STRUCTURAL AND STRATIGRAPHIC CONTINUITY OF THE OUACHITA AND APPALACHIAN MOUNTAINS

By William A. Thomas

Reprinted for private circulation from

ARKANSAS GEOLOGICAL COMMISSION

SYMPOSIUM ON THE GEOLOGY OF THE OUACHITA MOUNTAINS

VOLUME I

Stratigraphy, Sedimentology, Petrography,
Tectonics, and Paleontology

1977

PART II

TECHNICAL PAPERS

STRUCTURAL AND STRATIGRAPHIC CONTINUITY OF THE OUACHITA AND APPALACHIAN MOUNTAINS

By William A. Thomas[1]

ABSTRACT

Regional stratigraphic and structural relations of the Ouachita and Appalachian Mountains suggest an interpretation of structural continuity of the mountain systems; the regional Ouachita-Appalachian structure appears analogous to other salients and recesses elsewhere in the Appalachians. A curve in the structural front around the Ouachitas defines a structural salient. East of the Ouachitas in the subsurface, the structural front trends southeastward and converges with Appalachian structures in central Mississippi. That southeast-trending segment of the Ouachita front is not necessarily parallel with the strike of individual structures, and it may be a line along which east-striking frontal folds flatten and end. East of the Ouachita salient, the structural system curves into a recess in Alabama.

Lower Paleozoic rocks within the Ouachita salient are characterized by black shale. On the west, north, and east, an equivalent carbonate facies rims the area of the Ouachita shale facies. Distribution of Devonian-Lower Mississippian chert appears to be centered on the Ouachitas. Upper Paleozoic rocks of the Ouachitas comprise a thick flysch sequence, but the clastic sequence thins to the west, north, and east. Hence, in the Ouachita salient, the succession includes the lower Paleozoic black shale facies and the thick upper Paleozoic clastic sequence; but, eastward toward the Alabama recess, the structural system crosses into a lower Paleozoic carbonate facies and a thinner upper Paleozoic clastic sequence. Location and curvature of the Ouachita salient are interpreted to be related to the distribution of sedimentary facies and thickness.

INTRODUCTION

Paleozoic structures of the Appalachian Mountains plunge southwestward beneath the cover of Gulf coastal plain strata in central Alabama, and similarly Paleozoic structures of the Ouachita Mountains plunge eastward beneath the Gulf coastal plain in central Arkansas (Fig. 1). Wells drilled through the coastal plain cover are sparse, but available subsurface data show that a belt of deformed rocks extends from the Appalachians westward to the Ouachitas (Thomas, 1973). The sparse data allow for several different interpretations of geometry of the structural system (King, 1950; King, in Flawn and others, 1961, p. 97; Vernon, 1971; Thomas, 1973).

The exposed Appalachians in Alabama include a frontal belt of folded and thrust-faulted sedimentary rocks and an interior belt (Piedmont province) of metamorphic rocks (Fig. 1). Structures within the frontal belt involve a lower Paleozoic carbonate sequence and an upper Paleozoic clastic sequence (Table 1). The subsurface fold and thrust belt in western Alabama and eastern Mississippi includes at least two major structures and one apparently less extensive frontal structure. Structural strike apparently curves gradually westward, and subsurface data from about 30 wells indicate that the structural style of the fold and thrust belt persists as far west as central Mississippi (Fig. 1; Central Mississippi deformed belt of Thomas, 1973). No subsurface data are available farther west along the projected trend, and the westward extent and limits of the belt are unknown. A stratigraphic sequence, with a few exceptions like that in the Alabama Appalachians, also extends as far west as central Mississippi (Table 1). The Talladega Slate belt of metasedimentary rocks along the northwest side of the Appalachian Piedmont may be identified as far west as eastern Mississippi, and higher grade metamorphic rocks of the Piedmont province are known as far southwest as southern Alabama (Thomas, 1973, Fig. 4).

Exposed Ouachita structures include thrust faults and folds which involve a lower Paleozoic succession of black shale, sandstone, chert, and limestone and a much thicker upper Paleozoic clastic sequence (Table 1). The Ouachita structural system gives the impression of being more complex and including more disharmonic structures than the folded and thrust-faulted belt of the Alabama Appalachians. Apparent differences in structural style possibly reflect thicker and more numerous units of incompetent rocks which alternate with relatively competent units in the Ouachita succession. Rocks of the Ouachita core zone exhibit tight folds and slaty cleavage (Miser and Purdue,

---

[1]Dept. of Geology, Georgia State University, Atlanta, Georgia 30303. Manuscript received, May 30, 1974; revised manuscript received, May 16, 1975

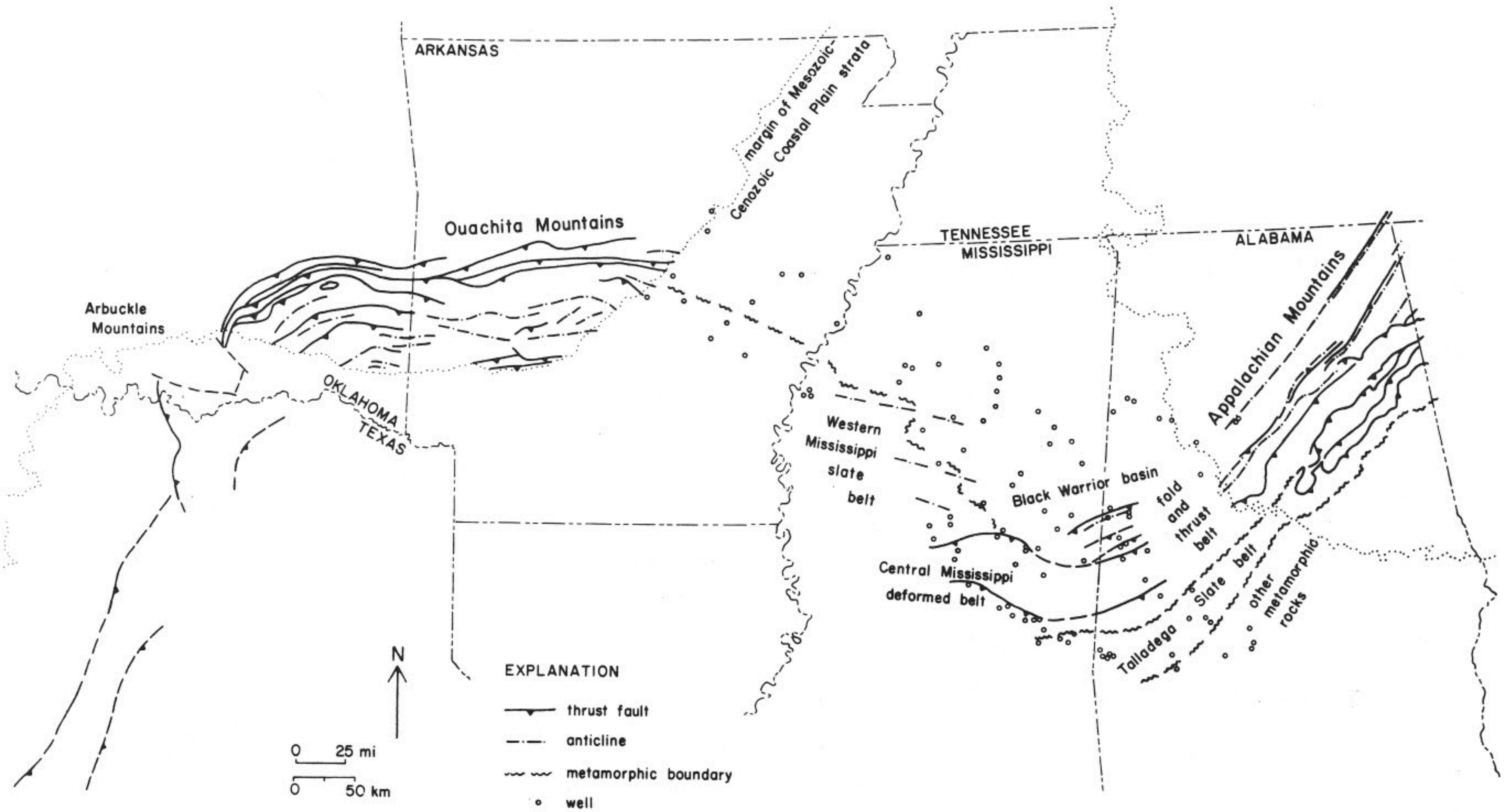


Figure 1. - Regional structural geology of Ouachita and Appalachian Mountains. Structural interpretation adapted from Flawn and others (1961), Stone (1966), and Thomas (1973). Wells on which interpretation is based are identified by Flawn and others (1961), Caplan (1964), and Thomas (1972a, 1973). Note: metamorphic boundaries may or may not be faulted.

	OUACHITA MOUNTAINS	MISSISSIPPI	APPALACHIAN MOUNTAINS, ALABAMA
MISSISSIPPIAN - PENNSYLVANIAN	ATOKA FORMATION SHALE; SANDSTONE; COAL IN UPPER PART. 19000+ FT. JOHNS VALLEY SHALE SHALE; ERRATIC BOULDERS; SANDSTONE. 1500 FT. JACKFORK GROUP SANDSTONE; SHALE; SILICEOUS SHALE. 7000 FT. STANLEY GROUP SHALE; SILICEOUS SHALE; SANDSTONE; TUFF IN LOWER PART. 12000 FT. ARKANSAS NOVACULITE 950 FT.	POTTSVILLE FORMATION SANDSTONE; SHALE; CONGLOMERATE; COAL. 10000 FT. PARKWOOD FORMATION SANDSTONE; SHALE. 2000 FT. FLOYD SHALE SHALE; SANDSTONE-LIMESTONE IN LOWER PART. 850 FT. FORT PAYNE-TUSCUMBIA CHERT; CHERTY LIMESTONE. 220 FT. ARKANSAS NOVACULITE 1100 FT.	POTTSVILLE FORMATION SANDSTONE; SHALE; CONGLOMERATE; COAL. 9000 FT. PARKWOOD FM. SANDSTONE-SHALE FACIES ON SOUTHWEST. 2600 FT. BANGOR LS. LIMESTONE FACIES ON NORTHEAST. 700 FT. FLOYD SHALE 1700 FT. HARTSELLE SANDSTONE 150 FT. PRIDE MTN. FM. SHALE; SANDSTONE. 400 FT. TUSCUMBIA LIMESTONE CHERTY LIMESTONE. 200 FT. FORT PAYNE CHERT CHERT; SILICEOUS LIMESTONE. 200 FT. MAURY SHALE GREEN SHALE. 10 FT.
DEVONIAN			CHATTANOOGA SHALE BLACK SHALE. 25 FT. -HIATUS- FROG MOUNTAIN SANDSTONE 200 FT.
SILURIAN	MISSOURI MOUNTAIN SHALE 300 FT. BLAYLOCK SANDSTONE 1500 FT.	UN-NAMED SILICEOUS LIMESTONE; CLAYSTONE; DOLOSTONE. DARK-COLORED SHALE AND LIMESTONE ON SOUTHWEST. 700 FT.	-HIATUS- RED MOUNTAIN FORMATION SANDSTONE; SHALE; LIMESTONE; HEMATITE. 500 FT.
MIDDLE & UPPER ORDOVICIAN	POLK CREEK SHALE BLACK SHALE; SANDSTONE; CHERT. 175 FT. BIGFORK CHERT CHERT; BLACK SHALE; LIMESTONE. 800 FT. WOMBLE SHALE BLACK SHALE; LIMESTONE; SANDSTONE. 3500 FT.	CHICKAMAUGA GROUP LIMESTONE; DOLOSTONE; SANDY LIMESTONE- DOLOSTONE AND SANDSTONE AT BASE. BLACK SHALE TONGUE NEAR TOP PINCHES OUT EASTWARD. SANDSTONE AT TOP ON NORTH. 3000 FT.	CHICKAMAUGA GROUP LIMESTONE; LOCAL CHERT CONGLOMERATE AT BASE. 900 FT.
LOWER ORDOVICIAN	BLAKELY SANDSTONE BLACK SHALE; SANDSTONE; CHERT; BOULDERS. 400 FT. MAZARN SHALE BLACK SHALE; LIMESTONE; SANDSTONE. 3000 FT. CRYSTAL MTN. SANDSTONE 850 FT. COLLIER SHALE BLACK SHALE; LIMESTONE; CHERT. 1000+ FT. -NO OLDER ROCKS EXPOSED-	KNOX GROUP DOLOSTONE; CHERTY DOLOSTONE.	KNOX GROUP DOLOSTONE; CHERTY DOLOSTONE. 3000 FT.

Table 1

Generalized Paleozoic stratigraphic columns (compiled and modified from Butts, 1926; Flawn and others, 1961; Sterling and others, 1966; Stone, 1966; Thomas 1972a; 1972b; Stone and others, 1973; Thomas and Drahovzal, 1973). Thicknesses are an approximate maximum for each area. Because maxima of different formations do not coincide geographically, total sedimentary thickness at any locality is less than the sum of the formation maxima for each area. Thicknesses of most units in Mississippi are from the Black Warrior basin, because formation thickness is generally undetermined within the Central Mississippi deformed belt.

1929, p. 118; Viele, 1973, p. 367). A belt containing quartz veins extends along the length of the Ouachitas (Miser, 1943, p. 94; 1959, p. 37; Engel, 1952).

In the subsurface of western Mississippi, a dark-colored shale succession is in part characterized by slaty cleavage (Fig. 1; Western Mississippi slate belt of Thomas, 1973). Quartz veins are also common in parts of the area. Identification of the subsurface Western Mississippi slate belt is based on the presence of slaty cleavage and quartz veins. However, within the area, slaty cleavage is not consistently distinct, and some rocks are not slaty. Presence of slate and quartz veins indicates an Ouachita deformational style and suggests that Ouachita structures extend into western Mississippi. The Western Mississippi slate belt apparently extends to the foreland side of Appalachian structures and, thus, is not comparable in tectonic setting to the Talladega Slate belt of the Appalachian interior (Fig. 1).

Although wells are sparse, a generalized structural front may be drawn northwestward from central Mississippi into an arc that curves around the exposed Ouachitas in Arkansas and Oklahoma (Fig. 1). The Ouachita structural system similarly may be traced southward in the subsurface of eastern Texas (Flawn, in Flawn and others, 1961, Pl. 2). The curve in outline of the Ouachita structural system defines a major structural salient convex toward the North American craton. East of the Ouachita salient, the structural system curves into a recess in Alabama. To the southwest, the structural system extends from the Ouachita salient into a major recess around the Llano uplift and farther west into the Marathon salient (Flawn, in Flawn and others, 1961, p. 166).

Enough data are available now to establish continuity of a belt of deformed rocks from the exposed Appalachians to the exposed Ouachitas; however, many details within the connecting structural system, particularly relation of the Western Mississippi slate belt to "Appalachian-style" structures, remain uncertain. Problems of specific structural interpretations and details of the subcrop map pattern evidently cannot be resolved by further review of presently available subsurface data. However, interpretation of the regional structural pattern and of the regional stratigraphy of Paleozoic rocks provides the basis for a working structural model of the "junction" of Ouachita and Appalachian structures. Some characteristics of Ouachita and Alabama Appalachian structures seem to be related to their positions within the regional salient and recess; these may be examined by analogy with exposed salients and recesses elsewhere in the Appalachians. Structures of the Ouachita salient and Alabama Appalachian recess are formed within substantially different sedimentary facies, and a genetic relationship between regional structure and stratigraphy is implied. The purpose of this paper is to review available structural and stratigraphic data from the area of the Ouachita-Appalachian junction, to compare structure and stratigraphy of other regional salients, and to develop a comprehensive Ouachita-Appalachian structural-stratigraphic model.

LOWER PALEOZOIC (CAMBRIAN-SILURIAN) STRATIGRAPHY

The lower Paleozoic succession in the Ouachita Mountains is characterized by black shale (Table 1). Conodont biostratigraphy indicates that the oldest rocks exposed in the Ouachitas are Early Ordovician (Repetski and Ethington, 1973, p. 277). Silurian rocks comprise only a small part of the total sequence, and the Silurian Blaylock Sandstone pinches out northward across the Ouachita outcrops (Sterling and others, 1966, p. 184). The Ouachita black shale facies includes distinctive units of chert, sandstone, limestone, and boulder conglomerate (Table 1). Although thickness and proportion of the different components vary, the characteristic lower Paleozoic black shale facies extends throughout the Ouachita outcrops. In contrast, in areas adjacent to the Ouachitas, the lower Paleozoic strata are mainly carbonate, and the carbonate succession generally includes quartzose sandstone and sandy carbonate (Fig. 2).

In the Arbuckle Mountains, the lower Paleozoic succession is mainly carbonate and contains quartzose sandstone units (Ham, 1959, p. 71). The Sylvan Shale is a distinctive interbed of dark-gray and greenish-gray shale in the upper part of the carbonate succession (Ham, 1959, p. 77; Frezon, 1962, p. 39). The Sylvan is interpreted to be a tongue of the Ouachita shale facies, and that shale tongue has served as a tie between the Arbuckle and Ouachita facies (Ham, 1959, p. 77).

Similarly, north of the Ouachitas in northern Arkansas, the lower Paleozoic succession is mainly carbonate and contains units of quartzose sandstone (Fig. 2). The Cason Shale within the carbonate succession of northern Arkansas is lithologically similar to the Sylvan Shale (Maher and Lantz, 1953; Frezon, 1962, p. 39), and the Cason evidently is also a tongue of the Ouachita facies. The Cason may be part of the same widespread shale unit as the Sylvan (Ham, 1959, p. 77); however, part of the Cason may be younger than the Sylvan (Wise and Caplan, 1967, Fig. 2; Craig, 1973, p. 253).

East of the Ouachitas in the subsurface of Mississippi, the lower Paleozoic succession is almost entirely carbonate, but it includes some sandy intervals (Table 1; Fig. 2). In north-central Mississippi, the Upper Ordovician includes a thin unit of black shale which pinches out eastward into the carbonate facies and has been drilled in only a few wells (Fig. 2; Thomas, 1972a, Fig. 7). The black shale is overlain by a sandstone unit which may be a distal tongue of the Sequatchie clastic wedge of the Tennessee Appalachians (Thomas, 1972a, p. 92). In central Mississippi, one well (Carter Oil Company No. 1 Denkman, Leake County) penetrated dark-gray and black shales and limestones (Thomas, 1972a, Table 5) which contain Silurian brachiopods (King, in Flawn and others, 1961, p. 355). This well marks the most southwesterly known Silurian rocks in Mississippi, and the dark-colored shales and limestones contrast with the lighter colored Silurian carbonate rocks and thin claystones farther northeast in Mississippi

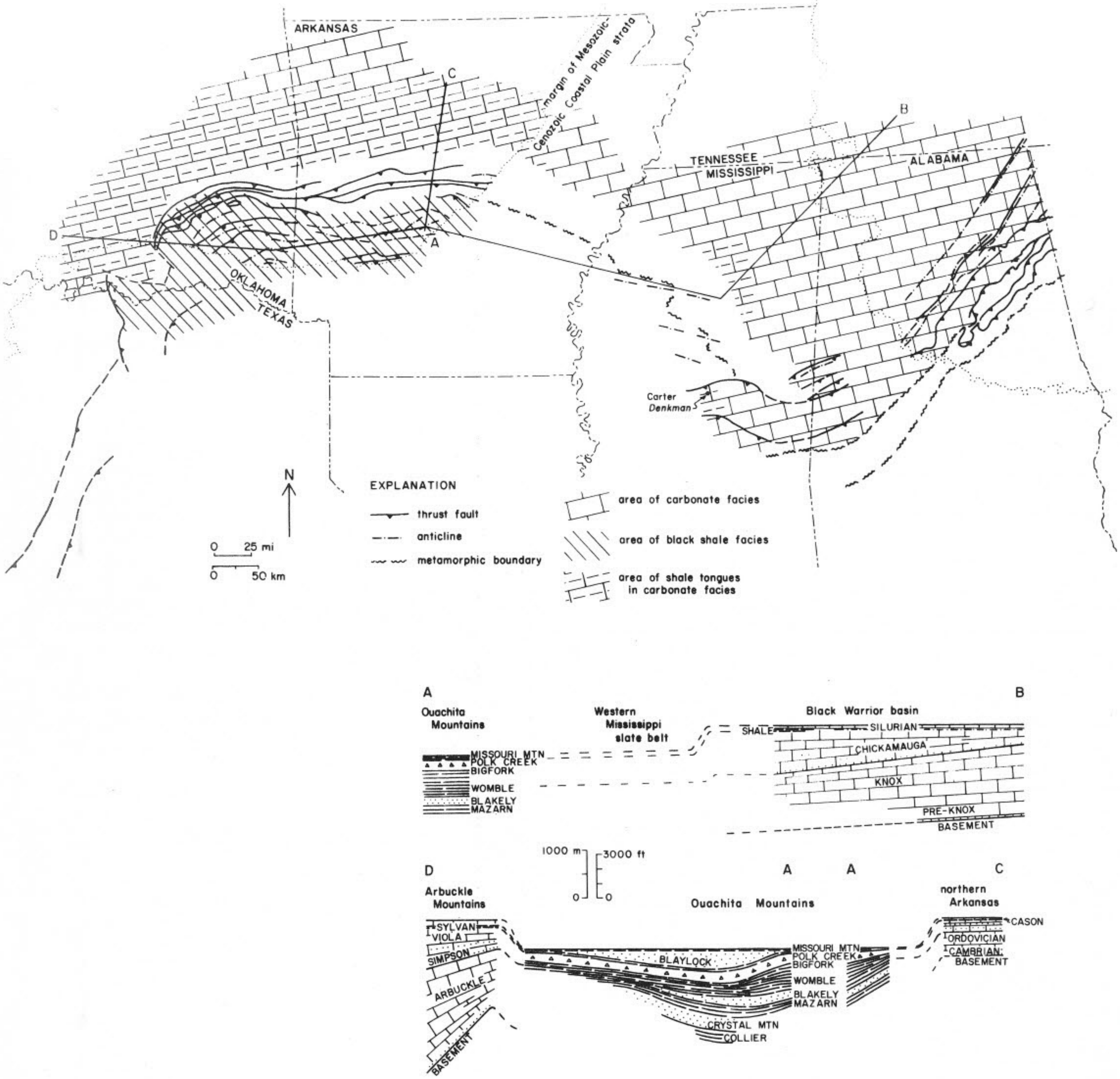


Figure 2. - Lower Paleozoic (Cambrian-Silurian) stratigraphy. Symbols on cross sections designate stratigraphic units but do not show lithologic details. Cross sections show interpreted depositional framework. Data from Miser and Purdue (1929), Wilson (1949), Maher and Lantz (1953), Huffman and others (1958), Frezon and Glick (1959), Ham (1959), Milhous (1959), Flawn and others (1961), Frezon (1962), Caplan (1964), Sterling and others (1966), Sellars (1967), Berry and Trumbly (1968), Haley and Hendricks (1968), Thomas (1972a).

(Thomas, 1972a, p. 96). In summary, the Ordovician and Silurian in the subsurface of Mississippi include two units which suggest tongues of the Ouachita black shale facies: (l) a thin tongue of black shale that pinches out eastward into the Ordovician carbonate sequence; and (2) dark-colored shale and limestone on the southwest in the Silurian (Fig. 2).

From the Arbuckle Mountains across northern Arkansas to central Mississippi, a lower Paleozoic carbonate facies rims the area of an equivalent black shale facies in the Ouachita Mountains (Fig. 2). Evidently the carbonate facies must change to black shale toward the Ouachitas. East of the Arbuckle Mountains, the Ouachita black shale facies is now in close proximity to the carbonate facies (Fig. 2), and subsurface data indicate that the Ouachita shale facies has been thrust over Arbuckle rocks (Flawn, in Flawn and others, 1961, Pl. 2). Although the original horizontal distance between the Ouachita and Arbuckle facies has been shortened by thrusting, the extent to which the black shale has been thrust over the carbonate facies is unknown. Shale tongues in the carbonate facies of the Arbuckle Mountains and northern Arkansas may be an indication of proximity to the facies boundary. Like the other shale tongues, the thin eastward-pinching black shale in the carbonate sequence of north-central Mississippi suggests a tie to the Ouachita facies and possible proximity to the facies boundary. Available data are not adequate to define the eastward extent of the Ouachita black shale facies. However, the known subsurface area of the carbonate facies and extent of the black shale tongue suggest that possibly the Ouachita black shale facies extends into western Mississippi, perhaps across the Western Mississippi slate belt (Fig. 2). Apparently the facies boundary crosses western Mississippi in a generally southeastward or southward direction. Several wells in western Mississippi have drilled dark-colored shale, the age of which is not precisely known; however, the lithology is similar to known upper Paleozoic rocks elsewhere in the region. Thus, no known lower Paleozoic shale facies has been drilled in western Mississippi, and precise definition of the eastward extent of the Ouachita shale facies awaits additional drilling.

Distributions of the carbonate and black shale facies suggest the interpretation that the facies boundary marks the steep edge of a shallow carbonate bank (see Rodgers, 1968, for discussion of carbonate bank and deep-water shale facies in the northern Appalachians). The carbonate facies and interbedded quartzose sandstone units reflect the shallow shelf environment. Shale tongues within the carbonate facies indicate transport of fine-grained clastic sediments across the bank. Apparently the carbonate bank around the Ouachita region outlined a basin in which black shale and related sediments accumulated. The inferred deep-basin setting of the black shale facies is in accord with the commonly held interpretation of a deep-water starved basin or leptogeosynclinal environment (Goldstein, in Flawn and others, 1961, p. 31; Viele, 1973, p. 363; but see summary of other interpretations by Viele, 1973, p. 363). Some sandstone interbeds within the black shale facies suggest a supply of quartz sand from the bank. Parts of the Ouachita clastic facies (for example, the southward-thickening Blaylock Sandstone) suggest a sediment source within or south of the basin (Goldstein, in Flawn and others, 1961, p. 32). Meta-arkose and granitic boulders in the Blakely Sandstone may have been derived from scarps on the north (Stone and others, 1973, p. 37).

The structures of the Ouachita salient are within the shale facies, and the frontal structures of the Ouachitas may be approximately parallel with the carbonate bank edge. Toward the Alabama recess, the front of the structural system crosses into the carbonate facies; and, in eastern Mississippi and Alabama, Appalachian structures are in the carbonate facies (Fig. 2).

MIDDLE PALEOZOIC (DEVONIAN-LOWER MISSISSIPPIAN) STRATIGRAPHY

The Arkansas Novaculite apparently is related to other Devonian and Lower Mississippian chert units in the region around the Ouachita Mountains (Fig. 3). The novaculite has a maximum thickness of nearly 1,000 feet in the Ouachita Mountains, but it thins northward across the Ouachita outcrops (Sterling and others, 1966, p. 184). The novaculite also thins westward, but the middle division of the novaculite is continuous with the Woodford Formation of the Arbuckle Mountains (Ham, 1959, p. 75). The Woodford consists of black shale and chert beds (Ham, 1959, p. 75; Frezon, 1962, p. 33).

In northern Arkansas, chert beds equivalent to the Arkansas Novaculite are included in the Penters and Boone Formations (Sterling and others, 1966, Table 1; Gordon and Stone, 1973, p. 259). Maximum thickness of the Penters-Boone sequence is less than that of the Arkansas Novaculite; however, locally in northern Arkansas, thickness of the Penters-Boone exceeds that of the relatively thin Arkansas Novaculite of the northern Ouachitas (Fig. 3). The Penters Chert pinches out northward (Fig. 3), and in northern Arkansas the Penters contains thin interbeds of limestone (Frezon and Glick, 1959, p. 177). The Boone thickens northward and extends beyond the limit of Penters Chert (Fig. 3).

The Boone Formation of northern Arkansas consists mainly of cherty limestone and chert (Frezon and Glick, 1959, p. 179). The formation thins and changes southward into a shale facies in the subsurface north of the Ouachitas (Fig. 3; Caplan, 1957, p. 4; Frezon and Glick, 1959, p. 179). Subsurface data indicate that the Penters Chert also thins southward across the same area (Maher and Lantz, 1953; Haley and Frezon, 1965, p. 3). The Arkansas Novaculite is shaly in outcrops along the northern Ouachitas (B. R. Haley and C. G. Stone, personal communication, 1974), and evidently an intermediate shaly facies separates the thick Arkansas Novaculite of the Ouachitas from the Penters-Boone sequence of northern Arkansas. Frezon and Glick (1959, p. 179) conclude that the Boone limestone and chert facies was deposited in a shelf environment,

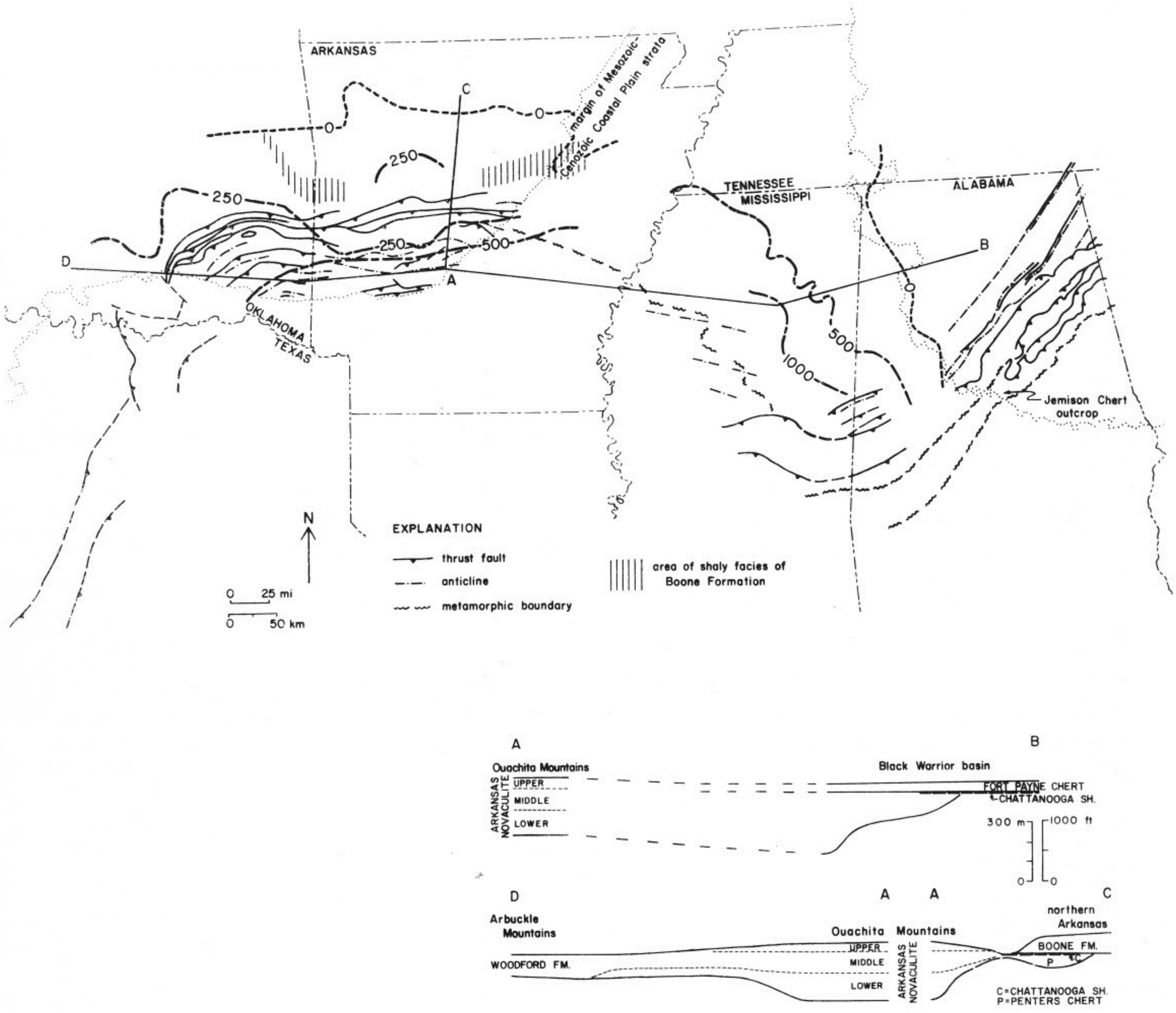


Figure 3. - Middle Paleozoic (Devonian-Lower Mississippian) stratigraphy. Isopach map of Devonian chert (contour values in feet; interval varies); Mississippian Boone and Fort Payne Formations extend north and northeast beyond pinch-out of Devonian chert. Datum of cross sections is top of Devonian. Data from Purdue and Miser (1923), Miser and Purdue (1929), Maher and Lantz (1953), Huffman and others (1958), Frezon and Glick (1959), Ham (1959), Frezon (1962), Haley and Frezon (1965), Sterling and others (1966), Sellars (1967), Wise and Caplan (1967), Thomas (1972a), Thomas and Drahovzal (1973).

whereas the shaly facies was deposited in a basin south of the shelf. Geographic relation of the Arkansas Novaculite to the shaly Boone suggests that the novaculite is also a basin sediment. Park and Croneis (1969, p. 109) interpret the novaculite to have been deposited in relatively deep water; however, Goldstein and Hendricks (1953, p. 441) conclude that the novaculite is of shallow-water origin.

In the subsurface of central Mississippi the novaculitic chert sequence locally exceeds 1,000 feet in thickness (Thomas, 1972a, p. 96). The chert unit thins northeastward across eastern Mississippi but evidently is continuous northward with a succession of chert, cherty limestone, and limestone in the Devonian of western Tennessee. The pattern of northeastward thinning of the Devonian chert terminates at a southeast-trending pinch-out line in the subsurface of western Alabama (Fig. 3). Near the pinch-out edge in Alabama, the chert unit includes limestone beds which are comparable in position to similar rocks in northern Arkansas and western Tennessee.

The Lower Mississippian Fort Payne Chert of Alabama consists mainly of beds of chert and fine-grained limestone, and it includes crinoidal chert and a few interbeds of bioclastic limestone. Stratigraphic relations in northeastern Mississippi suggest possible continuity of the Fort Payne with the upper part of the subsurface novaculite sequence (Thomas, 1972a, p. 96). The Osagean age of the Fort Payne (Drahovzal, 1967, p. 14) coincides with the probable age of the upper part of the Arkansas Novaculite (Hass, 1951, p. 2540). The Fort Payne thickens northeastward in Alabama and extends far northeastward beyond the limit of Devonian chert across most of northern Alabama and Tennessee. The Fort Payne evidently is a shelf deposit which thins southwestward into the Black Warrior basin (Fig. 3).

The Lower Devonian Jemison Chert (Butts, 1926, p. 147; Carrington, 1973, p. 31) at the southwestern exposed end of the Alabama Piedmont also may be part of the chert distribution that centers on the Arkansas Novaculite. Massive chert of the Jemison is common only on the southwest where the formation is about 450 feet thick (Carrington, 1973, p. 31), but the unit can be traced northeastward as a quartz schist (Neathery, 1973, p. 52). Chert interbeds in the Devonian Frog Mountain Sandstone of the Alabama Appalachians also may be related to the Arkansas Novaculite (Thomas and Drahovzal, 1973, p. 79).

The distribution of Devonian-Lower Mississippian chert thickness defines a semicircular pattern around the Ouachita Mountains (Fig. 3). The chert thins irregularly away from the Ouachitas and evidently represents a sedimentary system centered on the Ouachitas. Devonian chert pinches out northward and eastward from the Ouachitas (Fig. 3). The thickness of the chert unit in the subsurface of Mississippi is similar to that in the Ouachitas, and possibly the thick chert unit is continuous from Mississippi to the Ouachitas (Fig. 3). Any possible intermediate shaly facies or area of thin chert (analogous to that between northern Arkansas and the Ouachitas) has not been recognized in available subsurface data from Mississippi.

UPPER PALEOZOIC (UPPER MISSISSIPPIAN-LOWER PENNSYLVANIAN) STRATIGRAPHY

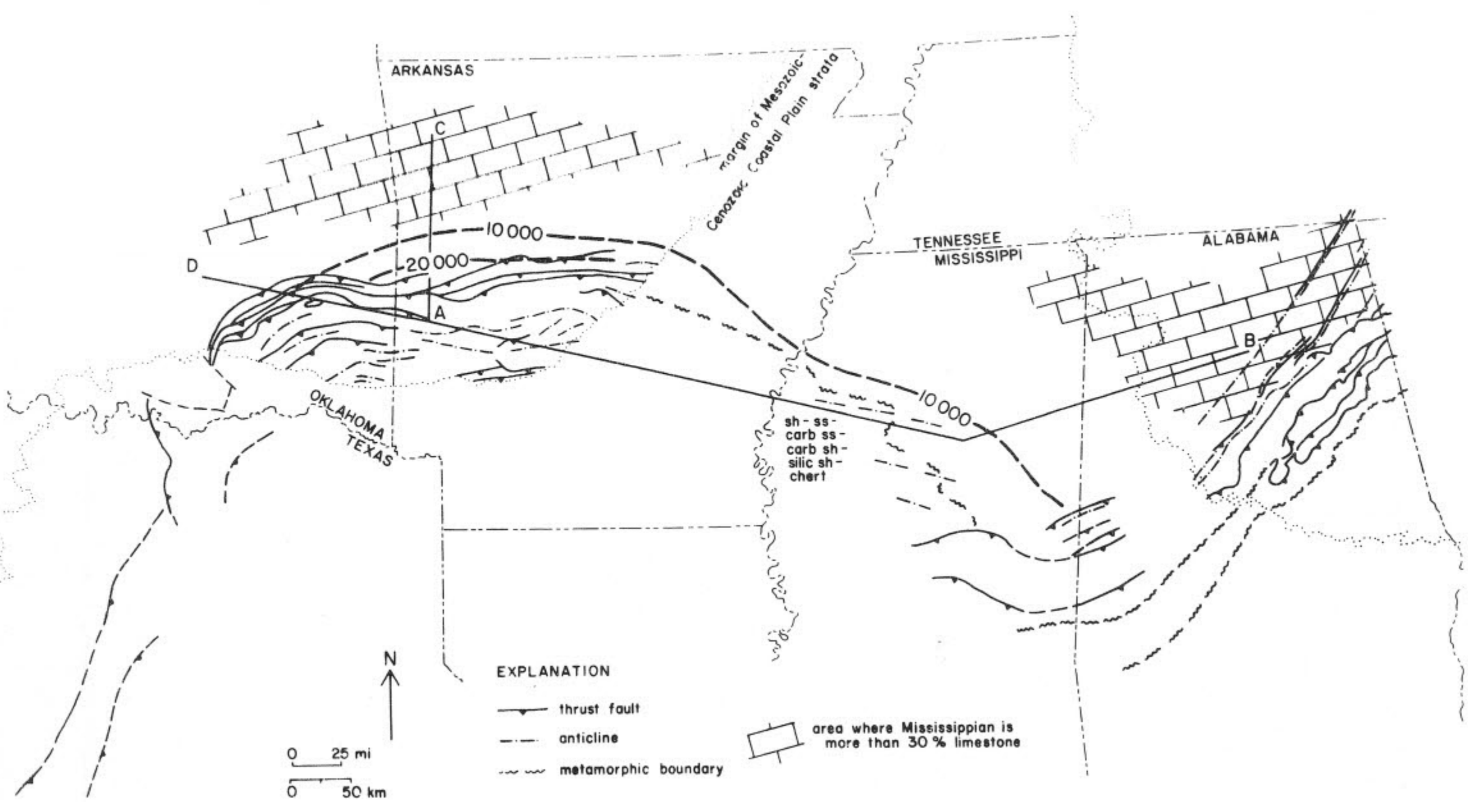
Upper Mississippian and Lower Pennsylvanian strata comprise a clastic sequence which thickens toward the Ouachita Mountains from the west, north, and east; and, the maximum thickness is as much as 30,000 feet in the Ouachitas (Table 1; Fig. 4). The clastic sequence is characterized by shale in the lower part and by a succession of interbedded sandstones and shales in the upper part (Table 1).

The Ouachita sequence includes dark-colored shales, several kinds of sandstones, boulder beds, and distinctive interbeds of dark-colored siliceous shale, chert, and tuff (Cline, 1960; Goldstein and Hendricks, 1962). The upper Paleozoic Ouachita sequence is interpreted to be a deep-water flysch facies (Cline, 1960, p. 100; 1966; 1970; King, in Flawn and others, 1961, p. 184; Chamberlain, 1971, p. 49).

In Oklahoma, the sequence thins westward and northward from the central Ouachitas (Fig. 4). The rate of thinning evidently has been exaggerated somewhat by thrust faulting; however, Cline (1960, p. 21) and Hammes (1965, p. 1678) suggest that the amount of overthrusting may be relatively less than is apparent because the rate of thinning may have been influenced significantly by original sedimentary convergence. Some thickening toward the Ouachitas is related to down-to-basin contemporaneous faults (Koinm and Dickey, 1967; Buchanan and Johnson, 1968; Haley and Hendricks, 1968, p. A7). Northwest of the Ouachitas, the Mississippian and Pennsylvanian include clastic and carbonate rocks which represent shallow marine and deltaic depositional environments (Laudon, 1959; Scull and others, 1959, p. 167; Visher and others, 1971). The Pennsylvanian includes prograding deltaic sandstones which were supplied from the north (Scull and others, 1959, p. 167; Visher and others, 1971, p. 1212).

In northern Arkansas, total thickness of Mississippian and Pennsylvanian strata is much less than that in the Ouachitas (Fig. 4). The Mississippian-Pennsylvanian succession includes units of shale, limestone, and sandstone (Maher and Lantz, 1953; Ogren, 1968; Glick, 1973; Zachry and Haley, 1973). These sediments reflect shallow marine and deltaic environments.

East of the Ouachita Mountains in the Black Warrior basin, the Mississippian-Pennsylvanian sequence thins northeastward from a maximum of more than 10,000 feet in east-central Mississippi (Fig. 4). A predominantly shale unit at the base of the sequence grades upward into a cyclical succession of sandstone, shale, and limestone (Thomas, 1972a, p. 98). These rocks indicate shallow marine and deltaic environments, and rock-stratigraphic relations indicate northeastward progradation of a delta complex. Upward gradation continues into a coal-bearing



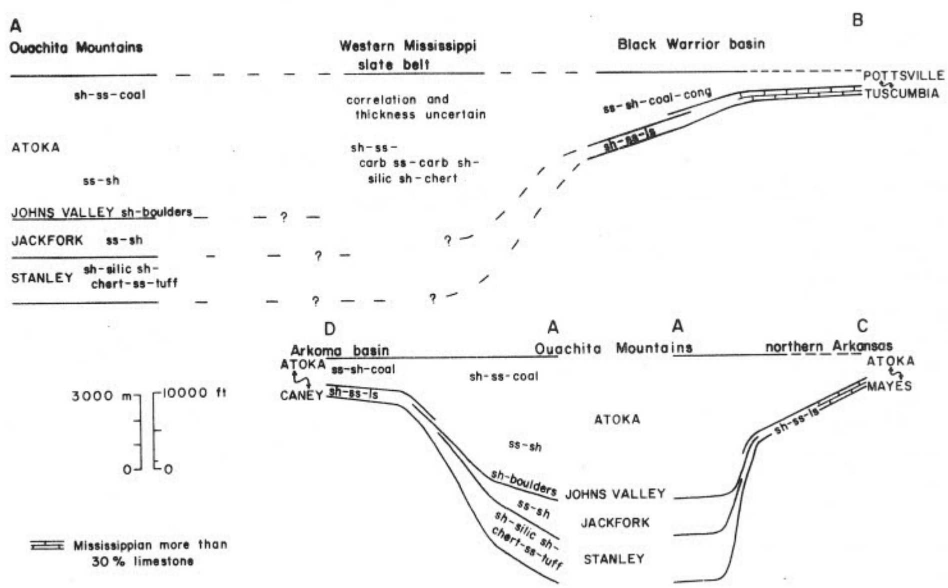


Figure 4. - Upper Paleozoic (Upper Mississippian-Lower Pennsylvanian) stratigraphy. Isopach map of Upper Mississippian-Lower Pennsylvanian (contour values in feet). Datum of cross sections is top of Atoka. Abbreviations: sh = shale, ss = sandstone, carb = carbonaceous, silic = siliceous, cong = conglomerate, ls = limestone. Data from Maher and Lantz (1953), Caplan (1957), Reinemund and Danilchik (1957), Frezon and Glick (1959), Laudon (1959), Scull and others (1959), Cline (1960), Branson (1962), Frezon (1962), Goldstein and Hendricks (1962), Haley and Frezon (1965), Stone (1966), Ogren (1968), Visher and others (1971), Thomas (1972a, 1972b).

cyclical succession dominated by carbonaceous sandstone, shale, and conglomerate beds. The lower (Mississippian) part of the clastic sequence grades northeastward into a limestone facies in the eastern part of the Black Warrior basin in Alabama (Fig. 4). The facies boundary trends southeastward and is paralleled by linear barrier sandstones and massive oolitic limestones (Thomas, 1972b, p. 103). Facies strike is nearly perpendicular to Appalachian structural strike in the frontal structures of the recess in Alabama; and, although far removed from the exposed Ouachita Mountains, the facies in Alabama are approximately concentric with the Ouachita structural front (Fig. 4). Distribution of clastic sediments indicates a sediment source southwest of the Black Warrior basin.

In the Western Mississippi slate belt, the age of the dark-colored shale is not known with certainty, but parts of the succession include components which appear similar to distinctive rocks within the Mississippian-Pennsylvanian sequences in the Ouachita Mountains and in the Black Warrior basin. The slate belt sequence includes some interbeds of carbonaceous shale and sandstone like those in the Black Warrior basin. Parts of the slate belt succession include dark-colored siliceous shale and chert similar to those of the Ouachita facies. Apparently western Mississippi is an area of facies transition from the thinner shelf sediments of the Black Warrior basin to the thicker deep-water flysch of the Ouachitas. That relation suggests correspondence between facies boundaries and thickness distribution and further indicates that western Mississippi belongs to the Ouachita stratigraphic province (Fig. 4).

The great volume of Upper Mississippian-Lower Pennsylvanian clastic sediment has been interpreted to indicate orogenic uplift of a sediment source south or southeast of the present Ouachita Mountains and within the Ouachita mobile belt (Miser, 1921; Miser and Purdue, 1929, p. 134; King, in Flawn and others, 1961, p. 184; Goldstein and Hendricks, 1962, p. 421; Johnson, 1966, p. 156; Cline, 1970, p. 100). The sediment source is described as having included basement rocks, metasedimentary rocks, and sedimentary rocks, as well as active volcanoes (which supplied tuff in addition to sediment). Petrographic data generally have been interpreted to indicate a lithologically complex sediment source at the southern margin of the Ouachita trough (Bokman, 1953, p. 168; Goldstein and Hendricks, 1962, p. 421; Hill, 1966, p. 120; Klein, 1966, p. 316; Walthall, 1967, p. 523). Other petrographic work suggests that quartz sand was introduced into the basin from a source north of the Ouachitas (Klein, 1966, p. 316; Morris, 1971, p. 398). Paleocurrent data indicate predominantly westward (axial) transport of sediment through the Ouachitas of western Arkansas and eastern Oklahoma (Briggs and Cline, 1967, p. 991; Cline, 1970, p. 93; Morris, 1971, p. 399). A comprehensive interpretation suggests that sediment was introduced into the Ouachita trough from both south and north and was transported westward along the axis of the trough (Klein, 1966, p. 323; Cline, 1970, p. 100). The orogenic sediment source south or southeast of the Ouachitas also supplied clastic sediment to the Black Warrior basin and southwestern Alabama Appalachians. Parts of the shelf north and west of the Ouachitas received clastic sediment from northern sources (Visher and others, 1971, p. 1212). Swann (1964, p. 653) proposes that the "Michigan River" delta system prograded through the Illinois basin and transported sand to the northeast edge of the Ouachita trough as well as to the western part of the Black Warrior basin. Fault scarps along the northern margin of the Ouachita trough are proposed as the source of erratic boulders in the Johns Valley Shale (Shideler, 1970, p. 803).

SUMMARY OF STRATIGRAPHY WITHIN THE OUACHITA SALIENT

Available data indicate a regional geographic coincidence of the Ouachita structural salient with the extent of the Ouachita sedimentary facies. The Ouachita salient structures are within the area of the lower Paleozoic Ouachita black shale facies. Eastward from the Ouachita salient, the belt of deformed rocks crosses into the carbonate facies in the Alabama recess (Fig. 2). Distribution of Devonian-Lower Mississippian chert defines a generally semicircular pattern that apparently is centered on the Ouachita salient (Fig. 3). Thickness of the upper Paleozoic clastic sequence decreases westward, northward, and eastward from the Ouachitas, and isopach lines appear to be roughly semicircular around the Ouachita salient (Fig. 4). Eastward toward the Alabama structural recess, the structural front intersects isopach strike, and the belt of deformed rocks crosses into a thinner upper Paleozoic clastic sequence. The Mississippian part of the clastic facies grades northeastward into a carbonate facies along the frontal part of the Alabama Appalachian recess; the Mississippian of northern Arkansas includes a similar carbonate facies.

In northwestern Mississippi, the boundary between the Western Mississippi slate belt and undeformed rocks of the Black Warrior basin trends generally southeastward, but subsurface data are too sparse to define precisely the position and shape of the boundary (Thomas, 1973, Fig. 8). Between the area of slaty rocks and the area of undeformed rocks of the Black Warrior basin, several wells have cored beds which have dips of 15 degrees or more (Thomas, 1973, p. 385), but the relation of strike of individual structures to strike of the structural front is unknown. Some rocks of the Western Mississippi slate belt suggest affinities with the upper Paleozoic Ouachita facies, whereas other slate belt rocks are similar to upper Paleozoic rocks of the Black Warrior basin. Northeast of the slate belt, the succession is typical of that in the Black Warrior basin. Thus, the front of the Western Mississippi slate belt may coincide approximately with the limits of the thick Ouachita clastic facies.

STRUCTURE AND STRATIGRAPHY OF OTHER APPALACHIAN SALIENTS

Interpretation of structures between the Ouachita salient

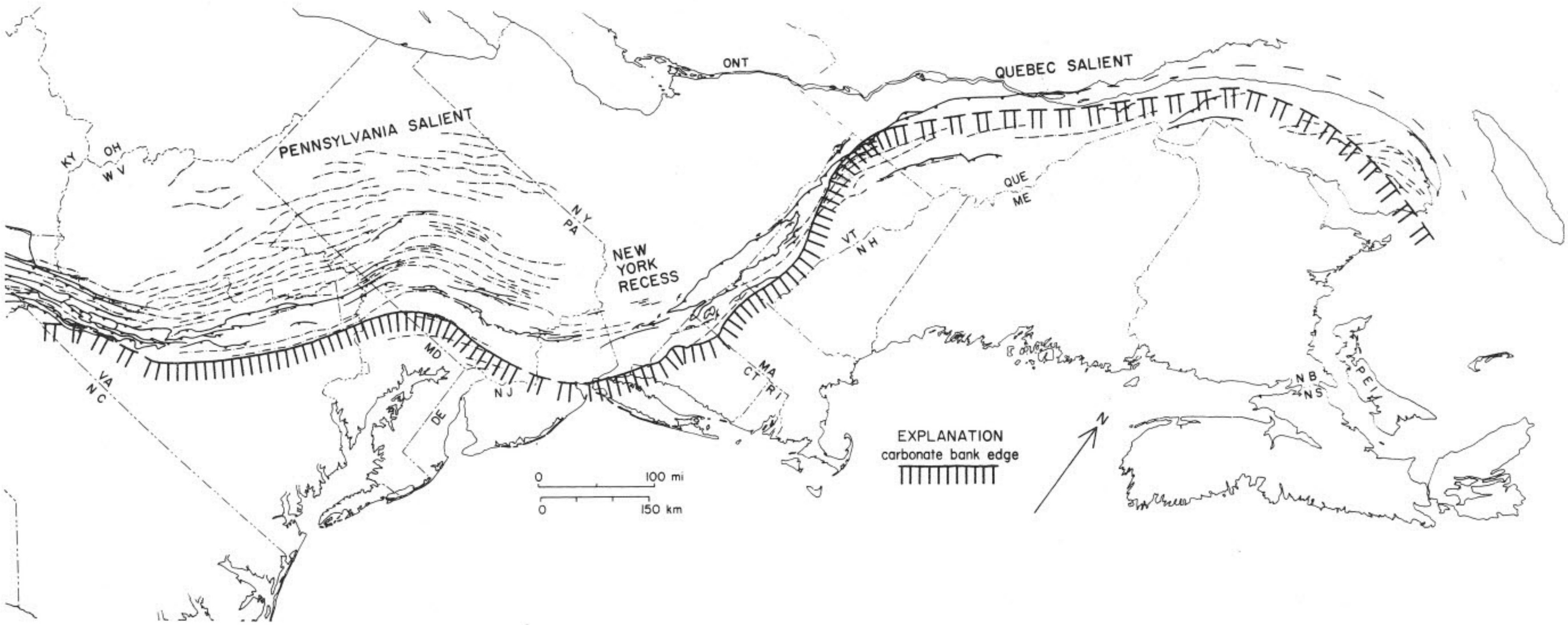


Figure 5. - Outline of Cambrian-Ordovician carbonate bank in northern Appalachians (after Rodgers, 1968).

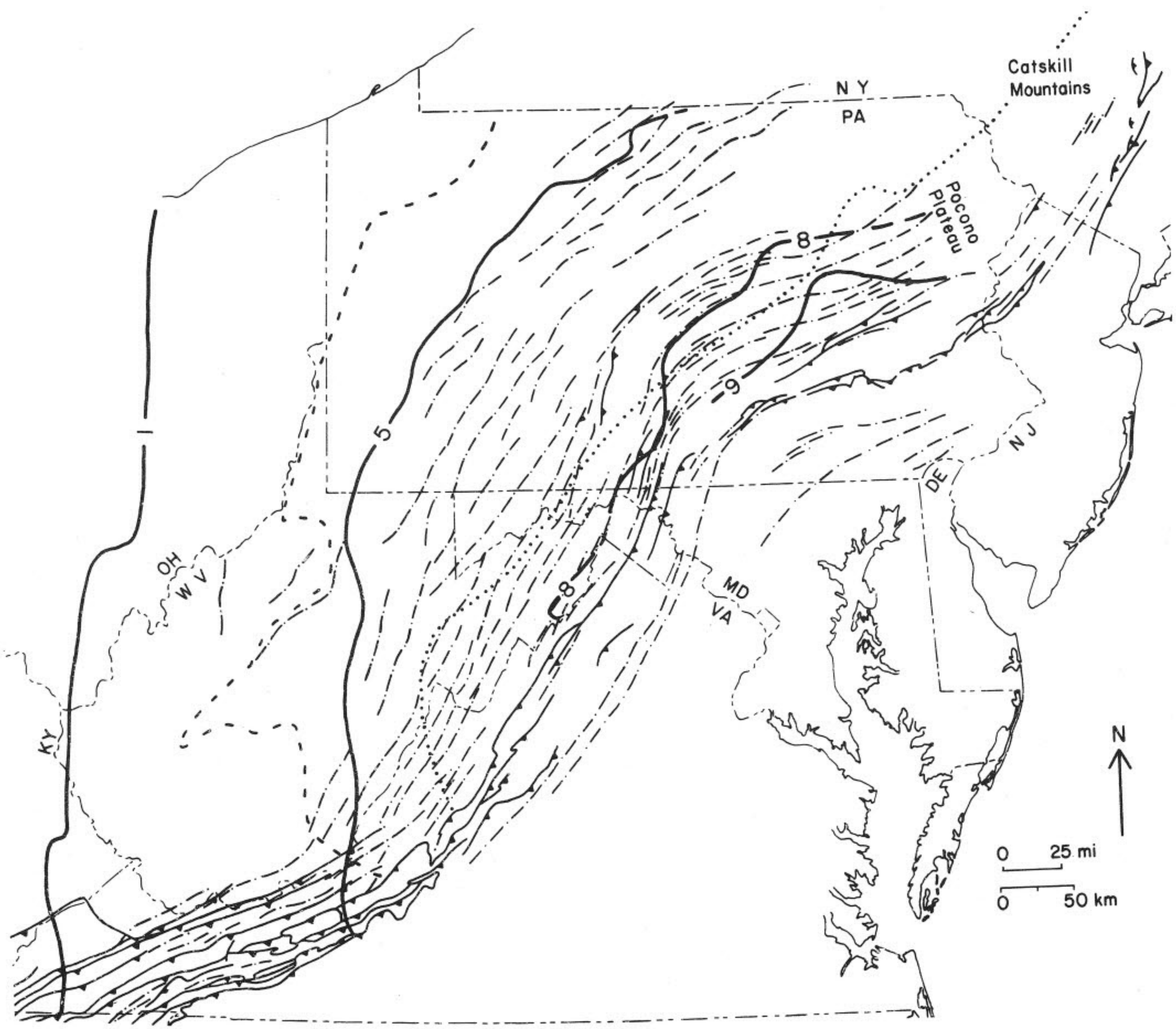


Figure 6. - Distribution of Devonian clastic wedge in Pennsylvania salient (after Oliver and others, 1967; Colton, 1970). Isopach map of Upper Devonian rocks (contour values in thousands of feet; interval varies). Explanation: short-dashed line = western limit of red beds; dotted line = western boundary of area where sandstone-shale ratio exceeds 1:4.

and Alabama recess may be guided by analogy with other salients and recesses in the Appalachians. The implied relations between Ouachita structure and stratigraphy also may be evaluated in other salients.

The structural configuration of the northern Appalachians may be described in terms of the Quebec and Pennsylvania salients and the New York recess (Fig. 5). In the northern Appalachians, the Cambrian and Ordovician include a carbonate facies on the northwest and a black shale facies on the southeast (Fig. 5). Rodgers (1968, p. 143) interprets the black shale to have been deposited in deep water east of a shallow carbonate bank; the facies boundary is interpreted to be the steep edge of the bank. In northern Vermont, the facies boundary crosses structural strike diagonally (Rodgers, 1968, p. 144). On the north in the Quebec salient, the deformed belt is within the black shale facies; but, southward toward the New York recess, the structural system crosses into the carbonate facies (Fig. 5). Similarly, a curve in the carbonate bank edge is concentric with the Pennsylvania salient (Rodgers, 1968, Fig. 10-3); however, that shale facies does not extend to the frontal structures of the salient (Fig. 5). In Quebec, the edge of the carbonate bank is obscured beneath the overthrust shale facies southeast of Logan's Line; and, outlying masses of the shale facies (for example, Taconic slate mass) within the area of the carbonate facies are interpreted to be allochthonous (Rodgers, 1968, p. 146).

The area of maximum thickness of Devonian clastic rocks of and related to the Catskill delta is shown to be within the Pennsylvania salient (Oliver and others, 1967, Fig. 9; Colton, 1970, Fig. 22). The Devonian clastic succession thins along strike from the Pennsylvania salient southwestward into the Virginia structural recess (Fig. 6). Isopach lines intersect structural strike at a large acute angle in the Virginia recess (Fig. 6), and the arcuate isopach lines are generally concentric around the center of the Pennsylvania salient. Boundaries of various facies components have been shown to be approximately parallel with isopach lines and, thus, also concentric with the structural salient (Fig. 6). At the northern limit of the salient, distributions of thickness and facies are obscured by erosion; however, there is a hint of an eastward curve of isopach lines and of northward thinning (Fig. 6). Possibly original isopach strike did not parallel structural strike in the New York recess.

COMPARISON OF OUACHITA AND NORTHERN APPALACHIAN SALIENTS

Regional structural salients coincide geographically with curves in the carbonate-black shale facies boundary and/or with areas of thick clastic wedges (Figs. 2, 4, 5, 6). Particularly in the Quebec and Ouachita salients, the curvature of the structural salient seems to coincide approximately with the facies boundary between black shales and carbonates (Figs. 2, 5). Similarly, the greatest thicknesses of clastic sediments in Pennsylvania and in the Ouachitas seem to be concentrated near the center of curvature of the structural salients. (Figs. 4, 6).

Salients are curves in the structural system convex toward the craton, and the belt of deformed rocks within salients extends farther toward the continental interior than that in the adjacent recesses. Part of that greater extent reflects a curve in structural strike. However, in the Pennsylvania salient, the deformed belt includes frontal folds that end along strike toward the recesses (Figs. 5, 6). Part of the greater extent of the Pennsylvania salient toward the craton reflects the greater width of the deformed belt in the salient. In the northeastern part of the Pennsylvania salient, the structural front trends southeastward and is not parallel with strike of individual structures (Fig. 6). Rather, that structural front is a line along which northeast-trending folds flatten along strike and end beneath undeformed rocks in the Pocono Plateau (Wood and Bergin, 1970, p. 147).

A similar interpretation of structural boundaries may be suggested for the frontal structures of the Ouachitas. In the subsurface of northwestern Mississippi, a southeast-trending structural front is defined between Ouachita structures on the southwest (Western Mississippi slate belt) and undeformed strata farther east (Fig. 1). Possibly that front is not parallel with structural strike but rather is a line marking the ends of east-striking folds that flatten eastward beneath undeformed rocks in the Black Warrior basin. The structures of the exposed Ouachitas may be analogous to part of the frontal structures of the Pennsylvania salient. And by analogy with the New York recess, structures within the Alabama recess perhaps project along strike westward into the Ouachita salient far south of the exposed Ouachita structural front. Identity of Appalachian structures may be lost where they cross westward into the lower Paleozoic black shale facies in the salient. The limits of Ouachita frontal folds and the structural front of the salient thus may coincide approximately with sedimentary facies and thickness outlines.

CONCLUSION: PROPOSED STRUCTURAL-STRATIGRAPHIC MODEL

Structural and stratigraphic relations suggest a theoretical model for evolution of the Ouachita salient and adjacent Alabama recess (Fig. 7). Lower Paleozoic facies relations may be interpreted in the framework of a carbonate bank (similar to the northern Appalachian carbonate bank of Rodgers, 1968). The shallow-water shelf extends southward to a steep bank edge, and the deep-water Ouachita black shale facies occupies a semicircular reentrant in the bank margin (Fig. 7 - panel 1). A limited amount of clastic sediment was supplied by sources within and/or south of the basin; erratic boulders were supplied from steep scarps within and around the basin.

The area of thick upper Paleozoic deep-water flysch is bordered on the west, north, and east by thinner shallow marine and deltaic sediments which occupy the area of the earlier carbonate bank (Fig. 7 - panel 2). Ouachita orogenesis on the south provided clastic sediment to the deep Ouachita trough as well as to the shallow marine shelf on

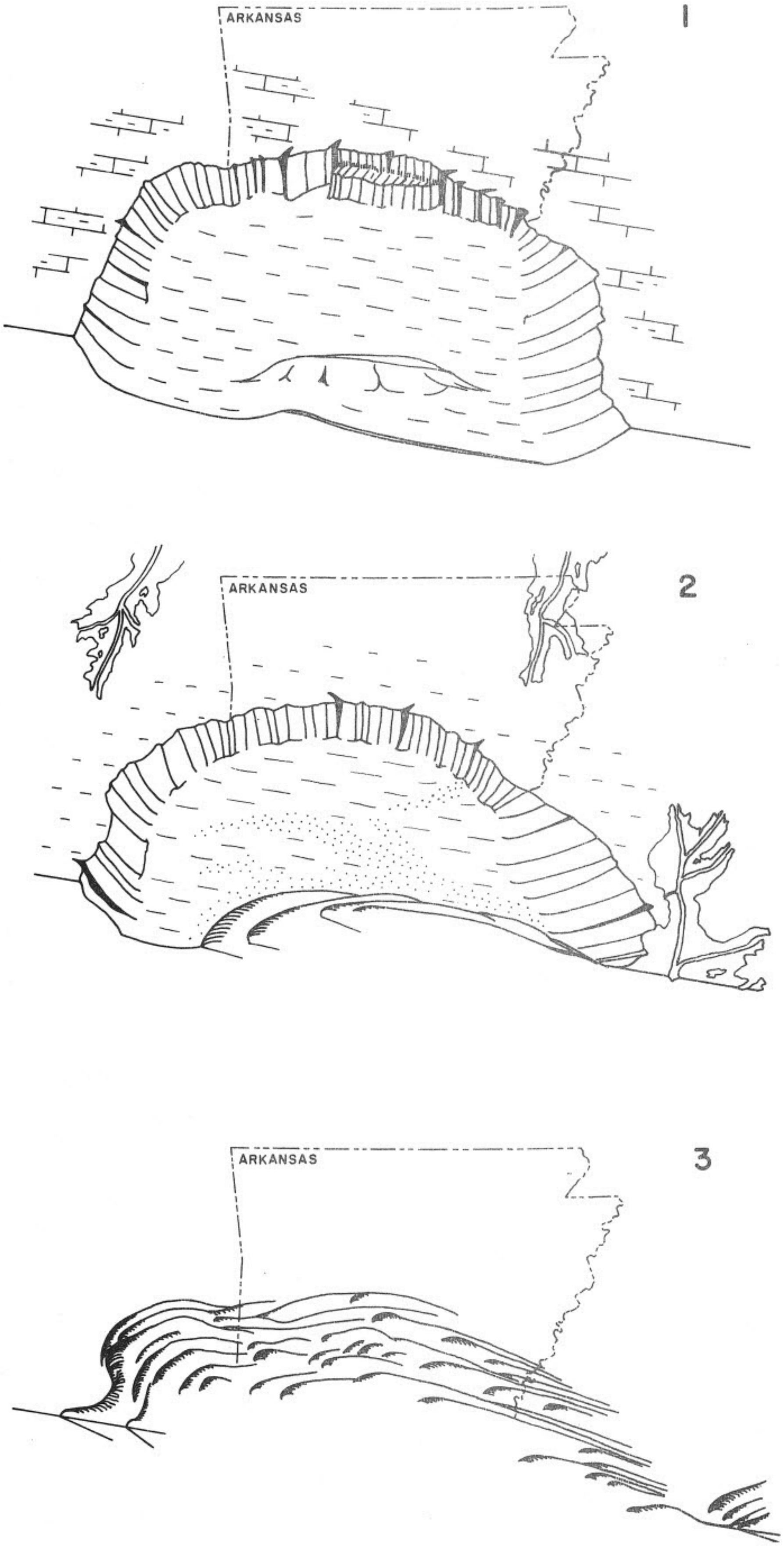


Figure 7. Sequential diagram of Ouachita-Appalachian structural-stratigraphic model.
Panel 1 - Lower Paleozoic carbonate bank and deep basin.
Panel 2 - Upper Paleozoic shelf and flysch basin.
Panel 3 - Structural configuration of the Ouachita Salient.

the east in the Black Warrior basin. Scarps within or marginal to the basin supplied erratic boulders. Other clastic sediments were supplied to parts of the shelf and the northern part of the Ouachita trough from the craton.

The structural configuration of the Ouachita system may be interpreted within the stratigraphic framework. The thrust faults and folds of the Ouachita Mountains have formed within the lower Paleozoic black shale facies and the thick upper Paleozoic clastic facies (Fig. 7 - panel 3). Possibly the frontal structures flatten toward the east into the carbonate facies and the thinner upper Paleozoic succession of the Black Warrior basin, and only the interior structures of the salient extend far across the facies boundaries into the Alabama recess.

Distribution of the major sedimentary facies was controlled by the shape and position of the scalloped edge of the shallow shelf (which possibly reflects the approximate shape of the margin of continental crust as proposed by Rodgers, 1968, p. 148). The ultimate structural configuration of the Ouachita salient appears to be related to the distribution of clastic facies and of maximum sedimentary thicknesses. Possibly the greater thickness of incompetent rocks permitted deformation to expand farther toward the craton in the salient, and tectonic transport apparently is greatest in the salient. Rodgers (1968, p. 144) concludes that the contrast in competence between the carbonate and black shale sequences served to localize thrusting along the facies boundary. King (in Flawn and others, 1961, p. 184) notes that Mississippian-Pennsylvanian clastic units have maximum volumes in the Ouachita and Marathon salients. The association of the structural salient with the black shale facies and thick clastic sequence suggests a genetic relationship between these major regional structural and stratigraphic elements.

ACKNOWLEDGEMENTS

Sincere appreciation is expressed to C. G. Stone and B. R. Haley who provided unpublished field data and to W. M. Caplan who provided subsurface data. The manuscript has been reviewed by L. F. Boland, B. R. Haley, P. B. King, D. E. Ogren, John Rodgers, A. C. Staheli, and C. G. Stone.

REFERENCES CITED

Berry, R. M., and Trumbly, W. D., 1968, Wilburton Gas Field, Arkoma Basin, Oklahoma, *in* Cline, L. M., ed., Geology of the Western Arkoma Basin and Ouachita Mountains, Oklahoma: Oklahoma City Geol. Soc. Guidebook, p. 86-103.

Bokman, J., 1953, Lithology and Petrology of the Stanley and Jackfork Formations: Jour. Geology, v. 61, p. 152-170.

Branson, C. C., 1962, Pennsylvanian System of the Mid-Continent, *in* Branson, C. C., ed., Pennsylvanian System in the United States: Am. Assoc. Petroleum Geologists, p. 431-460.

Briggs, G., and Cline, L. M., 1967, Paleocurrents and Source Areas of Late Paleozoic Sediments of the Ouachita Mountains, Southeastern Oklahoma: Jour. Sed. Petrology, v. 37, p. 985-1000.

Buchanan, R. S., and Johnson, F. K., 1968, Bonanza Gas Field -- a Model for Arkoma Basin Growth Faulting, *in* Cline, L. M., ed., Geology of the Western Arkoma Basin and Ouachita Mountains, Oklahoma: Oklahoma City Geol. Soc. Guidebook, p. 75-85.

Butts, C., 1926, The Paleozoic Rocks, *in* Geology of Alabama: Alabama Geol. Survey Spec. Rept. 14, p. 41-230.

Caplan, W. M., 1957, Subsurface Geology of Northwestern Arkansas: Arkansas Geol. Comm. Inf. Circ. 19, 14 p.

Caplan, W. M., 1964, In Eastern Arkansas Exploration is Shifting to Paleozoic Prospects: World Oil, v. 158, no. 4, p. 72-84.

Carrington, T. J., 1973, Metamorphosed Paleozoic Sedimentary Rocks in Chilton, Shelby and Talladega Counties, Alabama, *in* Carrington, T. J., ed., Talladega Metamorphic Front: Alabama Geol. Soc. Guidebook, 11th Ann. Field Trip, p. 22-38.

Chamberlain, C. K., 1971, Bathymetry and Paleoecology of Ouachita Geosyncline of Southeastern Oklahoma as Determined from Trace Fossils: Am. Assoc. Petroleum Geologists Bull., v. 55, p. 34-50.

Cline, L. M., 1960, Stratigraphy of the Late Paleozoic Rocks of the Ouachita Mountains, Oklahoma: Oklahoma Geol. Survey Bull. 85, 113 p.

Cline, L. M., 1966, Late Paleozoic Rocks of Ouachita Mountains, a Flysch Facies: Kansas Geol. Soc. Guidebook, 29th Field Conf., p. 91-111.

Cline, L. M., 1970, Sedimentary Features of Late Paleozoic Flysch, Ouachita Mountains, Oklahoma: Geol. Assoc. Canada, Spec. Paper 7, p. 85-101.

Colton, G. W., 1970, The Appalachian Basin -- Its Depositional Sequences and Their Geologic Relationships, *in* Fisher, G. W., Pettijohn, F. J., Reed, J. C., Jr., and Weaver, K. N., eds., Studies of Appalachian Geology: Central and Southern: New York, Interscience, p. 5-47.

Craig, W. W., 1973, Upper Ordovician Stratigraphy of Northern Arkansas (abs.): Geol. Soc. America Abs. with Programs, v. 5, p. 253.

Drahovzal, J. A., 1967, The Biostratigraphy of Mississippian Rocks in the Tennessee Valley, *in* Smith, W. E., ed., A Field Guide to Mississippian Sediments in Northern Alabama and South-Central Tennessee: Alabama Geol. Soc. Guidebook, 5th Ann. Field Trip, p. 10-24.

Engel, A. E. J., 1952, Quartz Crystal Deposits of Western Arkansas: U. S. Geol. Survey Bull. 973-E, p. 173-260.

Flawn, P. T., Goldstein, A., Jr., King, P. B., and Weaver, C. E., 1961, The Ouachita System: Univ. Texas Pub. No. 6120, 401 p.

Frezon, S. E., 1962, Correlation of Paleozoic Rocks from Coal County, Oklahoma, to Sebastian County, Arkansas: Oklahoma Geol. Survey Circ. 58, 53 p.

Frezon, S. E., and Glick, E. E., 1959, Pre-Atoka Rocks of Northern Arkansas: U. S. Geol. Survey Prof. Paper 314-H, p. 171-189.

Glick, E. E., 1973, Paleotectonic History of Carboniferous Rocks of Arkansas (abs.): Geol. Soc. America Abs. with Programs, v. 5, p. 258-259.

Goldstein, A., Jr., and Hendricks, T. A., 1953, Siliceous Sediments of Ouachita Facies in Oklahoma: Geol. Soc. America Bull., v. 64, p. 421-442.

Goldstein, A., Jr., and Hendricks, T. A., 1962, Late Mississippian and Pennsylvanian Sediments of Ouachita Facies, Oklahoma, Texas, and Arkansas, *in* Branson, C. C., ed., Pennsylvanian System in the United States: Am. Assoc. Petroleum Geologists, p. 385-430.

Gordon, M., Jr., and Stone, C. G., 1973, Correlation of Carboniferous Rocks of the Ouachita Geosyncline with Those of the Adjacent Shelf (abs.): Geol. Soc. America Abs. with Programs, v. 5, p. 259.

Haley, B. R., and Frezon, S. E., 1965, Geologic Formations Penetrated by the Shell Oil Company No.1 Western Coal and Mining Co. Well on the Backbone Anticline, Sebastian County, Arkansas: Arkansas Geol. Comm. Inf. Circ. 20-D, 17 p.

Haley, B. R., and Hendricks, T. A., 1968, Geology of the Greenwood Quadrangle, Arkansas-Oklahoma: Arkansas Geol. Comm. Inf. Circ. 20-F, 15 p.

Ham, W. E.,1959, Correlation of Pre-Stanley Strata in the Arbuckle-Ouachita Mountain Regions, *in* The Geology of the Ouachita Mountains, a Symposium: Dallas Geol. Soc. and Ardmore Geol. Soc., p. 71-86.

Hammes, R. R., 1965, Ouachita Overthrusting -- Stratigraphic Appraisal: Am. Assoc. Petroleum Geologists Bull., v. 49, p. 1666-1679.

Hass, W. H., 1951, Age of Arkansas Novaculite: Am. Assoc. Petroleum Geologists Bull., v. 35, p. 2526-2541.

Hill, J. G., 1966, Petrology and Provenance of Sandstones of the Stanley Group (Mississippian), Southern Ouachita Mountains, Oklahoma: Kansas Geol. Soc. Guidebook, 29th Field Conf., p. 112-124.

Huffman, G. G., and others, 1958, Geology of the South and West Flanks of the Ozark Uplift, Northeastern Oklahoma: Oklahoma Geol. Survey Bull. 77, 281 p.

Johnson, K. E., 1966, A Depositional Interpretation of the Stanley Group of the Ouachita Mountains, Oklahoma: Kansas Geol. Soc. Guidebook, 29th Field Conf., p. 140-163.

King, P. B., 1950, Tectonic Framework of Southeastern United States: Am. Assoc. Petroleum Geologists Bull., v. 34, p. 635-671.

Klein, G. deV., 1966, Dispersal and Petrology of Sandstones of Stanley-Jackfork Boundary, Ouachita Fold Belt, Arkansas and Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 50, p. 308-326.

Koinm, D. N., and Dickey, P. A., 1967, Growth Faulting in McAlester Basin of Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 51, p. 710-718.

Laudon, R. B., 1959, Some Age Relationships of Chesterian and Morrowan Rocks in Eastern Oklahoma, *in* The Geology of the Ouachita Mountains, a Symposium: Dallas Geol. Soc. and Ardmore Geol. Soc., p. 122-129.

Maher, J. C., and Lantz, R. J., 1953, Correlation of Pre-Atoka Rocks in the Arkansas Valley, Arkansas: U. S. Geol. Survey Oil and Gas Inv. Chart OC 51.

Milhous, H. C., 1959, Well Logs in Tennessee: Tennessee Div. Geol. Bull. 62, 606 p.

Miser, H. D., 1921, Llanoria, the Paleozoic Land Area in Louisiana and Eastern Texas: Am. Jour. Sci., v. 202, p. 61-89.

Miser, H. D., 1943, Quartz Veins in the Ouachita Mountains of Arkansas and Oklahoma (Their Relations to Structure, Metamorphism, and Metalliferous Deposits): Econ. Geol., v. 38, p. 91-118.

Miser, H. D., 1959, Structure and Vein Quartz of the Ouachita Mountains of Oklahoma and Arkansas, *in* The Geology of the Ouachita Mountains, a Symposium: Dallas Geol. Soc. and Ardmore Geol. Soc., p. 30-43.

Miser, H. D., and Purdue, A. H., 1929, Geology of the De Queen and Caddo Gap Quadrangles, Arkansas: U. S. Geol. Survey Bull. 808, 195 p.

Morris, R. C., 1971, Stratigraphy and Sedimentology of Jackfork Group, Arkansas: Am. Assoc. Petroleum Geologists Bull., v. 55, p. 387-402.

Neathery, T. L., 1973, Observations on the Lithologic Relationships Within the Talladega Group, Alabama, *in* Carrington, T. J., ed., Talladega Metamorphic Front: Alabama Geol. Soc. Guidebook, 11th Ann. Field Trip, p. 51-55.

Ogren, D. E., 1968, Stratigraphy of Upper Mississippian Rocks of Northern Arkansas: Am. Assoc. Petroleum Geologists Bull., v. 52, p. 282-294.

Oliver, W. A., Jr., deWitt, W., Jr., Dennison, J. M., Hoskins, D. M., and Huddle, J. W., 1967, Devonian of the Appalachian Basin, United States, *in* Oswald, D. H., ed., International Symposium on the Devonian System, v. 1: Alberta Soc. Petroleum Geologists, p. 1001-1040.

Park, D. E., Jr., and Croneis, C., 1969, Origin of Caballos and Arkansas Novaculite Formations: Am. Assoc. Petroleum Geologists Bull., v. 53, p. 94-111.

Purdue, A. H., and Miser, H. D., 1923, Description of the Hot Springs District: U. S. Geol. Survey Geol. Atlas Folio 215, 12 p.

Reinemund, J. A., and Danilchik, W., 1957, Preliminary Geologic Map of the Waldron Quadrangle and Adjacent Areas, Scott County, Arkansas: U. S. Geol. Survey Oil and Gas Inv. Map OM 192.

Repetski, J. E., and Ethington, R. L., 1973, Conodonts from Graptolite Facies in the Ouachita Mountains, Arkansas and Oklahoma (abs.): Geol. Soc. America Abs. with Programs, v. 5, p. 277.

Rodgers, J., 1968, The Eastern Edge of the North American Continent During the Cambrian and Early Ordovician, *in* Zen, E-an, White, W. S., Hadley, J. B., and Thompson, J. B., Jr., eds., Studies of Appalachian Geology: Northern and Maritime: New York, Interscience, p. 141-149.

Scull, B. J., Glover, G. D., and Planalp, R., 1959, The Atoka of the McAlester Basin--Arkansas Valley Region, *in* The Geology of the Ouachita Mountains, a Symposium: Dallas Geol. Soc. and Ardmore Geol. Soc., p. 166-174.

Sellars, R. T., Jr., 1967, The Siluro-Devonian Rocks of the Ouachita Mountains: Tulsa Geol. Soc. Digest, v. 35, p. 231-241.

Shideler, G. L., 1970, Provenance of Johns Valley Boulders in Late Paleozoic Ouachita Facies, Southeastern Oklahoma and Southwestern Arkansas: Am. Assoc. Petroleum Geologists Bull., v. 54, p. 789-806.

Sterling, P. J., Stone, C. G., and Holbrook, D. F., 1966, General Geology of Eastern Ouachita Mountains, Arkansas: Kansas Geol. Soc. Guidebook, 29th Field Conf., p. 177-194.

Stone, C. G., 1966, General Geology of the Eastern Frontal Ouachita Mountains and Southeastern Arkansas Valley, Arkansas: Kansas Geol. Soc. Guidebook, 29th Field Conf., p. 195-221.

Stone, C. G., Haley, B. R., and Viele, G. W., 1973, A Guidebook to the Geology of the Ouachita Mountains, Arkansas: Arkansas Geol. Comm., 113 p.

Swann, D. H., 1964, Late Mississippian Rhythmic Sediments of Mississippi Valley: Am. Assoc. Petroleum Geologists Bull., v. 48, p. 637-658.

Thomas, W. A., 1972a, Regional Paleozoic Stratigraphy in Mississippi Between Ouachita and Appalachian Mountains: Am. Assoc. Petroleum Geologists Bull., v. 56, p. 81-106.

Thomas, W. A., 1972b, Mississippian Stratigraphy of Alabama: Alabama Geol. Survey Monograph 12, 121 p.

Thomas, W. A., 1973, Southwestern Appalachian Structural System Beneath the Gulf Coastal Plain: Am. Jour. Sci. Cooper Vol., v. 273-A, p. 372-390.

Thomas, W. A., and Drahovzal. J. A., 1973, Regional Paleozoic Stratigraphy of Alabama, *in* Carrington, T. J., ed., Talladega Metamorphic Front: Alabama Geol. Soc. Guidebook, 11th Ann. Field Trip, p. 66-91.

Vernon, R. C., 1971, Possible Future Petroleum Potential of Pre-Jurassic, Western Gulf Basin: Am. Assoc. Petroleum Geologists Memoir 15, p. 954-984.

Viele, G. W., 1973, Structure and Tectonic History of the Ouachita Mountains, Arkansas, *in* DeJong, K. A., and Scholten, R., eds., Gravity and Tectonics: New York, John Wiley and Sons, Inc., p. 361-377.

Visher, G. S., Saitta B., S., and Phares, R. S., 1971, Pennsylvanian Delta Patterns and Petroleum Occurrences in Eastern Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 55, p. 1206-1230.

Walthall, B. H., 1967, Stratigraphy and Structure, Part of Athens Plateau, Southern Ouachitas, Arkansas: Am. Assoc. Petroleum Geologists Bull., v. 51, p. 504-528.

Wilson, C. W., Jr., 1949, Pre-Chattanooga Stratigraphy in Central Tennessee: Tennessee Div. Geol. Bull. 56, 407 p.

Wise, O. A., and Caplan, W. M., 1967, Silurian and Devonian Rocks of Northern Arkansas: Tulsa Geol. Soc. Digest, v. 35, p. 242-252.

Wood, G. H., Jr., and Bergin, M. J., 1970, Structural Controls of the Anthracite Region, Pennsylvania, *in* Fisher, G. W., Pettijohn, F. J., Reed, J. C., Jr., and Weaver, K. N., eds., Studies of Appalachian Geology: Central and Southern: New York, Interscience, p. 147-160.

Zachry, D. L., and Haley, B. R., 1973, Contact Between the Bloyd Shale and the Atoka Formation in Northern Arkansas (abs.): Geol. Soc. America Abs. with Programs, v. 5, p. 289.