of the Southern Midcontinent during Chesterian time. By now the trough was subsiding sharply along the arcuate trace of the present-day Ouachita Fold Belt. Shales, which reach 1,500 m in thickness within the Ouachita Trough, extend to the north and west into the area of the future Arkoma, Ardmore, and Fort Worth Basins where they interfinger with overlying shelf limestones. The river system in eastern Arkansas broadened to become the Ancestral Mississippi Embayment (Glick, 1979), and this introduced a thick sequence of clastics into the northern part of the Arkoma Basin.

Many of the apparent lithologic changes in Chesterian rocks shown on Plate 5-L do not result from facies variations during deposition. Instead, the changes commonly reflect the amount of post-Mississippian uplift and the depth of erosion around the margins of some of the basins; the upper limestone units have been removed, leaving only the lower shaley units at the basin margins. This is especially evident around the Palo Duro and Hardeman Basins, the Hugoton Embayment area, and the north, west, and south margins of the Fort Worth Basin. Post-Mississippian uplift and erosion along the Nemaha Uplift also account for the absence of Chesterian strata that were originally deposited across the large area that broadens northward in central Oklahoma. Areas where lithologic changes from limestone to shale do occur depositionally are in eastern Oklahoma and the central part of the Anadarko Basin.

The thickest Chesterian rocks in the region are the 600 m of shales in the eastern part of the Arkoma Basin (Plate 5-L), where these strata thicken sharply into the Ouachita basinal facies. Also, about 500 m of shales and limestones are present in the deep Anadarko Basin area. Maximum thicknesses of Chesterian strata in the northeast parts of the Fort Worth and Hardeman Basins are preserved in downthrown blocks on the south side of post-Mississippian faults.

Although the top of the Mississippian System is well marked by a pre-Pennsylvanian unconformity in most parts of the Southern Midcontinent, the Mississippian-Pennsylvanian boundary occurs within the thick sequence of Springer and equivalent shales where sedimentation was uninterrupted in the deep parts of the Anadarko, Ardmore, and Arkoma Basins. These Springer clastics are commonly grouped with the overlying Morrowan strata, from which they are not easily distinguished (McKee and others, 1975), and in this chapter they are described in the separate basin discussions that follow.

Total thickness of the Mississippian is greatest in the western part of the Anadarko Basin (about 1,000 m) and in the southern part of the Arkoma Basin of Arkansas (more than 750 m; Craig and others, 1979). The Mississippian is about 350 m thick in the northeastern part of the Fort Worth Basin, about 250 m thick in the south-central part of the Palo Duro Basin, and 400 m thick in the northern part of the Hardeman Basin. Elsewhere the Mississippian is commonly 100 to 200 m thick. Thickening of the entire Mississippian into the several major basins results partly from depositional thickening toward centers of ancestral basins that were to become predominant in Pennsylvanian time, but also partly from intermittent Mississippian and Pennsylvanian uplift and truncation along the margins of these basins.

PENNSYLVANIAN AND PERMIAN ROCKS

REGIONAL STRATIGRAPHIC FRAMEWORK

Kenneth S. Johnson

Great changes took place in the Southern Midcontinent in Late Mississippian and Pennsylvanian times. Epeirogenic movements and deposition of relatively simple shelf sequences of carbonates (with some shales and sandstones) over vast regions of the Oklahoma Basin, which were typical in the Early and Middle Paleozoic, ended with a series of orogenic movements that subdivided the region into the various tectonic provinces that are so easily recognized today (Plate 5-A). First, an episode of Late Mississippian–Early Pennsylvanian epeirogenic uplift throughout most of the region was accompanied by erosion and development of the pre-Pennsylvanian unconformity that is present in all areas, except where sedimentation was apparently continuous in the deep Anadarko and Ardmore Basins. Then a series of pulses in the Ouachita orogen and the Southern Oklahoma Aulacogen through Early and Middle Pennsylvanian time caused, or contributed to the following: folding and thrusting of the Ouachita Foldbelt; raising of the Amarillo, Wichita, Criner, Arbuckle, Nemaha, Matador, Red River-Electra, and Muenster Uplifts; pronounced downwarping of the Anadarko, Ardmore, Marietta, Arkoma, and Fort Worth Basins; and moderate subsidence of the Hugoton Embayment and the Palo Duro, Hardeman, and Dalhart Basins. Therefore, further discussion of geologic evolution of the Southern Midcontinent must focus on the individual basins into which the region was divided.

Pennsylvanian strata of the region can be characterized as sequences of marine and nonmarine shale, sandstone, conglomerate, and limestone that thicken markedly into the rapidly subsiding basins (Plates 5-M to 6-Q). The thick wedges of terrigenous clastic sediments were shed from nearby uplifts; thinner carbonate sequences were deposited on shallow-water shelf areas distal to the uplifts. Successively younger Pennsylvanian units commonly overlap older units at the margins of the basins and across some of the uplifts. Thin coal beds are abundant in Desmoinesian strata, mainly in the Arkoma Basin and on the Cherokee Platform. Total thickness of Pennsylvanian strata in the various basins is as follows: Anadarko, Ardmore, Marietta (Texas portion), and Arkoma Basins, at least 5,000 m; Fort Worth Basin, 2,000 m; Hardeman Basin, 1,200 m; Palo Duro Basin, 1,000 m; and Dalhart Basin, 750 m. In most of the shelf or platform areas, Pennsylvanian strata are typically 500 to 1,200 m thick.

In Permian time, a fairly well-defined seaway extended north-south from west Texas across the western half of the Southern Midcontinent. Coarse clastics were eroded from the Ouachita lowlands on the east, the ancestral Rocky Mountains (Sierra Grande and Apishapa Uplifts) on the west, and the Amarillo-Wichita Uplift in the center (Plates 6-R to 6-U). Early Permian (Wolfcampian) carbonates and shales, mostly red beds, in the region are overlain by a major evaporite and red-bed sequence (of Leonardian, Guadalupian, and Ochoan age) deposited north of the carbonate reefs that fringed the Midland and Delaware Basins of west Texas and southeast New Mexico. Evaporites (salt and gypsum/anhydrite) thicken into the various basins that continued to subside more than the adjacent uplifts and arches. The maximum thickness of Permian strata in the various basins is about 2,000 m in the Anadarko and Palo Duro Basins, 1,500 m in the Dalhart Basin, and 1,200 m in the Hardeman Basin. Permian strata typically are 600 to 1,200 m thick in nearby shelf or platform areas.

ANADARKO BASIN AND HUGOTON EMBAYMENT

Bailey Rascoe, Jr., and Kenneth S. Johnson

INTRODUCTION

The Anadarko Basin is the deepest interior cratonic basin in the conterminous United States. As much as 12,000 m of Paleozoic sedimentary rocks are present along the axis at the southern margin of this asymmetrical basin, and there may be another 6,000 m of Cambrian-age layered igneous rocks (mainly rhyolite flows and granite sills) beneath the Paleozoic sediments. In the western part of the Anadarko Basin the Paleozoic strata are only 4,000 to 5,000 m thick and they rest directly upon Precambrian igneous and metamorphic rocks (Fig. 7). The Hugoton Embay-

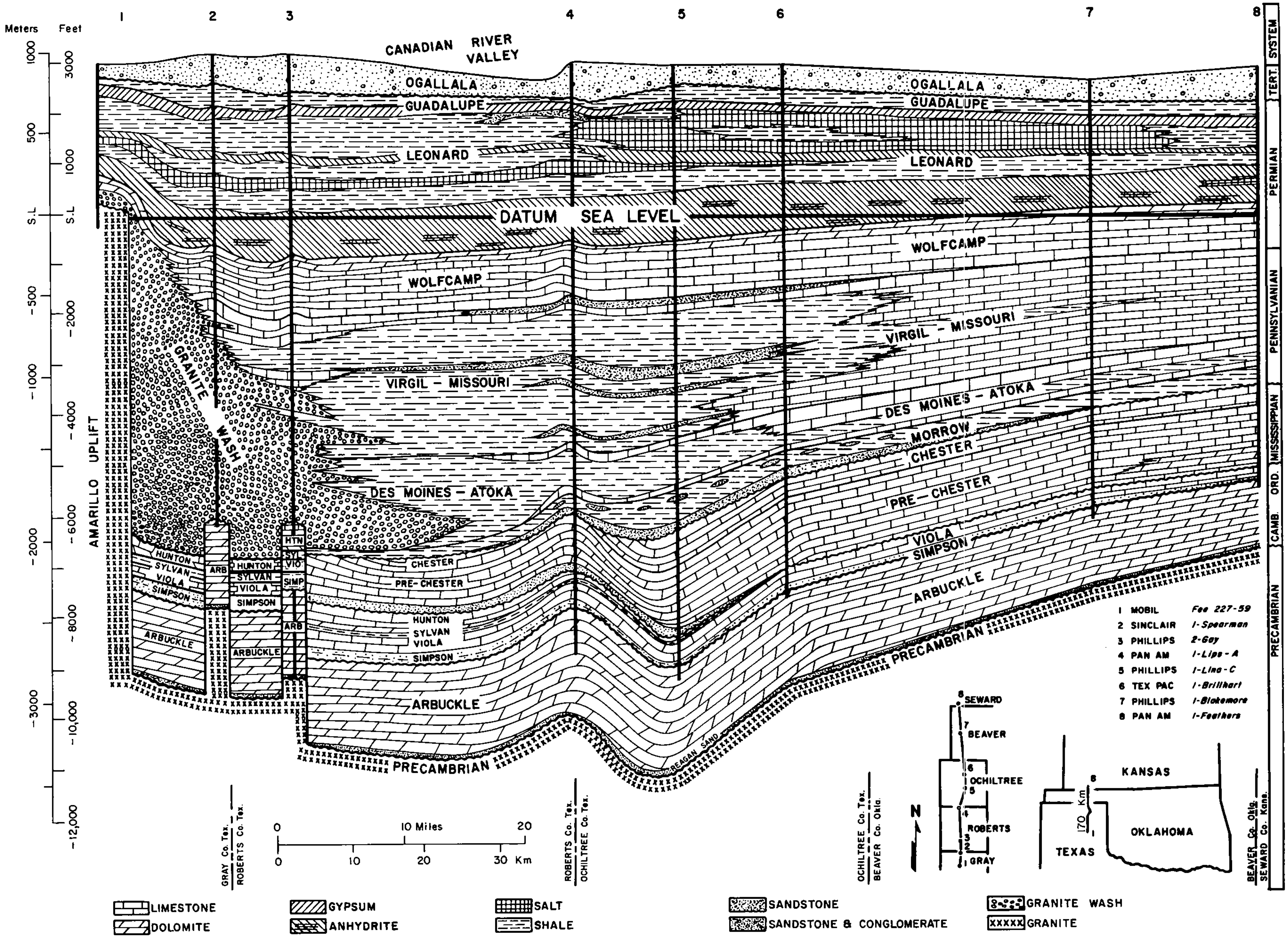


Figure 7. North-south structural cross section in the western part of the Anadarko Basin (modified from Adler and others, 1971).

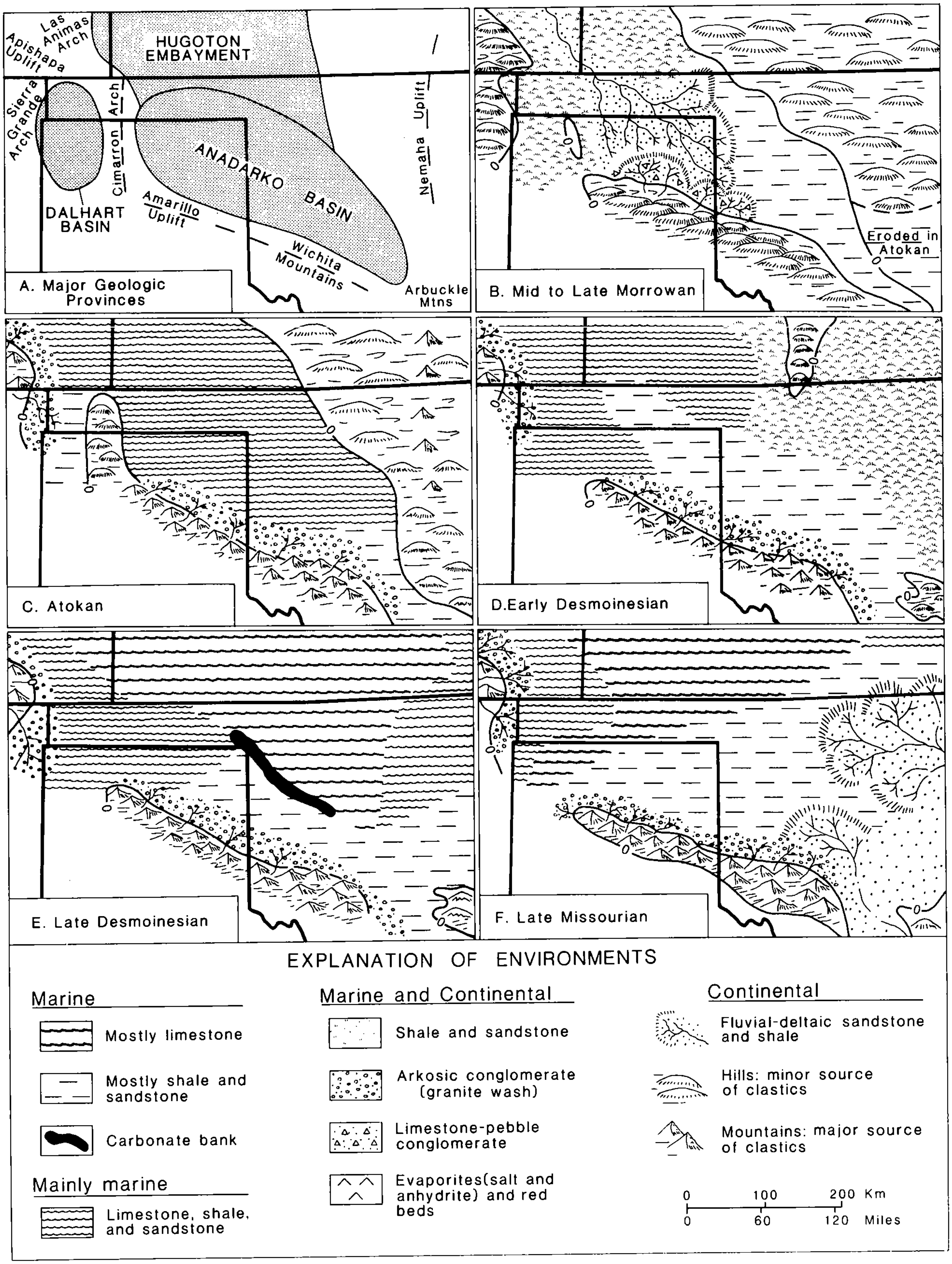
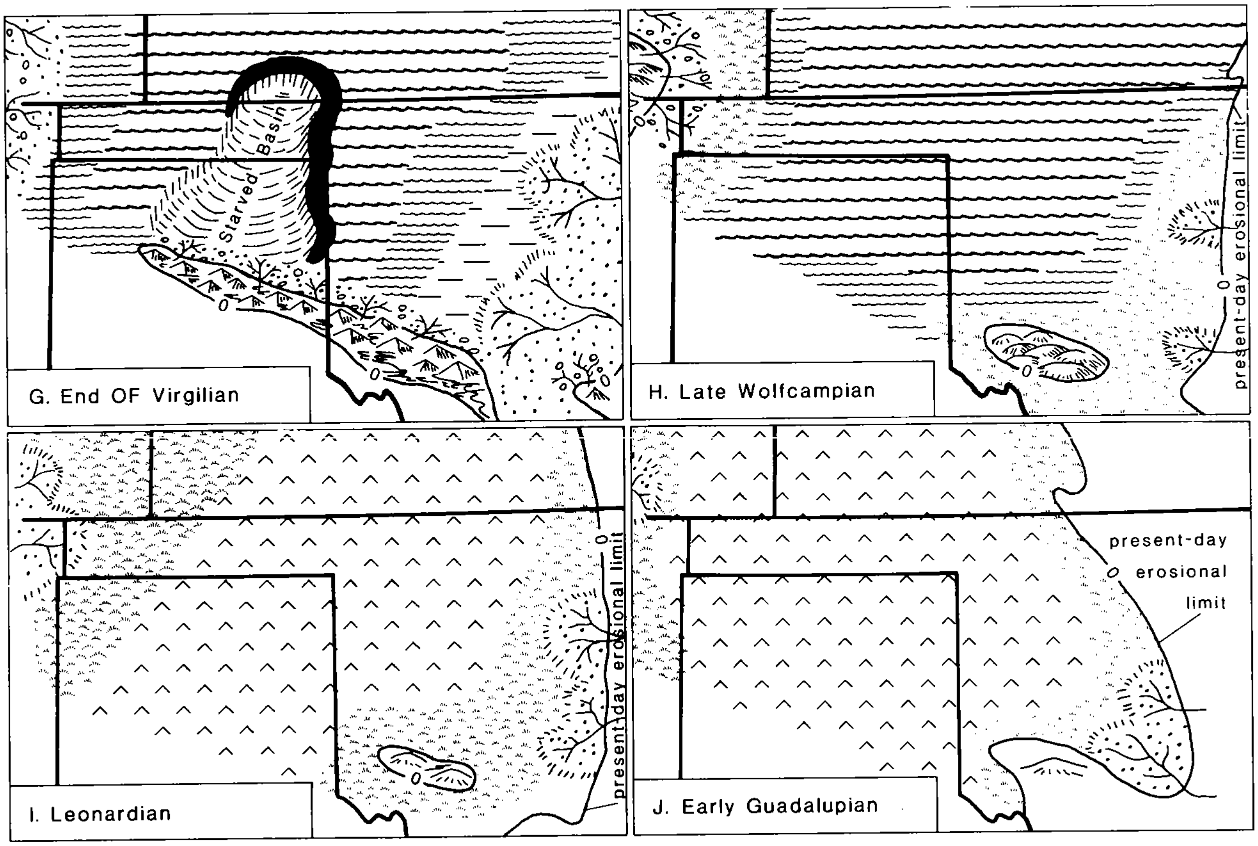


Figure 8. Paleogeography of the Anadarko Basin, Hugoton Embayment, and surrounding areas in Pennsylvanian and Permian times. Maps B through H modified from Rascoe and Adler (1983).



ment, and other areas on the far-northern shelf of the Anadarko Basin, generally contain 2,000 to 3,000 m of Paleozoic sediments resting upon a Precambrian granitic basement.

The Anadarko Basin and adjacent Wichita-Amarillo block subsided together as part of the Oklahoma Basin during early and middle Paleozoic time, and received as much as 4,500 m of pre-Pennsylvanian sediments. The Wichita-Amarillo Uplift was separated from the Anadarko Basin during late Morrowan and early Atokan time by a series of high-angle reverse faults, with displacements of as much as 12,000 m. The basin subsided markedly and received approximately 7,500 m of Pennsylvanian and Permian sediments. The orogenic episodes resulted mainly in block faulting and some folding along the margins of the basin; there was no igneous activity accompanying the tectonism.

The western margin of the Anadarko Basin is formed by the Cimarron Arch, which extends northward from the Wichita-Amarillo Uplift (Fig. 8A). The absence of Atokan and uppermost Morrowan rocks on the Cimarron Arch indicates that this feature was formed during the same tectonic episode as the Wichita-Amarillo Uplift. The Anadarko Basin is bounded on the east by the Nemaha Ridge. The northern shelf of the Anadarko Basin extends across much of western Kansas and is referred to, in that area, as the Hugoton Embayment. The Hugoton Embayment is bounded by the Central Kansas Uplift and the Cambridge Arch on the east and north, and by the Las Animas Arch on the west. Major Pennsylvanian-Permian stratigraphic units of the Anadarko Basin and Hugoton Embayment are given in Figure 9.

PENNSYLVANIAN SYSTEM

Morrowan Series

In most parts of the Anadarko Basin and the Hugoton Embayment, Morrowan sediments were deposited on a surface of eroded Mississippian rocks. Along and adjacent to the axis of the Anadarko Basin, Morrowan beds overlie lithologically similar Springer beds of Late Mississippian and (or) Early Pennsylvanian age. The contact of Morrowan and Springer rocks is typically difficult to determine, and in this area, deposition may have been continuous from Late Mississippian into Early Pennsylvanian time; thus, by convention, Springer strata are often grouped with the Morrowan in regional subsurface mapping (Plate 5-M).

The lower part of the Morrowan Series consists of shallow marine shales, sandstones, and limestones. These sediments, deposited in the transgressing Morrowan sea, onlap the surface of eroded Mississippian rocks and are markedly diachronous from the Anadarko Basin, where they are older, onto the shelf areas to the north and northeast where they are younger. A basal sandstone unit is a sporadic but prominent member of this transgressive sequence. Thickening of this sandstone unit appears to mark

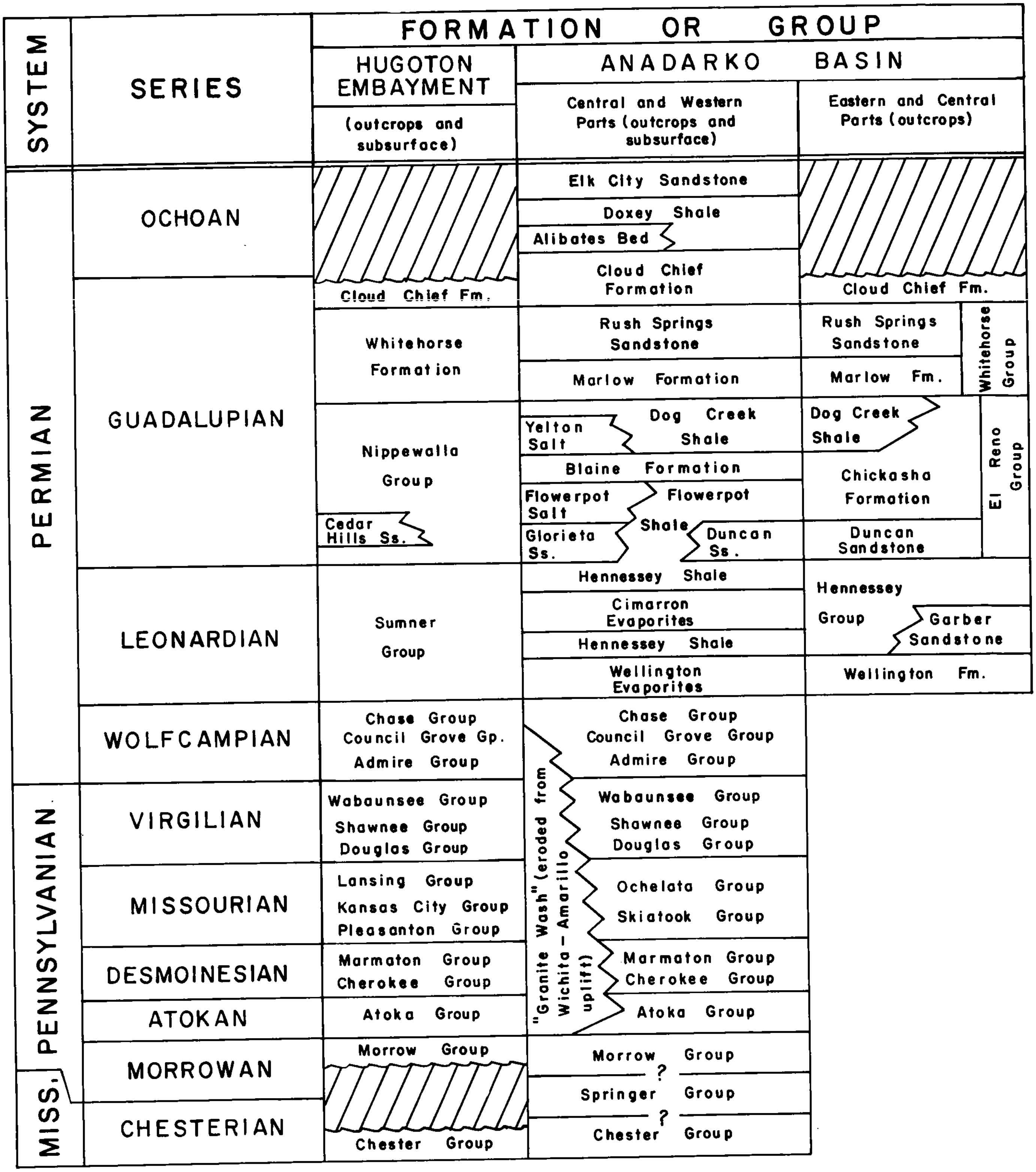


Figure 9. Stratigraphic column of Pennsylvanian and Permian strata in the Anadarko Basin and Hugoton Embayment (modified from Johnson, 1978; and Hills and Kottlowski, 1983).

the positions of ancient shorelines, which formed during stillstands of the Morrowan seas. Carbonate cement is a common constituent of these basal sandstones: it was probably introduced into the marginal marine environment by streams that flowed across the carbonate terrain of exposed Mississippian rocks and emptied into the Morrowan seas (Adams, 1964).

These transgressive lower Morrowan beds are overlain by a sequence that consists principally of shales with lenticular, discontinuous sandstones and minor conglomerates, coals, and thin, dark limestones. This upper Morrowan section is the product of a prograding deltaic phase (Fig. 8B) with the following environmental facies (Swanson, 1979): point-bar and stream-mouth-bar sandstones and conglomerates, prodelta shales, backswamp-marsh shales, and meander-channel-fill sandstones and shales.

Morrowan thickness patterns (Plate 5-M) were strongly influenced by several major tectonic elements: the Anadarko Basin, the Cimarron Arch, and the Dalhart Basin. The Wichita-Amarillo Uplift did not exist at the beginning of Morrowan time, based on two lines of evidence: first, a facies of "granite wash" (arkosic sandstone and/or conglomerate eroded from a nearby granitic terrain) from a southern source, which characterizes Middle and Upper Pennsylvanian units, is not present in the Morrowan section (Fig. 9), thus indicating the absence of the Wichita-Amarillo source area; and second, the intersection of Morrowan thickness patterns with the Wichita-Amarillo Uplift indicates that the formation of that structure followed Morrowan deposition. Shelby (1979) and Evans (1979) have described and mapped upper Morrowan fan-delta chert conglomerates in the Texas panhandle and western Oklahoma. The Wichita-Amarillo Uplift was the source area for these clastics, which were derived by the weathering of cherty limestones and dolomites of Mississippian age. The presence of these chert conglomerates in the upper part of the Morrowan Series dates the initiation of the Wichita-Amarillo Uplift.

Atokan Series

Atokan rocks in the Anadarko Basin and the Hugoton Embayment consist of a cyclic sequence of thin marine limestones and shales (Fig. 8C; Plate 5-N). These sediments compose the so-called "thirteen-finger limestone" of the Atoka Group, and the Atokan age of these rocks was established by the sparse occurrence of *Fusulinella* (Maher, 1948; Lee, 1953). This rock unit is generally 20 to 30 m thick, and the cyclic arrangement of these Atokan limestones and shales resembles the lower Desmoinesian section, which conformably overlies the Atokan.

Along the northern margin of the Wichita-Amarillo Uplift, Atokan limestones and shales grade abruptly into the massive clastic deposits, which consist of granite, limestone, and dolomite fragments. In this "granite wash" sequence the boundaries of the Atokan Series are uncertain; however, the Atokan appears to thicken into this clastic facies so that a maximum thickness of several hundred meters is possible.

In the Anadarko Basin the contact of the Atokan Series with the underlying Morrowan Series ranges from gradational to disconformable. On the northern shelf of the Anadarko Basin, Atokan sediments locally overstep the limit of the Morrowan Series and unconformably onlap rocks of Mississippian age.

Along the southern margin of the Anadarko Basin, pre-Atokan rocks underwent intense folding and faulting as a result of the Wichita orogeny of late Morrowan–early Atokan time. Consequently, Atokan rocks are commonly absent on local positive structures. Erosion of the carbonate and igneous terrain of the emerging Wichita-Amarillo Uplift continued during Atokan time. The Cimarron Arch, which strikes northward across the Texas and Oklahoma panhandles from the western termination of the Wichita-Amarillo Uplift, also experienced uplift in late Morrowan–early Atokan time; as a result Atokan rocks are not present on this arch.

Except for the "granite wash" facies, the relatively thin sequence of Atokan limestone and shale in the Anadarko Basin contrasts markedly with the thick series of Atokan clastic rocks in the Arkoma Basin. These differences are attributed to the rapid subsidence of the Arkoma Basin during Atokan time (in response to downwarping of the adjacent Ouachita geosyncline) compared to the slower, more stable subsidence of the Anadarko Basin. The Anadarko and Arkoma Basins were separated in Atokan time by uplift of a series of narrow, north-trending fault-block mountains along the Nemaha Uplift (Fig. 8C), and broad arching of most of central and northern Oklahoma (also called the Central Oklahoma Arch).

Desmoinesian Series

In the Anadarko Basin and the Hugoton Embayment the Desmoinesian Series consists mostly of cyclic marine limestones and shales; "granite wash" constitutes the Desmoinesian section in a belt adjacent to the Wichita-Amarillo Uplift (Figs. 8D and 8E; Plate 5-O). The lower part of the cyclic marine section is the Cherokee Group, which consists of numerous thin limestones interbedded with shales; on the northern shelf area in Oklahoma, lenticular point-bar and channel-fill sandstones occur in the Cherokee Group. In northwestern Oklahoma and the Texas and Oklahoma panhandles the proportion of limestones to shales is roughly equal. Eastward the increase in limestones in the Cherokee Group is gradual until along the Nemaha Uplift the ratio of limestone to shale is approximately 10:1. The Cherokee is conformably overlain by the Marmaton Group. In the Hugoton Embayment the Marmaton consists of four prominent limestone formations (Lenapah, Altamont, Pawnee, and Ft. Scott, in descending order); in the Anadarko Basin the Marmaton is composed of the Big Limestone (above) and the Oswego Limestone (below). Thickness of the Desmoinesian Series ranges from less than 75 m on the north, to more than 1,500 m along the foredeep of the Anadarko Basin (Plate 5-O).

Desmoinesian rocks conformably overlie the Atokan Series in the Anadarko Basin and the Hugoton Embayment; over this region these strata are very similar, so that the Atokan-

Desmoinesian boundary is difficult to determine. Missourian sediments are mildly disconformable on Desmoinesian strata.

Desmoinesian sediments overstep the limits of the Atokan Series on the northeastern margin of the Anadarko Basin, and onlap pre-Pennsylvanian rocks across the Nemaha Uplift. Thus, the thickness patterns of the Desmoinesian Series reflect the influence of regional positive and negative tectonic elements such as the Nemaha Ridge, the Central Kansas Uplift, the Cimarron Arch, and the Dalhart and Anadarko Basins. The Wichita-Amarillo Uplift continued to rise and to serve as a source of arkosic clastic sediments within the Anadarko Basin.

Missourian Series

The Missourian Series in the Hugoton Embayment and the northern shelf of the Anadarko Basin is predominately carbonate strata with shale interbeds. In the Anadarko Basin the Missourian Series consists of shale and sandstones with minor carbonate units (Fig. 8F; Plate 5-P). Along the western margin of the Hugoton Embayment the Missourian carbonate-shale section is replaced by a clastic sequence of shales, siltstones, and sandstones, commonly red in color. On the northern flank of the Wichita-Amarillo Uplift the Missourian Series is composed of arkosic and carbonate "wash" sediments which were eroded from the uplift (Figs. 7 and 9).

Boundaries of the Missourian Series in the shelf-carbonate section have been well established on faunal and physical evidence. In the basin-clastic section, however, the upper boundary of the Missourian Series has long been a matter of some disagreement. Due to the clastic nature of the section, diagnostic fusulinid evidence is far less plentiful than in the carbonate section to the north; compounding the problem is the difficulty in carrying physical correlations across the zone of lithologic change from the carbonates into the clastics.

The major positive tectonic elements active during Missourian time were: the Arbuckle Uplift, from which conglomeratic debris was eroded; the Wichita-Amarillo Uplift, which was a source area of coarse detritus; the Apishapa Uplift, from which mostly fine-grained clastics were eroded; and the southern part of the Central Kansas Uplift, which influenced the thickness of the Missourian sediments deposited over it. In addition, the northern portion of the Cimarron Arch appears to have influenced the thickness of Missourian rocks in the western Oklahoma Panhandle and southeastern Colorado.

The Missourian cyclic limestone and shale sequence in the Hugoton Embayment is the product of eustatic sea-level changes as described by Heckel (1977) and Watney (this volume). Southward across Kansas toward the Anadarko Basin, the carbonates of the early Missourian thicken at the expense of the shales and form locally thick, linear carbonate banks. Farther south these massive carbonates are replaced abruptly by gray and tan silty shales and fine-grained sandstones; in this section of terrigenous clastics there are several regionally extensive limestone marker beds, including the Checkerboard and Hogshooter Limestones, in the Skiatook Group, and the Dewey and Avant Limestones, in the Ochelata Group. The nature of the transition from shelf carbonates into the Anadarko Basin clastics toward the south is not well understood at this time. Although it is commonly indicated that the transition is "gradational," the existence of interfingering carbonate and clastic lithologies cannot be demonstrated by subsurface well control. It appears that the terrigenous clastics in the Anadarko Basin were not deposited contemporaneously with the thick carbonate deposits, but instead were mainly coeval with shale units of the shelf.

Work in recent years indicates that the Missourian clastic section of the Anadarko Basin is composed of a number of clastic wedges of limited areal extent. Along the eastern shelf of the Anadarko Basin, Galloway and others (1977) have demonstrated the presence of three west-facing clastic wedges or "depositional episodes." In the southern portion of the Anadarko Basin the Medrano Sandstone, in the upper part of the Skiatook Group, is regarded as a delta-front sandstone unit in a clastic wedge that prograded northward. In north-central Oklahoma, work by J. Glenn Cole (personal communication, 1983) demonstrated that the Avant Limestone was deposited on the shelf surface of a northward-prograding clastic wedge, and that on the northward-dipping slope surface, the Avant thins and disappears toward the Kansas shelf: this suggests that in the Anadarko Basin, some (or all) of the carbonate marker beds in the Missourian Series are not necessarily southward projections of carbonates from the Kansas shelf section.

Virgilian Series

The Virgilian Series consists of limestones with shale interbeds in the Hugoton Embayment and adjacent shelf area. In central Oklahoma the Virgilian Series consists of continental to shallow-marine shales, siltstones, and mudstones; to the west, in the Anadarko Basin, the Virgilian is represented by prodelta shales and delta-plain sandstones (Fig. 8G; Plate 6-Q). The shelf carbonates of the Hugoton Embayment grade westward into red shales, siltstones, and some sandstones in southeastern Colorado and northwestern New Mexico. These clastic sediments were probably derived from the Apishapa and Sierra Grande Uplifts, and they represent mixed marine and continental deposits. The Apishapa Uplift was almost completely covered by Virgilian sediment. The Wichita-Amarillo Uplift remained a positive feature during Virgilian time, and coarse detritus was deposited along its northern margin.

In the early part of Virgilian time, shales and sandstones of the Douglas Group and the equivalent Vamoosa Formation were widely deposited over the Hugoton Embayment and the Anadarko Basin. The Endicott Sandstone of the Douglas Group is a prominent unit in the Anadarko Basin across western Oklahoma and the Texas Panhandle; the formation is a fining upward sequence that exhibits a sharp basal contact with the underlying prodelta-shale section. These sediments represent fluvial-deltaic environments, indicating that basin filling was nearly complete.

After Douglas sedimentation the Oread Limestone of the lower Shawnee Group was deposited; the Heebner Shale Member of the Oread Limestone is the most widely distributed of the thin, black, phosphatic deep-water shales in the Upper Pennsylvanian of the Midcontinent, as described by Heckel (1977). The Heebner Shale is believed to mark the time of maximum Pennsylvanian transgression over the Midcontinent, and this marked a fundamental change in sedimentation in the Anadarko Basin: following deposition of the Heebner Shale and the Oread cyclothem, wedges of clastic material derived from the Ouachita source area to the east-southeast accumulated along the eastern margin of the Anadarko Basin and prograded westward. These clastic wedges were deposited during the regressive phases of cyclic sedimentation in response to the lowering of sea level. The transgressive phases, in response to rises in sea level, were marked by the deposition of limestones over the Hugoton Embayment and the adjacent shelf area. These limestones are characterized by shelf-edge carbonate banks that are as much as 100 m thick and consist mainly of fossil hash and oolites. In this manner a constructional shelf was established along the eastern margin of the Anadarko Basin in Virgilian time. Thirteen of these cycles have been delineated in Virgilian time after deposition of the Oread Limestone (Rascoe, 1978). Two of these cycles correlate with the formations that compose the Shawnee Group above the Oread Limestone. The remaining eleven cycles are correlative with formations of the Wabaunsee Group.

PERMIAN SYSTEM

Wolfcampian Series

The Pennsylvanian-Permian boundary, which has not been precisely determined on the basis of floral or faunal evidence in the Anadarko Basin–Hugoton Embayment area, is placed at the top of the Brownsville Limestone of the Wood Siding Formation (top of the Wabaunsee Group) in Oklahoma and southern Kansas. In most of the region the top of the Brownsville Limestone can be readily identified on wireline logs; however, the Brownsville Limestone grades into a clastic facies in southern Oklahoma, and in the northeastern portion of the Texas panhandle the Brownsville Limestone is very difficult to identify.

Tectonic elements present in the Anadarko Basin–Hugoton Embayment region during Late Pennsylvanian time persisted into Early Permian time; however, the influence of these features diminished greatly in the Permian Period. The Wichita-Amarillo Uplift, a significant positive element during Pennsylvanian time, probably was expressed topographically as an archipelago in Early Permian time (Fig. 8H; MacLachlan, 1967). There a terrain of Paleozoic limestone and Precambrian granite was eroded, and clasts of these rocks are found in Wolfcampian sediments on the flank of the uplift (Plate 6-R). The Amarillo Uplift was finally covered by sediments in Wolfcampian time. The Anadarko Basin continued to subside in Early Permian time, but far more slowly than in the Pennsylvanian Period. As a result of continued subsidence, Wolfcampian sediments lie conformably upon the Virgilian strata within the basin, and regional lithofacies patterns of the Wolfcampian and Virgilian Series are quite similar.

In the northeastern Texas panhandle, in an area encompassing the 600 m isopach (Plate 6-R), the Wolfcampian Series consists of massive shelf-margin carbonates and thick sections of slope and basinal shale. These shelf-edge and basinal sediments are unlike the orderly succession of widely traceable shelf limestones and shales to the north in that the vertical and lateral distribution of these rocks is extremely irregular and discontinuous. These rocks infilled the "starved" Anadarko Basin of Late Pennsylvanian age. In the Texas panhandle the Wolfcampian "Brown Dolomite" (upper Council Grove Group and lower Chase Group) covered the Amarillo Uplift. Shelf areas were present to the west, north, and east of the Anadarko Basin. In a northeast-southwest belt across the Midcontinent, Wolfcampian rocks consist mainly of cyclic shallow-marine limestones and shales. These sediments make up the Admire, Council Grove, and Chase Groups; these units and many of their constituent limestone formations can be recognized over Kansas, western Oklahoma, and the Oklahoma panhandle.

Mostly fine-grained clastic red-bed sediments border this belt of limestones and shales on the east and west; these strata represent mixed marine and continental environments, and they are indicative of marine regression from the region. In south-central Oklahoma, clastic sediments considered Wolfcampian in age (and referred to the upper part of the Pontotoc Group) covered all but the highest peaks of the Wichita Uplift. And in the far western part of the region, clastic sediments regarded as Wolfcampian in age are equivalent to part of the "detrital rocks" (McKee and others, 1967, Table I) and the upper part of the Sangre de Cristo Formation of southeastern Colorado and northeastern New Mexico.

Leonardian Series

Leonardian time was marked by continued subsidence of the Anadarko Basin and the Hugoton Embayment, and by continued regression of the sea from the region. As a result, the dominant lithologies of the Leonardian Series are red beds and evaporites deposited in continental and shallowing marine environments (Fig. 8I; Plate 6-S); cyclic patterns of sedimentation suggest that eustatic fluctuations of sea level continued in Leonardian time.

Strata now cropping out on the east side of the Anadarko Basin are the Wellington and Garber Formations and the Hennessey Group. These red-bed clastic units, deposited near the eastern shore of the basin, were derived by erosion of low-land areas that extended across eastern Oklahoma and adjacent areas. The Garber and Wellington outcrops comprise a complex system of interbedded alluvial and deltaic sandstones and shales that are thickest and coarsest in central and south-central Oklahoma. These strata, and shales of the overlying Hennessey, grade westward into two thick evaporite units called the Wellington and

Cimarron evaporites (Jordan and Vosburg, 1963). The Wellington evaporites contain more than 100 to 200 m of interbedded halite, shale, and anhydrite in a unit referred to as the Hutchinson Salt, whereas the Cimarron evaporites consist of more than 200 m of interbedded salt and shale, with a medial anhydrite/dolomite called the Cimarron (Stone Corral) anhydrite. To the west these evaporites grade laterally into sandstones along the western margin of the Permian seaway. The cyclicity of the evaporites is attested by the great lateral continuity and vertical repetition of individual anhydrite, salt, and shale beds 1 to 6 m thick over vast areas of the basin.

The Wichita Uplift continued to have a modest influence on sedimentation in the Anadarko Basin. Clastic debris was shed northward onto the south flank of the basin where it interfingered with the Wellington evaporites, and to a lesser extent with the Cimarron evaporites.

Guadalupian Series

In Guadalupian time the Anadarko Basin continued to subside, and it received as much as 500 m of red beds and evaporites along its depocenter (Fig. 8J; Plate 6-T). The Wichita Uplift subsided at a somewhat slower rate than the basin, and all but the highest mountain peaks were probably buried by fine clastics.

Guadalupian strata in the area are largely unfossiliferous, and thus, age assignments are based primarily upon lithostratigraphic correlation with equivalent strata in the Palo Duro Basin and farther south. The Blaine Formation, consisting of widespread anhydrite, shale, dolomite, and halite interbeds, is equivalent to the upper part of the San Andres Formation in the Palo Duro Basin. Regional correlations show approximate equivalency of the Glorieta, Cedar Hills, and Duncan Sandstones, in various parts of the Anadarko Basin, with the San Angelo Sandstone and basal beds of the San Andres farther to the south. The top of the Guadalupian Series is in the upper part of the Cloud Chief Formation.

An episode of marine regression marked the beginning of Guadalupian time in the Anadarko Basin. Sands entered the basin from the east (Duncan Sandstone), north (Cedar Hills), and northwest (Glorieta), and graded into shales and some salts toward the central and southwest parts of the basin. The Wichita Mountains were essentially buried, and the sources for clastics deposited in the southern and eastern parts of the basin were the lowland areas of eastern Oklahoma and the deeply eroded Ouachita belt of southeastern Oklahoma and northeastern Texas.

A later marine transgression permitted 30 to 60 m of Blaine evaporites to be deposited over all of the Anadarko Basin and Hugoton Embayment area. This in turn was followed by regression that introduced sandstones and scattered thin anhydrites across much of the area in the Whitehorse Group and Cloud Chief Formation. In the eastern part of the basin the Cloud Chief locally contains 30 m of massive anhydrite (gypsum on the outcrop).

Ochoan Series

Ochoan rocks are mainly red-bed sandstones and shales, but they contain some anhydrite and dolomite (Alibates Bed) in the western part of the Anadarko Basin (Plate 6-U). Little is known about Ochoan paleogeography in and around the Anadarko Basin, but it likely was similar to that of late Guadalupian time.

The key to regional correlation and age assignment in the Ochoan is the Alibates Bed. The Alibates is equivalent to the base of the Doxey Shale and to the upper part of the Rustler Formation in the Midland Basin, thus establishing equivalency of the overlying Doxey Shale with the Dewey Lake Formation. It is presumed that the upper part of the Cloud Chief Formation in the Anadarko Basin and Hugoton Embayment is equivalent to the lower Rustler and Salado Formations of the Midland Basin area.

Outcropping Ochoan strata typically contain chaotic structures, collapse features, and other evidence of disturbed bedding due to dissolution of underlying Guadalupian halite beds along the flanks of the Anadarko Basin. Such collapse features also occur in some of the Guadalupian and post-Permian strata.

ARDMORE AND MARIETTA BASINS

Patrick K. Sutherland

INTRODUCTION

The Ardmore and Marietta basins in southern Oklahoma are highly complex structural troughs that have equally complex depositional histories. The basins form a southeastern extension of the Anadarko Basin–Wichita Mountains complex in western Oklahoma. Ham and others (1964) termed this complex the Southern Oklahoma Geosyncline because of its extraordinary scale with as much as 12,200 m of strongly deformed Paleozoic sediments and volcanic flows. They recognized its uniqueness as the deepest sedimentary trough on the North American Craton. This striking feature stands out on tectonic maps of North America; this was probably the fact that led the Soviet geologist Shatski (1946) to apply his newly defined term "aulacogen" to the feature in southern Oklahoma. As used today in the context of plate tectonics, an aulacogen is a long trough of anomalously thick sediments that extends at a high angle onto the foreland of the craton from the continental margin. It has, however, been only during the past ten years that the term Southern Oklahoma Aulacogen has been generally applied in the area. This northwest-trending structural complex is in excess of 484 km in length and about 80 km in width in the area of the Ardmore and Marietta basins. The Upper Cambrian through Upper Pennsylvanian (Missourian) strata in the Ardmore Basin are about 9,100 m thick of which 5,500 m are made up of Mississippian and Pennsylvanian strata (Ham and others, 1964).

STRATIGRAPHIC AND TECTONIC FRAMEWORK

Ham and others (1964) divided the development and filling of the Southern Oklahoma Aulacogen into three stages. The first

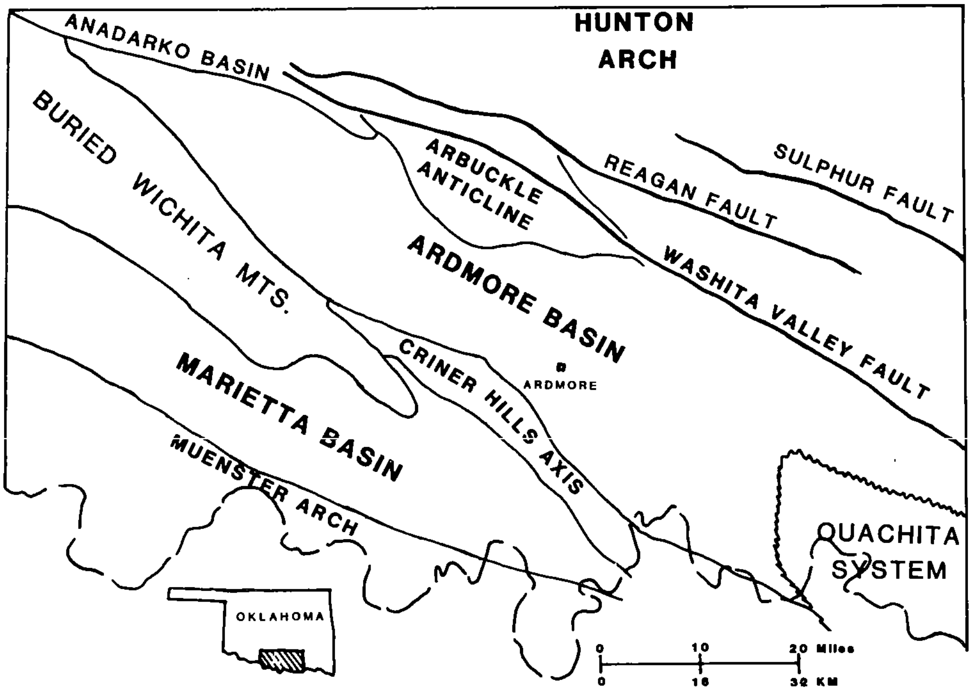


Figure 10. Southern Oklahoma fold belt showing structural provinces (modified from Hicks, 1971; but faults from Jordan, 1962).

(Rifting Stage) was marked during Early and Middle Cambrian time by the development of marginal faults and downwarp associated with both intrusive and extrusive igneous activity. The second (Subsiding Stage), during Late Cambrian through middle Mississippian time, was characterized by subsidence and the accumulation of a thick carbonate sedimentary sequence. The third (Deformation Stage), during the Late Mississippian and Pennsylvanian time, was marked by the development within the aulacogen of major elongated uplifts (e.g., Criner and Wichita Uplifts) in close proximity to long and typically deep basins (e.g., Ardmore, Marietta, and Anadarko Basins; Fig. 10) and the accumulation of a thick clastic sedimentary sequence.

The Southern Oklahoma Aulacogen, as a depositional feature, included also the area of the present Arbuckle Anticline, to the northeast of the Ardmore Basin. The northeastern boundary of the aulacogen was marked by the Washita Valley Fault, which originated in the Cambrian Period during the initial Rifting Stage of aulacogen development. It separates Precambrian granites of the Tishomingo Uplift to the northeast, which underlie the shelf, from Cambrian rhyolites to the southwest, which floor the aulacogen. Ham and others (1964) conclude that this difference in basement rock character affected the type and intensity of folding throughout the Paleozoic and that the older bordering faults associated with the first phase of Cambrian basin filling guided the structural pattern of the late Paleozoic. Thus, the Arbuckle Mountains are divided into two sections along the Washita Valley Fault. To the northeast, where Paleozoic rocks rest upon Precambrian granites, the Paleozoic strata on the craton are relatively thin and are deformed mainly by block faulting. To the southwest of the fault, in the area of the Arbuckle Anticline and Ardmore Basin, the Paleozoic strata are thick, have thick Cambrian volcanic rocks as a floor, and are much more highly deformed (Ham and Wilson, 1967).

During the early and middle Paleozoic, and extending through most of the Mississippian, the Southern Oklahoma Aulacogen was essentially a single broad depositional basin extending from the Washita Valley fault on the northeast to the Muenster Arch on the southwest (Fig. 10). The present division of the aulacogen into complex uplifts and basins is mainly the result of Pennsylvanian orogenies. Three major complex periods of folding and uplift (Deformation Stage) can be differentiated in the area of the Ardmore and Marietta Basins, as follows:

1. Late Mississippian-Early Pennsylvanian uplifts. The Wichita-Criner Orogeny is a term commonly given in the Ardmore Basin area to the time of initial folding of the Criner Hills Uplift, which provided great volumes of early and middle Paleozoic limestone cobbles to the Jolliff Formation (Morrowan) and later to the Bostwick Formation (Atokan). It is generally stated that this orogeny began in Early Pennsylvanian time (Ham and Wilson, 1967) but it, in fact, began in the Chesterian (Late

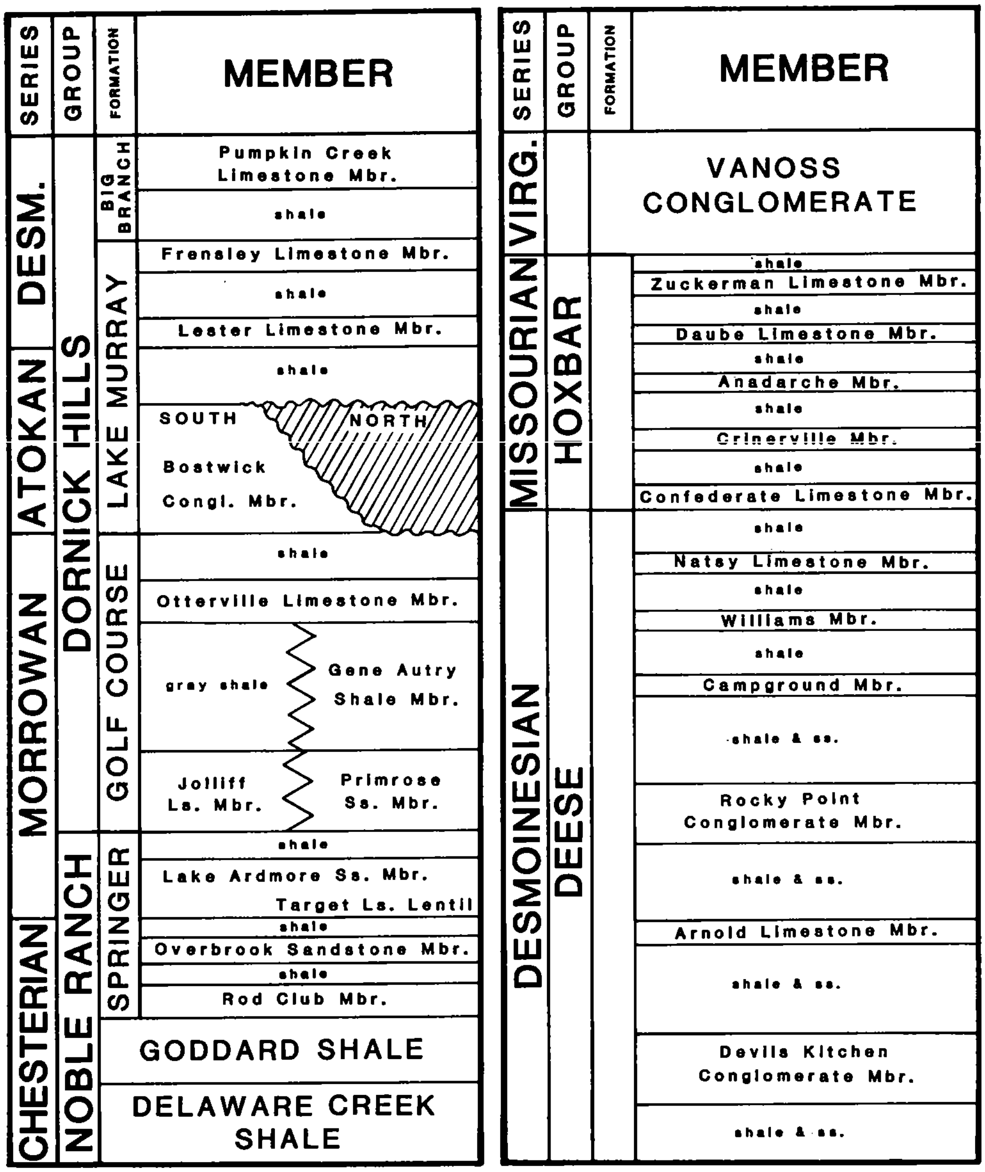


Figure 11. Columnar section of outcropping Pennsylvanian strata in the Ardmore Basin (modified from Tomlinson and McBee, 1959).

Mississippian), at least as early as the deposition of the lower part of the Springer Formation (Fig. 11). The initial folding and erosion along the Criner Hills axis during the Chesterian must have been extremely rapid in that Ordovician limestone pebbles are included in two thin lower Springer conglomerates, one first recorded by Tomlinson and McBee (1959) and the other by Lang (1966, Stop 4). The matrices from these conglomerates contain middle to late Chesterian conodonts (R. C. Grayson, Jr., personal communication, 1985). There was significant further folding during the Morrowan (Jolliff deposition) and even more profound uplift in early Atokan time (Bostwick deposition). In many areas in southern Oklahoma, particularly on crests of truncated uplifts, it is Atokan-aged strata, including conglomerates, that unconformably overlie strata as old as the Early Ordovician Arbuckle Group (Tomlinson and McBee, 1959). It is of interest to point out that the most widely developed and profound Paleozoic unconformity on the North American craton occurs below a surface that varies in age from Morrowan to Early Desmoinesian (Ham and Wilson, 1967).

It was only with the folding that marked the Criner Hills Uplift that the Ardmore and Marietta basins were differentiated for the first time (Ham and others, 1964).

2. Middle Pennsylvanian uplifts. The Criner Hills Uplift, with a northwest strike, shed limestone cobbles in a northeasterly direction in the Ardmore Basin primarily during the Morrowan and Atokan. By Middle Desmoinesian time the chert pebble conglomerates of the Devils Kitchen and Rocky Point reflect the initial uplift of the Ouachita System to the southeast (Fig. 10). On the outcrop in the southern Ardmore Basin area the southeastern source direction, particularly in the Devils Kitchen, is confirmed by the marked increase to the southeast of chert pebble size, percentage of chert pebbles, and thickness of individual chert pebble beds.

3. Late Pennsylvanian uplifts. The final and most profound structural deformation of the Southern Oklahoma Aulacogen is termed the Arbuckle orogeny and was one of strong compression and locally profound uplift, as exemplified by the Arbuckle Anticline. The Ardmore and Marietta basins and the Criner Hills were significantly deformed at this time (Ham and Wilson, 1967). A series of orogenic conglomerates, shed mostly from the Arbuckle Anticline, were deposited in southern Oklahoma during the Middle and Late Virgilian as well as the Early Permian. Those in the Ardmore Basin and around the Criner Hills, generally included in the Vanoss Formation, blanket significant parts of the area and rest with marked angular unconformity upon older rocks that range in age from Precambrian to Late Pennsylvanian (Ham and Wilson, 1967).

Evidence that the Southern Oklahoma Aulacogen was a major subsiding trough during the Late Mississippian and Pennsylvanian is provided by a comparison of thicknesses preserved in the Ardmore Basin with those on the craton to the north. In the Ardmore Basin, Chesterian and Pennsylvanian strata—composed mostly of shales and sandstones plus generally thin limestones—total as much as 5,200 m. Equivalent strata upon the craton, exposed along the northeastern margin of the Arbuckle Mountains, total about 880 m and consist mostly of shales with locally thick limestones and sandstones (Ham, 1969; Morris and Sutherland, 1984). Tomlinson and McBee (1959) provide the only detailed comprehensive description yet published of the stratigraphy and depositional history of the Ardmore Basin.

Little detailed information has been published on the stratigraphy and depositional history of the Late Mississippian and Pennsylvanian strata in the Marietta Basin; the rocks there exist completely in the subsurface are not well dated. The most striking difference in the sequence there compared to that in the Ardmore Basin is the presence of a major pre-Atokan to pre-Desmoinesian unconformity. Across the uplifted parts of the basin, Desmoinesian conglomerates generally rest directly on folded and faulted strata ranging from various formations in the Ordovician to the Devonian Woodford. Locally there are Mississippian shales preserved in the deeper basin areas possibly equivalent to some part of the Delaware Creek and/or the lower Goddard. In the Oklahoma portion of the Marietta Basin there are no strata preserved that are equivalent to the Springer or strata of Morrowan age except on the northeast flank of the basin, in the Enville–southeast Marietta field area in T.7S., Ranges 2 and 3 E. (C. D. Fenstermaker, personal communication, 1986). However, in the Gordonville Trough, a southeastern extension of the Marietta basin in Cook and Grayson Counties, Texas (not shown on Fig. 10), there are beds possibly equivalent to the Springer and also strata of possible Morrowan age (Bradfield, 1969). There are locally nonconglomeratic shales and sandstones that unconformably underlie the Desmoinesian conglomerates, but they rest unconformably on older strata; Bradfield (1959) considers these to be Atokan and possibly early Desmoinesian in age.

DEPOSITIONAL HISTORY

Introduction

In Early and middle Mississippian time the Southern Oklahoma Aulacogen was part of a broad area of starved sedimentation, and strata of these ages are thin and discontinuous. However, this trough clearly became reestablished in Chesterian time as a major subsiding basin. The aulacogen is characterized during Late Mississippian and Early Pennsylvanian time by differentiation of the basin into long, narrow, rapidly folding uplifts and basins (Fig. 10). The uplifts were deeply truncated, producing much detrital material that was deposited in the adjacent basins nearest to the uplifted sources. Deposition within the basins is characterized by marked changes in both facies and thickness as one moves away from the source areas. Some secondary structures within the basins, such as the Caddo Anticline and the Berwyn Syncline in the Ardmore Basin, show evidence of uplift and downwarp during deposition (Tennant, 1981).

Chesterian Series

Chesterian sediments in this area are mostly shales (Delaware Creek and Goddard), and source directions have not been clearly established. For the overlying Springer Formation (Fig. 11), however, paleocurrent data indicate a dominant source direction from the northwest, from the Anadarko Basin. There is also an increase to the northwest of maximum thickness of individual sandstone layers. Only rarely and locally do any Springer sandstone layers on the outcrop in the Ardmore Basin approach or exceed 12 m in thickness. In contrast, in the Sho-Vel-Tum area, located only 40 km to the northwest of the city of Ardmore, individual sandstone intervals commonly exceed 30 m in thickness. The Springer sandstones are parts of several large deltaic complexes that prograded southeastward into the Ardmore Basin. On the outcrop near the city of Ardmore, however, one sees a prodelta facies consisting mostly of shale and representing only the lower parts of deltaic sequences. They generally lack capping remnants of delta front channel or delta plain deposits. The more fully developed deltas are found in the subsurface several miles to the northwest. The Rod Club Sandstone, at the base of the Springer sequence, contains individual sandstone layers less than 3 m thick that consist of graded beds with basal flute casts (Meek, 1983). These layers represent turbidites at the far distal margin of a delta located to the northwest (Meek and others, 1983). The entire Springer sandstone sequence changes facies mostly to basinal shale in the subsurface to the southeast.

The Criner Hills axis began to be uplifted (Wichita-Criner Orogeny) in middle to late Chesterian time, as indicated by the occurrence of thin limestone-pebble conglomerates associated with Rod Club or Overbrook sandstones in the southern part of the Ardmore Basin. These conglomerates, possibly representing submarine debris via gravity flows, are thin and obscure, but the astonishing fact is that they include Ordovician pebbles, which indicates a remarkable rate of uplift and erosion along the Criner Hills axis in late Chesterian time.

Poorly dated shales that presumably correlate with the Delaware Creek and possibly the lower part of the Goddard basinal shales were deposited in the Marietta Basin area before the beginning of uplift on the Criner Hills axis. Tomlinson and McBee (1959, p. 15) postulate that the present area of the Marietta Basin formed part of a positive area, along with the Criner Hills axis, during middle and late Chesterian as well as during Morrowan times.

Morrowan Series

More profound uplift along the Criner Hills axis occurred during Morrowan time as indicated in the southern part of the Ardmore Basin by the occurrence of the Jolliff Limestone cobble conglomerates. The intensity of uplift was greatest along the buried Criner Hills axis south of the present day Criner Hills. In exposures south of Lake Murray the shale intervals between the Jolliff and Otterville and between the Otterville and Bostwick are mostly replaced by limestone cobble conglomerates (Cromwell, 1974). The Jolliff conglomerates accumulated possibly as alluvial outwash fans or as submarine fans (Maley, 1986) along the northeast margin of the uplifting Criner Hills axis but they did not extend across the Ardmore Basin to the northeast. In that area the Primrose Sandstone, with a source from the north and northwest, was being deposited simultaneously (Fig. 11), as indicated by the occurrence of similar conodont faunas in the two units (R. C. Grayson, Jr., personal communication, 1985).

South of Ardmore the base of the Jolliff conglomerates is marked by an unconformity that definitely cuts out the Lake Ardmore (Morrowan) Sandstone Member of the Springer Formation and possibly also the Overbrook (Chesterian) Sandstone Member.

The Morrowan interval in the northern part of the Ardmore Basin above the Primrose includes the Gene Autry Shale and the overlying Otterville Limestone. The Gene Autry was deposited in somewhat deeper water under more restricted conditions. The upper part shows a shallowing upward trend that continued with the deposition of the higher energy, locally shoaling, Otterville Limestone. The Otterville around the Caddo Anticline formed as an oolitic marine sand belt, which supports the conclusion that the Caddo Anticline was being slowly uplifted during the time of Otterville deposition (Maley, 1986). In the Berwyn Syncline, to the northeast of the Caddo Anticline, the Otterville consists of thin layers of fine-grained bioclastic limestone interbedded with shale, representing deposition in slightly deeper, quieter water. On the stable shelf to the northeast, as preserved in the Mill Creek Syncline, more than 120 m of cross-bedded oolitic limestones (Wapanucka Limestone) were deposited simultaneously with deposition of the aulacogen of both the upper Gene Autry Shale and the Otterville Limestone (Sutherland and others, 1982).

Atokan Series

The Wichita-Criner Orogeny intensified in Atokan time with further uplift and the deposition of the highly variable Bostwick Member along the northeast margin of the Criner Hills axis (Fig. 10). The dominant lithologies are limestone and chert pebble conglomerates interbedded irregularly with shales. As with the Jolliff, this unit is thickest, and the limestone cobbles are largest (in excess of 0.5 m) and most numerous at exposures in the southernmost part of the Ardmore Basin, indicating greatest uplift on the Criner Hills axis south of the present day Criner Hills. As with the Jolliff, the limestone cobble conglomerates did not extend northeastward across the Ardmore Basin, suggesting that the cobbles were not carried that far. However, in the northern part of the basin there is a regional unconformity at or near the base of the unnamed shale that overlies the Bostwick in the southern Ardmore Basin (Clopine, 1986; Fig. 11). This shale can be correlated across the entire basin. At several localities in the northeast, this shale—with a thin basal conglomerate and containing the upper Atokan fusulinid *Fusulinella*—rests directly on the Otterville Limestone (Morrowan). Thus, the Bostwick could have been all or partly removed in the northeast by erosion below this late Atokan unconformity.

Desmoinesian Series

By early Desmoinesian time the uplift along the Criner Hills axis had ceased and generally quiescent conditions prevailed across the Ardmore Basin. Detailed facies studies of the Lester, Frensley, and Pumpkin Creek Limestones across the Ardmore Basin show an increase in energy level to the southwest. For example, the Pumpkin Creek Limestone grades from phylloid algal wackestones in the northeast to sandy crinoidal grainstones in the southwest (Tennant, 1981). Much suspended mud was periodically introduced, as was more limited sand. Tennant (1981) records 26 independent paleocurrent flow estimates taken from cross-bedding in sandstone outcrops in this upper Dornick Hills sequence in the northern part of the Ardmore Basin. McGee (1985) made additional paleocurrent measurements in the southern part of the basin. In both areas these indicate a direction of source from the southwest. The sandstones are mostly fine grained and well sorted, and Jacobsen (1959) postulated that these sands came from the erosion of previous Springer sandstones or alternatively from a metamorphic source in the Red River–Muenster Arch, southwest of the Southern Oklahoma Aulacogen (Fig. 10). The latter would require transport across a quiescent Criner Hills and Marietta Basin. Tennant (1981) postulates just such a picture with the development of a deltaic complex prograding from the Muenster Arch, with only the prodelta and delta fringe facies reaching the Ardmore Basin to the northeast. Thus, the general depositional picture is one of alternating transgressions and regressions with the Lester, Frensley, and Pumpkin Creek Limestones representing, in a general way, periods of maximum transgression and intervening unnamed shale and minor sand intervals representing regressive cycles where prodeltaic and terrigenous shelf sediments prograded northeastward out over the carbonate facies (McGee, 1985). The detailed facies are complex; most of the thin limestone layers of the Frensley, in particular, are discontinuous laterally and in part represent deposition between prodelta lobes. The Caddo Anticline and Berwyn Syncline continued to rise and sink in early Desmoinesian time, as indicated by both the high-energy carbonate facies and thinner shale sequences on the Caddo Anticline and the lower energy carbonates and thicker shale sequences in the Berwyn Syncline (Tennant, 1981).

The deposition model just described provides a possible interpretation of the stratigraphic sequence found in the Marietta Basin. In Grayson County, Texas, resting unconformably on older strata, there is a sequence, more than 800 m thick, of gray shales, fine-grained sandstones, and thin limestones. This apparently continuous sequence is included by Bradfield (1959) in the Atokan (middle Dornick Hills), the Lower Desmoinesian (upper Dornick Hills), and the Desmoinesian "Gray Strawn" or "Deese." This interval is poorly dated paleontologically. The possibility is being suggested here that it may be in part equivalent to the Lower Desmoinesian Lester–Frensley–Pumpkin Creek interval in the Ardmore Basin and may be part of a deltaic complex directed toward the northeast from the Muenster Arch. Subsequently, part of this deltaic complex may have been removed by erosion prior to the great influx from the southeast of chert-pebble conglomerates that marked the beginning of deposition of the thick "Red Strawn" or "Deese" in the Marietta Basin and the Devils Kitchen conglomerates in the Ardmore Basin.

In the Ardmore Basin, the first indication of uplift on the Ouachita Foldbelt to the southeast is the occurrence in the southernmost exposure of the Pumpkin Creek Limestone in the Ardmore Basin (on Pumpkin Creek) of common chert granules and a few chert pebbles greater than 1.0 cm in diameter. The chert granules decrease in abundance northward along the outcrop, and chert pebbles have not been observed north of Pumpkin Creek.

The large volume of chert pebbles in the Devils Kitchen Member of the Deese Formation were introduced into the Ardmore Basin in the form of alluvial and/or deltaic deposits in the southern part of the Ardmore Basin. Wood imprints and mud cracks within the interbedded sand facies are common in this area. Cross-bedding transport directions at the Lake Murray spillway are to the west-northwest (Saether, 1976). The conglomerate facies decreases in thickness northwestward with decrease in pebble size. The Rocky Point Member represents a second and similar time of major introduction of chert pebbles from the southeast, but few chert pebbles were carried as far as the northern part of the basin. The upper Deese, above the Rocky Point, has no chert-pebble conglomerates and is more marine in character, with the occurrence of a few thin limestones. The thin sporadic limestone cobble conglomerates (Warren Ranch) in the northern part of the basin, apparently represent slope deposits with a source from the shelf to the north, presumably from the Hunton Arch. Equivalent upper Deese strata in the Marietta Basin are included in the "upper gray shale zone of the 'Strawn' or 'Deese'."

Missourian Series

The depositional history of the Hoxbar Group in the Ardmore Basin is poorly understood, and source directions have not been established. It is predominantly a marine sequence with several named limestone units, but there is one local coal layer (1 m thick) just below the Daube Limestone noted by Tomlinson and McBee (1959). Some of the scattered limestone and chert pebble conglomerates may have come from the uplifting Hunton Arch, on the shelf to the north.

Virgilian Series

The Virgilian Arbuckle Orogeny produced the uplift and sharp folding of the Arbuckle Anticline and simultaneously the sharp folding, compression, and faulting of the Ardmore Basin, Criner Hills axis, and the Marietta Basin. The Collings Ranch Conglomerate, preserved in the central Arbuckle Mountains, was deposited in Middle Virgilian time, followed in Late Virgilian by the deposition of great alluvial fans of limestone-cobble conglomerates (Vanoss Conglomerate) around the north, west, and south margins of the Arbuckle Anticline. In the Ardmore Basin, these limestone-cobble conglomerates were deposited across most of the area and rest unconformably on the steeply truncated margins of all of the Mississippian and Pennsylvanian formations described here, including the Missourian Hoxbar Group (Ham, 1969).

ARKOMA BASIN

Patrick K. Sutherland

STRATIGRAPHIC AND TECTONIC FRAMEWORK

The Arkoma Basin is an arcuate structural feature that extends from the Gulf Coastal Plain in central Arkansas westward 400 km to the Arbuckle Mountains in south-central Oklahoma (Fig. 12). It ranges from 32 to 80 km wide. It is bounded on the north and northwest by the Ozark Uplift and the Northeast Oklahoma Platform. Its southern margin is marked in Oklahoma by the Choctaw Fault and in Arkansas by the Ross Creek Fault.

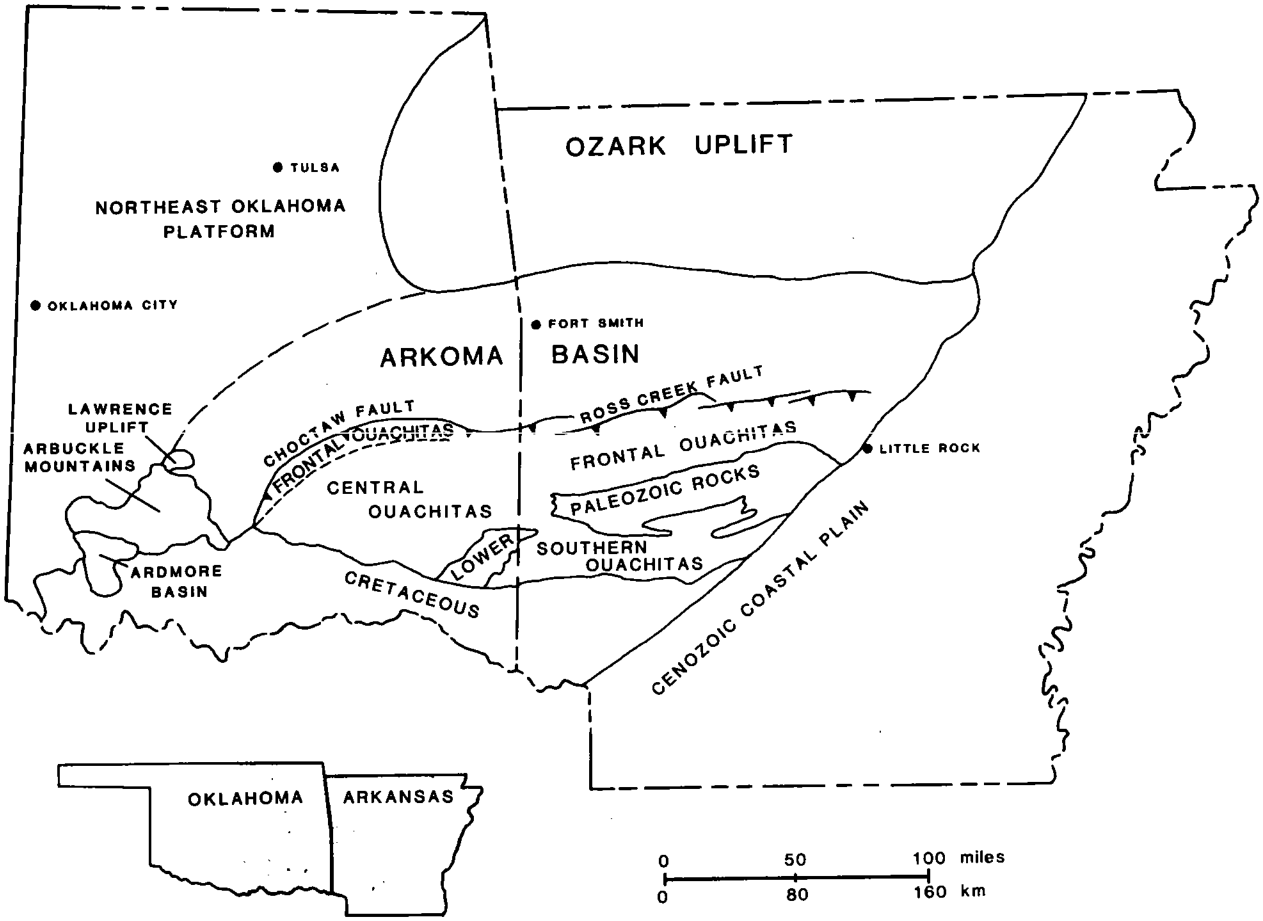


Figure 12. Arkoma Basin of Oklahoma and Arkansas, and surrounding geologic provinces.

Various tectonic models have been proposed for the Ouachita Foldbelt. One of the most widely quoted is a collision model with south-dipping subduction (Wickham and others, 1976; Lillie and others, 1983). There was gradual closure of the Ouachita Trough and the development of a foreland basin followed by uplift and erosion of the Ouachita orogenic belt.

The Arkoma Basin was depositionally part of a stable shelf (here named the Arkoma Shelf) along a passive continental margin during much of its history. Deep-water deposits accumulated in the basin south of the shelf. In Cambrian to Early Mississippian time a thick sequence of shallow-water carbonates was deposited on the shelf, and thinner, deep-water black shales and cherts accumulated in the basin. In middle Mississippian time there was the beginning of deposition of thick turbidites (Stanley Group) in the basin (Ouachita Trough) (Fig. 13), as a result of a gradual sequential narrowing of the Ouachita Trough from east to west (Graham and others, 1976). Turbidites were fed longitudinally westward into the trough. There was no significant change in depositional pattern on the shelf to the north except for the intermittent introduction of terrigenous clastics from the north.

The broad Arkoma Shelf, which included the southern part of the present-day Ozark Uplift as well as the Arkoma Basin, continued as a quiescent and significant depositional feature through Chesterian, Morrowan, and Early Atokan time. In Middle Atokan time the southern margin of the Arkoma Shelf was subjected to flexural bending, caused by continued basin closure, that resulted in sequential northward development of down-to-the-south syndepositional normal faults (Fig. 14). By this process the Arkoma Shelf evolved into an incipient foreland basin. By the end of middle Atokan time, fault movement had ceased and the fault-related basin had been filled with sediment. During the late Atokan, deposition of major deltaic systems prograded both westward and southward over the fault zones (Fig. 14).

In early Desmoinesian time the fully developed foreland basin continued to subside. Deltaic sedimentation, initially from the east but subsequently mostly from the shelf to the north, kept pace with the subsidence, resulting in the thick wedge of shallow-marine and nonmarine late Atokan and early Desmoinesian strata preserved in the present-day Arkoma Basin.

A post-Krebs (Fig. 15) regional unconformity (Oakes, 1953,

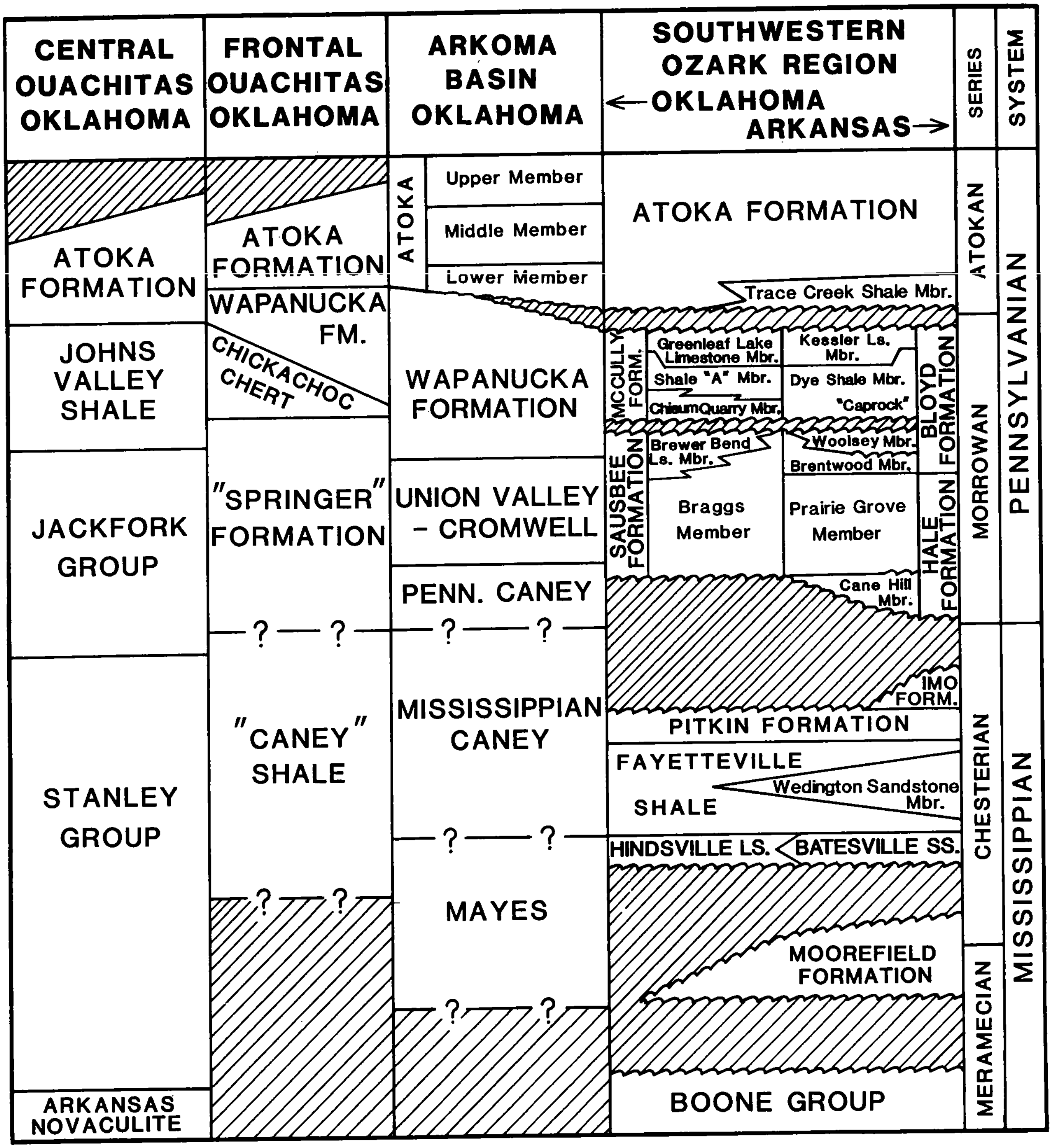


Figure 13. Correlation of Upper Mississippian and Lower Pennsylvanian formations and members across the Arkoma Basin from the Ozark Shelf to the Ouachita Trough.

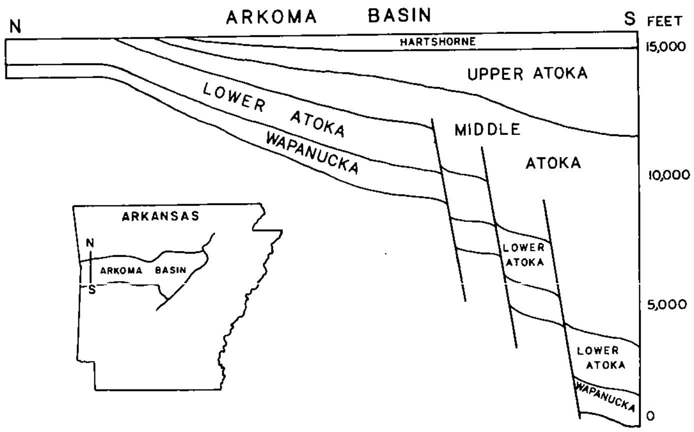


Figure 14. North-south section across Arkoma Basin depicting syndepositional faults that controlled sedimentation during deposition of middle Atoka Formation (modified from Zachry and Sutherland, 1984).

DESMOINESIAN SERIES	MARMATON GROUP	Holdenville Shale
		Wewoka Formation
		Wetumka Shale
		Calvin Sandstone
	CABANISS GROUP	Senora Formation
		Stuart Shale
		Thurman Sandstone
	KREBS GROUP	Boggy Formation
		Savanna Sandstone
		McAlester Shale
		Hartshorne Sandstone

Figure 15. Formations and groups of the Pennsylvanian Desmoinesian Series in the Arkoma Basin and adjacent area to the northwest, in south-central Oklahoma (from Oakes, 1953, 1967, 1977).

1967, 1977) marks the end of major subsidence of the Arkoma Basin, a time of folding and erosion in the Arkoma Basin of both Atoka and Krebs strata, and the sufficient uplift of the Ouachita Foldbelt to expose to erosion the Ordovician and Devonian chert-bearing formations of the core area. By the beginning of deposition of the overlying Cabaniss Group (Thurman Sandstone), chert-pebble conglomerates from a Ouachita source were funneled to the northwest, across the folded Arkoma Basin, into a narrow successor basin to the north of the Hunton Arch. These conglomerates rest unconformably on the Krebs Group (Oakes, 1967, p. 28).

Possible sources for sediments in the Ouachita Trough have been summarized by Thomas (1984). These are based on regional facies distributions, paleocurrent data, and/or sandstone petrography. Two of these source areas are believed to have also provided sediments to the Arkoma Shelf/Basin area to the north. They are (1) the Ouachita Foldbelt that had already been uplifted along the southwest margin of the Black Warrior Basin, which provided lithic arenites that were transported to the northwest along the axis of the sequentially narrowing Ouachita Trough, and (2) sediments transported southwestward through the Illinois Basin, which consisted mostly of quartz arenites. Additional sediments deposited in the Arkoma Shelf/Basin area (first quartz arenites and later sublitharenites) came from the continental interior north of Oklahoma and west of the Ozark Dome, and possibly secondarily, quartz arenites from the Ozark Dome itself in southern Missouri.

The depositional history of the Arkoma Shelf/Basin area can be divided into the following three intervals:

*1. **Chesterian through Early Atokan.*** During this interval, terrigenous sediments were derived almost solely from the northeast and north. Quartz arenites were transported southwestward through the Illinois Basin (Potter and Glass, 1958) and from the Ozark Dome and beyond. Some of these terrigenous sediments were transported westward along the Arkoma Shelf in Arkansas, while others were carried further south into the Ouachita Trough.

*2. **Middle Atokan through early Desmoinesian.*** During the middle Atokan there was major deposition of lithic arenites, south of the outer shelf margin, in the area where syndepositional faults developed in the southern half of the Arkoma Shelf/Basin as the basin margin shifted northward. These lithic arenites were most likely derived from the southeast, from the erosion of the already uplifted Ouachita orogenic belt to the southwest of the Black Warrior Basin (Graham and others, 1976; Mack and others, 1983; Thomas, 1984). On the Arkoma Shelf there were still quartz arenites with a source from the north. Lithic arenites apparently continued to be derived from the east in Late Atokan time and definitely in the earliest Desmoinesian during the deposition of the Hartshorne Sandstone. The latter was deposited westward along the axis of the newly developed Arkoma Foreland Basin (Houseknecht and others, 1983). Later in the early Desmoinesian, during the deposition of the McAlester, Savanna, and Boggy Formations, most of the terrigenous sediments in the area (mostly sublitharenites) were derived from the craton to the north and west of the Ozark Dome (e.g., Booch and Bartlesville/Bluejacket Sandstones; Bissell and Cleaves, 1986; Visher, 1968).

*3. **Middle Desmoinesian through early Virgilian.*** Beginning with the deposition of the Thurman Sandstone (Cabaniss Group; Fig. 15), chert-pebble conglomerates derived from the newly uplifted core area of the Ouachita Mountains were transported to the northwest. The older Paleozoic rocks in the Ouachita Mountains continued to provide chert-pebble conglomerates, along with muds and sands, to a shallow basin in central Oklahoma, north of the Hunton Arch, through the remainder of the Pennsylvanian.

DEPOSITIONAL HISTORY

Chesterian Series

The Mississippian Chesterian outcrops in the southern Ozark area in Oklahoma and Arkansas consist of interbedded shallow-marine limestones and shales that rarely exceed 200 m in thickness. Included are the upper Moorefield, Hindsville, Fayetteville, Pitkin, and Imo Formations (Fig. 13). Represented are at least two main shoaling-upward sequences. The southern limit of carbonate deposition during Chesterian time occurs in the subsurface 16 to 20 km south of the southern limit of the present outcrop area in Oklahoma (Tulsa Geological Society, 1961; Fig. 16). South of this line, facies change abruptly to shale on a continually deepening, east-trending outer shelf. The terrigenous source for the outer shelf muds is believed to have been to the east because of the marked increase in thickness of the Fayetteville Shale in that direction across northern Arkansas (Ogren, 1968).

The Chesterian interval in the Ouachita Mountains to the south is composed of turbidite deposits of the middle and upper Stanley Group, and the total thickness of that group in the central Ouachitas in Oklahoma is about 3,235 m (Cline, 1960). Sediment transport directions are from the southeast (Niem, 1976; Fig. 16).

Mississippian-Pennsylvanian unconformity

The Late Mississippian was marked by a sea withdrawal from the shelf areas throughout the Southern Midcontinent region. Rascoe and Adler (1983) attribute this emergence to a broad upwarping of the transcontinental arch. A contributing factor may have been the rapid relative sinking of the Ouachita Trough, some upwarping of the Ozark Dome, and a corresponding southward tilt of the Arkoma shelf north of the trough.

During the post-Mississippian emergence and accompanying southward tilt of the shelf, the Chesterian sequence was progressively truncated northward in both Arkansas and Oklahoma, producing a regional angular unconformity at the base of the Pennsylvanian. Both the Pitkin and Fayetteville Formations wedge out northward, and Morrowan strata locally rest directly on the Hindsville Limestone (Fig. 13) in the Oklahoma Ozarks. Regional relief on the unconformity in that area is over 24 m (Sutherland and Henry, 1977b).

Morrowan Series

In the early Morrowan the sea transgressed north from the Ouachita Trough onto the Arkoma Shelf, across the truncated Chesterian surface. The depositional pattern throughout the Morrowan is one of marked lateral changes in facies and thickness. The dominant source direction on the Arkoma Shelf was from the northeast, primarily from the Illinois Basin. Fluvial sandstones and shales (275 m thick) in north-central Arkansas (Glick and others, 1964) change facies westward to a mostly mixed shallow-marine shelf facies (90 m thick) in northwestern Arkansas (Henbest, 1953) and still farther to the west in northeastern Oklahoma to a shallow-marine offshore bank facies (60 m thick; Sutherland and Henry, 1977a).

The Morrowan Series was first described in northwestern Arkansas (Washington County), where it is subdivided into the Hale and Bloyd Formations (Fig. 13). Westward from Washington County, Arkansas, into Oklahoma the names Hale and Bloyd can be used only for a 25-km-wide belt at the eastern margin of Oklahoma. Farther west the lithologic distinction is lost, as there is an overall marked westward increase in percentage of limestone and a corresponding decrease in the percentage of sandstone. Sutherland and Henry (1977a) subdivided this carbonate sequence into the Sausbee and McCully Formations (Fig. 13) on the basis of regional disconformity at the top of the Sausbee. This break coincides in northwestern Arkansas with a regional disconformity at the base of the Dye Shale Member of the Bloyd Formation (Fig. 13).

The Morrowan carbonate facies in the southern Ozarks of northeastern Oklahoma extends southward for about 16 km in the subsurface of the Arkoma Basin south of the southern limit of the present outcrop area in Oklahoma. Farther south there is a distinct decrease in the percentage of limestone in the Morrowan interval below the Wapanucka Limestone, and an increase in the percentage of shale and sandstone (Fig. 17).

In the central and southern part of the Arkoma Basin the typical Morrowan sequence begins with the Pennsylvanian Caney, which cannot be subdivided in most places from the underlying Mississippian Caney. Most subsurface workers therefore use the base of the overlying Cromwell Sandstone as a marker for the base of the Pennsylvanian (Fig. 13).

The Cromwell Sandstone is a subsurface term, and the unit extends throughout most of the Arkoma Basin in Oklahoma as a fine- to medium-grained subrounded calcareous sandstone overlain in most areas by a thin arenaceous limestone. This interval is

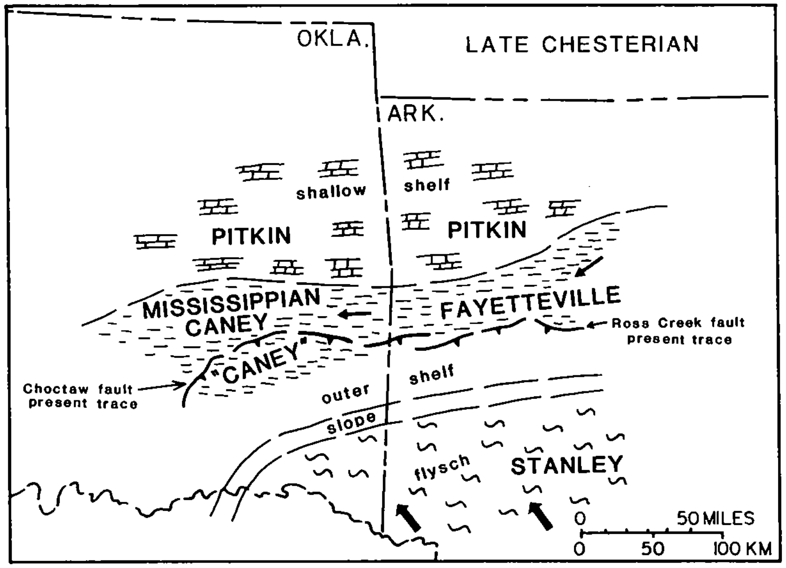


Figure 16. Late Chesterian paleogeographic map. Large and small red arrows indicate major and minor directions of sediment transport. Compare with Figure 12 for location. Dashed traces of present-day locations of Choctaw and Ross Creek Faults are given for reference on Figures 16 to 20. Sources include Tulsa Geological Society (1961), Niem (1976), Glick (1979), Thomas (1985), Hanford (1986).

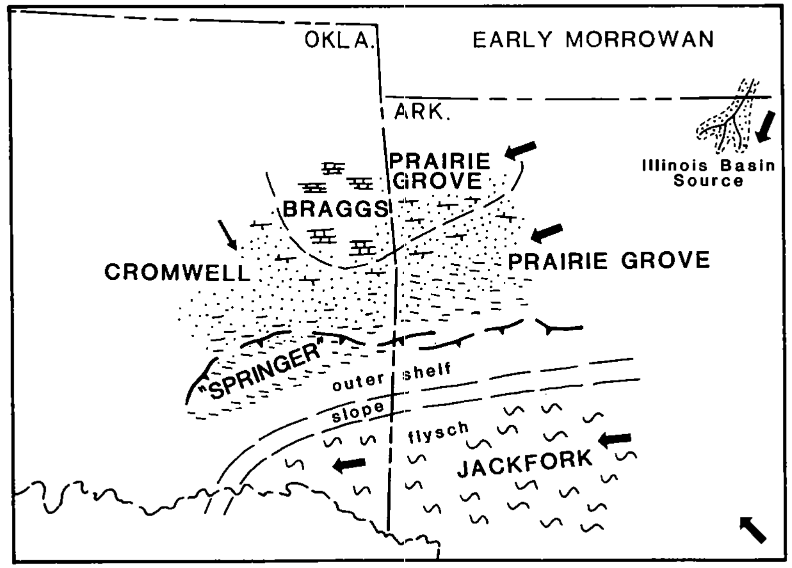


Figure 17. Early Morrowan paleogeographic map. Sources include Morris (1971), Sutherland and Henry (1977a), Foshee (1980), Jefferies (1982), and Moiola and Shanmugam (1984).

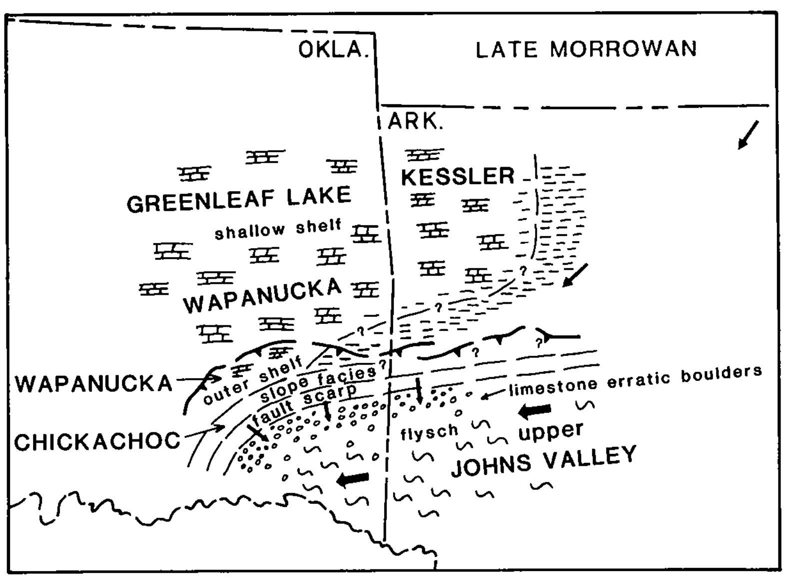


Figure 18. Late Morrowan paleogeographic map. Sources include Shideler (1970), Sutherland and Henry (1977a), and Grayson (1979).

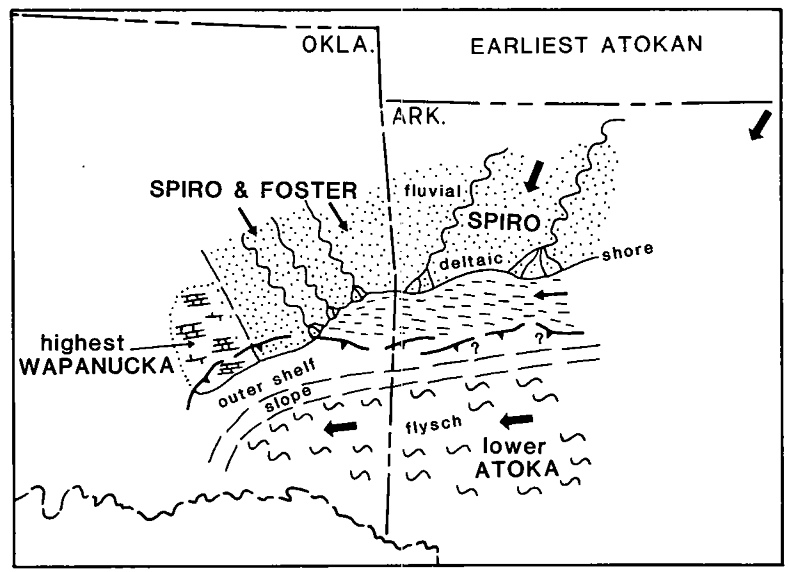


Figure 19. Earliest Atokan paleogeographic map. Sources include Lumsden and others (1971), Grayson (1979), Sutherland and Manger (1979), and Parker (1981).

equivalent to the Prairie Grove Member of the Hale Formation in Arkansas and to the Braggs Member of the Sausbee Formation in the southwestern Ozarks in Oklahoma (Fig. 13). It has not as yet been recognized in the frontal Ouachitas where apparently equivalent outer shelf shales are included in the "Springer" Formation (Fig. 17). The Cromwell is equivalent to the Union Valley, which crops out on the Lawrence Uplift at the north end of the Arbuckle Mountains in Oklahoma (Figs. 12, 13). In the subsurface of Oklahoma the Cromwell consists of multiple, discontinuous, calcareous sandstones separated by thin shales. The Cromwell is over 35 m in thickness across a broad western area in Oklahoma and exceeds 60 m locally (Jefferies, 1982; Fig. 17).

In the subsurface in Arkansas the equivalent Prairie Grove Formation reaches a maximum recorded thickness of 87 m. In addition to the overall thickening to the east there is a general coarsening in size of quartz grains and an increase in the number of sandstone intervals, indicating a quartz sand source to the northeast (Foshee, 1980).

Depositional patterns were complex on the Arkoma Shelf in middle Morrowan time (not shown on a figure). The Brentwood and upper Braggs Limestones were deposited on the inner shelf. This was followed by gradual regression, causing emergence and development of nonmarine environmental conditions in northwestern Arkansas (Woolsey), followed by erosion and the development of the middle Morrowan disconformity (Fig. 13). This was followed by rapid transgression and deposition in the late Morrowan of Kessler Limestone in Arkansas and the Greenleaf Lake Limestone in northeastern Oklahoma. With gradual shallowing on the outer shelf, deeper water shales in the lower part of the Wapanucka Formation gave way to the deposition of the overlying Wapanucka Limestone. Oolitic grainstones and carbonate mudstones were deposited across the entire shelf area (Fig. 18), followed by regional emergence and erosion.

The Wapanucka Formation crops out along Limestone Ridge in the frontal Ouachitas. In this area it was deposited on the outermost shelf. The highest limestone in the Wapanucka is of Atokan age and grades eastward along the ridge into the Spiro Sandstone (Grayson, 1979; Fig. 19; see following section). The total thickness of the Wapanucka on Limestone Ridge is typically about 88 m. Basinward (southward), closely spaced successive fault blocks show an equivalent slope facies (Chickachoc Chert), as much as 206 m thick, that consists of thick shale, thinner spiculites, and a few very thin spiculiferous limestones (Sutherland and Grayson, 1977; Fig. 18). Grayson (1979) has been able to correlate the shelf and slope facies using conodonts.

In the Ouachita Trough to the south, turbidite deposition continued during Morrowan time with the deposition of the Jackfork Sandstone, typically about 1,675 m thick (Fig. 17), and the Johns Valley Shale, as much as 265 m thick (Cline, 1960; Fig. 18). Transport directions recorded for the Jackfork Sandstone on the outcrop in both Arkansas and Oklahoma are to the west parallel to the basin axis (Moiola and Shanmugam, 1984; Fig. 17). Owen and Carozzi (1986) give evidence that part of the source for the upper Jackfork sandstones was to the southeast of Arkansas, from the orogenic belt southwest of the Black Warrior Basin. The Johns Valley is well known for its great variety of erratic limestone boulders that possibly originated from fault scarps on the shelf margin to the north (Shideler, 1970; Fig. 18).

Atokan Series

The Atokan Series is mainly represented by the Atoka Formation in most of the Arkoma Basin of Arkansas and Oklahoma and by the upper part of the Wapanucka Formation in the western segment of the frontal Ouachitas in Oklahoma and in the southwestern part of the Arkoma Basin (Fig. 19). The Atoka Formation ranges in thickness from 305 to 396 m along the northern margin of the Arkoma Basin in Arkansas (Zachry, 1983) to about 6,400 m at the southern margin of the basin in Arkansas just north of the Ross Creek Fault (Haley, 1982).

A regional unconformity separates the Atoka Formation from underlying strata of Morrowan age in all areas except along the southern part of the Arkoma Shelf and in the basin to the south. The sea was displaced from the shelf to the north primarily by a southward tilting of the Morrow surface (as an aspect of the subsidence of the Ouachita Trough), and extensive subaerial erosion resulted. Progressively older strata were eroded northward on this inclined surface. Stream valleys with a relief of at least 35 m were cut into the post-Morrowan surface (Lumsden and others, 1971).

The usage in this paper of informal lower, middle, and upper members of the Atoka Formation follows that of Buchanan and Johnson (1968) and Zachry (1983). In this usage the lower, middle, and upper intervals are based on the depositional history of each in response to the structural history of the basin during Atokan time. The middle Atoka was deposited during the development of syndepositional faults and was characterized by marked increases in thickness of section on the downthrown (south) side of these faults. The lower Atoka predates such faulting, and the upper Atoka postdates it. The development of the syndepositional faults was not synchronous and it appears that the southernmost syndepositional faults became active earliest and that active faulting migrated northward with time (Houseknecht, 1986). The middle Atoka makes up the major part of the thickness of the formation in the southern part of the basin.

Deposition of the lower Atoka in Oklahoma, with a source from the north or northwest, was initiated by the development of meandering fluvial systems and small deltas on the eroded surface of the underlying Wapanucka (Foster sand channels; Fig. 19). This was followed by a rapid northward transgression of a coastal sand complex (Spiro) to form a blanket sand unit (Lumsden and others, 1971). The maximum combined Spiro-Foster thickness recorded by Jefferies (1982) in Oklahoma is 62 m.

Depositional history of the Spiro in Arkansas was similar but with a much greater volume of sand being introduced from the northeast. Meandering fluvial systems that graded into deltas

(Fig. 19) were terminated by a broad regional marine transgression to the north. This caused the final redistribution of sand and produced the unit's sheet-like geometry (Parker, 1981). In Arkansas the name Spiro refers to the entire fluvial, deltaic, and sheet sand package that reaches a maximum recorded thickness of 89 m (Parker, 1981). To the south and southeast the Spiro changes facies to more basinal shale deposits (Fig. 19).

The lower Atoka in Arkansas ranges in thickness from 150 m adjacent to the northern margin of the present Arkoma Basin to approximately 305 m in the south (Zachry, 1983). The interval is composed of seven to eight sandstone units separated by units of shale and includes the Spiro at the base and the Sells at the top. The sandstones above the Spiro are replaced by shale westward in Oklahoma. Individual sandstone units above the Spiro (range from 6 to 60 m) show uniformity of thickness of individual sand units well into the southern part of the Arkoma Basin and are not affected by growth faulting (Zachry, 1983). A general increase in sandstone unit thickness occurs to the northeast in Arkansas, and intervals of shale are thinner, indicating a source to the northeast (Fig 19).

The lower Atoka sandstones in Arkansas, from the Spiro through the Sells, have the character of mature sandstones (quartz arenites), with a change in sandstone character occurring above the Sells in the central to southern part of the basin (D. L. Zachry, personal communication, 1987). The Spiro Sandstone in Oklahoma also has the character of a mature sandstone (Lumsden and others, 1971).

Beginning approximately with the deposition of the middle Atoka, the southern margin of the Arkoma Shelf was subjected to flexural bending, caused by continued basin closure, that resulted in the development of large east-trending normal faults (Fig. 20). The middle Atoka in the northern parts of the present Arkoma Basin in Arkansas is comparatively thin and is characterized by four to five sandstone units separated by intervals of shale (Zachry, 1983). These mature sandstones (quartz arenites) accumulated in delta and tidal flat systems that prograded southwestward across the northern part of the Arkoma Shelf from sources to the north and northeast.

In the middle Atoka south of the Mulberry Fault (Fig. 20) the sandstones have the composition of lithic arenites that contain 75 to 90 percent quartz, 5 to 25 percent metamorphic lithic fragments, and up to 8 percent feldspar (Houseknecht, 1986). The source of the latter two constituents cannot be from either the Ozarks or the Illinois Basin, and they most likely came from the southeast, from erosion of the already uplifted Ouachita Orogenic Belt, on the southwest margin of the Black Warrior Basin (Thomas, 1984). Thus, during the deposition of the middle Atoka, such sediments were carried westward along the axis of the incipient foreland basin that replaced the outer shelf at least as far north as the Mulberry Fault (Houseknecht, 1986; Fig. 20).

The middle Atoka interval in Oklahoma is composed dominantly of shale with a few thick sandstone units. It is best developed in the southern part of the basin and displays marked increases in thickness on the downthrown sides of east-trending syndepositional normal faults (Fig. 20). A major sandstone within this interval is the Red Oak, which is confined to the south side of the San Bois Fault (Fig. 20). Vedros and Visher (1978) believe that the Red Oak accumulated in a submarine-fan environment and that sediment was supplied by way of a submarine canyon cut into the scarp of a normal fault to the north. Houseknecht and Kacena (1983) propose that the normal fault blocks may have resembled half grabens in cross section and that these may have acted as sediment dispersal conduits that funneled sediment westward, parallel to the fault, from shallow to deeper portions of the slope. They state that sand-body geometry on the south side of the growth fault suggests a channel system and may not be associated with a submarine-fan complex.

Middle Atoka sandstones such as the Red Oak have been interpreted by many authors (e.g., Vedros and Visher, 1978) as having been deposited in "deep water" as a result of significant structural relief associated with the syndepositional faults. Houseknecht (1986) alternatively postulates that the Red Oak and similar sandstones in the area were deposited below wave base but at comparatively shallow-water depths (possibly in the order of 100 m), and that deposition possibly occurred on a gently dipping, muddy slope lacking a bathymetrically distinct shelf-slope-rise geometry.

In the southern part of the Arkoma Basin in Arkansas, Stone and McFarland (1981, Stop 16) describe strata exposed at Blue Mountain Dam as representing deep-water sediments. These strata consist of turbidites that show southward transport, which they interpret as upper submarine fan channels that partly dissect a probable slope facies. Still farther to the south in the Ouachita trough, turbidites moved westward on the deep basin plain (Fig. 20).

At the west margin of the Arkoma Shelf, Sutherland (1984) records that the initial uplift on the Hunton Arch is indicated by the occurrence of limestone pebbles and cobbles at the base of the Atoka Formation; these can be derived only from the underlying Wapanucka Limestone. Grayson (1984) has identified middle Atokan conodonts from the lower part of the Atoka Formation in that area, which crops out today on the northeast flank of the Arbuckle Mountains.

Upper Atoka strata are not cut by the normal faults that produced the thick sediment fill characteristic of the middle Atoka in the southern Arkoma Basin (Fig. 14). Upper Atoka sediments were deposited in a fully developed Arkoma Foreland Basin. Shallow-water sedimentation kept pace with continued subsidence. In the northern part of the basin, deltaic systems prograded southward. Paleocurrent directions have not been described for upper Atoka sandstones, but indirect evidence farther south in Arkansas suggests possible westward transport along the axis of the newly developed foreland basin in a manner similar to that found in the overlying Hartshorne Sandstone (lower Desmoinesian; Fig. 21).

The upper Atoka is up to 915 m in thickness in the south-

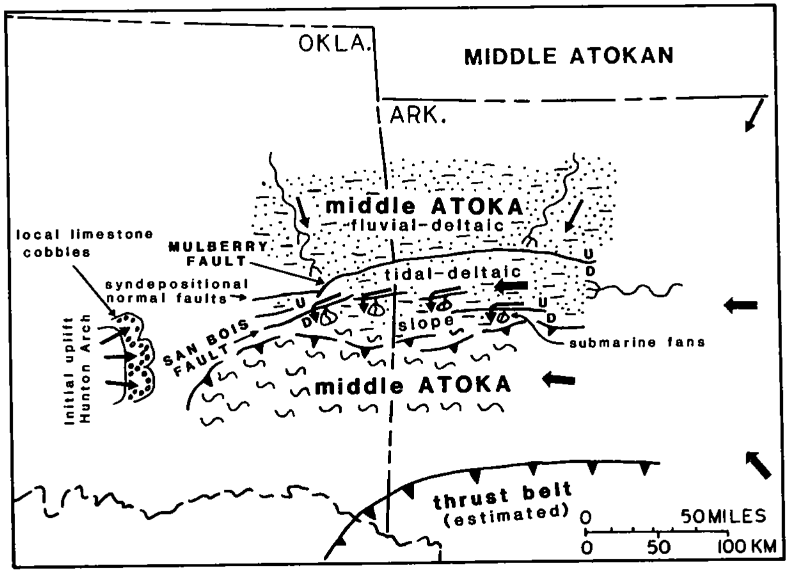


Figure 20. Middle Atokan paleogeographic map. Sources include Koinm and Dickey (1967), Vedros and Visher (1978), Houseknecht and Kacena (1983), Zachry (1983), Grayson (1984), Sutherland (1984), Zachry and Sutherland (1984), and Houseknecht (1986).

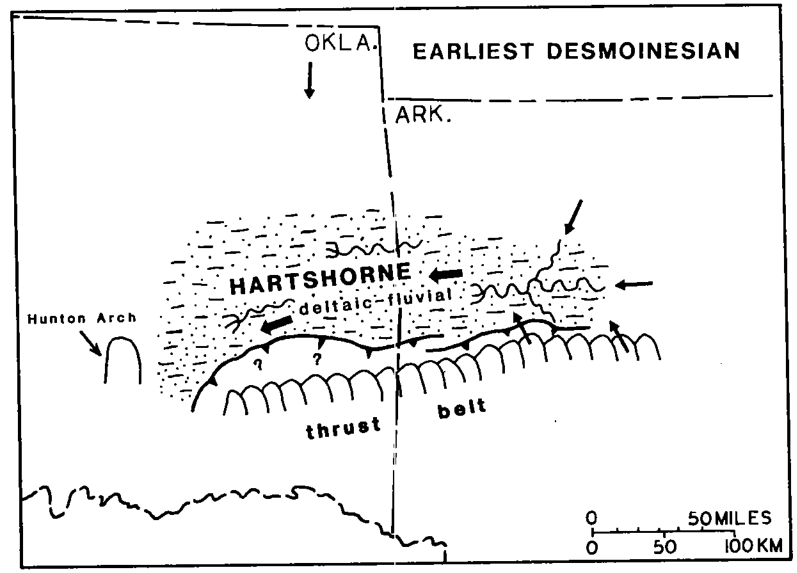


Figure 21. Earliest Desmoinesian paleogeographic map. Sources include Houseknecht and others (1983).

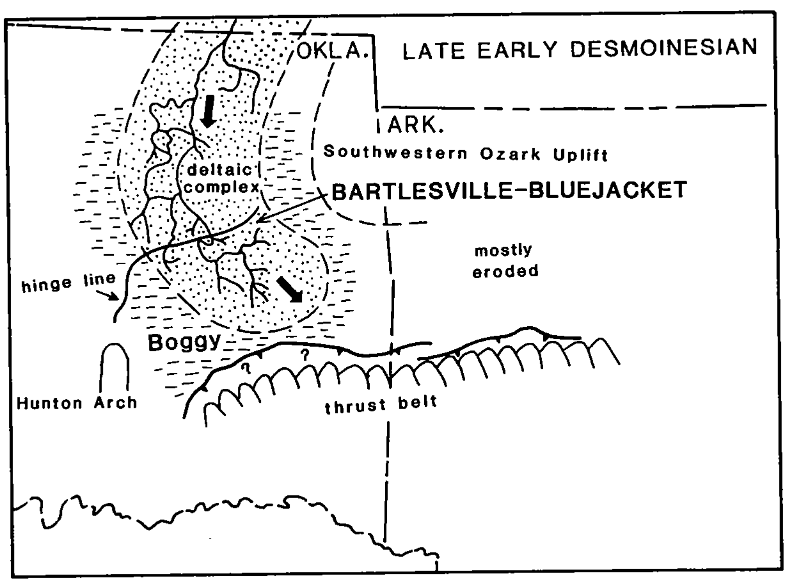


Figure 22. Late early Desmoinesian paleogeographic map. Sources include Weirich (1953), Visher (1968), and Visher and others (1971).

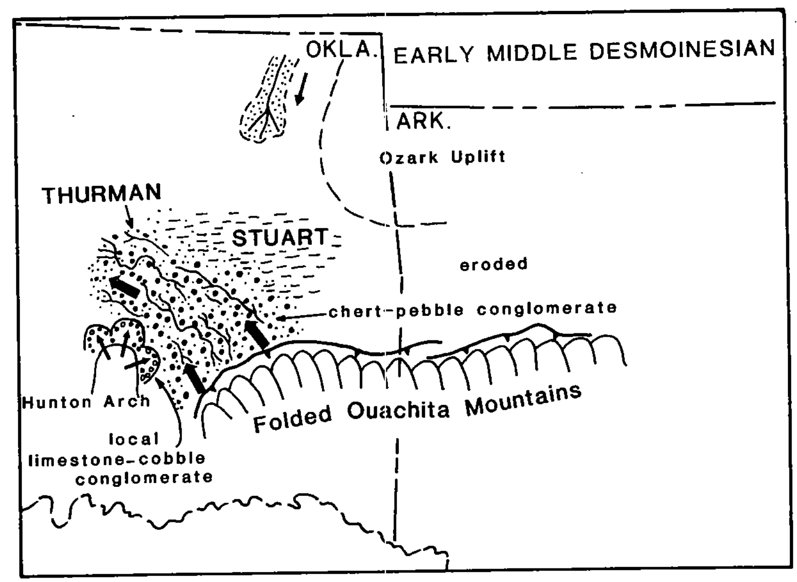


Figure 23. Early middle Desmoinesian paleogeographic map. Sources include Oakes (1948, 1953, 1967, 1977) and Jones (1957).

central part of the Arkoma Basin in Arkansas (Zachry, 1983). The interval in Oklahoma is similar to that in Arkansas but is composed predominantly of shale with thin discontinuous sands (Zachry and Sutherland, 1984).

Desmoinesian Series

The Desmoinesian Series in the Arkoma Basin and adjacent area to the northwest consists of the Krebs, Cabaniss, and Marmaton Groups (Fig. 15). Only the Krebs is preserved across the present-day basin, and units above the Hartshorne Sandstone have been mostly removed by erosion in Arkansas. The Cabaniss and Marmaton Groups crop out along the northwest margin of the basin in Oklahoma.

The Krebs Group consists of the Hartshorne, McAlester, Savanna, and Boggy Formations (Fig. 15). The Hartshorne Sandstone was deposited in high-constructive, tidally influenced deltaic systems that prograded from east to west, coinciding approximately with the present-day axis of the Arkoma Basin. Fluvial sediments in Arkansas came from the northeast, southeast, and possibly east (Houseknecht and others, 1983; Fig. 21). The sediments from the southeast apparently came from the developing Ouachita Foldbelt, but such a source is not recorded westward in Oklahoma (Fig. 21). In Arkansas, the Hartshorne displays a single progradational deltaic sequence, but in Oklahoma there are two such complexes with associated coal beds (Houseknecht and others, 1983; Fig. 21).

The only confirmed direction of source for the overlying McAlester, Savanna, and Boggy Formations (Fig. 15) is from the shelf to the north (Visher, 1968; Weirich, 1953). All of these units show marked thickening southward into the subsiding foreland basin (Fig. 22). The depositional pattern was nonmarine to deltaic, with rapid deposition of sands, muds, and thin coals. In the Morrowan and early Atokan, terrigenous sediments from the north were mostly quartz arenites (e.g., Spiro Sandstone). By the time of deposition of the McAlester Formation, sands from the north had changed mostly to sublitharenites (Bissell and Cleaves, 1986).

McAlester to Boggy depositional patterns were complex and included several major northwestward transgressions followed by regressive southward progradations of fluvial/deltaic systems across the shelf and into the Arkoma Basin. The largest such deltaic complex was developed during deposition of the lower part of the Boggy Formation and contains the Bartlesville-Bluejacket Sandstone Member of the Boggy (Visher, 1968; Visher and others, 1971; Fig. 22). This system extended southward across eastern Kansas and eastern Oklahoma and entered the Arkoma Basin as an extensive fluvial-dominated deltaic complex. The source was from the continental interior north of Oklahoma. The Boggy Formation, including the Bartlesville-Bluejacket, reached a thickness of 610 m in the Arkoma Basin (south of hinge line of Weirich, 1953; Fig. 22) compared to a thickness of less than 150 m on the shelf 80 km to the north (Weirich, 1953).

The initial uplift of the Ozark Mountains in northeastern Oklahoma is suggested by the arcuate pattern and the apparent southwestward deflection of the Bartlesville-Bluejacket deltaic complex in northeastern Oklahoma (Fig. 22).

Uplift, folding, and erosion of the foreland basin occurred following the deposition of the Krebs Group. Boggy and pre-Boggy rocks are more complexly folded and faulted than are post-Boggy strata and there is a conspicuous difference in strike between the two (Oakes, 1967, p. 30). Shales and fine-grained sandstones of the Boggy, below the unconformity, change abruptly to coarser sandstones and chert-pebble conglomerates in the overlying Thurman Sandstone (Oakes, 1953). Some southwest-trending faults, probably associated with the Ozark Uplift to the northeast, cut the Boggy but do not cut post-Boggy rocks (Oakes, 1967).

The Krebs is the only part of the Desmoinesian that was deposited during major subsidence of the Arkoma Foreland Basin before initial folding of the area. The Krebs is 2,195 m thick in the basin, compared to 240 m thick on the shelf 80 km to the north (Fig. 22).

The Thurman Sandstone, at the base of the Cabaniss Group, documents a marked change in depositional setting in the Arkoma Basin area. The Thurman chert-pebble conglomerates are the first indication of significant uplift of the Ouachita Foldbelt that exposed the Ordovician and Devonian cherts of the core area to erosion (Fig. 23). The conglomerates of the Thurman were deposited in a narrow successor basin, northeast of the Hunton Arch, in which the depocenter had shifted northwestward, farther onto the craton, from that of the late Atokan–early Desmoinesian foreland basin. The conglomerates of the Thurman are thickest and coarsest in western Pittsburg County, and the unit thins to the southwest onto the flank of the Hunton Arch and to the northeast. The Thurman is missing northeast of the Canadian River where it is overlapped by the Stuart Shale (Oakes, 1967; Fig. 23). The Thurman chert debris, derived from the Ouachita Foldbelt in Oklahoma, was transported toward the northwest as part of a fluvial system feeding deltaic and shallow-marine environments (Jones, 1957; Fig. 23).

During the deposition of the remainder of the Desmoinesian Cabaniss and Marmaton Groups (Fig. 15) the successor basin (termed the Arkoma seaway by Bennison, 1984) continued to receive terrigenous sediments, including some chert-pebble conglomerates, from the erosion of the Ouachita Foldbelt. The narrow basin was about 80 km in diameter immediately northeast of the Hunton Arch during the deposition of the Marmaton Group (Bennison, 1984, Fig. 4). A terrigenous Marmaton sequence reaches a thickness in this basin of 457 m compared to a more predominantly carbonate sequence on the shelf 80 km to the north, at Tulsa, Oklahoma, of 244 m.

The Ouachita Mountains continued through the remainder of the Pennsylvanian and into the Permian as the primary source of terrigenous sediments in central Oklahoma. These sediments bypassed the Hunton Arch (Fig. 23), which provided limestone cobbles only locally along the southern margin of the basin.

PALO DURO, HARDEMAN, AND DALHART BASINS

Shirley P. Dutton and Arthur G. Goldstein

INTRODUCTION

The Palo Duro, Dalhart, and Hardeman Basins are shallow, intracratonic basins located in the Texas panhandle and adjacent areas (Plate 5-A). These three basins (including the Hollis Basin, which is regarded as a distinct part of the Hardeman Basin by some workers) contain rocks of Precambrian to Quaternary age, but most of the fill is upper Paleozoic. They first developed as structural basins in Early Pennsylvanian time in conjunction with the uplift of surrounding basement blocks (Nicholson, 1960). Prior to this time they responded to the broad epeirogenic downwarps and arching seen elsewhere on the western side of the preexisting Oklahoma Basin. The Palo Duro Basin is asymmetrical and deepens to 3,000 m just north of the Matador Arch, whereas the Dalhart and Hardeman Basins are more symmetrical and are deepest in their centers.

TECTONIC AND STRATIGRAPHIC FRAMEWORK

The western part of the Oklahoma Basin was quiescent during early and middle Paleozoic time. Then the Palo Duro, Dalhart, and Hardeman Basins were formed, each bounded by crustal blocks uplifted during the Pennsylvanian Period in a thick-skinned (basement-involved) deformation (Goldstein, 1982). Each uplift is bounded on one side by a major fault that commonly shows evidence of having existed before late Paleozoic deformation. Northwest-trending faults are the dominant structures within the basins. Most fault movement occurred during the Pennsylvanian and Permian, but some faults cut the entire Permian System and affect the thickness and distribution of Triassic sediments (Dutton and others, 1982).

Post-Mississippian depositional history (Fig. 24) of these basins may be divided into four major stages (Handford and others, 1980): (1) formation of the basins between tectonic blocks, and subsequent deposition of basement-derived, fan-delta arkoses around uplifts flanking the basins (Fig. 25); (2) planation and burial of the uplifts and infilling of the deep basins with shelf-margin carbonate and basinal facies through Early Permian time (Fig. 26); (3) encroachment of continental red-bed facies from sources to the north and west, and deposition of thick Lower to Upper Permian evaporites in shallow-marine to subaerial environments (Fig. 25, Plates 6-S, 6-T, and 6-U); and (4) marine retreat during Late Permian time and development of a Triassic lacustrine basin caused by continental rifting and drainage reversal.

The subsidence and deposition that occurred during the Mississippian, Pennsylvanian, and Permian Periods account for almost all the sediments of the three basins. Peak subsidence occurred in Meramecian (middle Mississippian), Atokan (Early Pennsylvanian), and Missourian (Late Pennsylvanian) time (Goldstein, 1984). Regional control on subsidence is suggested by the burial of the bounding uplifts in Early Permian time (Fig. 25 and Plate 6-R). Both the Amarillo Uplift and the Matador Arch are now buried by 600 to 1,800 m of post-Pennsylvanian sediment, although they were subaerially exposed during Pennsylvanian time.

SYSTEM	SERIES	FORMATIONS AND GROUPS: PALO DURO BASIN		FORMATIONS AND GROUPS: DALHART BASIN	
PERMIAN	Ochoan	Post-San Andres interval	Dewey Lake Fm.	Post-Blaine red beds	Dewey Lake Fm.
			Alibates Formation		Alibates Fm.
			Salado Formation		Undifferentiated
	Guadalupian		Tansill Formation		
			Yates Formation		
			Seven Rivers Fm.		
			Queen/Grayburg Fm.		
		San Andres Formation		Blaine Formation	
	Leonardian	Clear Fork Group	Glorieta Formation	Glorieta Formation	
			Upper Clear Fork Fm.	Clear Fork Fm.	
			Tubb Formation	Undifferentiated Tubb – Wichita red beds	
			Lower Clear Fork Fm.		
			Red Cave Fm.		
		Wichita Group			
	Wolfcampian	Wolfcamp Group (Undifferentiated)			
PENNSYLVANIAN	Virgilian	Cisco Group			
	Missourian	Canyon Group			
	Desmoinesian	Strawn Group			
	Atokan	Bend Group			
	Morrowan				
MISS.	Chesterian	"Chester Limestone"			

Figure 24. Stratigraphic chart of Pennsylvanian and Permian strata in the Palo Duro and Dalhart Basins (after Nicholson, 1960; McGillis and Presley, 1981).

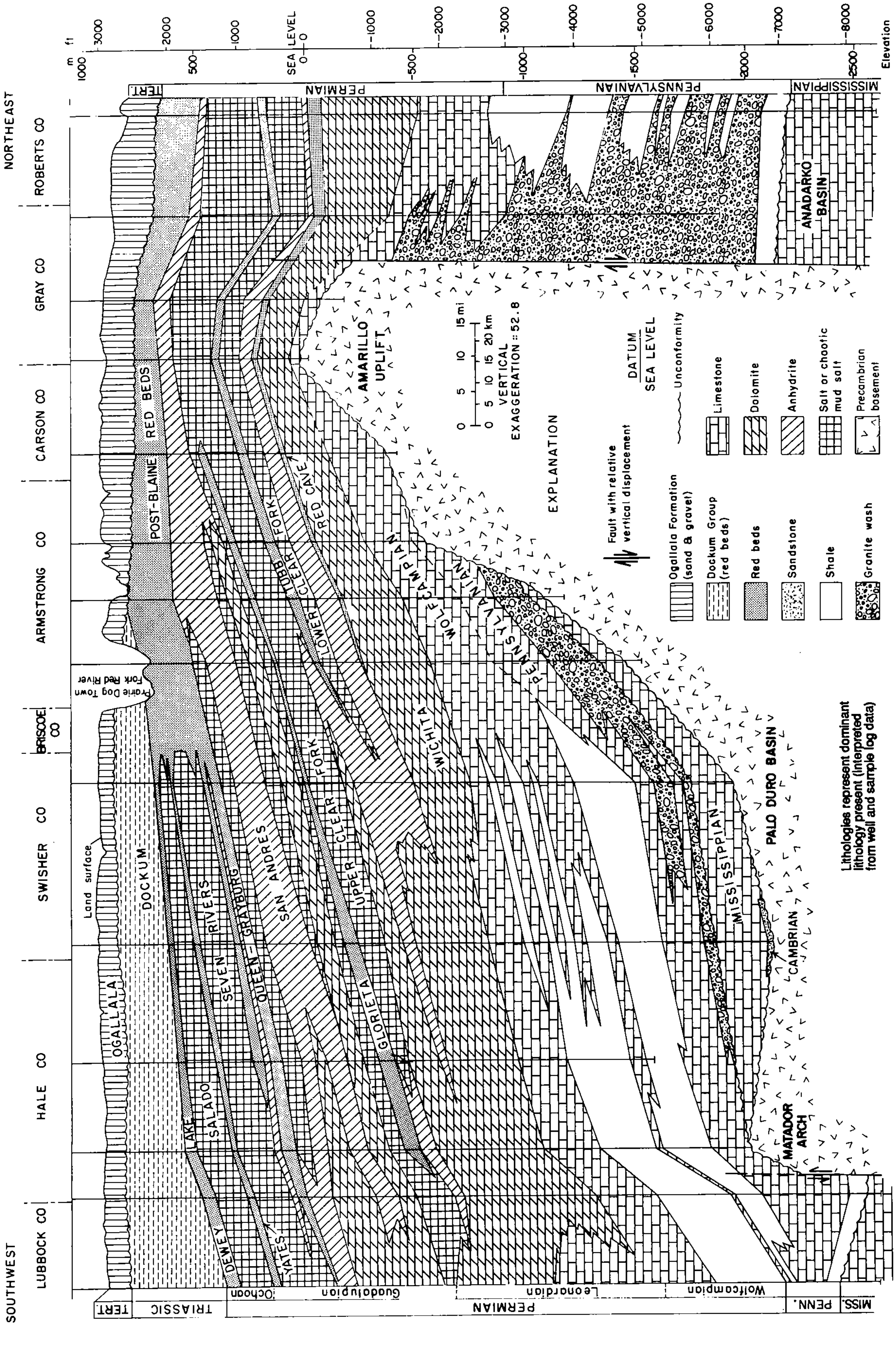


Figure 25. Structural cross section extending north-south through the Palo Duro Basin (after Dutton and others, 1982).

PENNSYLVANIAN SYSTEM AND WOLFCAMPIAN SERIES

Sedimentation during Pennsylvanian and Wolfcampian time was influenced by basin structure and subsidence, and by faulting in the surrounding uplifts. Some basement highlands remained exposed throughout the Pennsylvanian (Plates 5-M to 5-P and 6-Q). Pennsylvanian rocks in the Palo Duro, Dalhart, and Hardeman Basins include the following groups (Fig. 24): Bend (Morrowan and Atokan Series), Strawn (Desmoinesian Series), Canyon (Missourian Series), and Cisco (Virgilian Series).

Depositional conditions were generally similar during the Late Pennsylvanian and the beginning of the Permian (Fig. 26). Wolfcampian rocks record the transition in the three-basin area from relatively deep basins to restricted carbonate platforms (Handford, 1980). Basement uplifts remained emergent at the beginning of the Early Permian, but were finally covered by shallow-marine deposits at the end of Wolfcampian time (Fig. 27).

Pennsylvanian and Wolfcampian strata can be divided into four depositional systems (Figs. 26 and 27): (1) fan-delta system, (2) carbonate shelf and shelf-margin system, (3) high-constructive delta system, and (4) slope and basin system. Each system is characterized by a distinctive facies assemblage, vertical sequence, spatial distribution, and geophysical log signature (Handford and Dutton, 1980; Handford and others, 1981).

Fan-delta system

During the Pennsylvanian and Early Permian, a large volume of coarse arkosic sediment (granite wash) was eroded from the basement uplifts that rimmed the Palo Duro, Dalhart, and Hardeman Basins. The volume of granite wash was greatest in the Desmoinesian, which suggests that the major movement of the Amarillo Uplift occurred during this time (Goldstein, 1984). By Late Pennsylvanian and Wolfcampian time, the extensively eroded highland areas no longer supplied as much clastic sediment to the basins, and granite-wash deposition was confined to the flanks of the uplifts (Fig. 27, Plates 5-P, 6-Q, and 6-R).

Sequences of granite wash in the Texas panhandle are interpreted to be fan-delta deposits (Dutton, 1980). Faults commonly bound thick, proximal fan-delta deposits, indicating that structural displacement occurred during deposition. Fan-delta sequences in the Palo Duro Basin are commonly capped by shallow-marine limestones that were deposited on abandoned fan surfaces following compaction and subsidence. Interbedded granite wash and limestone indicate repeated episodes of fan-delta progradation into a shallow carbonate-shelf environment.

Shelf and shelf-margin system

Carbonate shelf and shelf-margin complexes developed seaward of the fan-delta systems (Figs. 26 and 27). Shelf margins retreated landward during the Pennsylvanian because of combined effects of subsidence and clastic sedimentation (Dutton, 1980). The early Wolfcampian shelf-edge position marked the maximum retreat (Fig. 27). In middle to late Wolfcampian time, the basin closed as shelf margins prograded basinward and southward toward the Midland Basin (Fig. 27; Handford and Dutton, 1980).

Shelf-margin deposits in the Texas panhandle are probably similar to other Late Paleozoic carbonate buildups in the Midcontinent that were formed by encrusting and sediment-baffling organisms, especially phylloid algae (Wilson, 1975). These carbonate buildups probably did not form a wave-resistant framework.

Shelf-margin deposits in the Palo Duro Basin are commonly dolomitized (Fig. 26). The dolomite is most likely a diagenetic replacement mineral because it crosses apparent bedding or facies boundaries.

High-constructive delta system

Elongate to lobate sandstone bodies in the Hardeman and southeastern Palo Duro basins delineate a system of westward prograding, high-constructive deltas (Figs. 26 and 27). The sediment source was probably the Wichita Mountains in Oklahoma. Deltaic progradation had reached as far west as Cottle County in the Hardeman Basin by Late Pennsylvanian time (Fig. 27; Frezon and Dixon, 1975). Clastics entering the Palo Duro Basin generally remained confined to the shelf, but in a few areas they were transported through the shelf margin into the basin.

Basin and slope system

Missourian, Virgilian, and Wolfcampian rocks along the basin axes consist of silty shales, dark micritic limestones, and thin sandstones that were deposited in slope and basinal environments (Figs. 26 and 27). Pulses of sediment probably entered the basin through passes between carbonate buildups along the shelf margins. Between these depositional episodes the basin was essentially starved. Clastic detritus and carbonate debris from the shelf margins were carried by turbidity currents and debris flows into the basin through submarine channels.

LEONARDIAN SERIES THROUGH OCHOAN SERIES

By late Wolfcampian time, the shelf margins had migrated to the southern edge of the Palo Duro Basin. The Palo Duro, Dalhart, and Hardeman Basins became a low-relief, back-shelf environment. Post-Wolfcampian Permian strata are composed of evaporites and red beds (Fig. 25, Plates 6-S to 6-U) that record deposition in a range of marine shelf to supratidal environments along an arid coastline (Presley and McGillis, 1982). Evaporite depositional systems in the Palo Duro Basin interfingered to the south with a shallow-marine shelf and shelf-margin system in the northern Midland Basin.

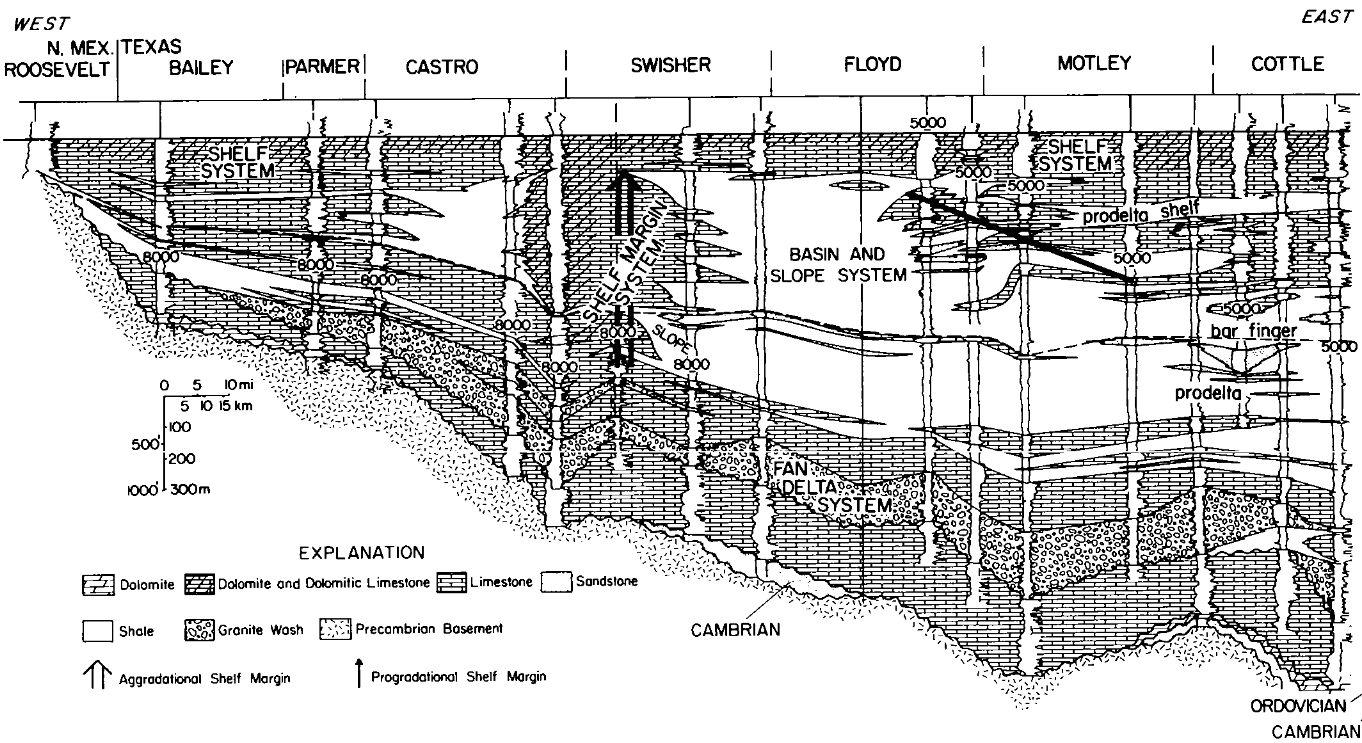


Figure 26. East-west cross section showing stratigraphic framework and depositional systems of Pennsylvanian-Wolfcampian strata and underlying rocks in the Palo Duro and Hardeman Basins (after Handford and Dutton, 1980). Datum is top of Wolfcampian Series. Depths are in feet below ground surface.

The evaporite section can be divided into five major genetic units (Figs. 24 and 25): (1) the Wichita and Red Cave, (2) the lower Clear Fork and Tubb, (3) the upper Clear Fork and Glorieta, (4) the San Andres, and (5) the post–San Andres (Presley, 1980). Each genetic unit except the post–San Andres records a major basinward (southerly) facies shift through time (Presley, 1980). These genetic sequences can be subdivided into secondary cycles that record more localized episodes of transgression and regression. The youngest unit, the post–San Andres, is primarily a grouping of similar facies, and it does not exhibit a broadly regressive character (Presley, personal communication, 1983).

Wichita-Red Cave genetic unit

The Wichita Group marks the beginning of evaporite deposition in the Palo Duro Basin (Fig. 25). Strata in the Wichita Group were deposited in a coastal sabkha that was bordered on the south by the deep Midland Basin and on the west and northwest by an alluvial-fan plain (Handford, 1979). Dolomite and anhydrite were deposited in the Texas panhandle, whereas bedded salt was deposited farther landward in Oklahoma and Kansas. The Wichita sabkha deposits pass into terrigenous red beds in the Dalhart Basin and east-central New Mexico.

The Wichita Group is conformably overlain by and laterally equivalent to the Red Cave Formation (Clear Fork Group; Fig. 24). The Red Cave consists of red-bed clastics and interbedded carbonate-evaporite members (Fig. 25). The clastics were deposited in mud-rich, coastal to continental sabkhas and, farther landward, a wadi-plain system (Handford and Fredericks, 1980; Handford and others, 1981). The Red Cave clastics interfinger to the south with anhydrite and dolomite that were deposited in carbonate-evaporite coastal sabkhas (Handford and Fredericks, 1980).

Lower Clear Fork-Tubb genetic unit

Lower Clear Fork strata were deposited in coastal-evaporite and carbonate environments that were similar to Wichita environments (Handford and others, 1981). However, because of a southerly migration of evaporite environments, bedded salt was deposited in the northern Palo Duro Basin for the first time (Fig. 25). A southerly facies tract in the lower Clear Fork consists of: (1) terrigenous red beds deposited on an alluvial-eolian plain

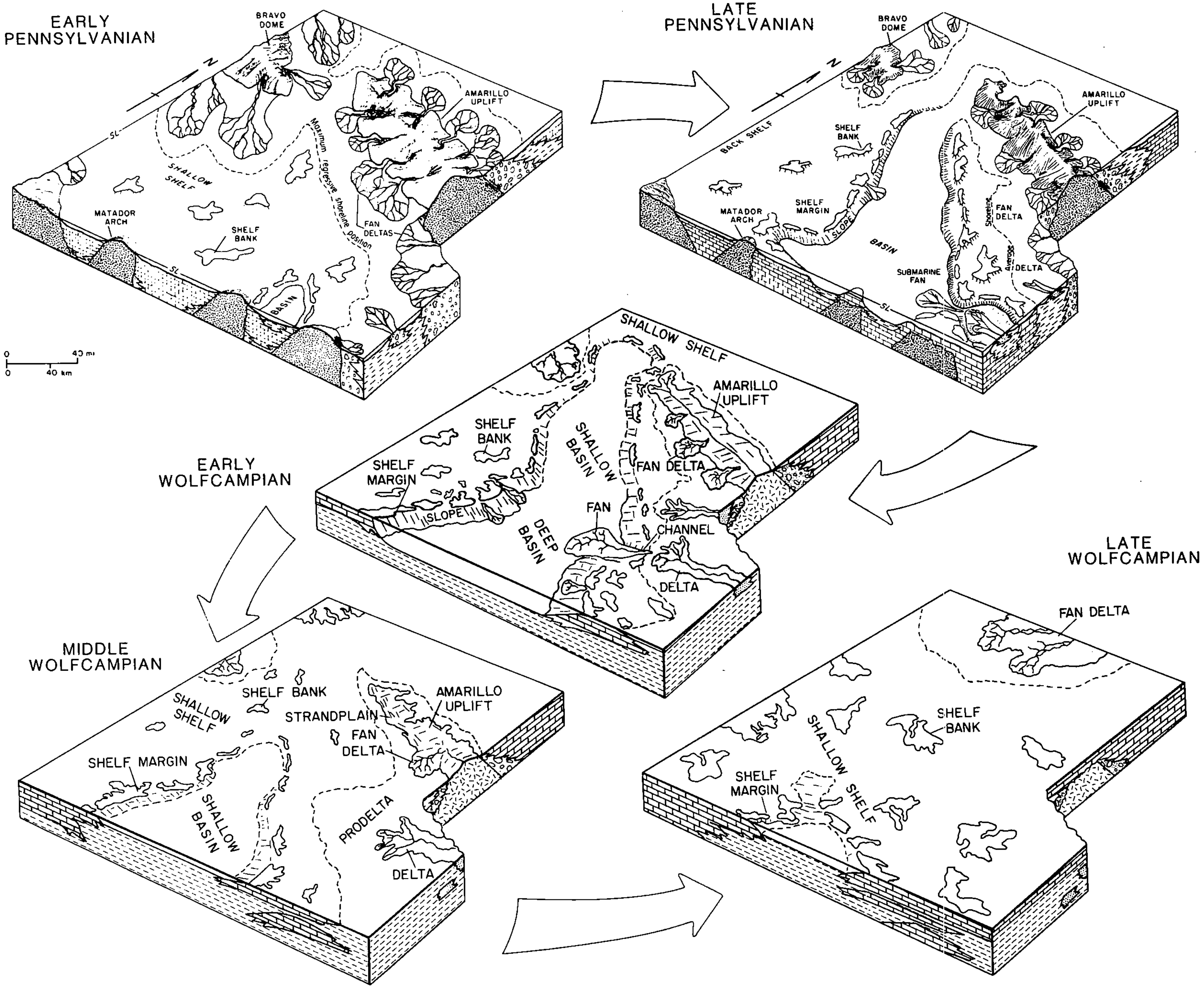


Figure 27. Block diagrams of paleogeographic evolution of Palo Duro and Dalhart Basins during Pennsylvanian and Wolfcampian time (after Handford and Dutton, 1980).

and inner-sabkha mud flat; (2) chaotic mudstone-halite formed in a saline mud flat; (3) banded to massive halite and laminated anhydrite deposited in inner-sabkha salt pans; and (4) dolomite and nodular to massive anhydrite deposited in marginal-sabkha and inner-shelf environments (Handford, 1981).

The overlying Tubb Formation (Fig. 25) contains two facies assemblages: (1) laterally persistent red beds, and (2) evaporites and carbonates that interfinger updip with the red beds (Presley, 1980). Each red bed records a southerly migration of siliciclastic mud-flat environments. Subsequent transgression of the mud flats permitted the resumption of carbonate-evaporite sedimentation.

Upper Clear Fork–Glorieta genetic unit

The upper Clear Fork Formation (Fig. 25) consists of a north-south facies tract similar to that of the lower Clear Fork (Presley and McGillis, 1982). A common facies in the updip part of the upper Clear Fork and other evaporite units is chaotic mudstone-salt, which varies from salt containing intercrystalline mudstone to mudstone with scattered salt crystals. This facies is interpreted as a saline mud-flat deposit in which halite crystals grew displacively near the surface (Presley and McGillis, 1982). The other evaporites in the upper Clear Fork probably formed in salt-pan environments basinward of the saline mud flats. Terrigenous red beds were deposited updip of the evaporites in mid-flat and wadi-plain environments (Presley, 1981).

In Glorieta time, terrigenous-clastic environments migrated basinward. Glorieta clastic units in the Palo Duro Basin are primarily mudstones and siltstones that were deposited in mud flats (Fig. 25). Glorieta clastics in the Dalhart Basin are eolian sheet sandstones (Presley and McGillis, 1982).

San Andres genetic unit

The San Andres Formation marks return to coastal evaporite and carbonate sedimentation in the Palo Duro Basin; the formation is characterized by thick (up to 100 m) carbonate-anhydrite-halite cycles (Fig. 25; Presley, 1981). Thick, salt-pan halite beds in the San Andres Formation are commonly banded into layers of dark halite with disseminated mud and other impurities and purer, clear salt layers (Presley and McGillis, 1982). San Andres deposits in the Palo Duro Basin contain less terrigenous sand or mud than do other Upper Permian formations. However, the Hardeman Basin was the site of terrigenous clastic deposition in early San Andres time, as deltas of the San Angelo Formation prograded into the area from the east (Smith, 1974). In later San Andres time, sabkha and tidal-flat environments developed in the Hardeman Basin (Smith, 1974).

Post–San Andres genetic unit

Post–San Andres strata (Figs. 24 and 25) are composed predominantly of salt and terrigenous red beds deposited in salt pans, saline mud flats, and eolian/continental sabkha environments (Presley, 1980, 1981). In the Seven Rivers and Salado Formations, mudstones interfinger basinward with massive salts (Fig. 25). Salt-bearing facies in the post–San Andres formations extend south of the Palo Duro Basin into the Midland and Delaware Basins. These deposits accumulated during the last stages of the regional Permian regression and record the final Paleozoic marine incursions in the Texas panhandle (McGillis and Presley, 1981).

FORT WORTH BASIN

Diana Morton Thompson

INTRODUCTION

The Fort Worth Basin, north-central Texas, is a Paleozoic foreland basin that was downwarped during Early Pennsylvanian time in response to the same tectonic stresses that produced the Ouachita Thrust Belt. It is bounded on the east by the Ouachita Thrust Belt, on the north by the Red River–Electra and Muenster Arches, on the south by the Llano Uplift, and on the west by the Concho Platform–Bend Arch (Plate 5-A). The basin strikes north-south and is asymmetric to the east.

In its deepest part the Fort Worth Basin contains a maximum known thickness of 4,000 m of Paleozoic rocks unconformably overlain by outcropping Cretaceous strata (Turner, 1957). The majority of the basin fill is Pennsylvanian in age (Figs. 28 and 29) with Cambrian, Ordovician, Mississippian, and Permian rocks also present.

The Paleozoic sedimentary sequence reflects a general transition from a passive continental margin to an actively subsiding basin. As part of the greater Oklahoma Basin, the Fort Worth area was subjected to epeirogenic movements and predominantly carbonate deposition during the early and middle Paleozoic. The Fort Worth Basin was then filled during Pennsylvanian time by terrigenous clastics derived from the adjacent uplifts. Pennsylvanian terrigenous sequences offlap to the west, indicating a progressive westward shift of depocenters as high-constructive fan-delta and delta systems prograded across the basin. The distribution of depositional environments and facies was highly variable with carbonate slope, shelf, and deltaic environments existing contemporaneously (Fig. 29).

TECTONIC AND STRATIGRAPHIC FRAMEWORK

In Pre-Pennsylvanian time the area that later became the Fort Worth Basin lay on the eastern side of the Texas Arch in the southern part of the Oklahoma Basin. The Texas Arch acted as a stable cratonic element throughout much of the Paleozoic, while the Fort Worth Basin area subsided intermittently to receive approximately 1,500 m of early to middle Paleozoic carbonates and other marine sediments. Recognition of the regional extent and longevity of this part of the Oklahoma Basin implies that present structural divisions between the Fort Worth Basin and adjacent

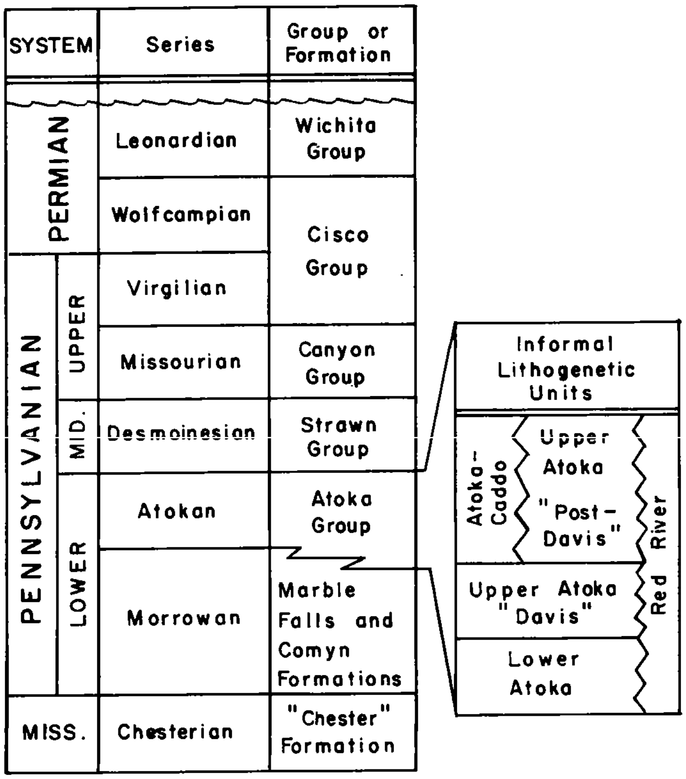


Figure 28. Generalized stratigraphy of the Fort Worth Basin, including a classification of the subsurface Atoka Group. Modified from Thompson (1982).

basins, such as the Hardeman and Ardmore Basins, are strictly Pennsylvanian features that resulted from reactivation of old fault systems during Ouachita deformation. With the advent of the Ouachita Orogeny, the regional structural elements surrounding the Fort Worth Basin were formed. Those structures are: the Ouachita Thrust Belt, the Red River–Electra–Muenster Arches, the Bend Arch, and the Llano Uplift (Plate 5-A).

The Ouachita Thrust Belt is a 2,000-km-long band of deformed Paleozoic rocks that marks the southern margin of the North American Craton (Hatcher and others, 1988). The thrust belt is exposed only in the Ouachita Mountains of Oklahoma-Arkansas, and in the Marathon Uplift of Texas. Most of the belt, including that portion just east of the Fort Worth Basin, is covered unconformably by Cretaceous and Cenozoic strata.

The Red River–Electra Arch, on the north side of the Fort Worth Basin, is composed of a series of discontinuous fault blocks that strike west-northwest. The faults are believed to have been controlled by basement fractures that were initiated in the Late Precambrian and reactivated during Ouachita deformation (Ham and others, 1964).

The Muenster Arch, to the northeast of the basin, consists of a northwest-trending uplifted block of Cambrian to Mississippian age sedimentary rocks mantling Precambrian igneous and metamorphic basement. The southwest flank of the Muenster Arch, adjacent to the Fort Worth Basin, is bounded by a series of faults that exhibit displacement down to the southwest. Total displacement across these faults is estimated to be 1,500 m (Flawn and others, 1961).

The Bend Arch is a broad structural element west of the Fort Worth Basin. It is observed in the subsurface as an elongate ridge that strikes north-south and plunges to the north. The Bend Arch represents the hingeline between the subsiding Fort Worth Basin to the east and the stable Concho Platform to the west. The hingeline formed in Late Mississippian and Early Pennsylvanian time as stresses generated by Ouachita deformation created the Fort Worth Basin. It did not act as a physical barrier to sediment transport or as a sediment source.

The Llano Uplift is located at the south end of the Bend Arch. It is a structural dome that was stabilized by massive granitic intrusions in late Precambrian time (Flawn and others, 1961). During the Early–Middle Pennsylvanian the area was uplifted and faulted into a series of horsts and grabens that strike parallel to the leading edge of the Ouachita Thrust Belt. The Llano Uplift was an intermittent positive feature throughout the Paleozoic and even exerted an influence on Cretaceous facies distribution. Today, it is a topographic basin floored by Precambrian igneous and metamorphic rocks, and rimmed by outcrops of Cambrian, Ordovician, Devonian, Mississippian, Pennsylvanian, and Cretaceous rocks.

As the Fort Worth Basin subsided, Atokan-age intrabasinal faults developed in response to extensional deformation. Faulting and deposition were contemporaneous, with individual faults acting as subsidiary hingelines. In the central part of the basin, faults strike northeast, subparallel to the western edge of the Ouachita Thrust Belt, and coincide with trends of major faults in the Llano Uplift. These faults are inferred to exhibit normal displacement, and most are downthrown to the southeast. However, they also form an en-echelon series of horsts and grabens. Near the northern margin of the basin the faults strike subparallel to the Electra and Muenster Arches and are downthrown toward the center of the basin (Thompson, 1982).

The generalized stratigraphy of the Fort Worth Basin, lithologic descriptions of major units, and a partial list of the more recent workers are summarized in Kier and others (1979) and Thompson (1982). Nomenclature has been extrapolated from outcrop work in the Llano Uplift and Eastern Shelf areas; however, these terms are not always applicable in the subsurface. Because of time-transgressive facies and facies changes, many discrepancies exist, particularly within the Pennsylvanian.

PENNSYLVANIAN SYSTEM

Morrowan Series

During Morrowan time the Fort Worth Basin was inundated by transgressive seas, indicating renewed subsidence. The

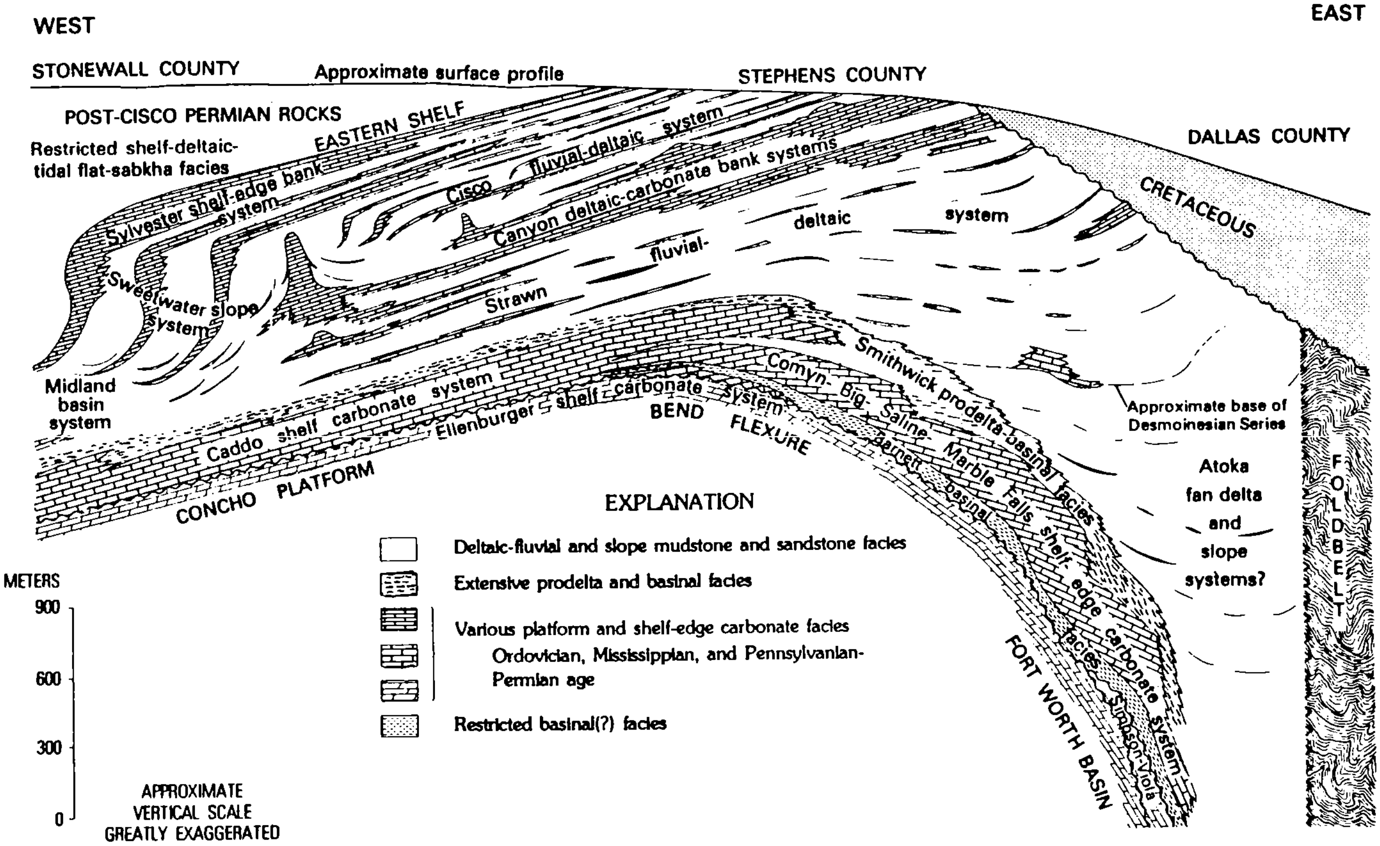


Figure 29. Schematic cross section illustrating sedimentary fill of the Fort Worth Basin and offlap of depositional systems across the Concho Platform (Eastern Shelf). From Kier and others (1979).

resulting carbonates compose the Marble Falls Formation. On the Llano Uplift, a Bahama-like carbonate platform developed that was periodically emergent and submergent. Algal bioherms and oolite shoal facies predominated (Kier, 1980). In the Fort Worth Basin a deeper water facies characterized by black shale and spiculitic limestone was deposited (Plate 5-M), with more than 150 m of strata still preserved in the subsurface.

Springer-age rocks have not been recognized within the Fort Worth Basin area. This may be due to either nondeposition or post-Springer pre-Morrowan erosion. The author favors erosion because Mississippian rocks are irregularly truncated within the basin, and a break in deposition is also observed in the Hardeman and Palo Duro Basins. This suggests broad regional uplift, perhaps associated with movement of the Amarillo-Wichita Mountains.

Atokan Series

Although the Ouachita orogeny was initiated earlier, clear evidence of major structural movement is not recorded in sediments of the Fort Worth Basin until the Atokan Epoch (Plate 5-N). During Atokan time the Ouachita Thrust Belt was emplaced, and reactivation of old faults along with residual positive features gave the Fort Worth Basin distinct geologic and geographic boundaries. Atokan rocks consist of interbedded shales, conglomerates, sandstones, and thin limestones. Chert conglomerates derived from the Ouachita Thrust Belt were shed into the rapidly subsiding basin, along with arkosic granite washes derived from the Red River and Electra Arches, and minor amounts of sediment derived from the Muenster Arch and Llano Uplift. Subsidence was greatest along the leading edge of the Ouachita Thrust Belt and at the southern end of the Muenster Arch where approximately 1,800 m of sediments (or 50 to 75 percent of the Paleozoic basin fill) were deposited (Plate 5-N). Principal studies of Atokan strata in the area include Ng (1979), Lovick and others (1982), and Thompson (1982).

Atokan stratigraphic relationships are highly complex, and there are significant variations in the interpretation of the subsurface data. In the northern half of the basin, five packages of sedimentation can be defined (Fig. 28): (1) the lower Atoka lithogenetic unit, (2) the upper Atoka "Davis" lithogenetic subunit, (3) the upper Atoka "Post-Davis" lithogenetic subunit,

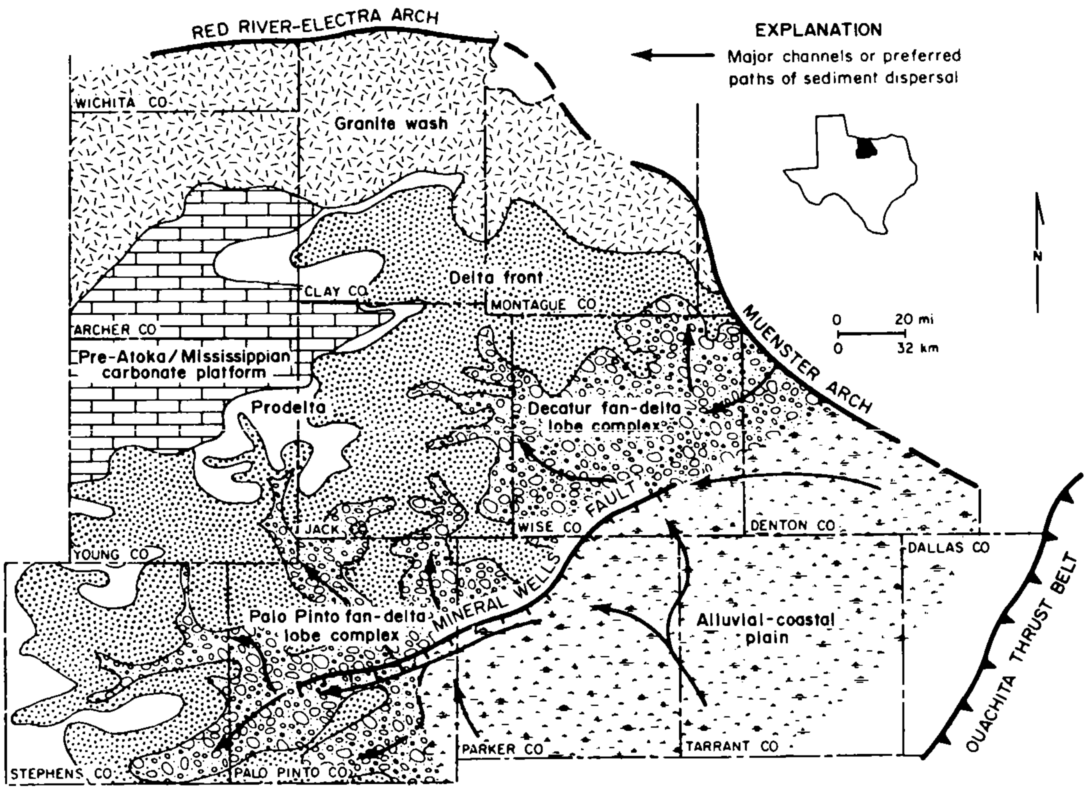


Figure 30. Distribution of lower Atoka facies, northern Fort Worth Basin, Texas. Similar depositional systems are inferred to have existed in the southern half of the basin. From Thompson (1982).

(4) the Red River lithogenetic unit, and (5) the Atoka-Caddo lithogenetic unit (Thompson, 1982).

The lower Atoka unit is interpreted to be a fluvially dominated fan-delta system, characterized by a highly digitate sandstone geometry, extensive interfingering of contemporaneously deposited terrigenous and carbonate strata, progradational facies sequences, and fault-controlled facies distribution (Fig. 30). This lithogenetic unit reflects the initial transition from a shallow marine to a terrigenous-dominated environment as chert-rich sediment was rapidly shed from the tectonically active Ouachita Thrust Belt and locally from the Muenster Arch.

The upper Atoka "Davis" subunit is interpreted to be a system of coalesced wave-dominated deltas, characterized by a thick, strike-oriented sandstone geometry, absence of significant contemporaneous limestone deposits, a predominance of coastal barrier facies, and electric log patterns that suggest concurrent progradation and aggradation. This lithogenetic subunit reflects a period of tectonic quiescence that allowed coastal marine processes to dominate fluvial processes and terrigenous sediment input.

The upper Atoka "Post-Davis" subunit is interpreted to be a thin, poorly integrated, fluvially dominated fan-delta system, similar to the lower Atoka unit. It is characterized by a narrow, highly digitate sandstone geometry and three east-west–trending axes of deposition along which delta lobe complexes prograded into the basin (Fig. 31). This lithogenetic subunit reflects renewed Ouachita tectonic activity that resulted in sporadic influx of sands and gravels rich in chert and metamorphic and volcanic rock fragments derived from the Ouachita Thrust Belt and Muenster Arch.

The Red River lithogenetic unit is characterized by thick, stacked sequences of arkosic conglomerate derived from the Red River–Electra Arch. The granite wash was deposited in a series of alluvial fans and fan deltas that existed throughout Atokan time and reflects continual uplift of the Red River–Electra Arch. The Atoka-Caddo lithogenetic unit roughly corresponds to the "Caddo reef" facies and is contemporaneous with upper Atoka deposition. It is interpreted to be a series of algal buildups that grew along the western margin of the basin out of the intense influence of terrigenous sedimentation and along the axis of the Bend Arch.

Desmoinesian Series (Strawn Group)

The Strawn Group of Desmoinesian age consists mainly of

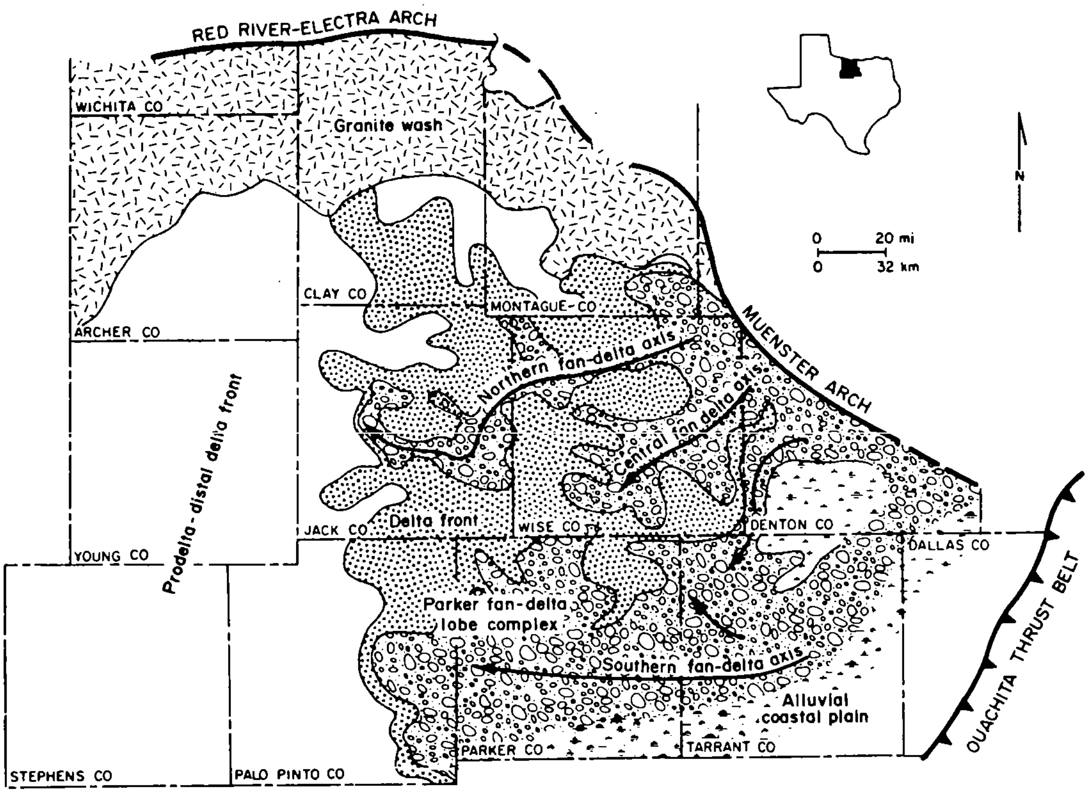


Figure 31. Distribution of upper Atoka "post-Davis" facies, northern Fort Worth Basin, Texas. Similar depositional systems are inferred to have existed in the southern half of the basin. From Thompson (1982).

shales and other fine-grained clastics, and it is more than 1,200 m thick in the northern part of the Fort Worth Basin (Plate 5-O). Two styles of deposition are present in the Strawn Group: (1) the lower Strawn, believed to be genetically related to the Atoka Group, and (2) the middle and upper Strawn, believed to be related to the overlying Canyon Group (Brown and others, 1973).

There is a lack of published information on the lower Strawn. This may be due to scattered well control in the eastern part of the basin, and due to the limited distribution of the unit. Lower Strawn depositional systems are assumed to be similar to those of the upper Atoka "Post-Davis" and imply continuing tectonic uplift to the north and east coupled with basin subsidence.

Middle and upper Strawn rocks are known from outcrops on the east side of the basin and from subsurface work on the Concho Platform to the west. By middle Strawn deposition, subsidence rates were substantially reduced, and high-constructive fluvial-deltaic systems were able to prograde over the older basin fill out onto the Concho Platform. Eight transgressive-regressive cycles are present in the middle and upper Strawn (Cleaves, 1982). Cyclicity was controlled by avulsion of major delta complexes, moderate subsidence within the Fort Worth Basin, and subsidence of the Midland Basin, which resulted in progressive regional tilting to the west.

Major Strawn depositional features present in the Fort Worth Basin are: (1) the Perrin Delta complex, a major site of deposition for the remainder of the Pennsylvanian; (2) the Eastland Delta complex; (3) the Bowie Delta complex; and (4) the Thurber Embayment (Fig. 32; Cleaves, 1982). The Perrin and Eastland Delta complexes are characterized by high-constructive elongate and lobate deltas, incised valley fill systems, multilateral sandstone distribution reflecting low subsidence rates, and chert-rich sediment derived from the Ouachita Thrust Belt. The Bowie Delta complex is characterized by high-constructive elongate deltas, thin prodelta facies, multistoried sandstone distribution reflecting contemporaneous subsidence in the northern end of the basin, and coarse conglomerates derived from the Red River–Electra Arch and possibly the Arbuckle Mountains. The Thurber Embayment, a major deltaic embayment, is characterized by sheet sandstones, bituminous shale, and coal.

Adjacent to the Llano Uplift, rocks of Desmoinesian age contain pebbles of the Marble Falls Formation within prodelta shale. This implies the emergence of the Llano Uplift and extensive transport of prodelta shale from westward-building Strawn deltas (Kimberly, 1961; Turner, 1970; Watson, 1980).

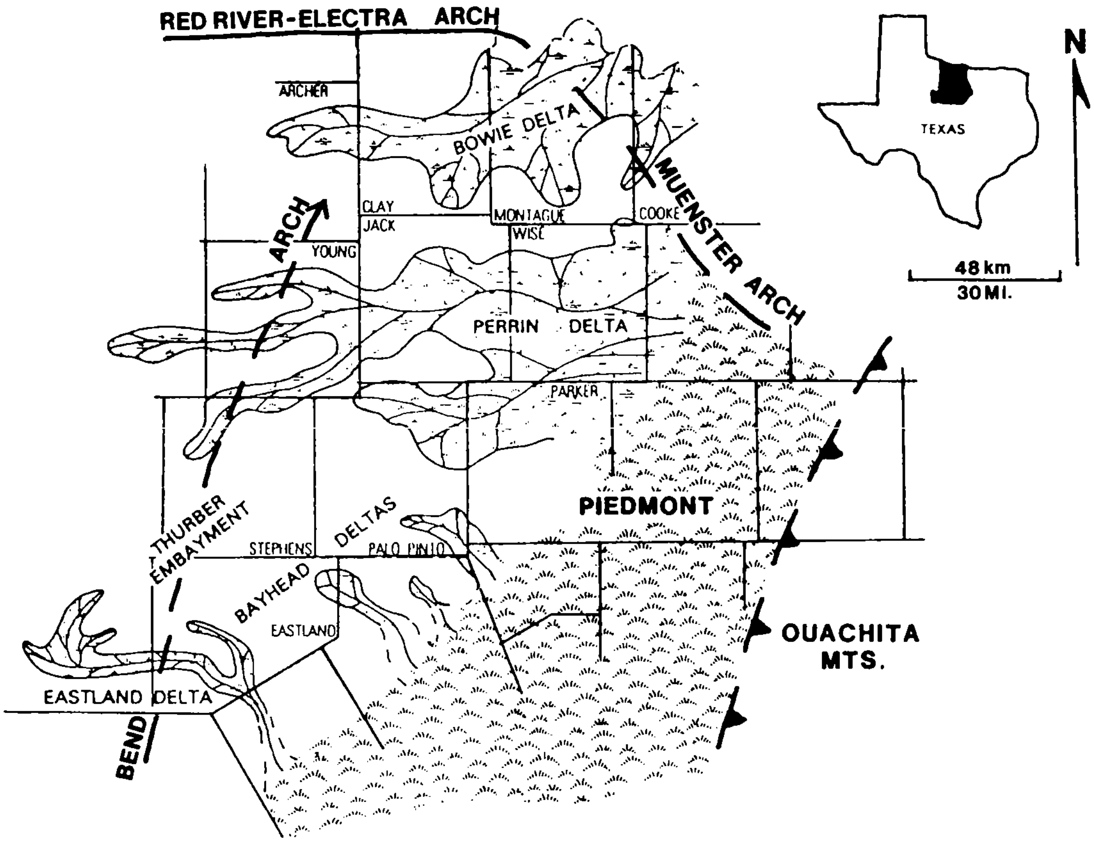


Figure 32. Distribution of Strawn Group depositional systems in the Fort Worth Basin, north-central Texas. Similar types of systems are inferred to have existed in the southern part of the basin. Modified from Cleaves (1975, 1982) and Kier and others (1979).

Missourian Series (Canyon Group)

Rocks of the Canyon Group crop out in the northwest corner of the Fort Worth Basin and are present in the shallow subsurface to the west (Fig. 29 and Plate 5-P). The tectonic and depositional style during Missourian time was similar to that of late Desmoinesian, and nearly 900 m of strata, mostly shales, are still preserved. During Canyon deposition, high-constructive deltas continued to prograde over the older basin fill and across the Concho Platform farther west (Fig. 29). A facies tract of piedmont-fluvial-deltaic-carbonate shelf and shelf edge became well established. However, slow subsidence and sedimentation rates resulted in an increase in destructive facies.

Three cycles of delta building and destruction are present in the Canyon (Erxleben, 1975). Cycles reflect periods of delta progradation, avulsion, abandonment, destruction, marine encroachment, and subsequent deposition of shelf carbonates.

Major Canyon depositional features present in the Fort Worth Basin are: (1) the Perrin Delta complex, (2) the Henrietta Fan-Delta complex, and (3) the Red River, Chico Ridge, and Winchell carbonate bank ("build-up") systems (Fig. 33; Erxleben, 1975). The Perrin Delta is characterized by the same depositional processes established during Strawn deposition. It reflects progradation of sediment interpreted to have been derived from the Ouachita Thrust Belt and from rocks of the Atoka and Strawn Groups that were uplifted along the eastern edge of the basin. The Henrietta Fan-Delta complex is characterized by thick, stacked sequences of arkosic and lithic conglomerate interpreted to have been derived from the Ouachita Thrust Belt and from the Wichita Uplift. Subsidence and sedimentation rates in the northern end of the basin were comparable, and a low-relief fan-delta plain facies with thin coal beds developed. Canyon carbonate-bank systems had depositional relief but were composed of nonframework-building organisms, such as phylloid algae, bryozoa, and crinoids (Erxleben, 1975; Wermund, 1975; Cherng, 1982). The Red River bank formed on the fault blocks of the Red River–Electra Arch. The Winchell and Chico Ridge banks grew on top of abandoned delta lobes. The relief on these banks was sufficient to deflect the prograding Perrin Delta complex.

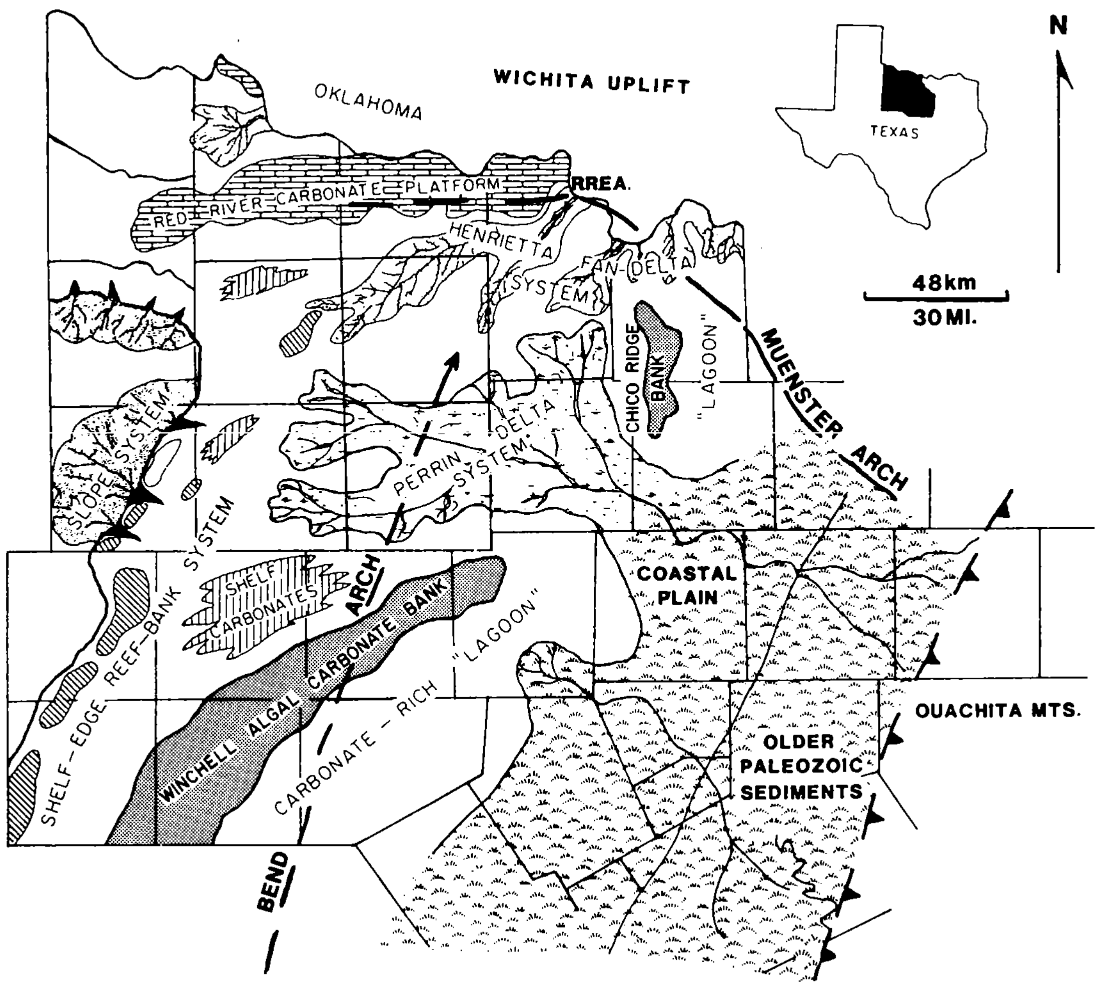


Figure 33. Distribution of Canyon Group depositional systems, north-central Texas. Similar types of systems are inferred to have existed in the southern part of the basin. RREA, Red River–Electra Arch. Modified from Erxleben (1975).

Virgilian Series (Lower part of Cisco Group)

Rocks of Virgilian age, in the lower part of the Cisco Group, are restricted to the northwestern corner of the Fort Worth Basin (Plate 6-Q). Up to 450 m of strata are preserved in the far northern part of the basin. Like the underlying Canyon Group, they consist of mixed terrigenous and carbonate depositional systems, with shales dominant. Although extensive systems of fluvial-deltaic clastics and shelf-edge carbonates exist downdip farther to the west, only the updip fluvial and deltaic facies are preserved in outcrop and shallow subsurface of the Fort Worth Basin (Turner, 1957; Galloway and Brown, 1972).

PERMIAN SYSTEM

Permian rocks are restricted to the northwest corner of the basin and consist of nearly 500 m of alluvial-deltaic and marginal-marine sandstones, mudstones, and shales of Wolfcampian and earliest Leonardian age (Plates 6-R and 6-S). These strata make up the upper portion of the Cisco Group and also the Wichita Group. The clastics consist of detritus from the Ouachita Thrust Belt, which by this time had been eroded down to low mountains or hills of only moderate relief. Clastic units are red, brown, and gray, and they grade westward across the Concho Platform into thick carbonates of the Hardeman Basin and the Eastern Shelf of the Midland Basin.

SYSTEM	SERIES	SOUTWESTERN TEXAS PANHANDLE (Palo Duro Basin area)	SOUTWESTERN KANSAS (Hugoton Embayment area)	WEST-CENTRAL OKLAHOMA (Anadarko Basin area)	SOUTH-CENTRAL OKLAHOMA (Ardmore Basin area)	NORTH-CENTRAL TEXAS (Ft. Worth Basin area)
QUATERNARY	Holocene	Alluvium and Terrace Deposits				
	Pleistocene	Tule Group	Meade Group			
TERTIARY	Pliocene	Ogallala Fm.	Ogallala Fm.	Ogallala Fm.		
	Miocene					
CRETACEOUS	Upper	Duck Creek Fm.	Dakota Group	Dakota Group		Austin Group Eagle Ford Fm. Woodbine Fm. Washita Group
	Lower	Kiamichi Group	Kiowa Shale	Kiowa Shale		Fredericksburg Group
		Edwards Limestone	Cheyenne Sandstone		Antlers Formation	Trinity Group
JURASSIC		Morrison Fm. Exeter Sandstone	Morrison Fm.			
TRIASSIC		Dockum Group	Dockum Group			

Figure 34. Correlation of post-Permian stratigraphic units in the Southern Midcontinent, based upon COSUNA Charts (Hills and Kottlowski, 1983; Mankin, 1987).

POST-PERMIAN ROCKS

Kenneth S. Johnson

Post-Permian rocks of the Southern Midcontinent include remnants of Triassic, Jurassic, Cretaceous, Tertiary, and Quaternary strata (Fig. 34). Deposition of these sediments was not influenced by the tectonic provinces that were so pronounced and critical to Pennsylvanian and Permian sedimentation.

TRIASSIC SYSTEM

Triassic strata, limited to the western part of the Southern Midcontinent (Plate 6-V), are a red-bed sequence referred to the Dockum Group of Middle and Late Triassic age (Hills and Kottlowski, 1983). These strata were described on a regional basis by McKee and others (1959), and more detailed studies were conducted later by McGowan and others (1979) and Dutton and Simpkins (1986).

The Dockum Group was deposited in a closed continental basin in fluvial, deltaic, and lacustrine environments (McGowan and others, 1979). The thickness of the Dockum ranges from less than 75 m around the now-eroded periphery of the basin to more than 600 m in the southwest (Plate 6-V). This unit has been subdivided informally into the lower Dockum and upper Dockum. The lower Dockum Group consists of fine- to coarse-grained quartzose sandstones and conglomerates deposited in braided and meandering streams, in alluvial fans and fan deltas, and in high-constructive lobate deltas (McGowan and others, 1979; Dutton and Simpkins, 1986). These coarse-grained sediments are more abundant around the periphery of the basin but they are interbedded with mudstones, and they grade laterally into mudstones deposited in lacustrine and prodelta environments toward the central parts of the basin.

The upper Dockum Group is more mud rich than the lower part. Thick sandstone units are not extensive in the upper

Dockum, except in the southern part of the region, because the fluvial-deltaic systems at this time were generally small (McGowen and others, 1979).

JURASSIC SYSTEM

Late Jurassic strata consist of sandstones and shales of the Exeter Sandstone and overlying Morrison Formation in the northwestern part of the Southern Midcontinent (Fig. 34 and Plate 6-W). They are a westward-thickening wedge of fluvial sediments derived by erosion of low plains areas that lay to the east. The Exeter is fine- to medium-grained, cross-bedded sandstone that is white, light brown, and orange (Barnes, 1984). The overlying Morrison consists of red-brown, green, and gray mudstone, sandstone, and minor limestone (Stovall, 1943); fossil dinosaur bones are common (Stovall, 1938).

CRETACEOUS SYSTEM

Lower and Upper Cretaceous shales, sandstones, and limestones are present around the perimeter of the Southern Midcontinent (Fig. 34 and Plate 6-X). The Cretaceous seaway extended across most of the western half of the region during the last great marine inundation of the western interior of the United States. Formation of the Rocky Mountains during the Laramide orogeny of Late Cretaceous and Early Tertiary time imparted an eastward and southeastward tilt to the entire region and eventually caused withdrawal of the Cretaceous sea.

Cretaceous strata in north-central Texas are considered part of the Gulf Coastal Plain, but they overlap the area of the Fort Worth Basin (Fig. 29). A series of transgressive deposits were spread northward from the ancestral Gulf of Mexico (Scott and others, 1978; Corwin, 1982) and they interfinger with alluvial and deltaic complexes to the north and northwest. Deposition was cyclic, with alternation of terrigenous and shallow-marine facies reflecting eustatic sea-level changes or a combination of irregular subsidence and sedimentation rates. Eventually, the encroaching seas submerged all of north-central Texas and then spread northwestward across western Oklahoma, the Texas panhandle, and the Western Interior. A major unconformity is well exposed throughout north-central Texas and southern Oklahoma where Cretaceous strata rest on rocks ranging in age from Precambrian through Permian.

Cretaceous strata in the western part of the Southern Midcontinent are isolated erosional remnants of widespread sediments deposited in the interior seaway. More than 150 m of predominantly marine sandstones, shales, and limestones were deposited in the area (Merriam, 1963). Southward thinning of the Cretaceous results from broad uplift and truncation before the overlying Tertiary sediments were deposited. Small outliers of Cretaceous marine strata in western Oklahoma consist of chaotic blocks and masses (typically 10 to 500 m across) of limestone and shale that have collapsed some 50 to 100 m, due to dissolution of underlying Permian salts, and are now juxtaposed against Permian rocks exposed at the land surface.

TERTIARY SYSTEM

The Ogallala Formation, of Miocene-Pliocene age, is widespread in the High Plains area of the Southern Midcontinent (Plate 6-Y). It is a buff- and light-colored sequence of interbedded fluvial and windblown sediments deposited upon an erosional surface cut into Permian red beds (and locally into Triassic, Jurassic, or Cretaceous strata). The Ogallala was deposited by low-gradient alluvial systems that flowed to the east and southeast from the Rocky Mountains (Seni, 1980). Medial-fan facies, which occur in the northern and northwestern Texas panhandle, include sand and gravel deposited in narrow stream channels separated by interchannel mud and silt (Seni, 1980).

Whereas early work indicated that the Ogallala was almost entirely fluvial in origin (Seni, 1980), more recent studies show that the fluvial deposits are confined to the lower part of the Ogallala and that the middle and upper parts of the Ogallala are mainly windblown deposits (Gustavson and Holliday, 1985). Ogallala deposition apparently ended between 3.5 and 2.4 Ma, which would be in the late Pliocene (Gustavson and Finley, 1985). Beds of calcrete or silcrete, commonly called caliche, are at or near the top of the Ogallala, and they form the cap rock of the High Plains.

QUATERNARY SYSTEM

Quaternary sediments are alluvial, eolian, and lacustrine deposits derived from rivers and streams flowing eastward and southeastward across all parts of the region. The Tule Group and Meade Group consist in part of sediments deposited in local subsidence basins formed by subsurface dissolution of Permian salt in the Texas and Oklahoma panhandles and southwestern Kansas (Gustavson and Finley, 1985). The Tule Group includes, in ascending order, the Blackwater Draw, Double Lakes, and Tahoka Formations.

Younger Pleistocene and Holocene sediments consist of terrace deposits and alluvium along and near the present-day streams and rivers of the region. Typically these deposits are 3 to 15 m thick, although locally they reach 30 m along the major rivers.

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