Late Mississippian and Pennsylvanian depositional history in the Arkoma basin area, Oklahoma and Arkansas

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ABSTRACT

The Arkoma basin was depositionally part of a broad, stable shelf along a passive continental margin during much of its history. During the Chesterian, Morrowan, and early Atokan, the depositional patterns on the shelf varied greatly, depending on the inconsistent development of carbonate environments and the intermittent introduction of terrigenous clastics (quartz arenites) from the north.

Beginning with the middle Atokan, flexural downwarping of the south margin of the shelf was accompanied by down-to-the-south syndepositional normal faults developed sequentially to the north, as a result of continued collapse of the Ouachita trough. Lithic arenites were introduced into this developing trough from the east, apparently derived from a tectonic provenance southeast of the Ouachita trough, on the southwest margin of the Black Warrior basin. Further closure plus rapid deposition resulted in the closing and filling of this incipient foreland basin by the end of deposition of the middle Atoka.

With further compressional deformation, the axis of deposition shifted farther northward with the development of a fully formed and continually subsiding foreland basin (beginning in late Atokan). Lithic arenites were transported westward along the axis of the basin (documented in earliest Desmoinesian). In Arkansas some of the early Desmoinesian sediments apparently came from the uplifted Ouachita thrust belt immediately to the south.

During the rest of the early Desmoinesian (most of Krebs Group), with the continued subsidence of the foreland basin, extensive deltaic deposits (sublitharenites) were introduced from the north and provided the primary source of sediments to the foreland basin in Oklahoma. They apparently came from the continental interior to the west and north of the Ozark dome.

Although there is evidence of a limited source of sediments from the Ouachita fold belt in Arkansas during the deposition of the Hartshorne Sandstone (earliest Desmoinesian), the fold belt to the west in Oklahoma was apparently quiescent and presumably standing at or near sea level throughout the time of deposition of the upper Atoka and the whole of the early Desmoinesian Krebs Group (Hartshorne, McAlester, Savanna, and Boggy Formations).

Although added field confirmations are needed, it is concluded that renewed folding and uplift of the Ouachita fold belt following the deposition of the early Desmoinesian Krebs Group involved also the compression and folding of the Arkoma basin. This ended the progressive downwarping of this basin and shifted the depocenter still farther to the northwest. The core area of the Ouachita fold belt was extensively elevated for the first time resulting in the erosion and transportation of chert pebbles and other sediments to the northwest (Thurman Sandstone).

Beginning with the middle Desmoinesian, Cabaniss Group deposition was in a narrow successor foreland basin located to the northwest of the Arkoma basin and to the northeast of the Hunton arch. The Ouachita fold belt was the primary source for terrigenous sediments, periodically including chert-pebble conglomerates, to this area throughout the remainder of the Pennsylvanian.

INTRODUCTION

Strata of the Arkoma basin and the Ouachita fold belt document the history of gradual collapse and closure of the Ouachita trough and the development of a foreland basin as a result of continental collision. The primary purpose of this paper is to put the depositional events related to the development of this foreland basin into the broader context of depositional history in the area extending from the Late Mississippian through the Middle Pennsylvanian. This time interval includes the depositional history on the passive stable Arkoma shelf (named by Sutherland, 1988) immediately prior to the development of the foreland basin; the history of the filling of the foreland basin; and the folding, uplift, and erosion of both the Ouachita fold belt and the foreland basin. Particular emphasis is placed on evaluations of changing directions of sediment source accompanied by changing types of sediments in a time-stratigraphic framework.

The goal of interpreting the depositional history is inhibited at some key points by lack of information and at others by conflicts in interpretation. In the next section, some of these unresolved issues are reviewed with the hope of clarification and with the intention of pointing out areas where additional investigations are needed. The depositional history is discussed in a later section.

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. 1). 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, both of which define the cratonward margin of the Ouachita fold belt.

Various tectonic models have been proposed for the Ouachita fold belt. A widely accepted one is a collision model with south-dipping subduction (Wickham and others, 1976; Lillie and others, 1983). An important aspect of the collision model relevant to the interpretation of deposition in the Ouachita trough and later in the Arkoma basin is that of sequential east-to-west closure of the remnant ocean basin (Graham and others, 1975). Thus, continental collision to the southwest of the Black Warrior basin is believed to have provided sediments northwestward to the Ouachita region preceding final closure in that area (Thomas, 1984). The actual method of closure of the remnant ocean basin (Ouachita trough) was apparently one of northward-advancing thrust sheets (Arbenz, 1984; Link and Roberts, 1986).

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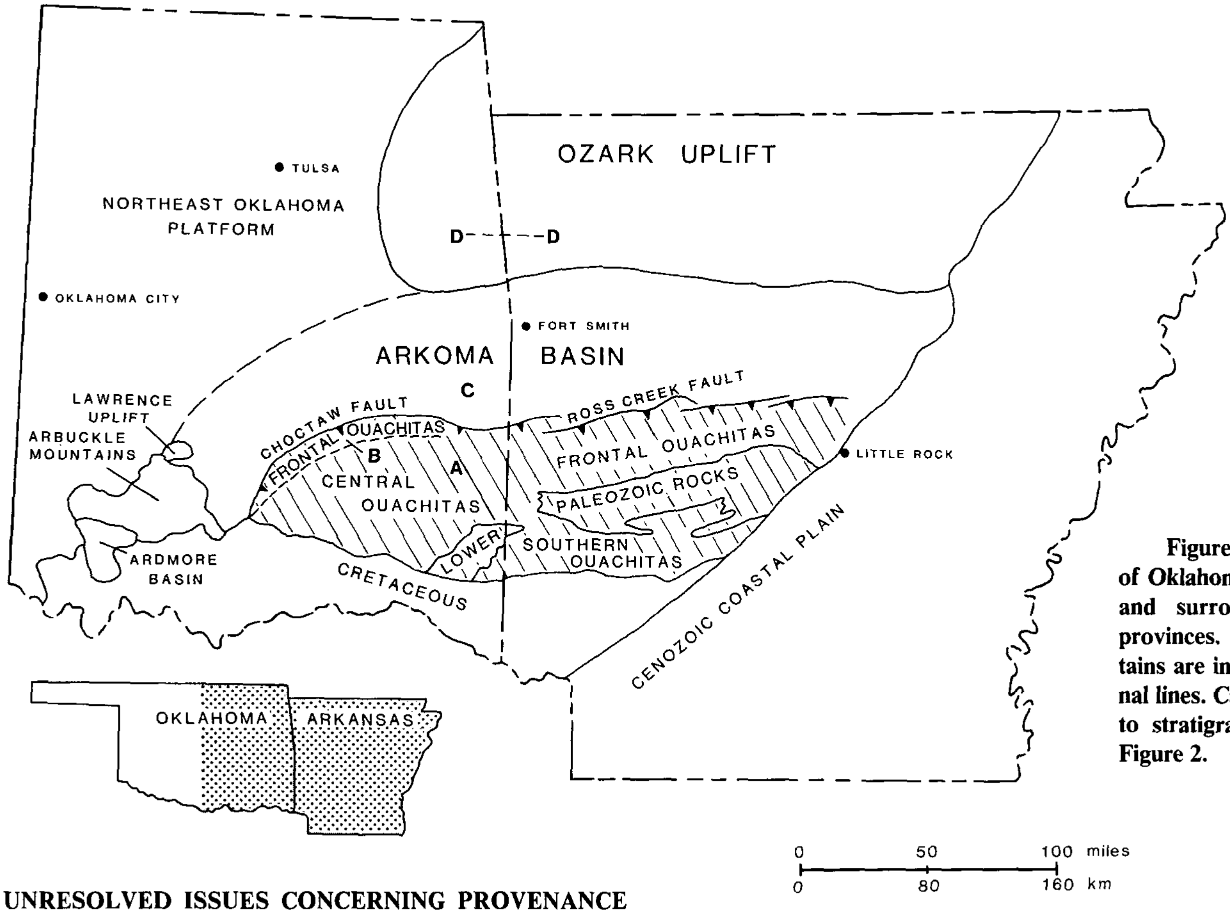

Figure 1. Arkoma basin of Oklahoma and Arkansas, and surrounding geologic provinces. Ouachita Mountains are indicated by diagonal lines. Capital letters refer to stratigraphic columns in Figure 2.

UNRESOLVED ISSUES CONCERNING PROVENANCE AND STRUCTURAL FRAMEWORK

Provenance of Johns Valley Boulders in the Ouachita Facies

Tomlinson (1959), among others, has summarized various ideas that have been proposed concerning the origin of the erratic boulders in the Johns Valley and other formations in the Ouachita facies. One of the most widely accepted postulations is that the erratics came from a submarine fault scarp on the north side of the trough (Shideler, 1970). It is this interpretation that is shown in this paper in Figures 5 and 6 (below). Boyd R. Haley, after having examined Figures 3 and 4 (this paper, below), brought it to my attention that this theory requires that units on the shelf that provided some of the erratics, such as the Pitkin Limestone and the Prairie Grove calcareous sandstone, must have extended south across the shelf during their times of deposition if they were to be encountered in a later submarine fault scarp. Figures 3 and 4 record subsurface information indicating that the limestones and calcareous sandstones of the late Chesterian and Morrowan change facies to shales on the southern parts of the Arkoma shelf. In addition, on the outcrop in the frontal Ouachitas in Oklahoma the entire Chesterian-Morrowan sequence below the Wapanucka Limestone consists mostly of shale and is included in the "Caney" and "Springer" Formations (Figs. 3 and 4 below). The Pitkin Limestone and the Prairie Grove calcareous sandstone could not have been available in a submarine fault scarp on the north margin of the Ouachita trough that lay somewhere south of the present-day Choctaw fault. Alternative theories for the origin of the Pitkin and Prairie Grove erratics found in the upper Stanley and Johns Valley must be formulated. One might postulate deep submarine canyons across the outer shelf. Eventual drilling in the deeper parts of the Arkoma basin may provide answers.

Sources of Sediments to the Ouachita Trough and the Arkoma Shelf/Basin Area

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) a tectonic provenance east and southeast of the Ouachita trough, on the southwest margin of the Black Warrior basin, that provided lithic arenites (Mack and others, 1983); and (2) sediments, mostly quartz arenites, transported southwestward through the Illinois basin. In the latter case, most of the sediments were presumably deposited in the Ouachita trough, but some were transported westward along the Arkoma shelf. An additional secondary source could have been the Ozark dome, in southern Missouri, but quartz arenites possibly coming from that area have not been differentiated from those coming from the Illinois basin.

Sediments about which there is major uncertainty are those that came from west of the Ozark dome. The Early Morrowan Cromwell Sandstone and the Early Atokan Spiro Sandstone, deposited on the Arkoma shelf in Oklahoma, both came in part from that direction (see Figs. 4, 7 below). Both are primarily quartz arenites.[1] Higher stratigraphically, early Desmoinesian fluvial/deltaic complexes in the Arkoma basin and on the shelf

[1]A detailed description of the petrography of the Cromwell Sandstone, a subsurface unit in the Oklahoma part of the Arkoma basin, has not been published. Thin sections made from chips from five scattered cores are primarily quartz arenites. The petrography of the Spiro in Oklahoma has been described by Lumsden and others (1971).

to the north are, where known, composed of sublitharenites. These include the Booch sandstones in the McAlester Formation "that prograded south-southeastward from eastern Kansas" (Bissell and Cleaves, 1986, p. 212) and the Bartlesville-Bluejacket Sandstone (Boggy Formation) (Visher, 1968) (see Fig. 12 below). Does the change from quartz arenites in the Morrowan and early Atokan to sublitharenites in the early Desmoinesian mean a change in source area or possibly an unroofing in a single source area? The fact that the early Desmoinesian transgression was much more extensive than those that came before suggests at least an expansion and probably a total shift in source area. Both Morrowan and Atokan rocks have a distinctly limited northward distribution in northeastern Oklahoma, and both are restricted to the area east of the Nemaha ridge (Frezon and Dixon, 1975). Both intervals are truncated northward, and these pinch-outs can be seen along the southwest margin of the Ozark uplift (Geologic Map of Oklahoma, Miser, 1954; Morrowan truncation, T. 20 N.; Atokan truncation, T. 23 N.). In contrast, the Desmoinesian transgression covered most of the mid-continent and progressively covered the Nemaha ridge in both Oklahoma and Kansas (Frezon and Dixon, 1975; Stewart, 1975).

1. **Possible Morrowan Patterns.** There is no evidence that Morrowan deposition extended north of Oklahoma. The only obvious possible source was the Nemaha ridge immediately to the west. This possibility is placed in some doubt by the fact that the exposed Ordovician to Devonian rocks in that area were mostly carbonates, and sand could have been provided only by limited exposures of the Ordovician Simpson Group (see pre-Pennsylvanian map, Jordan, 1962).

2. **Possible Atokan Patterns.** Atokan deposition extended farther to the north. In southwestern Missouri, there are tiny marine outliers of fusulinid-bearing Atokan strata preserved in sinkholes on the eroded Mississippian surface (Thompson, 1953). In addition, there is a thin probable Atokan sequence preserved in the deeper part of the Forest City basin in northeastern Kansas and northwestern Missouri (Stewart, 1975; Wanless, 1975). These sandstones, shales, thin coals, and rare thin limestones were interpreted by Stewart (1975) as representing both nonmarine and marine environments; a postulated source for the sands is the lower Paleozoic and Precambrian rocks exposed on the northern part of the Nemaha ridge in Kansas and southern Nebraska. The petrography of these subsurface units in the Forest City basin is not well described. Possibly the Atokan Spiro sands in Oklahoma came in part from the Nemaha ridge in Kansas, which was higher topographically than the ridge in Oklahoma and which exposed Precambrian as well as lower Paleozoic rocks.

3. **Possible Early Desmoinesian Patterns.** Visher (1968, fig. 1) showed the early Desmoinesian–Bluejacket fluvial complex entering Kansas at its northeast corner. A source for that unit was therefore somewhere to the north or east of that point. Wanless (1975, p. 106) stated that the north-south-oriented Mississippi River arch "evidently served as a low barrier to marine transgression across east-central Missouri" during early Desmoinesian time. A source from the east, across Missouri, would thus not be possible. Perhaps the Canadian shield to the north was an ultimate source for the early Desmoinesian sublitharenites in eastern Oklahoma.

Sediment Transport Directions in the Arkoma Foreland Basin

Movement had ceased on the syndepositional faults that were so active during the middle Atokan by the beginning of the late Atokan, and a peripheral foreland basin, with the axis of deposition lying still farther cratonward, was formed. A continuation of compressional deformation is indicated by the continued downwarping of the newly formed foreland basin throughout late Atokan and early Desmoinesian time. Late Atokan and early Desmoinesian formations in the Arkoma basin are made up of shallow-marine, deltaic, fluvial, and coal-bearing sediments. Houseknecht (1986, p. 332) has termed this sequence "a typical coal-bearing molasse." Although the evidence is mixed and incomplete, it appears more likely that a major part of the sediments preserved in the Arkoma basin was derived not from the Ouachita fold belt but from the craton to the north.

Sediments derived from the Ouachita fold belt should show evidence either of northward transport or possibly of westward transport along the axis of the basin. Published examples of northward or westward transport are few and are restricted, with one exception (see paragraph 3 below), to the upper Atoka and the Hartshorne, as follows.

1. The upper Atoka is not well described in the Arkoma basin, and paleocurrent directions have not been published for this specific unit. Zachry (1983) stated that the upper Atoka in the northern parts of the basin in Arkansas is made up of deltaic systems that prograded southward. In the central part of the basin (T. 7 N.), an isopach map of the Alma Sandstone (Stephens, 1985, Fig. 25), in the lower part of the upper Atoka, shows an east-west orientation of the sand body that possibly indicates westward transport along the axis of the newly developed foreland basin, in a manner similar to that found in the overlying Hartshorne Sandstone. In addition, rock samples of the Alma Sandstone from a surface exposure in T. 5 N. (Normand, 1986) shows a fine-grained mature sublitharenite that may represent a mixing of sediments from the east and from the north.

2. Paleocurrent directions in the Lower Hartshorne Sandstone in the Arkoma basin in Arkansas indicate "transport into the eastern end of the basin from the northeast, southeast and possibly east" (Houseknecht and others, 1983, p. 75) (see also Fig. 11 below). Those from the southeast are interpreted as having come from the uplift of the adjacent Ouachita fold belt. Those from the east may have come from the fold belt southwest of the Black Warrior basin. Those from the north were transported through the Illinois basin.

3. There was an apparent local Ouachita source at the west end of the Ouachita fold belt. In the Arkoma basin immediately west of the towns of Atoka and Stringtown, Oklahoma, Taff (1902) recorded beds in the Atoka composed of "fine brown sand and subangular chert pebbles." He stated further that "a peculiar feature of this chert conglomerate is that its limit in range north and south corresponds with the occurrence of Silurian [known today to be Ordovician and Devonian] chert in Black Knob Ridge" (p. 5). He further stated that in the same limited area there are chert pebbles in the Hartshorne, McAlester, Savanna, and Boggy Formations. Hendricks and others (1936) commented on these occurrences, but no author has recorded petrographic data or paleocurrent directions.

Examples of sediments derived from the north are more common.

1. Morris (1974) recorded undifferentiated paleocurrent directions for the early Desmoinesian Krebs Group (Hartshorne, McAlester, Savanna, and Boggy Formations; see Fig. 10 below) in the Arkoma basin in both Oklahoma and Arkansas, including areas immediately north of the Choctaw fault. Briggs and Cline (1967) gave a similar set of directions for Oklahoma only. Almost all of the recorded directions are from the north with a minute number from the east. None is from the south.

2. During the time of deposition of the McAlester, Savanna, and Boggy Formations, there were several times that major deltas, derived from the craton west of the Ozark dome, prograded southward across the shelf in eastern Oklahoma. Large volumes of mud and sand were discharged into the sinking Arkoma basin in Oklahoma (Busch, 1971: McAlester Formation, Booch Sandstones; Visher, 1968: Boggy Formation, Bartlesville-Bluejacket Sandstone) (see Fig. 12 below). There is no published evidence that sediments were transported regionally either westward along the axis of the Arkoma basin or northward from the Ouachita fold belt during the deposition of the McAlester, Savanna, and Boggy Formations. In Arkansas, with the exception of Morris' (1974) moderate number

of paleocurrent directions, there is a lack of provenance information for these formations.

Timing of Folding of Arkoma Basin Structures

Uplift of the Ouachita fold belt extended at least through Desmoinesian, Missourian, and early Virgilian time (Ham and Wilson, 1967), but is it possible to more specifically identify a primary time of deformation of the linear folds in the Arkoma basin that parallel the Ouachita Mountain front? An examination of the Arkoma basin on the Geologic Map of Oklahoma (Miser, 1954) shows that all formations up through the Boggy (top of Krebs Group, see Fig. 10 below) are involved in these folds. The overlying Thurman Sandstone (base of Cabaniss Group, see Fig. 10) and the formations above it appear not to be involved.[2]

There is disagreement, however, as to the precise stratigraphic relationship of the Boggy and Thurman. The Boggy is composed of shale with sandstones; and the Thurman, of sandstones and shales with chert-pebble conglomerates common at the base. Some authors recorded continuity of the two formations (Hendricks, 1937; Hare, 1969 [in part]; Bennison, 1979). Others reported the occurrence of an unconformity at the base of the Thurman (Bloesch, 1919; Clawson, 1928; Dane and others, 1938; Hare, 1969 [in part]; Oakes, 1967, 1977). Part of the problem is that the countryside is wooded and rough, and contacts are mostly poorly exposed and difficult to trace laterally.

Additional direct and indirect evidences that should be considered in an evaluation of the stratigraphic relationships of the Krebs and Cabaniss Groups include the following.

1. The Krebs Group (Boggy at its top; see Fig. 10 below) is the only part of the Desmoinesian that was deposited during major subsidence of the Arkoma basin. The Krebs is 2,195 m thick in the basin (T. 6 N.) compared to 240 m thick on the shelf 80 km to the north (T. 15 N.; see Fig. 12 below). In contrast, the overlying Cabaniss Group (Thurman at base), which crops out along the northwest margin of the Arkoma basin, is 305 m thick in T. 6 N. (see Fig. 13 below) and decreases in thickness to 146 m (Senora only) in T. 15 N. (thicknesses from Weirich, 1953; and Oakes, 1967, 1977).
2. The transport direction for sediments in the Bartlesville-Bluejacket deltaic sandstone, in the lower part of the Boggy is from the north (see Fig. 12 below). Transport directions for the thinner sandstones in the middle and upper part of the Boggy have not been published. Those for the sandstones and chert-pebble conglomerates at the base of the overlying Thurman Sandstone are from the southeast (Jones, 1957), from the Ouachita fold belt.
3. The Stuart overlaps the Thurman northward and is in turn overlapped by the Senora (Oakes, 1967), which is a depositional pattern that would imply the presence of an unconformity at the base of the Cabaniss Group.
4. In McIntosh County (T. 10 to 12 N.), the Stuart (see Fig. 10 below), predominantly shale, rests directly on the Boggy, which is also composed primarily of shale. It is difficult to find an actual exposed contact between the two. Oakes (1967) was able to map the contact using structural differences. The Boggy is more complexly and sharply folded and faulted than the Stuart. The "Boggy rocks strike in various directions . . . in contrast to the almost constant strike of post-Boggy rocks a few degrees east of north" (Oakes, 1967, p. 30). Oakes also reported that some southwest-trending faults that are probably associated with the Ozark uplift to the northeast cut the Boggy but do not cut post-Boggy rocks.

[2]Hendricks (1937) mapped as Thurman a sandstone layer preserved in the Arkoma basin in the axis of a shallow syncline located in T. 4 N., R. 13 E., located 6.5 km southeast of the Thurman escarpment. A preliminary examination suggests that this fine-grained sandstone, which contains no chert pebbles, is more probably in the upper part of the Boggy Shale.

It is tentatively concluded that a regional unconformity truncates the Boggy Formation particularly because of the discordance of the Boggy below the Stuart (no. 4 above).

DEPOSITIONAL HISTORY

Introduction

The Arkoma basin was depositionally part of a stable shelf (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 mostly shallow-water carbonates was deposited on the shelf, and thinner, deep-water black shales and cherts accumulated in the basin. Conditions changed dramatically in middle Mississippian time with the beginning of deposition of thick turbidites (Stanley Group) in the basin (Ouachita trough) (Fig. 2), but there was no significant change in depositional pattern on the shelf to the north except for the intermittent introduction of terrigenous clastics from the northeast. Turbidites were fed longitudinally (east to west) into the gradually deepening and narrowing Ouachita trough (Graham and others, 1975).

The broad Arkoma shelf, which included the southern part of the present-day Ozark uplift as well as the Arkoma basin, continued as a significant depositional feature through Chesterian, Morrowan, and early Atokan time.

Chesterian Series

The Mississippian Chesterian Series, which crops out in the southern Ozark area in Oklahoma and Arkansas, consists 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. 2). At least two main shoaling-upward sequences are represented. 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 (T. 9 N.) (Tulsa Geol. Society, 1961) (Fig. 3). South of this line, facies change abruptly to shale on a continually deepening, east-trending outer shelf. Undifferentiated Chesterian shales in the subsurface in the southern Arkoma basin in Arkansas are poorly known but are all generally termed Fayetteville (Doy L. Zachry, 1986, personal commun.). A similar, almost continuous shale sequence found in the subsurface of the southern half of the Arkoma basin to the west in Oklahoma, and underlying the Lower Pennsylvanian Cromwell Sandstone, is subdivided into Mississippian Caney and Pennsylvanian Caney (Tulsa Geol. Society, 1961) (Fig. 2). The Mississippian part of this interval is termed "Caney"[3] on the outcrop in the frontal Ouachita Mountains in Oklahoma (Fig. 3). The terrigenous source for the outer shelf muds is

[3]Hendricks and others (1947) used Caney Shale and Springer Formation for the Mississippian and pre-Wapanucka part of the Pennsylvanian, respectively, in the frontal Ouachitas. The entire interval is composed mostly of shale and is differentiated into two formations partly on the basis of stratigraphic position but also on the occurrence of Mississippian or Pennsylvanian goniatites, mostly in scattered but unrelated localities. The two names are here enclosed in quotation marks (Fig. 3; see also Figs. 4 and 5 below) to stress their uncertain usage in this area. The original type locality of the Caney Shale is apparently in an erratic block in the turbidite facies in the central Ouachita Mountains (Elias and Branson, 1959), and thus the term cannot be properly defined. The type area for the Springer Formation is in the Ardmore basin where it straddles the Mississippian-Pennsylvanian boundary (Tomlinson and McBee, 1959). It is used in the frontal Ouachitas by Hendricks and others (1947) to designate only strata of Early Pennsylvanian age. The interval badly needs to be redefined, but such a project would be hampered by the exceptionally poor nature of the exposures. Some recent workers have changed the terminology but apparently without any significant new field data. Marcher and Bergman (1983) replaced the name Caney with the names Delaware Creek Shale

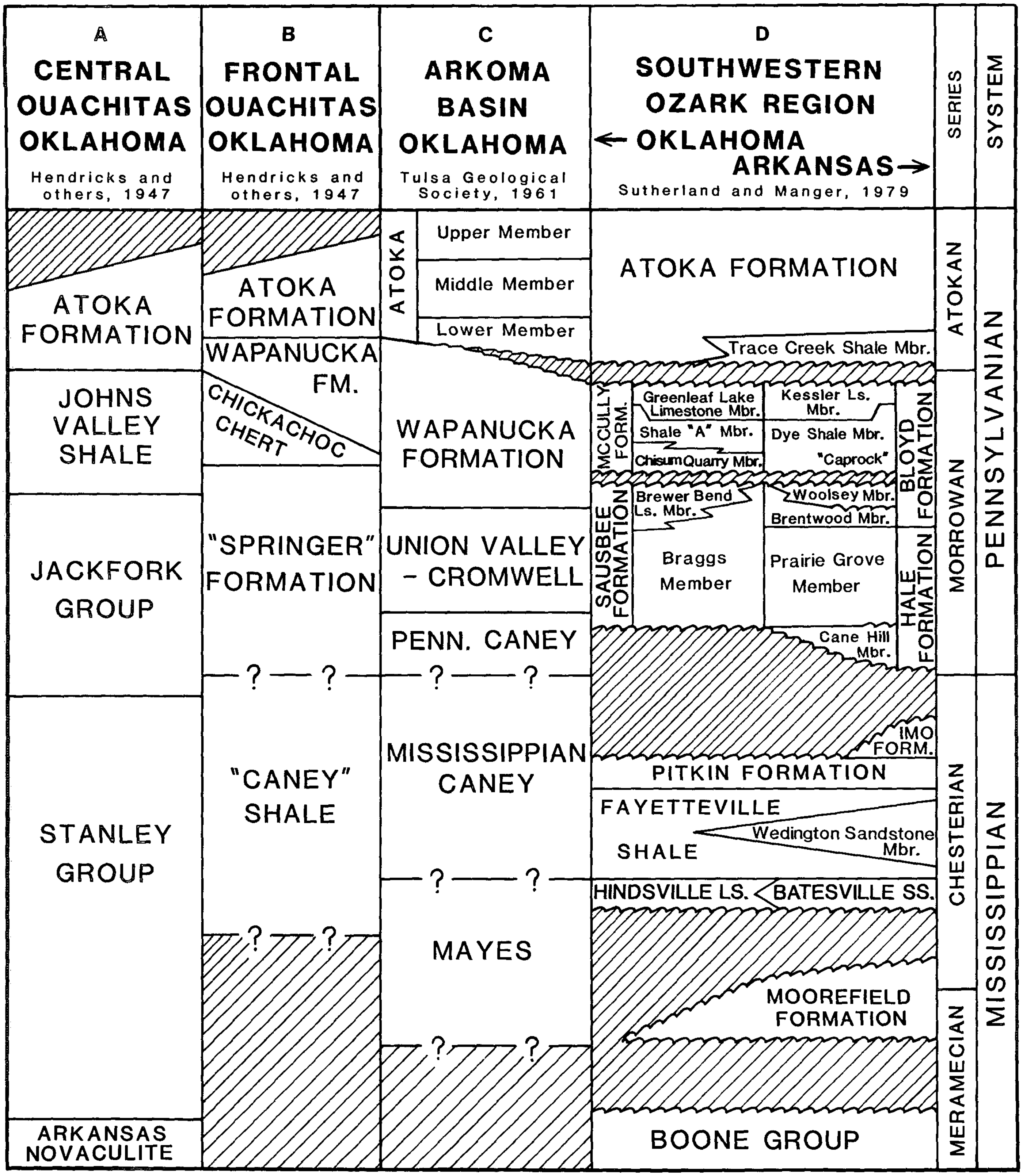

Figure 2. Correlation of upper Mississippian and lower Pennsylvanian formations and members across the Arkoma basin from the Ozark shelf to the Ouachita trough. See Figure 1 for localities.

and Goddard Shale, terms borrowed from the Ardmore basin and Arbuckle Mountains area. In addition, they replaced the name Springer with Limestone Gap Shale (Harlton, 1938), but the latter at its type locality in the frontal Ouachitas is 13.4 m thick and may not be equivalent to what has been termed Springer in the area. On the COSUNA CHART (American Association of Petroleum Geologists, 1987) "Caney" is used, but Springer is inexplicably replaced by the name Union Valley. As can be seen in Figure 2, Union Valley equals only a part of the interval that has been termed "Springer" in the frontal Ouachitas, and the lithologies are different.

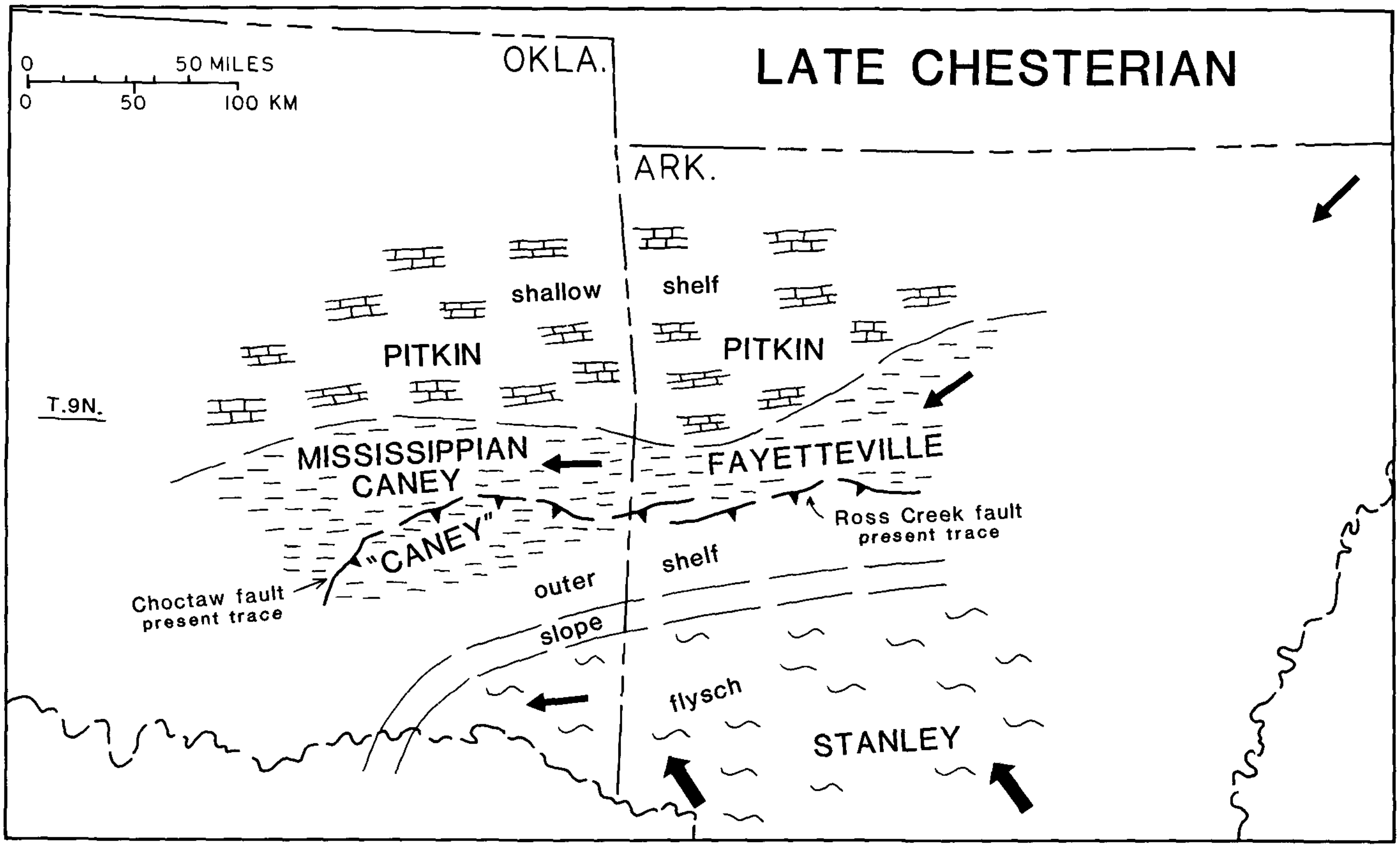

Figure 3. Late Chesterian paleogeographic map. Large and small red arrows indicate major and minor directions of sediment transport. Compare with Figure 1 for location. Dashed traces of present-day locations of Choctaw and Ross Creek faults are given for reference in Figures 3–7, 9, 11–13. Sources include Tulsa Geological Society, 1961; Niem, 1976; Glick, 1979; Thomas, 1984; and Morris, 1974.

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 ~3,235 m (Cline, 1960). Sediment transport directions are primarily from the southeast (Niem, 1976) (Fig. 3).

Mississippian-Pennsylvanian Unconformity

The Late Mississippian was marked by a sea withdrawal from the shelf areas throughout the southern mid-continent region. Rascoe and Adler (1983) attributed 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. Deposition is considered to have been continuous from Late Mississippian into Early Pennsylvanian time in the Ouachita trough. It may have also been continuous on the southernmost part of the outer shelf, but the Mississippian-Pennsylvanian boundary is difficult to study on the outcrop in the frontal Ouachita Mountains in Oklahoma because of the poor exposure of the "Caney" and "Springer" formations (Fig. 2; compare Figs. 3 and 4).

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. 2) in the Oklahoma Ozarks. Regional relief on the unconformity in that area is more than 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, which included the southern and southwestern Ozark areas, was from the northeast, primarily by way of the Illinois basin. Fluvial sandstones and shales (274 m thick) in north-central Arkansas (Glick and others, 1964) change facies westward to a mostly mixed shallow-marine shelf facies (91 m thick) in northwestern Arkansas (Henbest, 1953) and still farther to the west in northeastern Oklahoma to a shallow-marine offshore bank facies (61 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, and each of these is separated into several members (Fig. 2). Westward from Washington County, Arkansas, into Oklahoma, the names Hale and Bloyd can be used for about 24 km into eastern Okla-

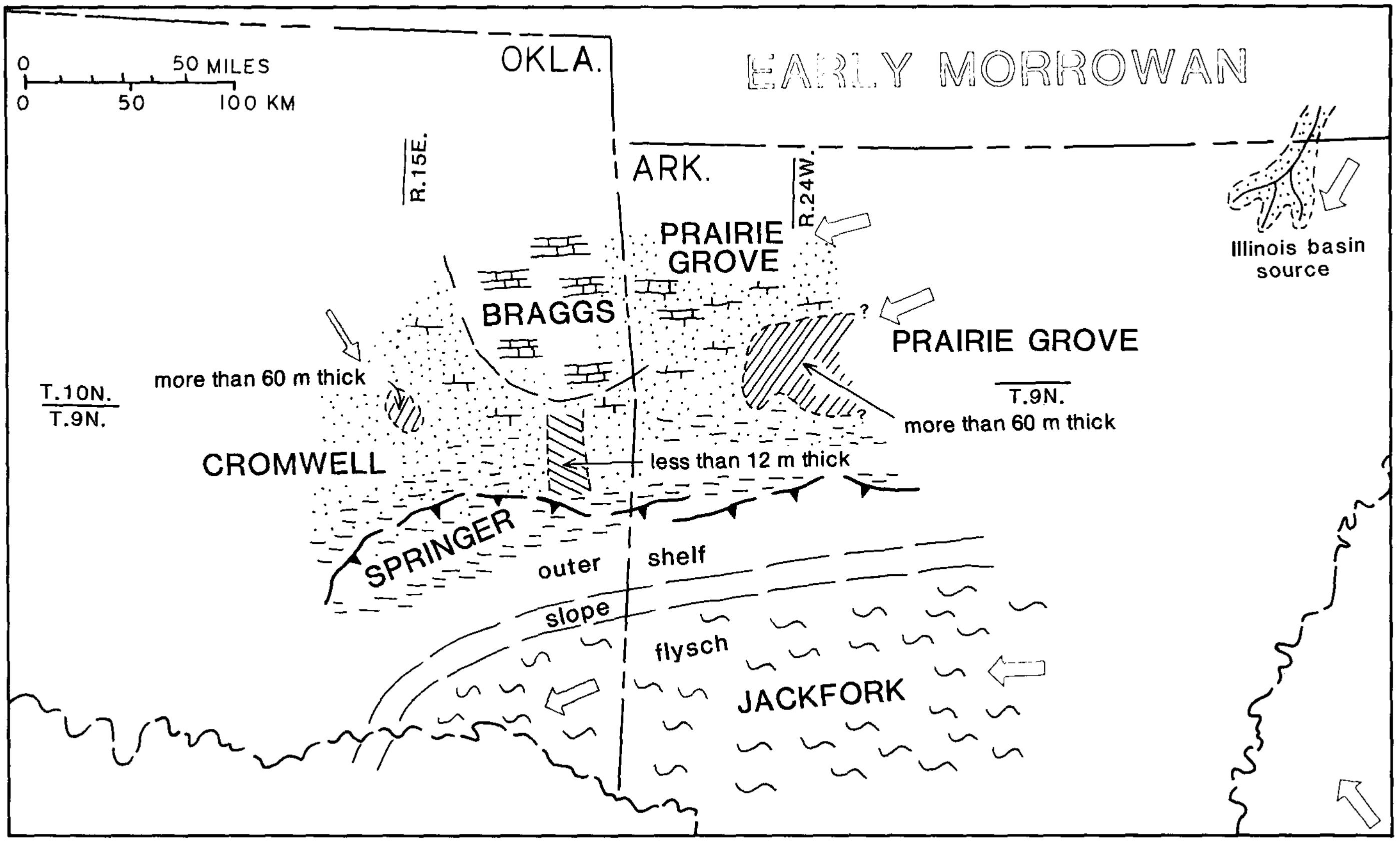

Figure 4. Early Morrowan paleogeographic map. Sources include Glick and others, 1964; Morris, 1971, 1974; Sutherland and Henry, 1977a; Foshee, 1980; Jefferies, 1982; and Moiola and Shanmugam, 1984.

homa before the lithologic distinction is lost. There is an over-all 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. 2) on the basis of a 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. 2). The Sausbee and McCully represent two shallowing-upward carbonate shelf cycles. In each case, the final shallow-bank facies is followed by emergence and erosion on the inner shelf.

The Morrowan carbonate facies in the southern Ozarks of northeastern Oklahoma extends southward into the subsurface of the Arkoma basin to about T. 10 N. 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 (Tulsa Geol. Society, 1961) (Fig. 4).

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. 2).

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 (primarily quartz arenite) overlain in most areas by 1.5 to 4.5 m of arenaceous limestone. This interval is 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. 2). It does not occur in the frontal Ouachitas where equivalent outer-shelf shales are included in the "Springer" Formation (Fig. 4). 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. 1, 2).

In the subsurface of Oklahoma, the Cromwell consists of multiple, discontinuous, calcareous sandstones separated by thin shales. These units were deposited as a series of transgressive-regressive episodes across the shelf with a sediment source to the northwest (Jefferies, 1982) (Fig. 4). The Cromwell is more than 35 m in thickness across a broad western area in Oklahoma and exceeds 60 m thick in T. 9 N., R. 15 E. (Fig. 4). Farther to the east, near the Arkansas border, a north-south subsurface belt about 16 km in width shows the unit to be less than 12 m thick with only one sandstone unit present near the top of the sequence (Jefferies, 1982). This belt coincides with the area of maximum limestone thickness (Braggs) immediately to the north (Fig. 4), suggesting the presence of a north-south-oriented high on the pre-Morrowan surface.

In the subsurface in Arkansas just east of the state line, the equivalent Prairie Grove Formation is 17 m thick but increases to a maximum of 87 m about 58 km farther east, in T. 9 N., R. 24 W. (Fig. 4). In addition to the over-all thickening to the east, there is a decrease in limestone and an increase in calcareous sandstone content, a general coarsening in size of quartz grains and an increase in the number of sandstone intervals, generally to five (Foshee, 1980). The sandstone beds are separated by thinner shale units and are interpreted as a series of relatively rapid transgressive pulses across the shelf followed by southward progradations of barrier islands, followed higher stratigraphically by prograding deltaic complexes (Foshee, 1980). This produced a series of discontinuous sand and sandy carbonate units separated vertically by deeper water shale units. The source of quartz sand was from the northeast; it was brought to the area by both fluvial processes and long-shore currents (Foshee, 1980).

Depositional patterns were complex on the Arkoma shelf in middle Morrowan time (Fig. 5). There was a gradual regression, causing emergence and nonmarine environmental conditions in northwestern Arkansas. These deposits included fluvial sandstones from the northeast (Middle Bloyd Sandstone) and a coastal coal swamp (Woolsey) (Fig. 5). In the shallow sea still farther to the west, an algal bank (Brewer Bend) was characterized by small coral patch reefs (*Petalaxis*) (Sutherland and Henry, 1977a). Basinward, open-marine deposits of the Brentwood and upper Braggs limestones gave way southward to Wapanucka and "Springer" shales on the outer shelf (Fig. 5). In western Arkansas, the Brentwood Limestone changes facies eastward into the Cline Sandstone in Range 25 W., apparently as a result of a north-south–oriented high on the underlying Prairie Grove surface, which deflected sand coming from the northeast (Foshee, 1980) (Fig. 5).

Further regression produced emergence of the inner shelf, followed by erosion and the development of the middle Morrowan disconformity (Fig. 2). This was followed by rapid transgression and the deposition of the Dye Shale and Kessler Limestone Members of the Bloyd Formation in Arkansas and the McCully Formation in northeastern Oklahoma. With gradual shallowing on the outer shelf, deeper water shales in the lower part of the Wapanucka Formation (equivalent in part to the Dye Shale) gave way to the deposition of the overlying Wapanucka limestone. Oolitic grainstones and carbonate mudstones were deposited across the entire shelf area (Fig. 6), followed by regional emergence and erosion. The character of the Wapanucka shale and limestone in the subsurface of the Arkoma basin has not been extensively described. The combined thickness is ~147 m in the southern part of the present-day Arkoma basin in Oklahoma (Tulsa Geol. Society, 1961) with irregular northward thinning to less than 23 m for the equivalent McCully Formation on the outcrop (Fig. 2). Part of the northward decrease in thickness results from truncation below the pre-Atoka unconformity (Lumsden and others, 1971). An upper limestone of the Wapanucka is apparently missing as a result of truncation north of T. 9 N. (Tulsa Geol. Society, 1961, p. 63).

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. 7) (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. 6). 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 ~1,675 m thick (Fig. 6) and the Johns Valley Shale as much as 265 m thick (Cline, 1960). Transport directions recorded for the Jackfork

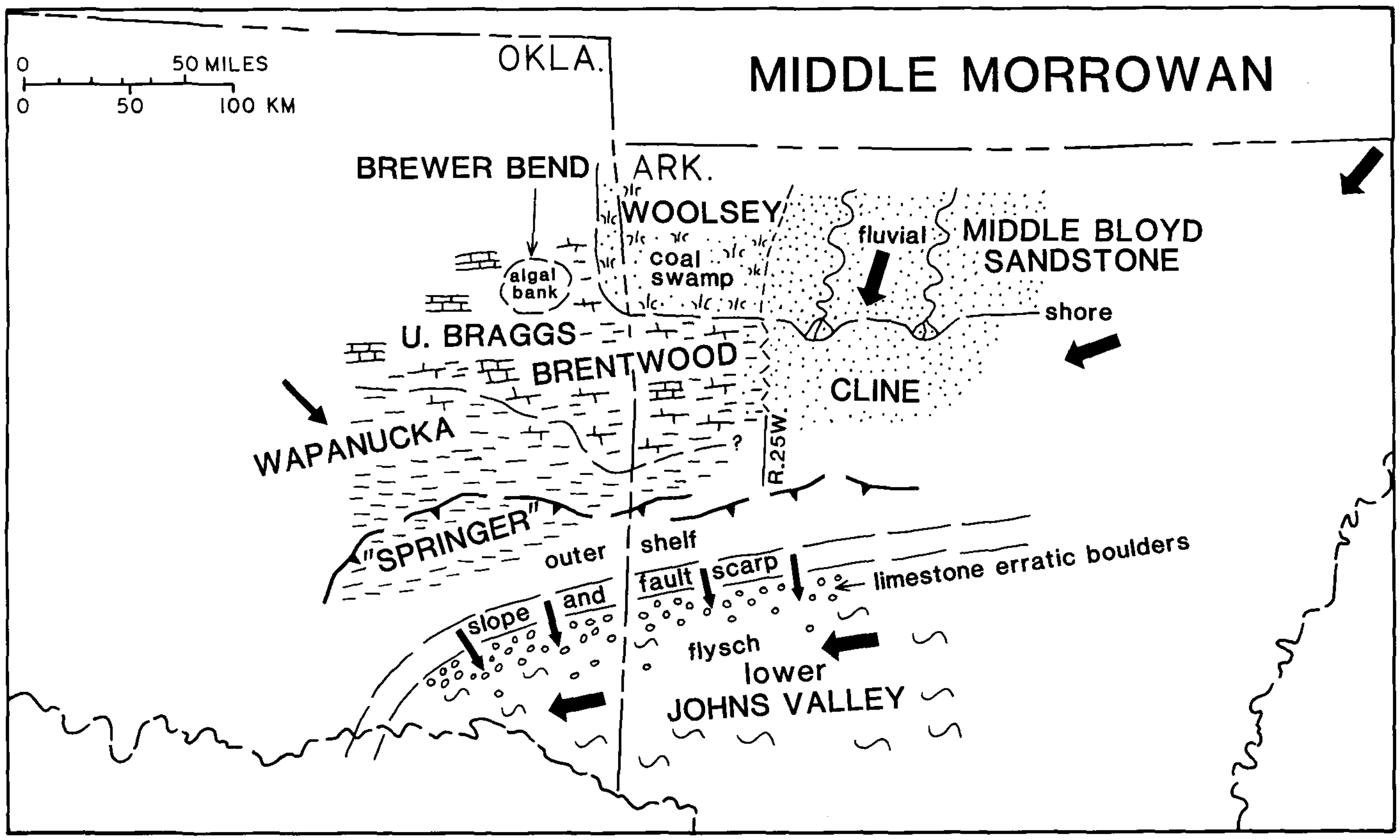

Figure 5. Middle Morrowan paleogeographic map. Sources include Shideler, 1970; Sutherland and Henry, 1977a; Zachry, 1977; Foshee, 1980; and Jefferies, 1982.

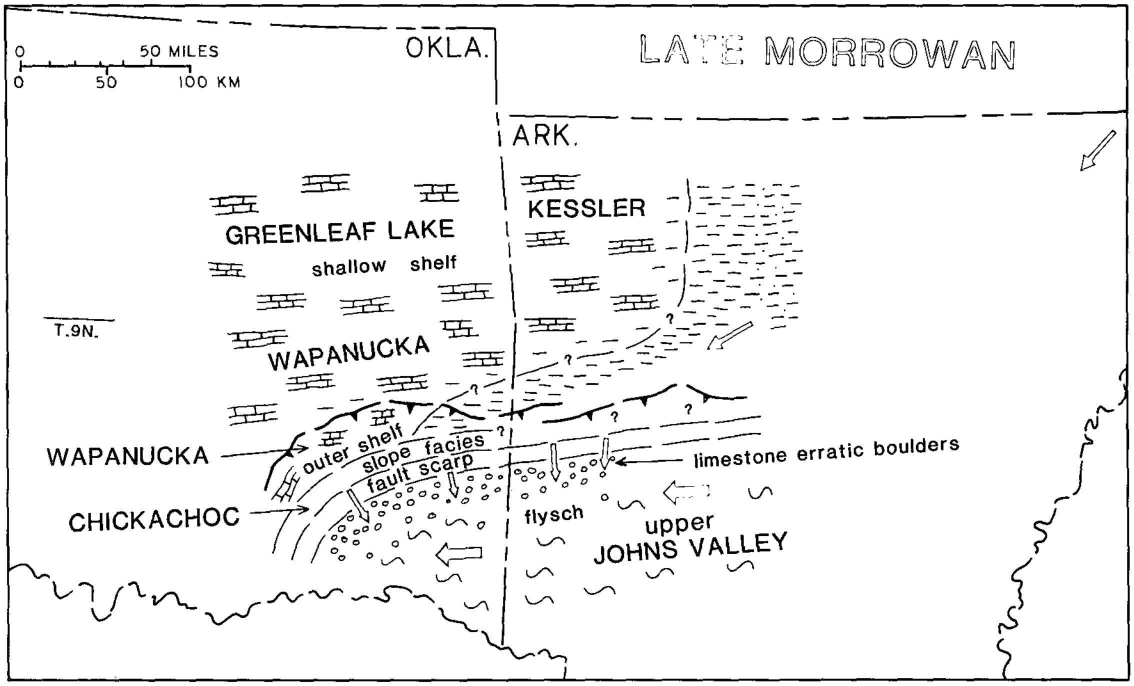

Figure 6. Late Morrowan paleogeographic map. Sources include Shideler, 1970; Sutherland and Henry, 1977a; and Grayson, 1979.

Sandstone on the outcrop in both Arkansas and Oklahoma are to the west parallel to the basin axis (Moiola and Shanmugam, 1984) (Fig. 4). Owen and Carozzi (1986) have given evidence, based on cathodoluminescence petrology of quartz, that part of the source for the upper Jackfork sandstones was to the southeast of Arkansas by way of the Black Warrior basin. The Johns Valley is well known for its great variety of erratic limestone boulders, but there are unanswered questions concerning the source of these boulders (see section above on Provenance of Johns Valley boulders).

Atokan Series

The Atokan Series is represented mainly by the Atoka Formation in most of the Arkoma basin of Arkansas and Oklahoma and by the upper

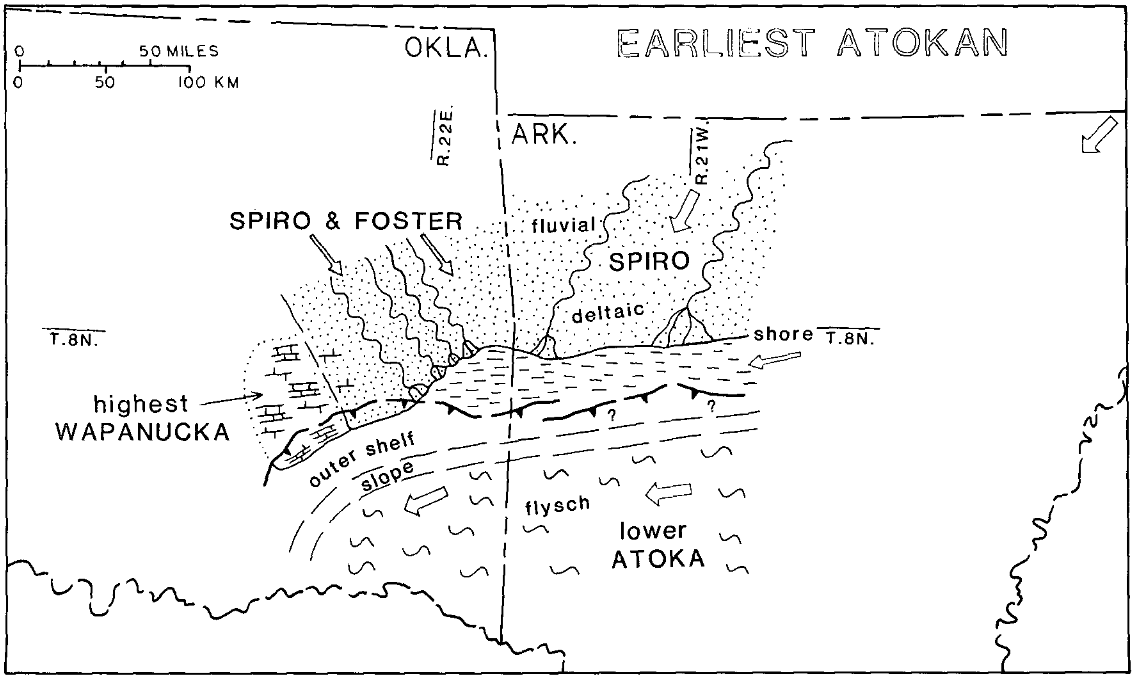

Figure 7. Earliest Atokan paleogeographic map. Sources include Lumsden and others, 1971; Grayson, 1979; Sutherland and Manger, 1979; and Parker, 1981.

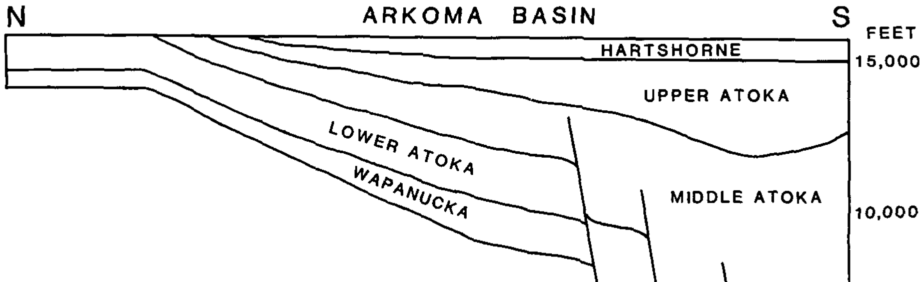
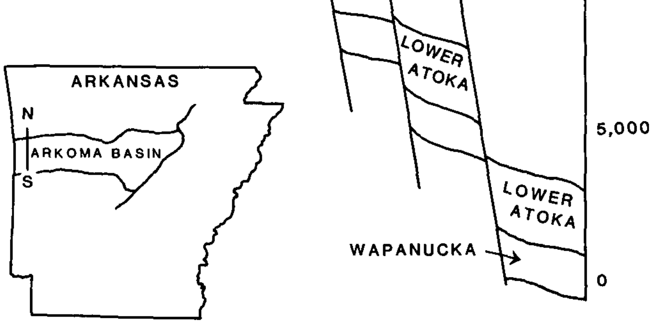

Figure 8. North-south section across Arkoma basin depicting syndepositional faults that controlled sedimentation during deposition of middle Atoka Formation (modified from Zachry and Sutherland, 1984).

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. 7). 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).

Nomenclatural confusion occurs at the Wapanucka-Atoka boundary in the southern Arkoma basin and frontal Ouachitas where deposition was apparently continuous. The Spiro Sandstone, the basal unit of the Atoka Formation in the subsurface of the Arkoma basin north of the Choctaw fault, crops out in the frontal Ouachitas in the Wilburton area, Oklahoma. Westward on the outcrop, the Spiro sandstones change facies to shallow-shelf limestones that are traditionally included in the Wapanucka Formation. These high limestones, which carry conodonts of early Atokan age (Grayson, 1979), are stratigraphically separated in the frontal Ouachitas from the main Wapanucka by a thin shale. These limestones are also present in the subsurface in the southwestern Arkoma basin (Lumsden and others, 1971, fig. 6) (Fig. 7).

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 displacement of the sea from the shelf to the north coincided with a southward tilting of the Morrow surface, an aspect of the rapid sinking of the Ouachita trough, that was followed by extensive subaerial erosion. Progressively older strata were truncated northward, and stream valleys with a relief of at least 35 m were cut into the post-Morrowan surface (Lumsden and others, 1971).

The Atoka Formation has been subdivided within the Arkoma basin into informal lower, middle, and upper intervals by several authors. The scheme followed here is that used by Buchanan and Johnson (1968) in Oklahoma and followed by Zachry (1983) in Arkansas.[4] Their division into basal, middle, and upper intervals was 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 down-thrown (south) side of these faults. Their basal Atoka predates such faulting, and their upper Atoka postdates it. In the Buchanan and Johnson (1968) and Zachry (1983) usages, it is the middle Atoka that makes up the major part of the thickness of the formation in the southern half of the Arkoma basin in both Oklahoma and Arkansas (Fig. 8).

Early Atokan. Buchanan and Johnson's (1968) basal Atoka in Oklahoma includes the Spiro Sandstone and a "remarkably persistent and correlative" overlying shale (p. 78), which has a combined thickness with the Spiro, shown on their cross section, of ~365 m. Sedimentation in this interval, here called lower Atoka, was initiated in Oklahoma with a source from the northwest, by the development of fluvial systems and small deltas on the eroded surface of the underlying Wapanucka (Foster sand channels) (Fig. 7). This was followed by a rapid northward transgression of a coastal sand complex (Spiro) to form a blanket sand unit (Lumsden and others, 1971). A combined Spiro-Foster thickness of 62 m has been recorded in T. 8 N., R. 22 E. by Jefferies (1982). The Spiro Sandstone in Oklahoma is typically composed of moderately to very well sorted quartz grains that make up well over 95% of the detrital grains (quartz arenite) (Lumsden and others, 1971).

Depositional history of the Spiro in Arkansas was similar, but a much greater volume of sand was introduced from the northeast. Meandering fluvial systems that graded into deltas (Fig. 7) 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 thickness of 89 m in T. 8 N., R. 21 W. (Parker, 1981). To the south and southeast, the Spiro changes facies to more basinal shale deposits (Fig. 7).

The lower Atoka in Arkansas ranges in thickness from 150 m adjacent to the northern margin of the present Arkoma basin to ~305 m in the south (Zachry, 1983). The interval is composed of 7 to 8 sandstone units separated by units of shale and includes the Spiro at the base and the Sells at the top. All of these sandstones are composed primarily of quartz arenites (Doy L. Zachry, 1987, personal commun.). The sandstones above the Spiro are replaced by shale westward in Oklahoma. Individual sandstone units above the Spiro range from 6 to 60 m in thickness and are continuous throughout the northern and central parts of the basin. These represent streams and deltas prograding southwestward across the shelf followed by periodic northward transgressions bringing open-shelf environments across the Arkoma shelf area and forming shale units. 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 (Parker, 1981; Gilbreath and Haley, 1982). In the southern part of the

[4]There is a lack of consensus as to the distribution of subdivisions of the Atoka Formation in the Arkoma basin area. The formation was possibly first subdivided into lower, middle, and upper intervals by Scull and others (1959). The basis for their division into three subequal parts was not given. In Arkansas, Stone (1968) also subdivided the Atoka into three divisions but he included about half of the formation in the lower Atoka. Haley and Hendricks (1971, Table 1) followed Stone's (1968) usage approximately, and they placed the top of their lower Atoka at the top of the Bynum sand and the top of their middle Atoka at the top of the lower Carpenter Sand.

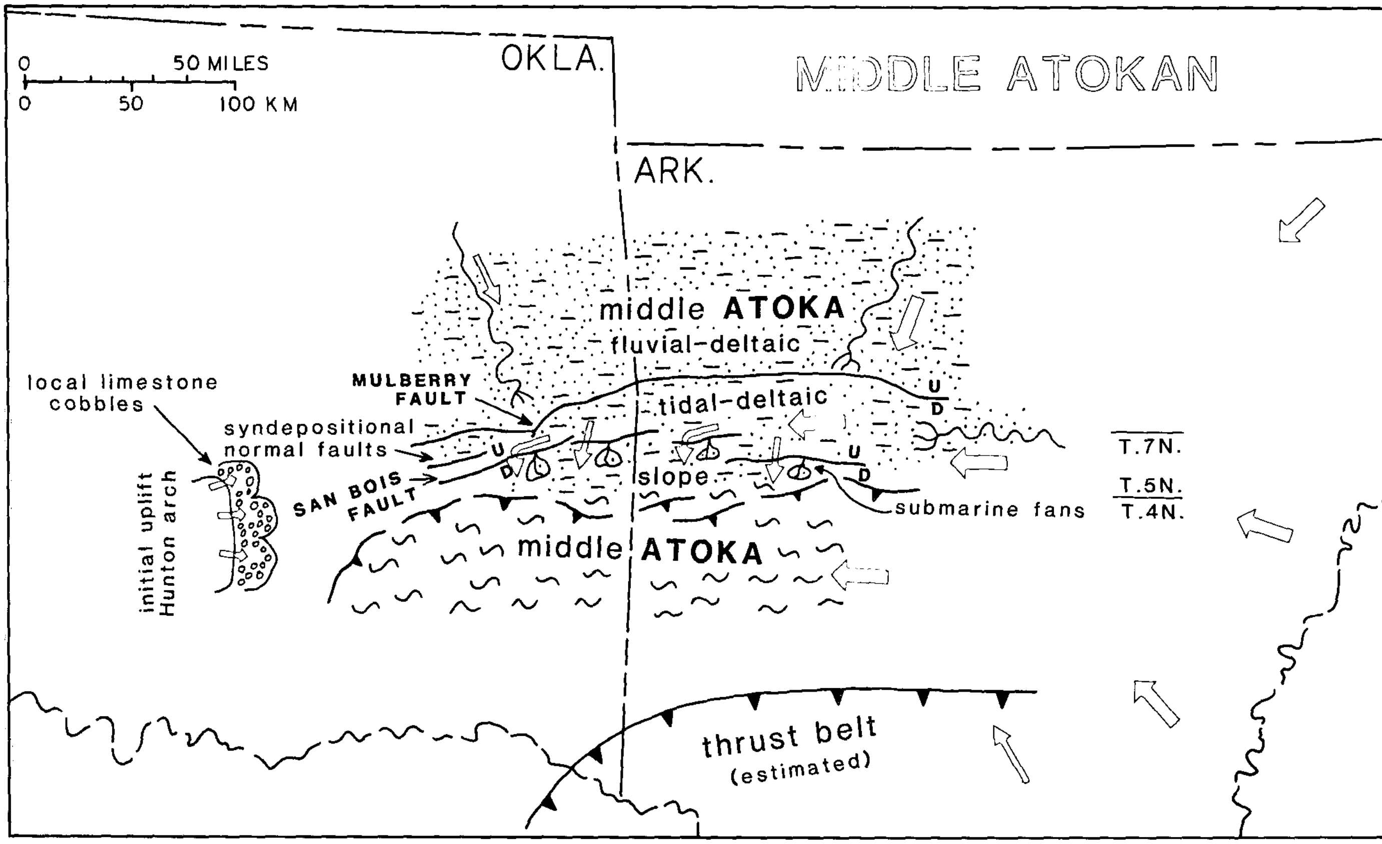

Figure 9. Middle Atokan paleogeographic map. Sources include Koinm and Dickey, 1967; Vedros and Visher, 1978; Houseknecht and Kacena, 1983; Zachry, 1983; Grayson, 1984; Sutherland, 1984; Zachry and Sutherland, 1984; and Houseknecht, 1986.

Arkoma basin in Arkansas, sandstone units above the basal Spiro thin southward and are replaced by shale (Zachry, 1983).

Middle Atokan. 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 collapse, that resulted in the development of large east-trending syndepositional normal faults (Fig. 9). The development of these faults was not synchronous, and it appears that the southernmost faults became active earliest and that active faulting migrated northward with time (Houseknecht, 1986).

The middle Atoka sandstones in the central and southern part of the area have a composition of lithic arenites, and they most likely came from the southeast, from erosion of the already uplifted orogenic belt, on the southwest margin of the Black Warrior basin (Thomas, 1984). 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. 9).

The middle Atoka sandstones north of the Mulberry fault in both Oklahoma and Arkansas (Fig. 9) continue to have a composition primarily of quartz arenite (Zachry, 1983). In Arkansas, this interval is characterized by four to five sandstone units separated by intervals of shale. Zachry (1983) places the top of the middle Atoka at the top of the Morris sand. These sandstones accumulated in delta and tidal flat systems that prograded southwestward from sources to the north and northeast.

The middle Atoka interval in Oklahoma is composed predominantly 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 down-thrown sides of the east-trending syndepositional normal faults (Fig. 8). A major sandstone within this interval is the Red Oak, which is confined to the south side of the San Bois fault (Fig. 9). 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) proposed 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 concluded 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 several authors (for example, 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 postulated that the Red Oak and similar sandstones in the area were deposited below wave base but at comparatively shallow water depths (possibly on the order of 100 m) for the following reasons: numerous widespread key beds display continuity across the associated syndepositional faults, and there is no evidence of erosional truncation of strata upthrown by the faults. These relationships are said to imply that the rate of mud deposition kept pace with the rate of subsidence and that the sea floor above the faults displayed little or no relief. Thus, deposition possibly occurred on a gently dipping, muddy slope lacking a bathymetrically distinct shelf-slope-rise geometry (Houseknecht, 1986).

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 10. 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).

In the southern part of the Arkoma basin in Arkansas, Stone and McFarland (1981, stop 16) described strata exposed at Blue Mountain Dam, in T. 5 N., from the top of their lower Atoka (middle Atoka of this paper), as representing deeper-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 (T. 2 N.), turbidites moved westward on the deep basin plain (Fig. 9).

At the west margin of the Arkoma shelf, Sutherland (1984) recorded the initial uplift on the Hunton arch as indicated by the occurrence at the base of the Atoka Formation in that area of limestone pebbles and cobbles 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.

Late Atokan. Upper Atoka strata are not cut by the normal faults that are associated with the thick sediment fill characteristic of the middle Atoka in the southern Arkoma basin (Fig. 8). The greatest recorded thickness of the middle Atoka is at the margin of the Choctaw and Ross Creek faults in T. 3 N. in Arkansas, but the axis of greatest thickness almost certainly lies somewhere farther to the south beneath the Ouachita thrust sheets. Haley (1982) recorded a thickness of 6,400 m for the Atoka Formation in the southernmost Arkoma basin, but no upper Atoka extends so far south. The southern limit of preserved upper Atoka is in T. 4 N., and the maximum thickness, ~914 m, is at the southern margin of T. 6 N. (Doy L. Zachry, 1987, personal commun.). This location of maximum thickness coincides approximately with that of the overlying early Desmoinesian Hartshorne Sandstone and marks approximately the axis of the newly defined Arkoma foreland basin. In addition, the prodelta facies of the overlying Hartshorne Sandstone is gradational with Atoka shales and cannot be lithostratigraphically differentiated from them (Houseknecht and others, 1983). Thus, at least the upper part of the upper Atoka in this area can be assumed to have been transported westward along the axis of the basin as a part of the Lower Hartshorne Sandstone progradations. In the northern part of the basin, upper Atoka deltaic systems show southward progradations (Zachry, 1983).

Desmoinesian Series

The Desmoinesian Series in the Arkoma basin and adjacent area to the northwest consists of the Krebs, Cabaniss, and Marmaton Groups (Fig. 10). Only the Krebs is preserved across the present-day basin. The Cabaniss and Marmaton Groups crop out along the northwest margin of the basin.

Early Desmoinesian. The Krebs Group consists of the Hartshorne,

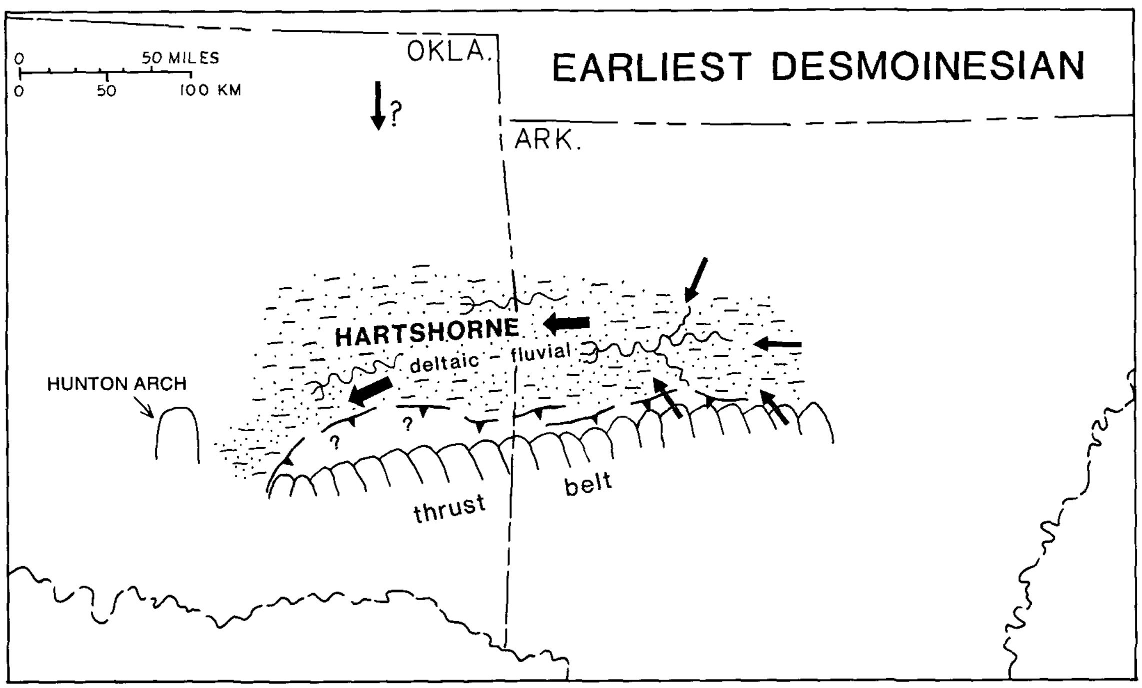

Figure 11. Earliest Desmoinesian paleogeographic map. Sources include Houseknecht and others, 1983; and McDaniel, 1968.

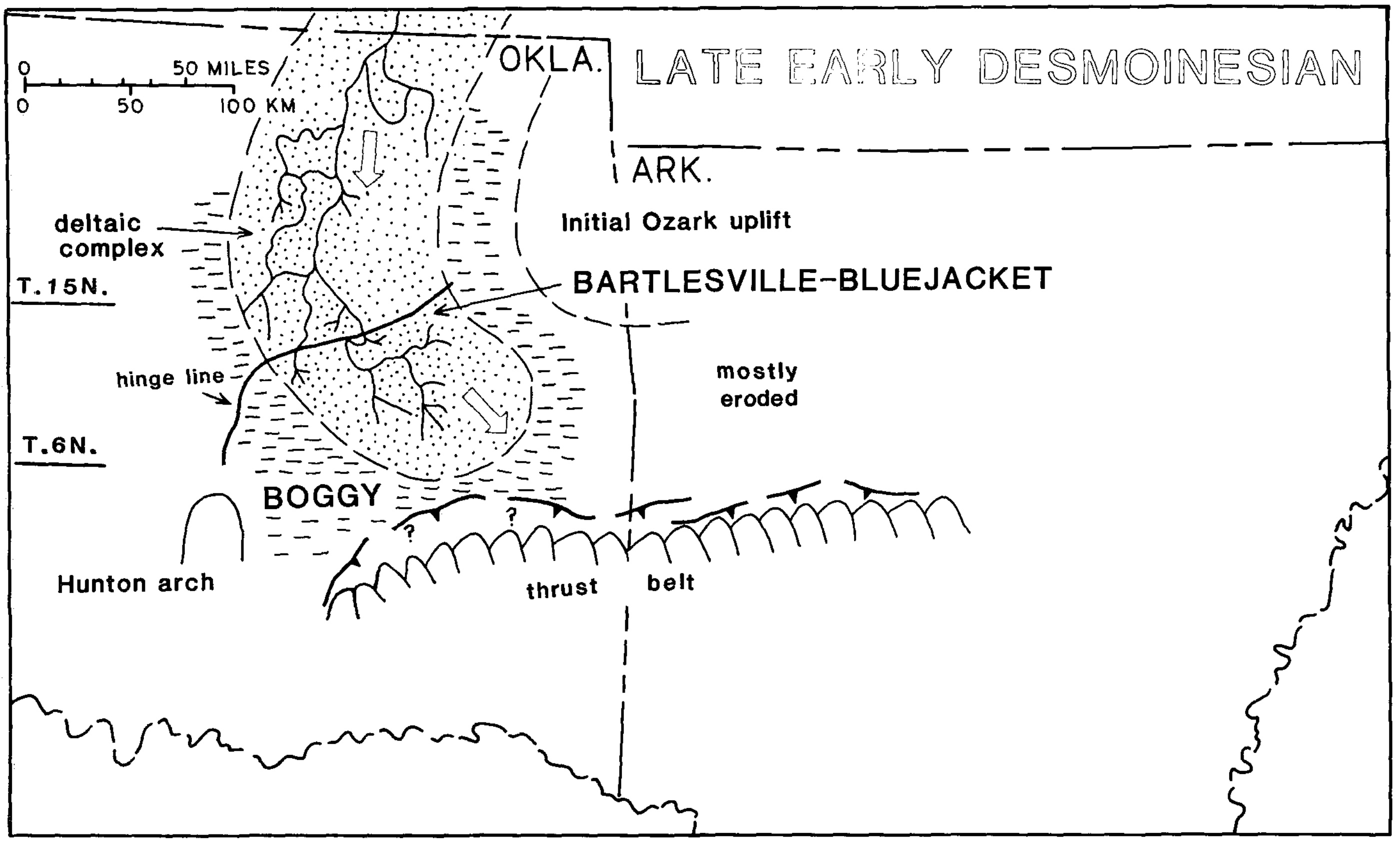

Figure 12. Late early Desmoinesian paleogeographic map. Sources include Weirich, 1953; Visher, 1968; Visher and others, 1971; and Morris, 1974.

McAlester, Savanna, and Boggy Formations (Fig. 10). The Hartshorne Sandstone, depositionally gradational with the underlying upper Atoka Formation, 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. 11). The sediments from the southeast apparently came from the developing Ouachita fold belt, but such a source is not recorded westward in Oklahoma (Fig. 11).

The only confirmed direction of source for the overlying McAlester, Savanna, and Boggy Formations is from the shelf to the north (Busch, 1971; Visher, 1968; Weirich, 1953). All of these units show marked thickening southward in Oklahoma into the subsiding foreland basin (Fig. 12). These sediments, where known, are mostly 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 (Weirich, 1953). The largest such deltaic complex was developed during deposition of the lower part of the Boggy Formation and comprises the Bartlesville-Bluejacket Sandstone Member of the Boggy (Visher, 1968; Visher and others, 1971) (Fig. 12). This system extended southward across eastern Kansas and eastern Oklahoma and was derived from the continental interior to the northeast of Kansas (Visher, 1968, fig. 1) (see previous discussion on sources of sediments to the Arkoma shelf). The Boggy Formation, including the Bartlesville-Bluejacket, reached a thickness of 609 m in the Arkoma basin (T. 6 N.), compared to a thickness of less than 152 m on the shelf to the north (T. 15 N.) (Weirich, 1953) (Fig. 12).

The northwestern shelf margin (hinge line of Weirich, 1953) of the Arkoma basin generally shifted northwestward as successive units of the Krebs Group were deposited (Weirich, 1953). The hinge line for the Boggy Formation, shown in Figure 12, is located about 40 km northwest of its location during the deposition of the McAlester and Savanna Formations (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. 12).

The evidence is conflicting and incomplete, but it appears most likely that uplift, folding, and erosion of the foreland basin, in conjunction with that of the Ouachita fold belt, 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 to coarser sandstones and chert-pebble conglomerates in the overlying Thurman Sandstone (Oakes, 1953).

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 uplift of the Ouachita fold belt and the accompanying compression and folding of the Arkoma basin ended the sinking of that basin (see previous discussion on time of folding of Arkoma basin structures).

Middle Desmoinesian. 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 demonstrable uplift of the Ouachita fold belt that exposed to erosion the Ordovician and Devonian cherts of the core area (Fig. 13). The conglomerates of the Thurman were deposited in a narrow successor basin, northeast of the Hunton arch (northeast of present-day Arbuckle Mountains), 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 T. 5 to 6 N. 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 (T. 9 N.), where it is overlapped by the Stuart Shale (Oakes, 1967) (Fig. 13). The Thurman chert debris, derived from the Ouachita fold belt in Oklahoma, was transported toward the northwest as a part of a fluvial system feeding deltaic and shallow-marine environments (Jones, 1957) (Fig. 13).

Late Desmoinesian. During the deposition of the remainder of the Desmoinesian Cabaniss and Marmaton Groups (Fig. 10), 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 fold belt. During this same time interval, there were secondary periodic incursions of terrigenous sediments from the north, but these decreased in magnitude and essentially ended before the end of the Desmoinesian (Visher and others, 1971; Bennison, 1979). The narrow successor basin extended from about T. 5 N. to T. 12 N. during the deposition of the Marmaton Group (Bennison, 1984, fig. 10). A terrigenous Marmaton sequence in this basin reaches a thickness of 457 m, compared to a more predominantly carbonate sequence on the shelf to the north at Tulsa (T. 19 N.) of 244 m.

The Ouachita fold belt continued through the remainder of the Pennsylvanian to provide terrigenous sediments to the successor basin in central Oklahoma (Ham and Wilson, 1967). These sediments bypassed the Hunton arch (Fig. 13), which provided limestone cobbles only locally along the southern margin of the basin.

SUMMARY AND CONCLUSIONS

1. Deposition on the passive stable Arkoma shelf margin, extending through the Chesterian, Morrowan, and early Atokan, varied greatly depending on the variable development of carbonate environments and on the intermittent introduction of terrigenous clastics (quartz arenites) from the north. Terrigenous sediments from the northeast and north were derived primarily by way of the Illinois basin and secondarily from the Ozark dome. An additional secondary source from the northwest came possibly from the Nemaha ridge in Oklahoma and Kansas but provenance studies on the Nemaha ridge and petrographic analysis of the Cromwell Sandstone are needed for confirmation.

2. Interpretations of late Chesterian and early Morrowan paleogeography on the Arkoma shelf (Figs. 3 and 4) have an unexpected impact on

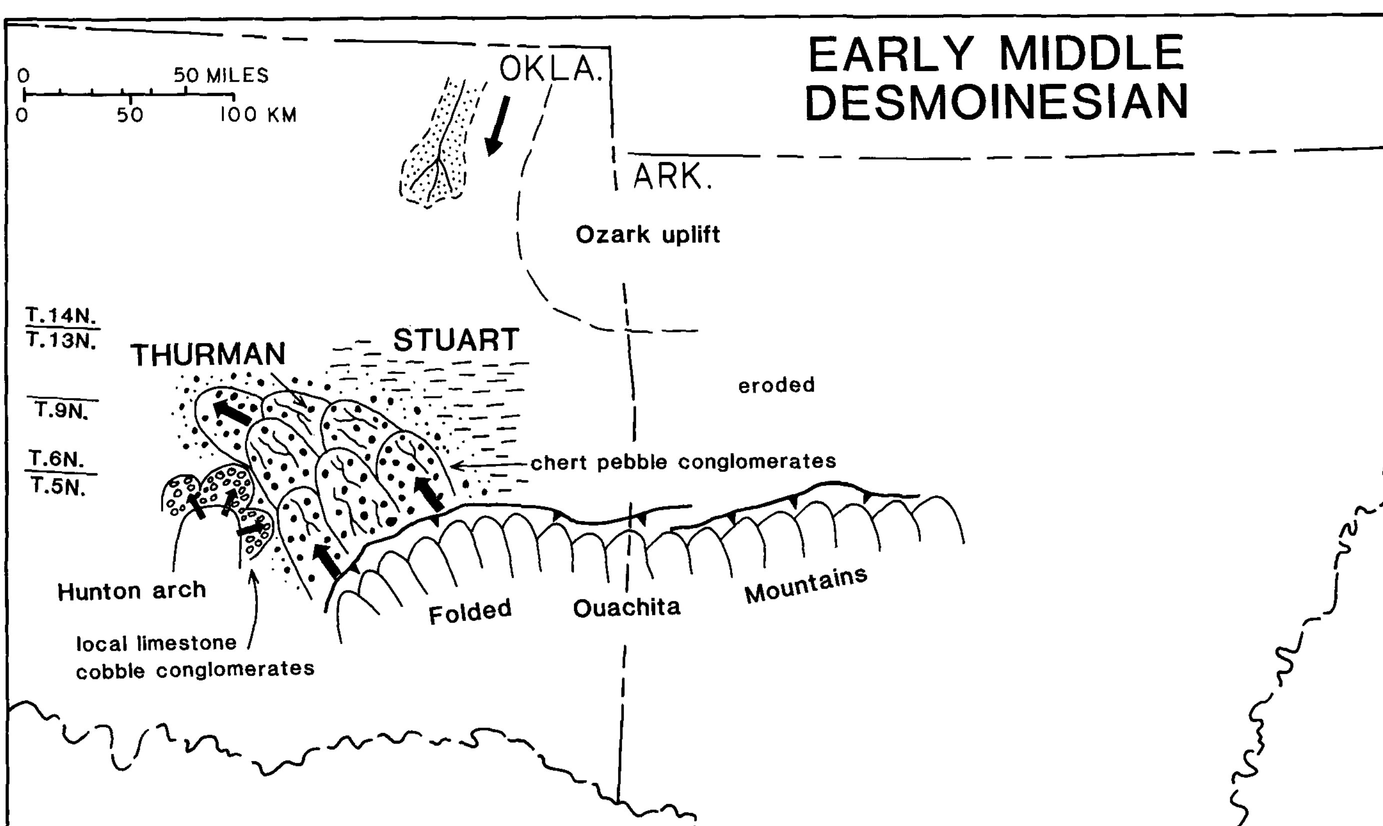

Figure 13. Early middle Desmoinesian paleogeographic map. Sources include Oakes, 1948, 1953, 1967, 1977; and Jones, 1957.

the widely accepted fault-scarp hypothesis for the origin of erratic boulders in the turbidite facies of the upper Stanley and Johns Valley Formations in the Ouachita trough. They show that the Pitkin limestones (Chesterian) and Prairie Grove calcareous sandstones (Morrowan) change facies to shale southward on the outer shelf and could not have been available in a fault scarp south of the location of the present-day Choctaw fault (Figs. 5, 6).

3. During the middle Atokan, flexural downwarping of the south margin of the shelf was accompanied by down-to-the-south syndepositional normal faults developed sequentially to the north, as a result of continued collapse of the Ouachita trough. Lithic arenites were introduced into this developing trough from the east, possibly from the fold belt on the southwest margin of the Black Warrior basin. Further closure plus rapid deposition resulted in the closing and filling of this incipient foreland basin by the end of deposition of the middle Atoka.

4. With further compressional deformation, the axis of deposition shifted farther northward with the development of a fully formed and continually subsiding foreland basin (beginning in late Atokan). Lithic arenites were transported westward along the axis of the basin (documented in earliest Desmoinesian). In Arkansas some of these sediments apparently came from the uplifted Ouachita thrust belt immediately to the south.

5. During the remainder of the early Desmoinesian, with the continued subsidence of the foreland basin, extensive deltaic deposits (sublitharenites) were introduced from the north. These came apparently from the continental interior west and north of the Ozark dome, and provided the primary source of sediments to the foreland basin in Oklahoma. There are erosional remnants of the early Desmoinesian McAlester, Savanna, and Boggy Formations in Arkansas. The moderate number of published paleocurrent directions in this area (Morris, 1974) are virtually all from the north. Evidence is lacking, but it is possible that some sediments, particularly during the deposition of the McAlester, were transported westward along the axis of the basin, as had been the case with the underlying Hartshorne Sandstone. Detailed provenance studies are needed in these formations in the areas to the southeast of the deltaic complexes in Oklahoma that originated to the north (Fig. 12).

6. Although there is evidence of a limited source of sediments from the Ouachita fold belt in Arkansas during the deposition of the Hartshorne Sandstone (earliest Desmoinesian), it seems astounding that the fold belt to the west in Oklahoma was apparently quiescent and presumably standing at or near sea level throughout the time of deposition of the upper Atoka, Hartshorne, McAlester, Savanna, and Boggy Formations (Figs. 11, 12). An exception is the local elevation of Black Knob ridge (lower middle Paleozoic cherts) located at the westernmost margin of the Ouachitas, just east of Atoka, Oklahoma. It provides local chert pebbles to the Arkoma basin just to the west.

7. Although added field confirmations are needed, it is concluded that renewed folding and uplift of the Ouachita fold belt following the deposition of the early Desmoinesian Krebs Group involved also the compression and folding of the Arkoma foreland basin. This ended the progressive downwarping of this basin and shifted the depocenter still farther to the northwest. The core area of the Ouachita fold belt was demonstrably elevated for the first time, resulting in the erosion and transportation of chert pebbles and other sediments to the northwest (Thurman Sandstone). These conclusions are based in part on the important observations by Oakes (1967) of the occurrence of folded and faulted early Desmoinesian strata (Boggy) below the middle Desmoinesian (Stuart). Oakes' conclusions need to be verified and augmented by additional detailed field observations and mapping, particularly concerning the nature of the Boggy/Thurman and Boggy/Stuart contacts.

8. Beginning with the deposition of the middle Desmoinesian Cabaniss Group and extending through the remainder of the Pennsylvanian, the Ouachita fold belt provided the primary source of terrigenous sediments, including periodic chert-pebble conglomerates, to a successor foreland basin located northeast and north of the Hunton arch, in central Oklahoma. This successor basin subsided much more slowly than did the earlier Arkoma basin.

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