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THE GEOLOGY OF THE ARDMORE BASIN IN THE LAKE MURRAY STATE PARK AREA, OKLAHOMA

AN INTRODUCTION AND FIELD-TRIP GUIDE

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INTRODUCTION

Lake Murray State Park is located in a geological province known as the Ardmore Basin (Fig. 1). The rocks that make up the Ardmore Basin are exposed at the surface in a roughly triangular area extending from Lake Murray on the south, to the small town of Woodford on the northwest, and to the small town of Russell on the northeast. The "true" Ardmore Basin is much larger, but the rocks that make up the basin are buried by much younger rocks; the only way geologists know the true outline of the basin is by studying the formations that have been drilled by oil and gas wells. The Ardmore Basin that geologists have recognized is nearly 100 miles long and 20 miles wide. It is elongated in a west-northwest - east-southeast direction and extends from Duncan to Durant (Fig. 1).

GEOLOGIC PROVINCES OF OKLAHOMA
Compiled by
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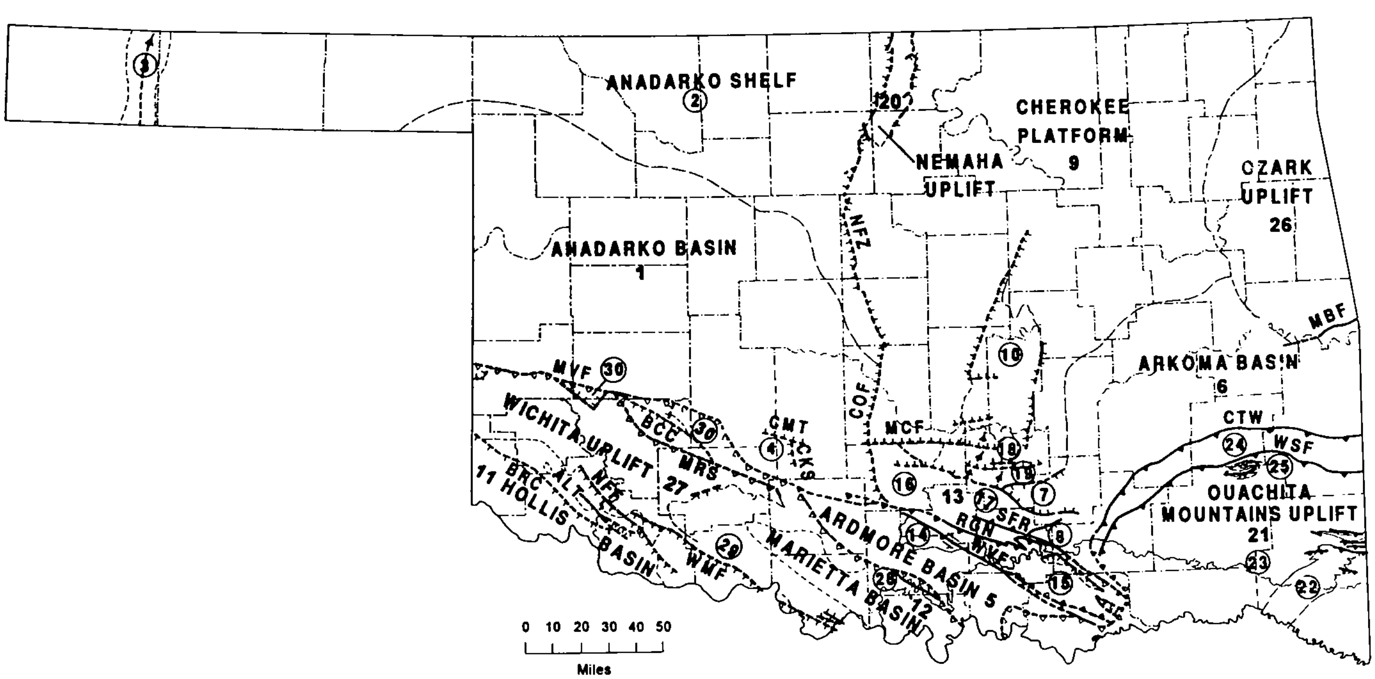

Figure 1. Geologic provinces of Oklahoma. The Ardmore Basin is in south-central Oklahoma, mostly in Marshall, Carter, and eastern Stephens Counties.

At the outset, it is important to understand what geologists mean when they use the term "basin". Most people think of a basin in terms of a topographically low area - an area surrounded by uplands or mountains. The Basin and Range province of Nevada, in which large, elongate, and seemingly flat areas are bordered by mountain ranges, is a good example of an area characterized by many *topographic* basins. A *geologic* basin, however, is different. A geologic basin is an area in which a greater thickness of sediments has accumulated over some period of geologic time compared to surrounding areas. In order for an anomalously thick pile of sediments to accumulate, a geologic basin has to subside relative to surrounding areas. Typically, these kinds of basins are bordered on at least one side by mountain ranges or uplands and the sediment eroded off the uplands accumulates in the adjacent basin.

It may be obvious that there must be some overlap between topographic and geologic basins. Geologic basins must once have been topographic basins. For our study of the Ardmore Basin, however, it is important to recognize that the area is no longer low, therefore, it is not currently a topographic basin, but that it once was and that a tremendous volume of sediment accumulated there. The fact that large volumes of sediment accumulate in geologic basins is of critical importance to geologists exploring for oil and gas because 99.9% of the oil and gas in the world was generated from and accumulated in sedimentary rocks. Thus, geologic basins are especially interesting to petroleum geologists. The Ardmore Basin is no exception, and many of Oklahoma's large oil and gas fields (e.g., Sho-Vel-Tum) are found there.

The Ardmore Basin is bounded on the northeast by the Arbuckle anticline (Arbuckle Mountains)(labelled 14 on Fig. 1), the Washita Valley fault (labelled WVF), and the Tishomingo-Belton uplift (labelled 15). The basin is bounded on the southwest by the Criner Hills uplift (labelled 28) and the Waurika-Muenster uplift (labelled 29). The basin is terminated on its southeast end by the buried Ouachita Mountains. To the northwest, the Ardmore Basin passes into the Anadarko Basin (Fig. 1), one of the deepest sedimentary basins in the world. Lake Murray is located in that part of the Ardmore Basin adjacent to the Criner Hills and much of our study of the basin will focus on the relationship between the subsiding basin and the Criner Hills / Waurika-Muenster uplift.

EARLY GEOLOGIC HISTORY OF THE ARDMORE BASIN

The Ardmore Basin, together with the Marietta Basin to the south, the Anadarko Basin to the northwest, and the adjacent uplifts (Fig. 1), have a long and complicated geologic history. The most impressive aspects of this history are (1) the extraordinary thickness of late Mississippian and Pennsylvanian (about 340 to 290 million years ago) sediments that accumulated in the basins and (2) the complexly folded and faulted nature of the rocks compared to surrounding areas. But the unique geology of the area had its underpinnings in a much older geologic period.

The oldest exposed rocks in Oklahoma are the Tishomingo and Troy Granites; these crop out on the surface in the Tishomingo-Belton uplift north, northwest, and northeast of the town of Tishomingo. These granites are about 1.35 to 1.4 billion years old and form much of what geologists call the "basement" of southern Oklahoma. Beginning about 550 million years ago and lasting for about 25 million years (during the Cambrian period of geologic time), the granite basement of the North American continent began to extend and a series of northwest-trending faults formed in the broad zone across southern and southwestern Oklahoma and extending to near Amarillo. With continued extension, a rift (or opening) formed and a series of volcanic rocks erupted and filled the rift (Fig. 2A). (One of these volcanic formations, the Colbert Rhyolite, is present beneath the radio towers just west of I-35 at the top of the Arbuckles.) At the same time as the volcanic rocks were being erupted, magma intruded the crust to shallow levels and cooled. (The granites of the Wichita Mountains and Quartz Mountain are examples.) This intense igneous activity was concentrated in southern Oklahoma because the "basement" of the continental crust had been weakened by the faulting associated with the rifting.

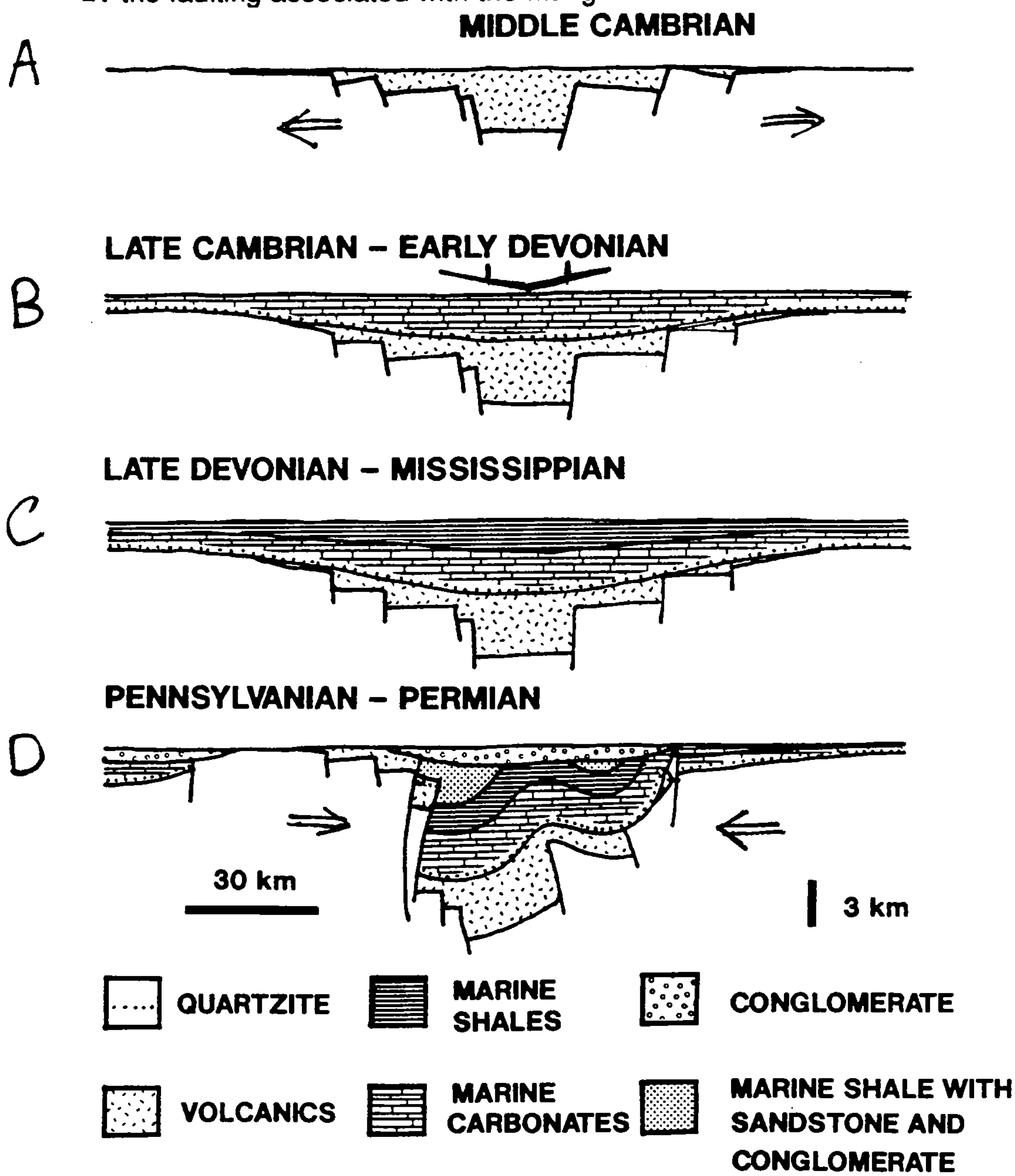

Figure 2. Structural development of the Southern Oklahoma aulacogen. A. Middle Cambrian extension, faulting (rifting), and filling of rift with volcanic rocks. B. Late Cambrian to Early Devonian subsidence and accumulation of mostly marine limestone and lesser sandstone and shale. C. Continued subsidence in Late Devonian to Late Mississippian and deposition of mostly marine shale and minor sandstone and limestone. D. Folding and faulting during Wichita and Arbuckle orogenies. Note the angular unconformity at the base of the conglomerate that formed as a result of the Arbuckle orogeny (see text for discussion).

This zone of weakness in the crust is called the "Southern Oklahoma aulacogen" (Fig. 3). In the terms of plate tectonics, an aulacogen is a "failed arm", or a place where continents tried to separate (like South America did from Africa, and where east Africa is currently splitting), but failed. For our purposes, this zone of weakness was the site of future tectonic activity. But more about that later.

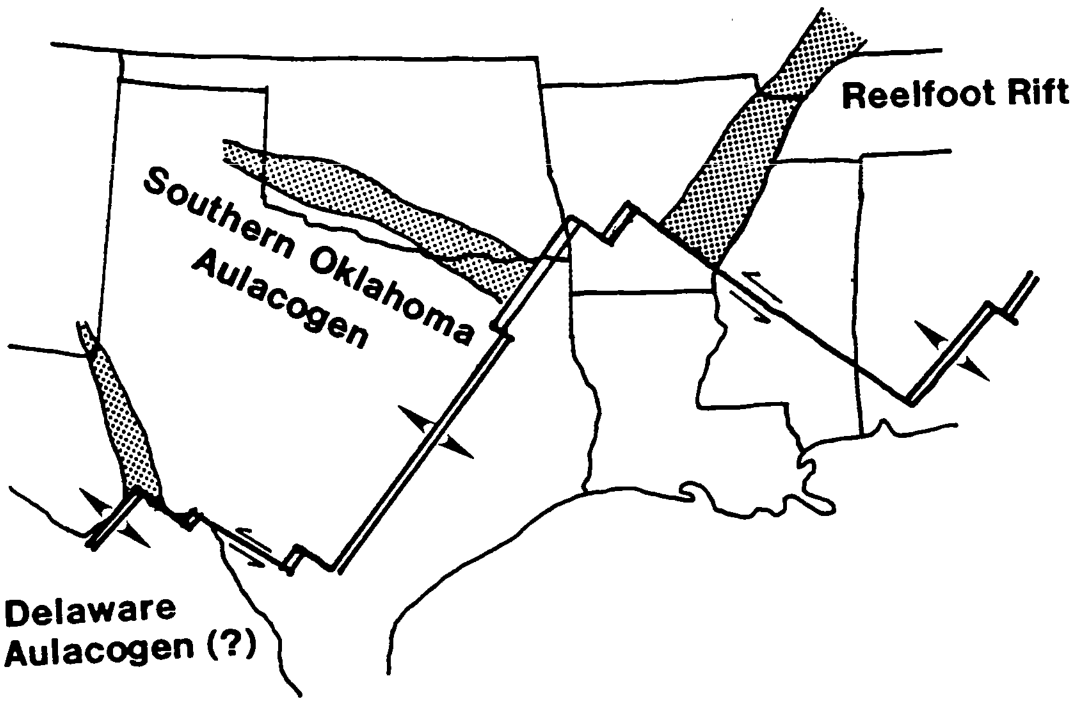

Figure 3. One plate tectonic model of southern North America in the Cambrian. The divergent arrows show places where an old North American plate was separating from a plate to the south. Opposing arrows show where the two plates slid by each other. The stippled areas show where the North American plate tried to separate, but failed.

Beginning in the late Cambrian (between about 525 and 500 million years ago) and lasting until the late Mississippian (about 340 million years ago), southern Oklahoma was the site of a broad, epicontinental sea that extended across most of the southern midcontinent. Shallow-marine limestone and lesser amounts of sandstone and shale were deposited throughout the area (Fig. 2B, C). These late Cambrian through late Mississippian formations are relatively thin throughout Oklahoma; in the Southern Oklahoma aulacogen, however, they are considerably thicker. The late Cambrian to early Devonian (525 to 390 million years ago) sediments deposited in the aulacogen may have been as thick as 45,000 ft; this contrasts with the approximately 10,000 ft of equivalent strata deposited on the adjacent cratonic shelf in southern Oklahoma and Texas (Fig. 2B). Many geologists believe that the reason unusually thick accumulations of sediments were deposited in the Southern Oklahoma aulacogen is that the crust there cooled, contracted, and subsided after the Cambrian igneous episode ceased.

In summary, the site of the future Ardmore Basin, which is part of a larger feature known as the Southern Oklahoma aulacogen, was an area of weakened crust. It suffered extension, faulting, and rifting during the Cambrian period of the Earth's history, as well as volcanism and intrusion of magma to shallow levels. The subsequent cooling of the igneous rocks caused the area of the aulacogen to subside; as a result, thicker deposits of sedimentary rocks, mostly limestone, and shale were deposited in it relative to surrounding areas.

Beginning as early as the middle Mississippian (about 350 million years ago), and certainly by the beginning of the Pennsylvanian (330 million years ago), southern Oklahoma began to experience a major period of orogeny, or mountain building. This was particularly true in southeastern Oklahoma where the Ouachita Mountains provide evidence for the orogeny. However, effects of the orogeny were more widespread and extended to southern and southwestern Oklahoma; perhaps it is not surprising that the area that had previously experienced an unusual degree of geologic activity, the Southern Oklahoma aulacogen, would be affected the most by the late Mississippian - Pennsylvanian tectonic activity (Fig. 2D).

The evidence for the orogeny is contained in the rocks deposited in the Ardmore Basin. It is only in the basin adjacent to the uplifted mountains where the evidence is preserved. The most direct evidence - the mountains themselves - are largely eroded away.

THE STRATIGRAPHY OF THE ARDMORE BASIN

Not all the rocks that tell the story of the Ardmore Basin and adjoining mountains are exposed in Lake Murray State Park. The geology of most of the park consists of Pennsylvanian rocks tilted steeply to the northeast. As a result of this tilt, the rocks get younger as one goes to the northeast. The oldest rock unit exposed in the park is the Bostwick Conglomerate (Fig. 4). It is exposed along the road on the ridge about 1.5 mi north of the intersection with the road to Tucker Tower. The upper part of the Dornick Hills Group is exposed from across the water from Buzzard Roost campground to the Tucker Tower road intersection. Most of the west and south side of Lake Murray State Park is underlain by the Deese Group. The overlying Hoxbar Group is exposed in the very northern part of the park and all but the southern part of the finger of land that separates the East and West Anadarche Arms of the lake. The Vanoss Conglomerate covers a small area in the northeastern part of the park and the flat-lying Cretaceous Antlers Sandstone caps the tops of the low hills in the eastern part of the park.

EVIDENCE FOR THE WICHITA OROGENY

The first evidence for tectonic activity in the Ardmore Basin area is in the latest Mississippian to earliest Pennsylvanian Springer Formation (Fig. 4). The Springer Formation consists mostly of shale with three named sandstone members: from oldest to youngest, these are the Rod Club, Overbrook, and Lake Ardmore. The Springer Formation accumulated in a northwest- southeast-trending marine basin, roughly parallel to the Southern Oklahoma aulacogen. Most of the sediment appears to have entered the basin at its northwest end because the sandstones in the formation are thicker and coarser there compared to the same sandstones to the southeast. The sediments were deposited on deltas to the northwest; near Ardmore and Lake Murray, the dominant environment of deposition is moderately deep marine and the sandstones appear to represent a series of marine bars.

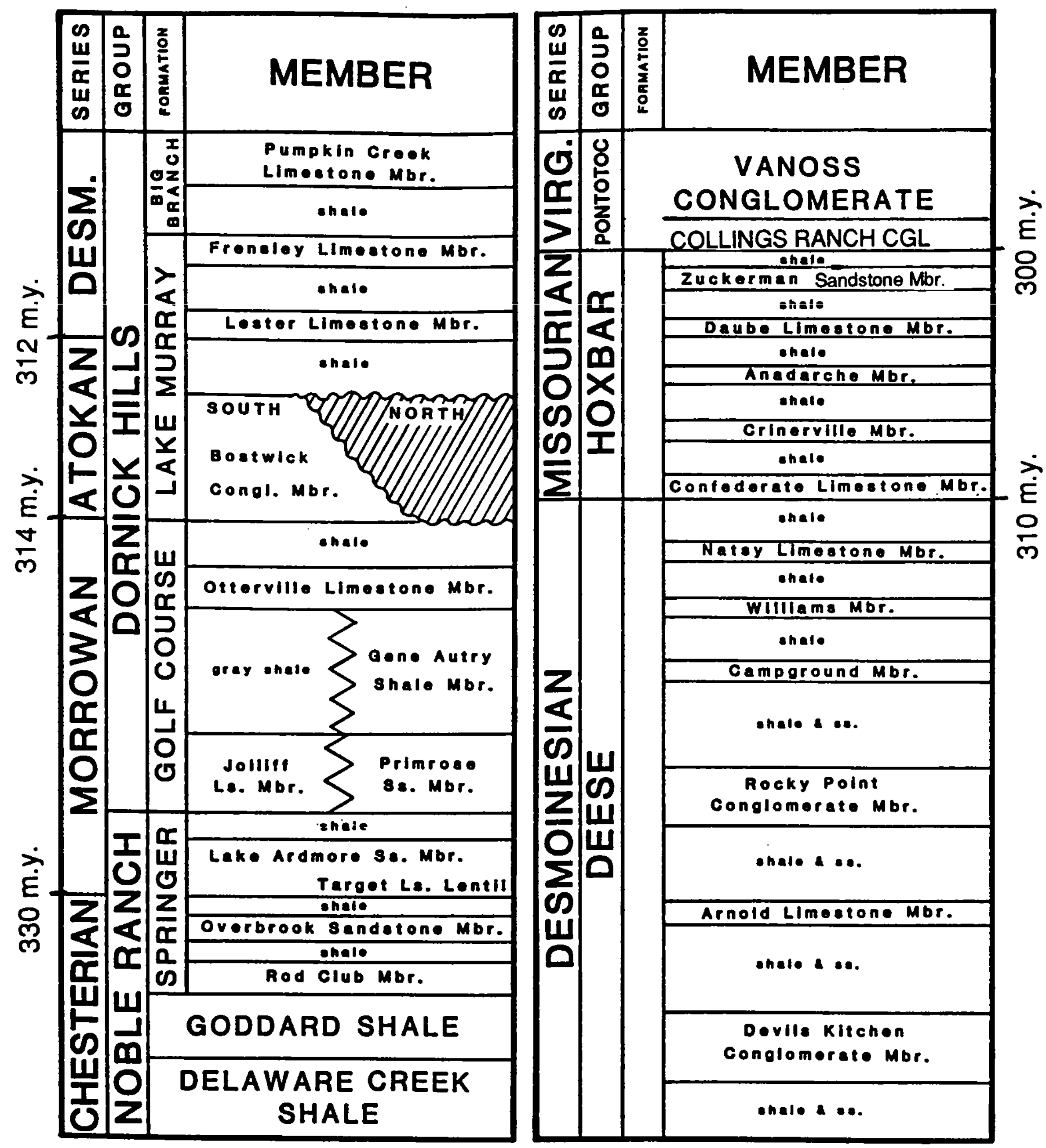

Figure 4. Stratigraphic column for the Ardmore Basin.

The first evidence for tectonic uplift is in the Lake Ardmore Sandstone Member of the Springer Formation. South of the town of Ardmore, the member contains limestone-pebble conglomerate beds. The limestone pebbles, some of which are Ordovician in age, must have been eroded from the adjacent Criner Hills area; this indicates that the Criner Hills must have been uplifted along a fault or fault zone at least 5,000 ft in order to be eroded down to the level of the Ordovician.

The next younger formation, named the Golf Course Formation (Fig. 4), contains abundant evidence for continued uplift of the Criner Hills and subsidence of the Ardmore Basin. The lowest named member of the Golf Course is the Jolliff Limestone Member which is only present along the southwestern margin of the basin. There it is composed partly of chert- and limestone-cobble conglomerate; the coarse sediments indicate proximity to a substantial highland - in this case, the area of the Criner Hills. Geologists know this was the source terrane for the Jolliff conglomerates because the rock types seen in the cobbles are identical to those exposed in the Criner Hills. Also, the conglomerate beds are concentrated near the Criner Hills; to the northeast across the Ardmore Basin, the Jolliff is replaced by the Primrose Sandstone Member. The Primrose is dominantly a fine-grained sandstone that was probably derived from distant sources to the north.

The Otterville Limestone Member is the youngest named member of the Golf Course Formation. It is dominantly a fossiliferous limestone. Careful study of just this member has enabled geologists to show that it was deposited as folds were developing in the previously deposited Ardmore Basin sediments. Near the Criner Hills, the Otterville contains conglomerate beds, as do the shale intervals between the Jolliff and Otterville Members and the Otterville and Bostwick Members.

Clearly, during deposition of the Golf Course Formation, the Criner Hills were being actively uplifted along the southwest margin of the Ardmore Basin and the sedimentary rocks in the interior of the basin were being folded (Fig. 5). This tectonic activity, which is first marked by the conglomerate beds in the Lake Ardmore Member, is known as the **Wichita orogeny**.

The base of the next younger formation, the Lake Murray Formation, is marked by the Bostwick Conglomerate Member (Fig. 4). (We will visit the Bostwick at Stop 3 on the field trip.) The Bostwick near Lake Murray consists mostly of a pebble conglomerate; the pebbles are mostly chert and limestone identical to the rocks in the Cambrian - Ordovician (approx. 500 m.y. old) Arbuckle Group exposed in the Criner Hills. It is clear that the Criner Hills area continued to be uplifted and eroded during deposition of the Bostwick (Fig. 6). The Bostwick cannot be positively identified in the northeast part of the Ardmore Basin; however, strata that appear to be in proper stratigraphic position to be the Bostwick are present. The rocks present in the Bostwick "interval" include sandstone, limestone, conglomerate, and coal. The limestone indicates a shallow marine environment whereas the coal indicates a swamp or marsh environment (Fig. 7). The Bostwick in the interior part of the Ardmore Basin represents a variety of depositional environments, which may be related to evolving topographic highs and lows. This, in turn, suggests that the interior of the Ardmore Basin continued to be tectonically active during Bostwick deposition.

The Lake Murray Formation also contains the Lester Limestone and Frensley Limestone Members (Fig. 4). These, together with the Pumpkin Creek Limestone Member of the overlying Big Branch Formation, indicate that conditions in the Ardmore Basin were relatively stable. (We will visit the Pumpkin Creek at Stop 6 on the field trip.) Thick chert- and limestone-conglomerates eroded off a rising Criner Hills are absent. Instead, the members consist of a discontinuous and diverse assemblage of limestones, sandstones, and shales. Detailed studies of these members indicate they were deposited in a complex paleoenvironment which includes fluvial, lagoonal, nearshore, deltaic, shoal, and open shallow marine (Fig. 8). Most of the sediments appear to have been derived from a low source terrane southwest of the Criner Hills, which were not high at this time. The interior of the Ardmore Basin was not inactive, however. High-energy (wave-influenced) limestones coupled with thin shale intervals indicate the

Caddo anticline was actively rising at the same time low-energy limestones and thick shale intervals were being deposited in the sinking Berwyn syncline (Fig. 9).

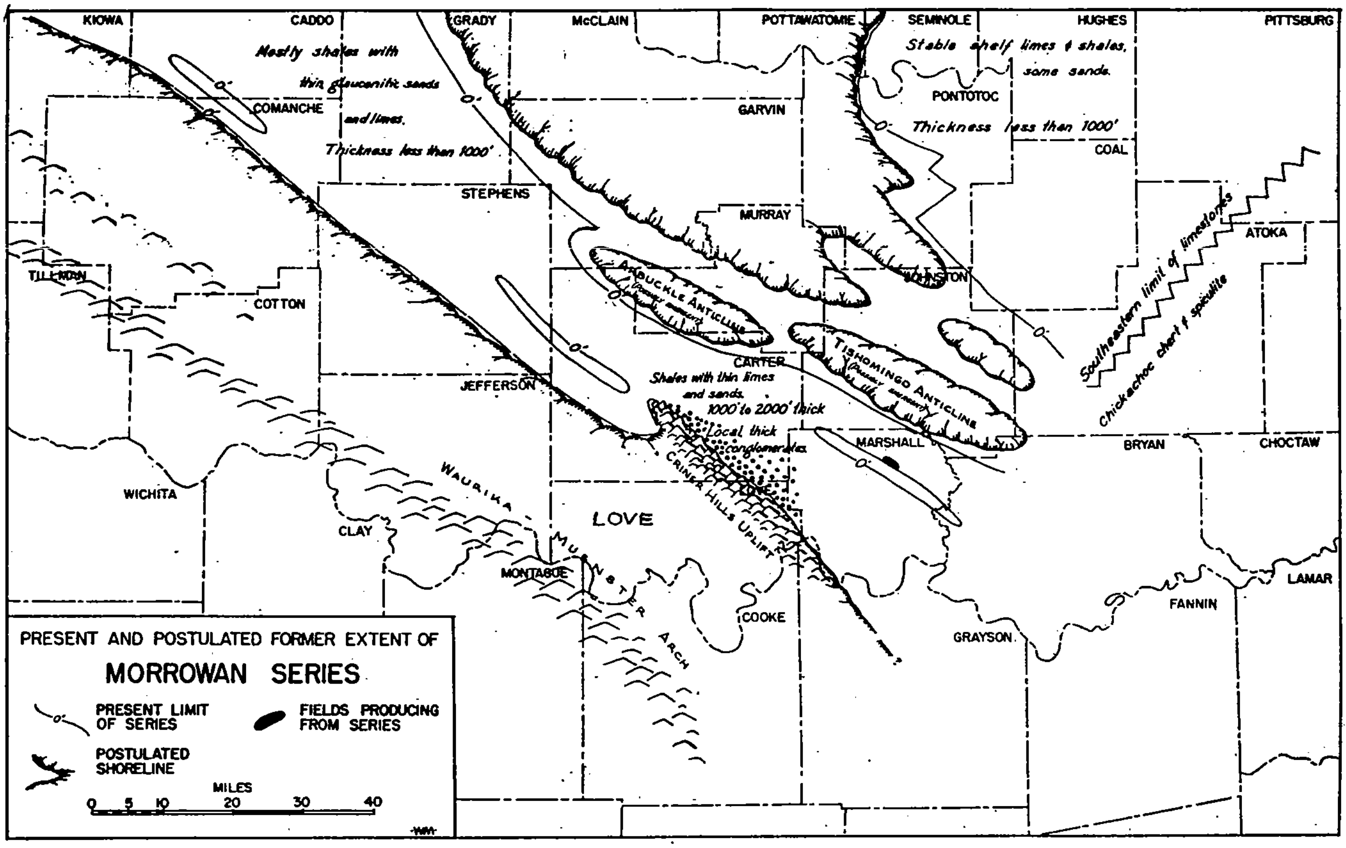

Figure 5. Paleogeographic map of south-central Oklahoma during Early Pennsylvanian (Morrowan) time. The Anadarko and Ardmore Basins are bounded on the southwest by the low Waurika-Muenster uplift and the high Criner Hills. Note the conglomerates eroded off the Criner Hills. Northwest-southeast trending anticlines that developed within and at the same time as the basin(s) are shown as 0' "isopachs". No sediment was deposited in these areas because the anticlines were high.

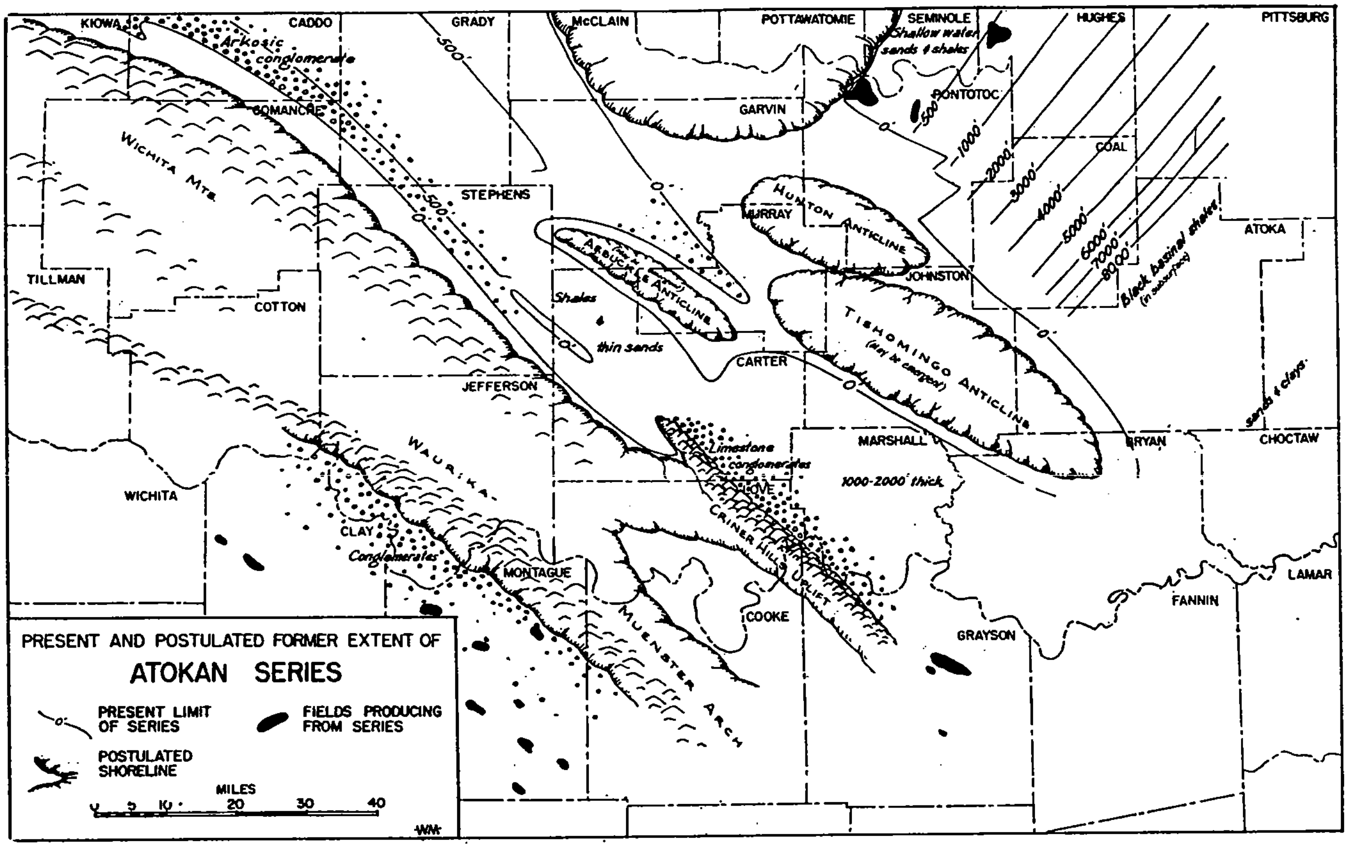

Figure 6. Paleogeographic map during deposition of the Bostwick Conglomerate Member near Lake Murray. The Criner Hills continue to shed coarse sediments into the Ardmore Basin. Elsewhere, the Waurika-Muenster and Wichita uplifts become active and begin to erode into adjacent basins. Note that this model suggests the Arbuckle Mountains are emergent and that no sediment was deposited across them.

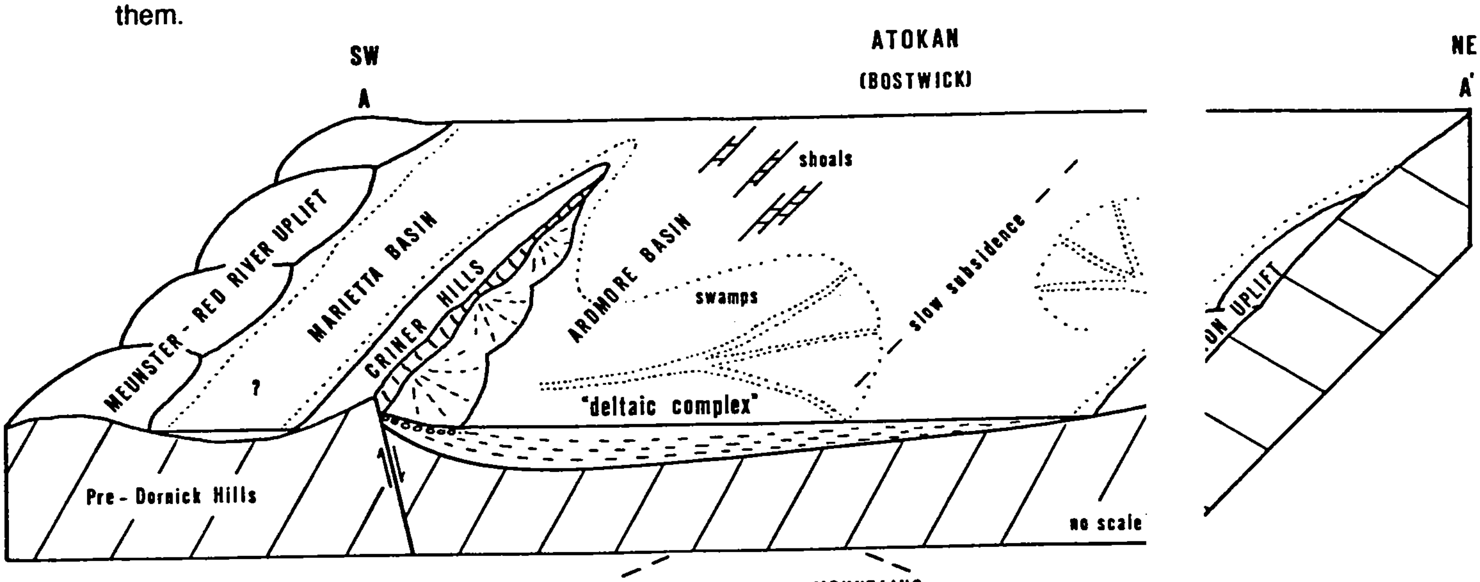

Figure 7. Cross section showing the complex depositional patterns in the Ardmore Basin in Bostwick time. Conglomerate is deposited near the Criner Hills; deltas composed of sandstone, shale, and coal locally extend far into the basin; limestone is deposited in areas with little sediment input, possibly in shallower areas over rising anticlines; and shale dominates the deeper, middle part of the basin. Note the future location of the Arbuckle Mountains, which, according to this model, are not emergent. (Compare with Figure 6.)

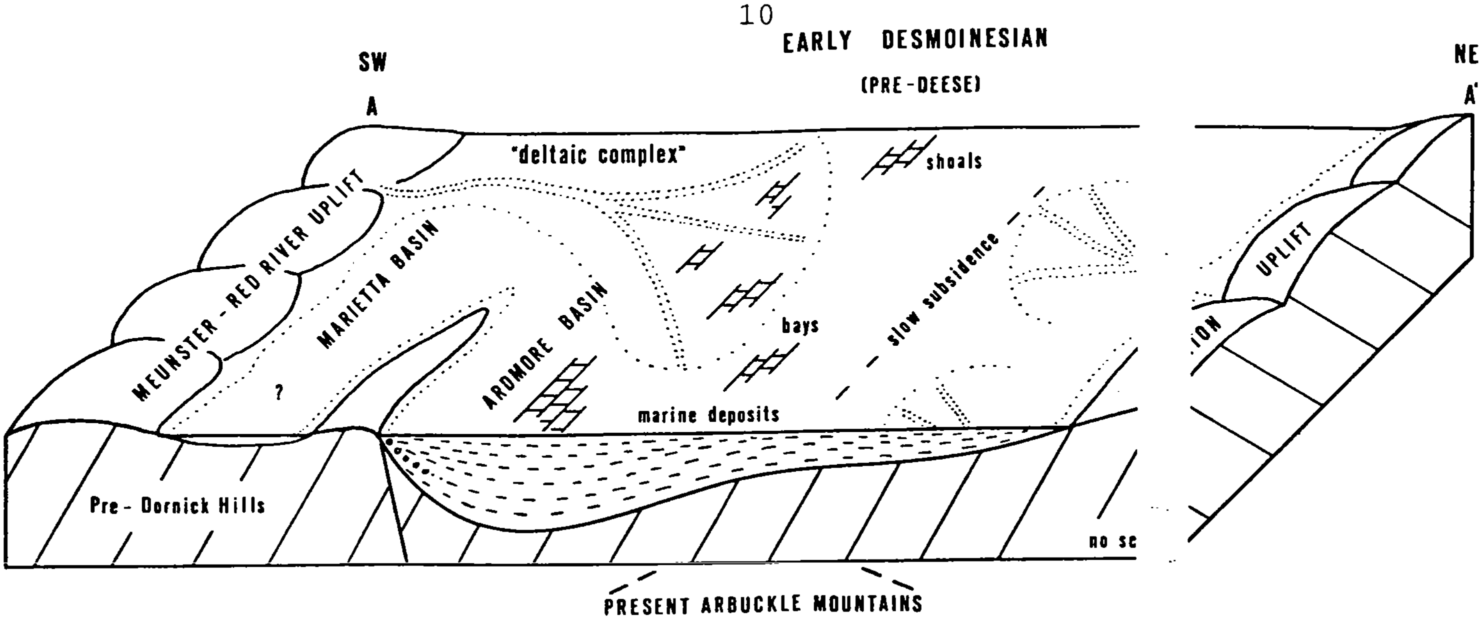

Figure 8. Depositional environments in the Ardmore Basin in Lester, Frensley, and Pumpkin Creek time.

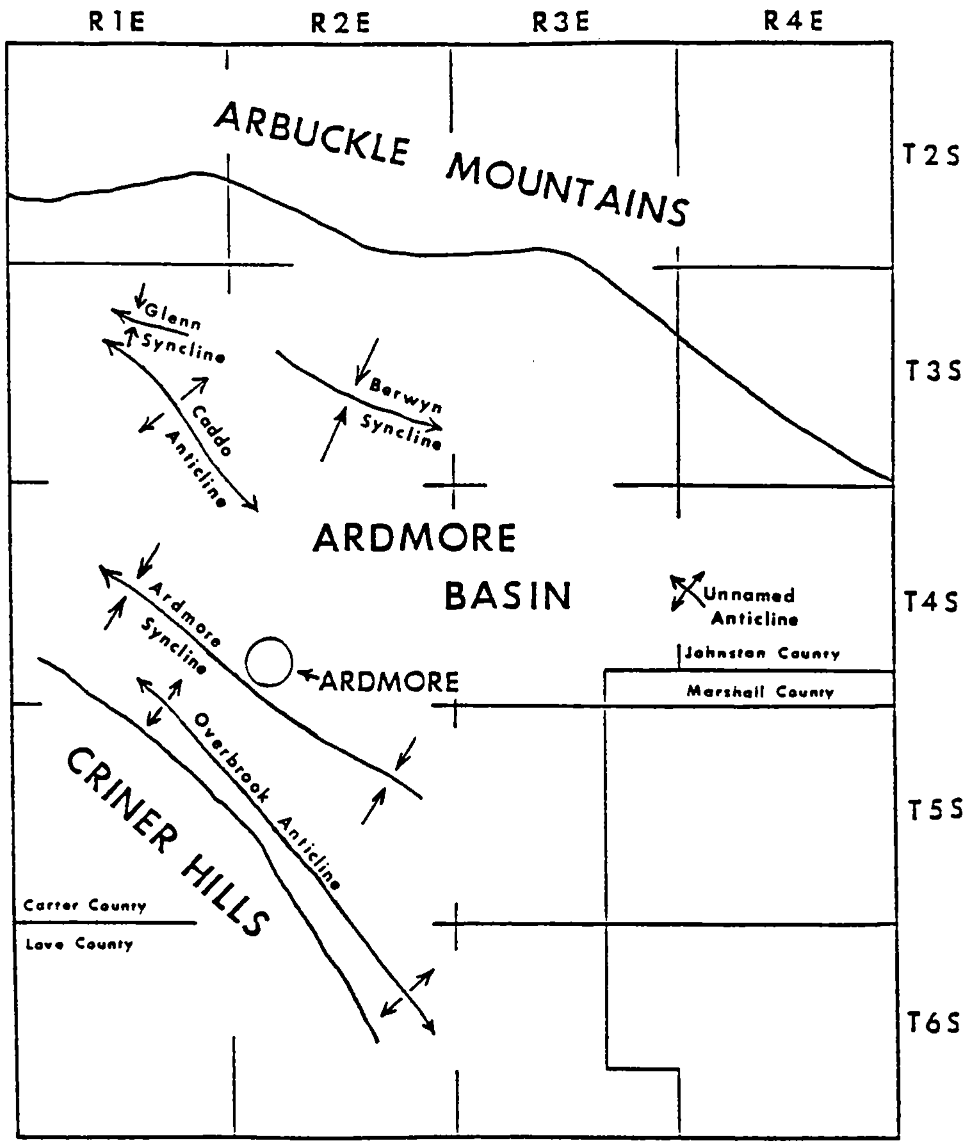

Figure 9. Major structural features in the Ardmore Basin.

EVIDENCE FOR THE OUACHITA OROGENY

The Deese Group is the most widespread unit along the west side of Lake Murray. It consists of six named members separated by units composed mostly of shale. The six named members are, from oldest to youngest, the Devils Kitchen, Arnold, Rocky Point, Campground, Williams, and Natsy Limestone (Fig. 4). The age of these members is Middle Pennsylvanian (Desmoinesian), or about 310 m.y. Although the members of the Deese Group resemble, to a large extent, the named members of the Dornick Hills Group, there are some significant differences that are described below.

The lowest member of the Deese Group is the Devils Kitchen Conglomerate. The field trip will examine the Devils Kitchen at Stops 4 and 5; therefore, a more detailed description of the member will be included in the road log. Suffice it to say here that the Devils Kitchen consists of as many as three ridge-forming sandstones separated by valleys underlain by shale and minor limestone. The highest sandstone bed becomes a conglomerate just southeast of Ardmore and the pebbles and cobbles become larger and the conglomerate becomes thicker as it is traced to the southeast. The pebbles and cobbles are relatively angular and composed of chert; limestone is absent. These observations suggest that the Devils Kitchen or, at the very least, the highest sandstone bed in the Devils Kitchen, was derived from highlands to the southeast, toward the (now buried) Ouachita Mountains (Fig. 10). (The Ouachita Mountains, near Atoka, contain abundant chert.) Outcrops of the Devils Kitchen nearest the Arbuckles are sandstone, indicating that the Arbuckles were not high during Devils Kitchen time.

The Arnold Limestone Member consists of very fossiliferous limestone and thin shale overlain by sandstone. Crinoid calices with attached stems (Fig. 11) have been collected from the Arnold in an old quarry near Lake Murray Lodge, but this area is now in the state park and collecting is no longer permitted. The fossiliferous limestone could only form in relatively clear, shallow water, suggesting that sediment input into the Ardmore Basin was drastically reduced during Arnold time.

The field trip will also examine the Rocky Point Conglomerate of the Deese Group (Stop 2). In many respects, a description of the Rocky Point is similar to that of the Devils Kitchen. Chert pebbles are a conspicuous component of this member and they increase in size to the southeast - toward the buried extension of the Ouachita Mountains. Once again, a flood of sediments appears to have moved into the Ardmore Basin following the relatively slow and deeper-water sedimentation represented by the shales between the Rocky Point and Arnold. One question that geologists ask themselves (and others) is do these periodic floods of coarse-grained sediments reflect repeated uplifts in the source terrane which, in this case, is the Ouachita Mountains? Or do they reflect a general lowering of sea level, which would expose more areas to erosion and allow deltas to extend farther across the basin? The relative importance of tectonism vs. sea-level changes on sequences of sedimentary rocks is widely debated among many geologists.

The Campground Member consists of ridge-forming sandstone and limestone. By and large, it is a relatively nondescript sandstone in Lake Murray State Park, but just west of the Ardmore Municipal Airport its character completely changes in an extremely significant way. In an area of 2 -3 square miles, the rocks have been given the name "Warren Ranch Conglomerate facies". (Geologists define facies as a "group of rocks distinguished from other more or less related or comparable rocks of different appearance or composition, and identified by any observable feature ...".) Here, nearly 100 ft of boulder conglomerate beds are distributed through about 1000 ft of shale. It appears that some of these conglomerate beds are equivalent to the Campground, but some may be as young as the Natsy Limestone Member. There are several important features of the conglomerates: 1. They are located very near the Arbuckle Mountains. 2. They become finer-grained to the south. 3. The boulders are the same kind of rocks as are found in the Arbuckles. Some geologists suggest the Warren Ranch Conglomerates record the first period of uplift of the Arbuckle Mountains. Others suggest a source farther north, perhaps the Hunton anticline, located near where Pontotoc and Murray Counties border each other (Fig. 10).

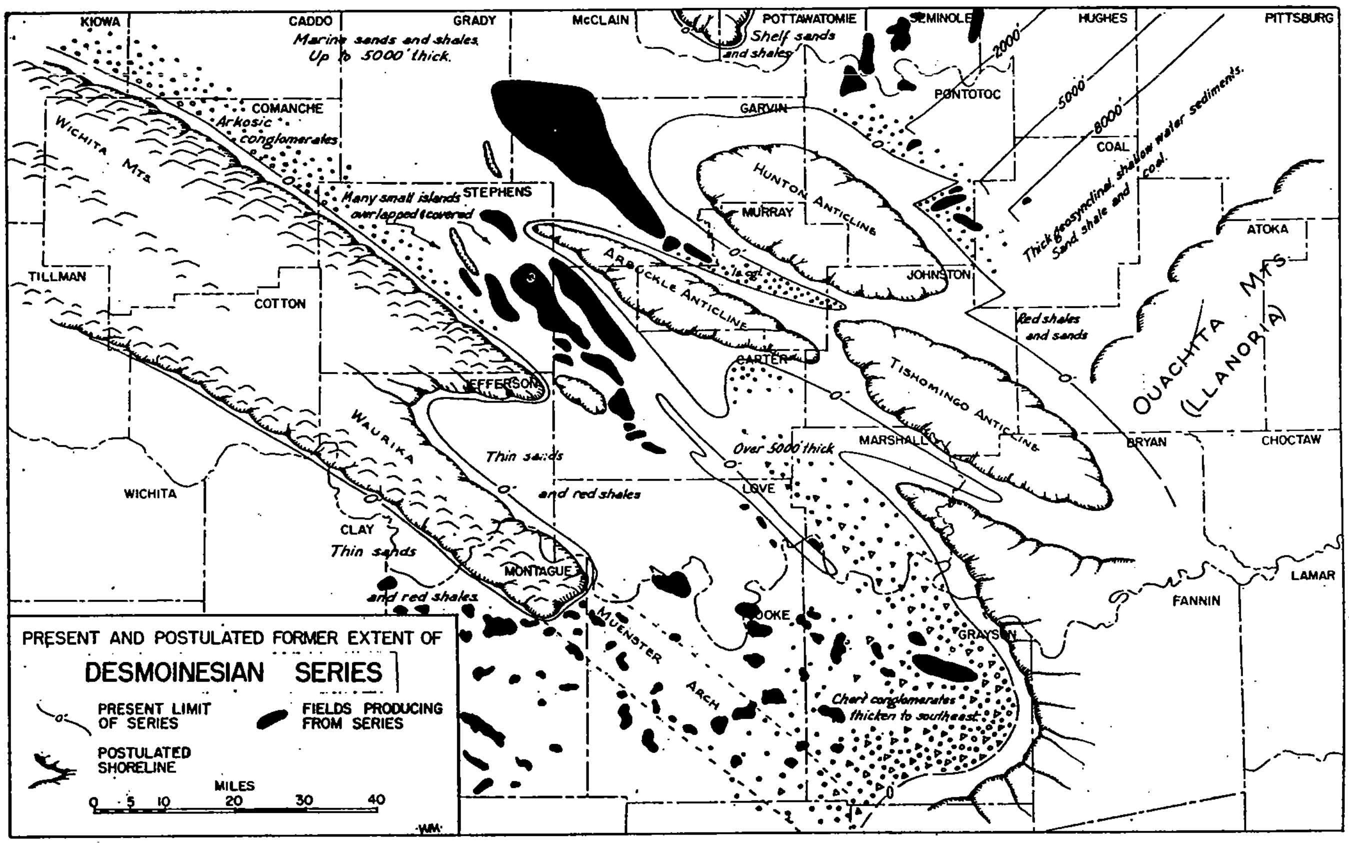

Figure 10. Paleogeographic map during deposition of the Deese Group. The Ouachita Mountains contributed much coarse sediment to the Ardmore Basin. There is some question as to whether the Warren Ranch Conglomerates were eroded from an emergent Arbuckle Mountains or the Hunton anticline area.

The Williams Member of the Deese Group consists of fossiliferous limestone and sandstone. In places, the limestone is a mass of broken shells, suggesting a fair amount of wave action which, in turn, suggests shallow marine water.

The youngest member of the Deese Group is the Natsy Limestone. The field trip will visit a good exposure of the Natsy (Stop 1), which consists in many places of sandstone overlain by fossiliferous limestone. The Natsy becomes slightly conglomeratic to the southeast, suggesting renewed erosion from highlands in that direction (Ouachita Mountains). Conglomerate beds also occur in the Natsy northwest of Ardmore and as part of the Warren Ranch Conglomerate, suggesting renewed erosion of the Arbuckles or a source terrane farther north.

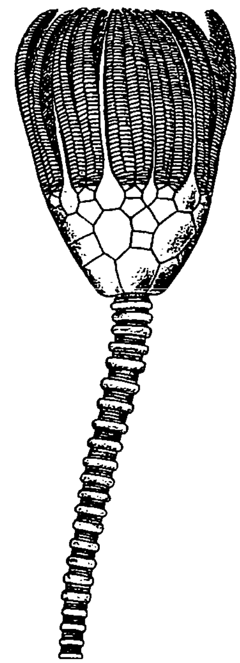

Figure 11. Crinoid showing the calyx and stem.

The next youngest group in the Ardmore Basin is called the Hoxbar Group (Fig. 4). It is distinguished from the underlying Deese by the prevalence of limestone in the named members, compared to sandstone in the named members of the Deese. But like the Deese, the Hoxbar consists of ridge-forming named members separated by valley-forming unnamed shales. The Hoxbar is upper Pennsylvanian (Missourian) in age, or about 310 to 300 m.y. old. It has not been studied in as great a detail as either the Dornick Hills or Deese Groups and will only be very briefly reviewed here. The named members of the Hoxbar are, from oldest to youngest, the Confederate Limestone, Crinerville, Anadarche, Daube Limestone, and Zuckerman Sandstone (Fig. 4).

Most of the Confederate Limestone Member is a fine-grained limestone, but to the southeast, the limestone is replaced by sandstone that increases in grain size. Pebbles of limestone and chert are found in the southeasternmost outcrops of the Confederate, suggesting a source to the southeast. The Ouachitas are one possible source, but the abundance of limestone (rare in the Ouachitas) pebbles indicates the southern part of the Waurika-Muenster uplift may have been the source (Fig. 12). Exactly where the Confederate sediments came from requires more study, however.

The Crinerville consists of fossiliferous limestone and sandstone. Crinoids, pelecypods, brachiopods, gastropods, and corals are common. The overlying Anadarche Member also consists of limestone and sandstone. Like the Confederate and underlying members of the Deese, the Crinerville and Anadarche become coarser grained to the southeast, indicating highlands in that direction.

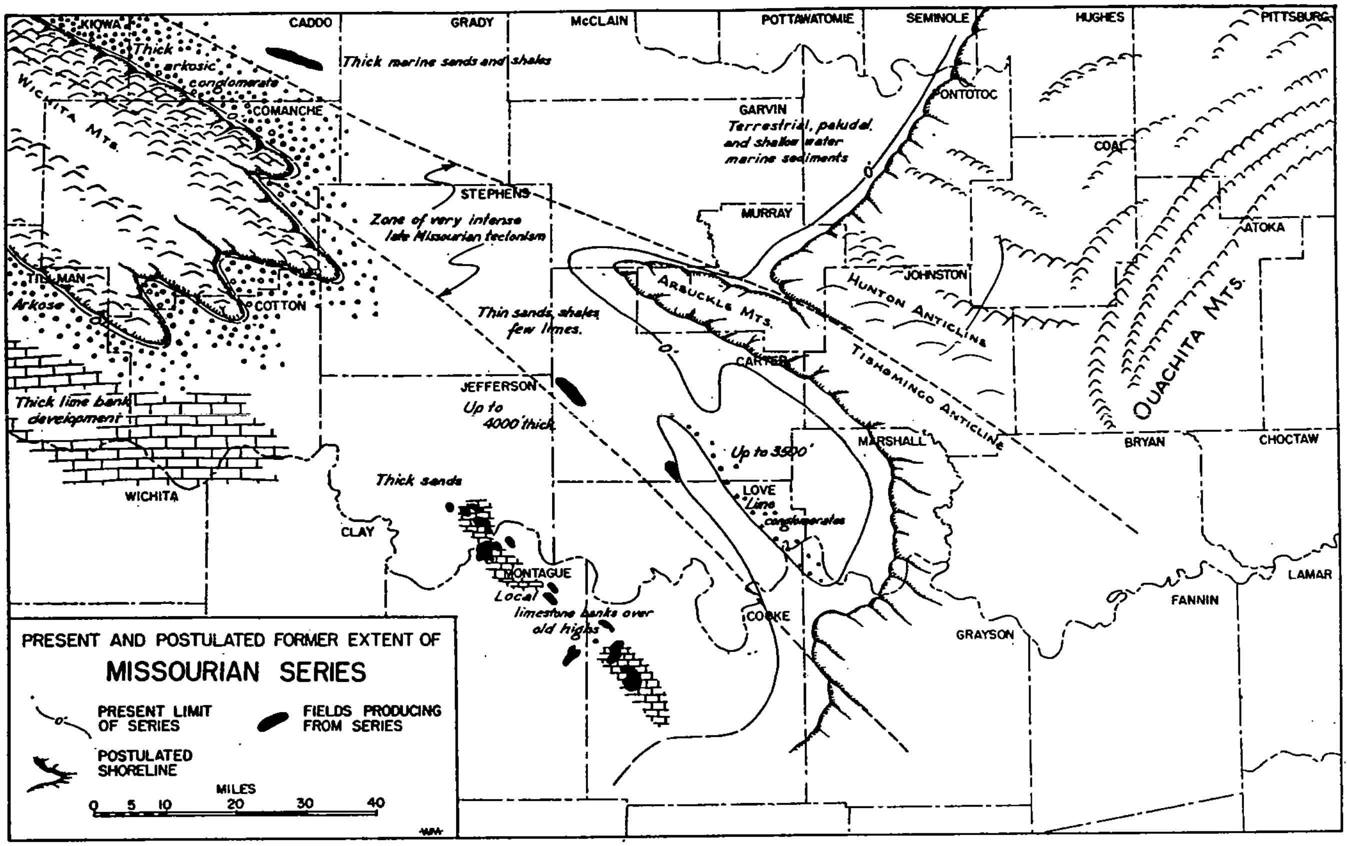

Figure 12. Paleogeographic map during deposition of the Hoxbar Group

The Daube Member is characterized by a 10-ft-thick limestone with large, brown brachiopods. The Daube also includes the most economically significant coal in the Ardmore Basin. The coal was mined in the late 1890's and again in 1935. The presence of coal indicates a swamp environment in at least part of the Ardmore Basin during Hoxbar time; the overlying limestone indicates the basin was subsequently covered by shallow marine waters. Conglomerate beds are also present in the Daube in places, but their source terrane is unknown.

The youngest member of the Hoxbar is the Zuckerman Sandstone. It is mostly a sandstone.

To summarize the Deese and Hoxbar Groups, one would have to admit that to the casual observer, the different named members look very similar to those in the underlying Dornick Hills Group. The members consist of limestone, sandstone, and conglomerate that typically form ridges, and are separated from each other by dominantly shale valleys. The fossils that are found in the Deese and Hoxbar are very similar to those found in the Dornick Hills; this is not surprising because the three groups are about the same age and the environments of deposition are similar. However, the source of the sandstone and conglomerate in the Deese and Hoxbar was the uplifted Ouachita Mountains to the southeast, or perhaps the southern part of the Waurika-Muenster uplift, and not the Criner Hills area to the southwest.

The Ardmore Basin in Deese and Hoxbar time was a moderately deep basin that received tremendous volumes of mud that later lithified to form shale. Periodically, sandy deltas advanced across the basin from the southeast. Swamps developed locally on parts of the deltas. At other times, parts of the basin were shallow enough and the water clean enough for limestone to accumulate. There is some evidence for highlands to the northeast, but whether these are incipient Arbuckle Mountains or a slightly emergent Hunton anticline is unknown.

Thus far, the history of the Ardmore Basin has been one of deposition of a variety of sedimentary rocks. Some represent deposition in relatively deep water, others shallow water. The source of the coarser sediments was originally to the southwest (Criner Hills area) from highlands that formed during the Wichita orogeny. Later, the principal source of sediments filling the basin was to the southeast, toward the (now buried) Ouachita Mountains (Ouachita orogeny). Through the end of Hoxbar time, the sedimentary rocks of the basin were essentially flat-lying. This serene picture was about to change ... dramatically.

EVIDENCE FOR THE ARBUCKLE OROGENY

Perhaps the most impressive period of mountain building in the Ardmore Basin area was the latest Pennsylvanian (Virgilian) **Arbuckle orogeny**. The evidence for this orogeny lies not so much in the mountains themselves, but in the deposits they left behind (Fig. 13). Other evidence is the magnificant angular unconformity that separates all the older rocks of the Ardmore Basin from those eroded off the mountains (Fig. 2D). This angular unconformity is expressed as highly folded, faulted, and tilted rocks of the Dornick Hills, Deese, and Hoxbar Groups (as well as older rocks) being overlain by much less tilted rocks of the Pontotoc Group. This angular unconformity is evidence that the Ardmore Basin was compressed, uplifted, and eroded, and then covered with sediments derived from the bordering and higher Arbuckle Mountains.

In southern Oklahoma, the Pontotoc Group consists of the Collings Ranch Conglomerate and the Vanoss Conglomerate. The Collings Ranch is spectacularly exposed along I-35 near the top of the Arbuckles, where it is a limestone-boulder conglomerate that has been folded into a broad, open syncline overlying with angular unconformity steeply dipping Ordovician limestones. The Vanoss Conglomerate is well-exposed north of the Arbuckle Mountains, particularly around Chickasaw National Recreation Area. In the Ardmore Basin, the Vanoss can be seen resting unconformably across the steeply tilted Hoxbar and older rocks.

Two characteristics of the Collings Ranch and Vanoss Conglomerates should be noted. The first is the large size of the limestone cobbles and boulders in the deposits. Clearly, the source terrane for these conglomerates was close and relatively rugged; given the size of the boulders, it is difficult to imagine how they could be transported any great distance. The second is the presence of "arkosic" debris in the conglomerates. "Arkose" is a sandstone made up of feldspar and quartz, the principal constituents of granite. Evidently, somewhere near the Arbuckles was a highland underlain by granite; the most likely area was the Belton-Tishomingo uplift just east-southeast of the Arbuckles. The mountain range created by the Arbuckle orogeny must have extended far beyond the present-day Arbuckles; it included the Tishomingo area, the folded and faulted rocks of the Ardmore Basin, as well as the Criner Hills area and the Marietta Basin. In fact, there is abundant evidence that the Wichita Mountains were also uplifted and eroded at this time (Fig. 13).

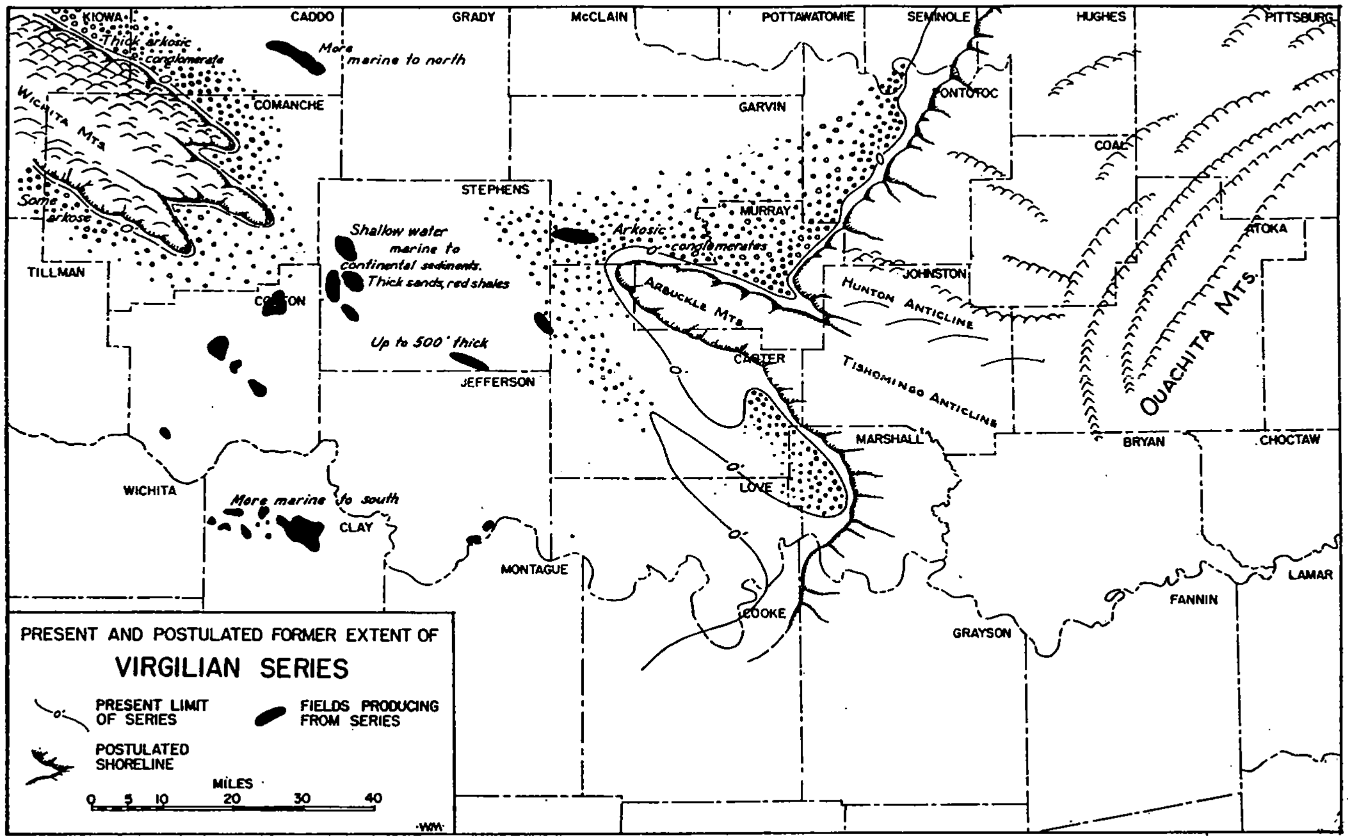

Figure 13. Paleogeographic map during deposition of the Pontotoc Group and showing the distribution of mountain ranges. The high Arbuckle Mountains and Tishomingo anticline contributed coarse sediments to the Ardmore Basin

GULF COASTAL PLAIN SEDIMENTARY ROCKS

The youngest formation near Lake Murray State Park is the Early Cretaceous Antlers Sandstone. (The field trip will look at the Antlers Sandstone at Stop 6.) Unlike all the older rocks in this part of Oklahoma, the Antlers does not record a period of basin formation or orogeny. Rather, in Cretaceous time, the southern part of North America was tectonically quiescent and the mountains had been largely eroded. A much larger Gulf of Mexico covered a large part of Texas and southern Oklahoma; how far north it extended is uncertain because any sediments that may have been deposited in it have been eroded.

A broad coastal plain covered much of southern Oklahoma (Fig. 14). Slow-moving deltas carrying sand, silt, and mud crossed the area. This material, known as the Antlers Sandstone, was deposited across the older, steeply tilted and strongly deformed rocks. Periodically, the sea would advance and deposit a layer of shale or limestone, and then retreat. Deltas carrying sand would once again cross the area and sandstone would be deposited on top of the limestone. The Gulf Coastal Plain sediments of Oklahoma, therefore, consist of a series of nearly flay-lying sandstones, shales, limestones, and rare coals, and represent the repeated advance and retreat of a Cretaceous ocean.

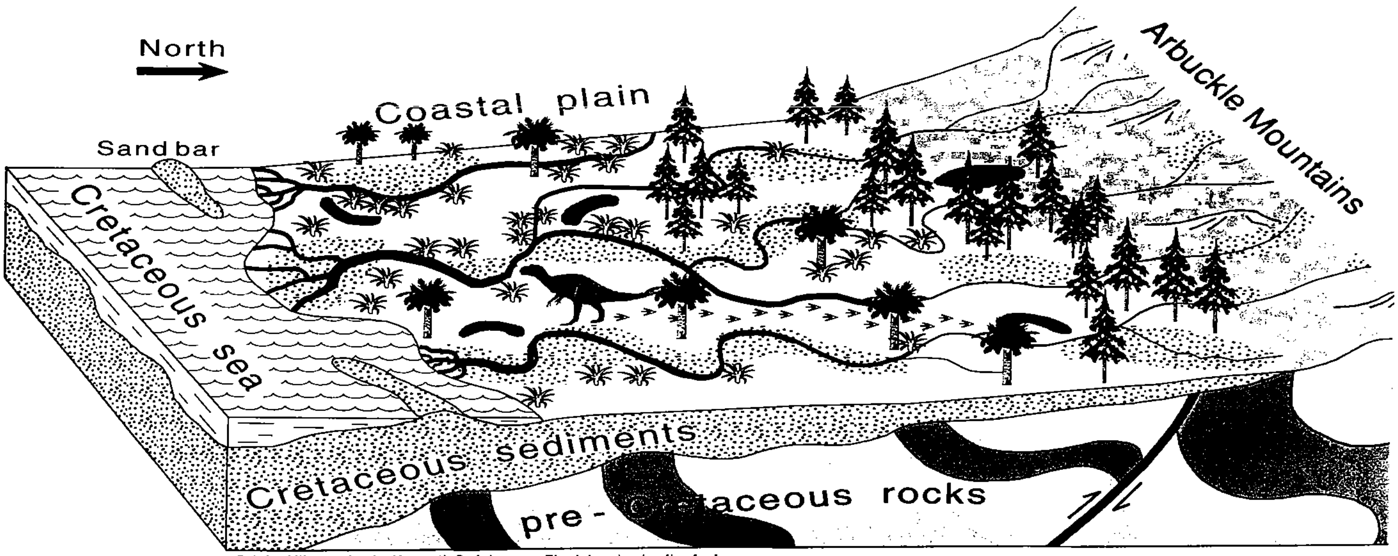

Figure 14. Block diagram showing Cretaceous coastal plain of southern Oklahoma. The relatively low Arbuckle Mountains, rivers, coastal plain, beach, swamps, and offshore sand bars are shown diagrammatically.

ROAD LOG FOR FIELD TRIP

The site of the spring 1996 field meeting of the Oklahoma Academy of Science is Group Camp 3 on the south end of Lake Murray. The camp lies in the middle part of the Deese Group of Desmoinesian (middle Pennsylvanian - about 312 to 310 million years ago) age.

Our field trip will take us counter-clockwise around Lake Murray. From the camp, drive east to the intersection with Hwy. 77s. Turn left (north). We will drive for several miles to the intersection with Hwy. 70, at which point we will turn left (west) toward Ardmore. The road along the east side of the lake crosses strata of the Missourian (upper Pennsylvanian - about 310 to 300 million years ago) Hoxbar Group and the Lower Cretaceous (about 125 million years ago) Antlers Sandstone. The low areas and creeks expose the Hoxbar, the tops of hills are in the Antlers. Obviously, the ages of the Hoxbar and Antlers are very different; we will discuss this difference at our last stop.

At Hwy. 70, turn left (west) toward Ardmore. Drive about 4 miles to the intersection with Hwy. 77s. Turn left (south) toward the Lodge and Tucker Tower. Drive .2 miles, bear right, staying on the road toward the Lodge. Drive south about .9 miles, turn left into the picnic area, and park. We will walk down Hwy. 77s a short distance, cross the bridge (**BE CAREFUL** - the bridge is narrow and this is a busy road!!) and look at the outcrop on both sides of the road on the other side of the bridge.

STOP 1. NATSY LIMESTONE MEMBER (DEESE GROUP)

This outcrop is the Natsy Limestone Member of the Deese Group. The Natsy is the youngest named member of the Deese Group (Fig. 4) and, like most of the sedimentary rocks in this part of the Ardmore Basin, is Pennsylvanian in age. More specifically, the Natsy is in the upper part of the Desmoinesian series which lasted from about 312 to 310 million years ago.

Look carefully at the outcrop. What kinds of rocks do you see and how thick are they? At this locality, the Natsy consists of about 15 ft of limestone overlying about 25 ft of sandstone. The "good-looking" sandstone overlies about 20 ft of poorly consolidated sandstone and siltstone. Look at the base of the hard sandstone. Is it sharp (abrupt)? Is it planar or curved? Does it look like the upper hard sandstone eroded into the softer sandstone, forming a channel?

Now look carefully at the sandstone. How coarse-grained is it? If is wasn't a rock, would you call it a sand, fine sand, or silt? Can you find any small pebbles scattered about in the sandstone? What color is the sandstone? Why do you think it's that color? Stand back a bit from the outcrop and see if you can recognize any sedimentary structures, for example, ripple marks (Fig. 15). Can you determine if the ripple marks are current or oscillation ripples?

Now look carefully at the limestone. Break off a fresh piece. What color is it? Does it smell? Are there any fossils in it? If so, can you identify them? In some places, the Natsy contains gastropods, brachiopods, and bryozoans (Fig. 16). Are the fossils (especially shells) broken or whole? Don't be afraid to look at more than one piece. Is the "limestone" all limestone, or are there eroded intervals that might be some other rock type?

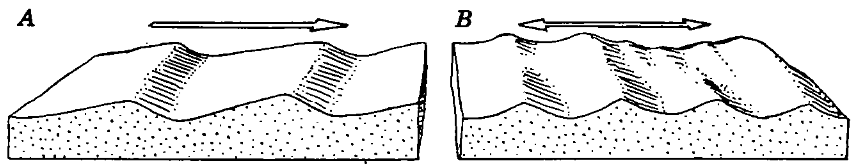

Figure 15. Current (A) and oscillation (B) ripple marks. Current (asymmetrical) ripple marks are formed from unidirectional current flow. Oscillation (symmetrical) ripple marks form perpendicular to the direction of wave propagation.

Based on your observations, what can you say about what the environment of deposition of the Natsy was at this location? Geologists would suggest that the relatively uniform and fine grain size of the sandstone coupled with the absence of pebbles suggests deposition in quiet water some distance from the source terrane of the sand. Fossil molds indicate a marine environment and ripple marks suggest relatively shallow water, one where waves would periodically disturb the bottom. The limestone, particularly one containing fossils, would have been deposited in a marine environment shallow enough for large organisms to live. The absence of sand and silt in the limestone indicates that the sediment source of the immediately underlying sandstone was somehow cut off, allowing limestone to be deposited.

A possible environment of deposition for the Natsy at this location might be the distal reaches of a delta, but without knowing exactly how the Natsy changes character throughout the region, not only on the surface but in the subsurface, it is impossible to know precisely under what conditions it was deposited. But even then, geologists would probably argue with each other over how to interpret their observations! While the details might not seem important to the non-professional, they might be critical to the geologist exploring for hydrocarbons.

Before we leave Stop 1, a brief description of the Natsy elsewhere in the Ardmore Basin seems appropriate. The following description is taken from the classic paper on the Ardmore Basin (Tomlinson and McBee, 1962).

"... At its type locality (about 2 miles southeast of our Stop 1), its most distinctive bed comprises 4 to 6 feet of impure, silty, ferruginous, brown massive limestone with fairly abundant fossils including gastropods, brachiopods, and bryozoans. Farther northwest it is purer, less massive, and bluish gray. The limestone lies upon 20 feet of sandstone. In its southeasternmost outcrops both units become partially conglomeratic, containing many small variegated pebbles, mostly of limestone. ...

Chert conglomerate occurs in the member ... near Deese, northwest of Ardmore; also near Gene Autry ... and southeast of that village. Another mass of chert conglomerate, limited in lateral extent and apparently occurring as a channel fill in upper Deese beds near the same stratigraphic position, (is present about 7 miles to the north)." (p.487)

Clearly, the Natsy doesn't look the same everywhere. The conglomerate to the southeast suggests highlands in that direction, possibly the Ouachita Mountains. The conglomerate to the north suggests highlands in that direction, possibly the Arbuckle Mountains or the Hunton anticline. (See discussion in first part of this booklet.)

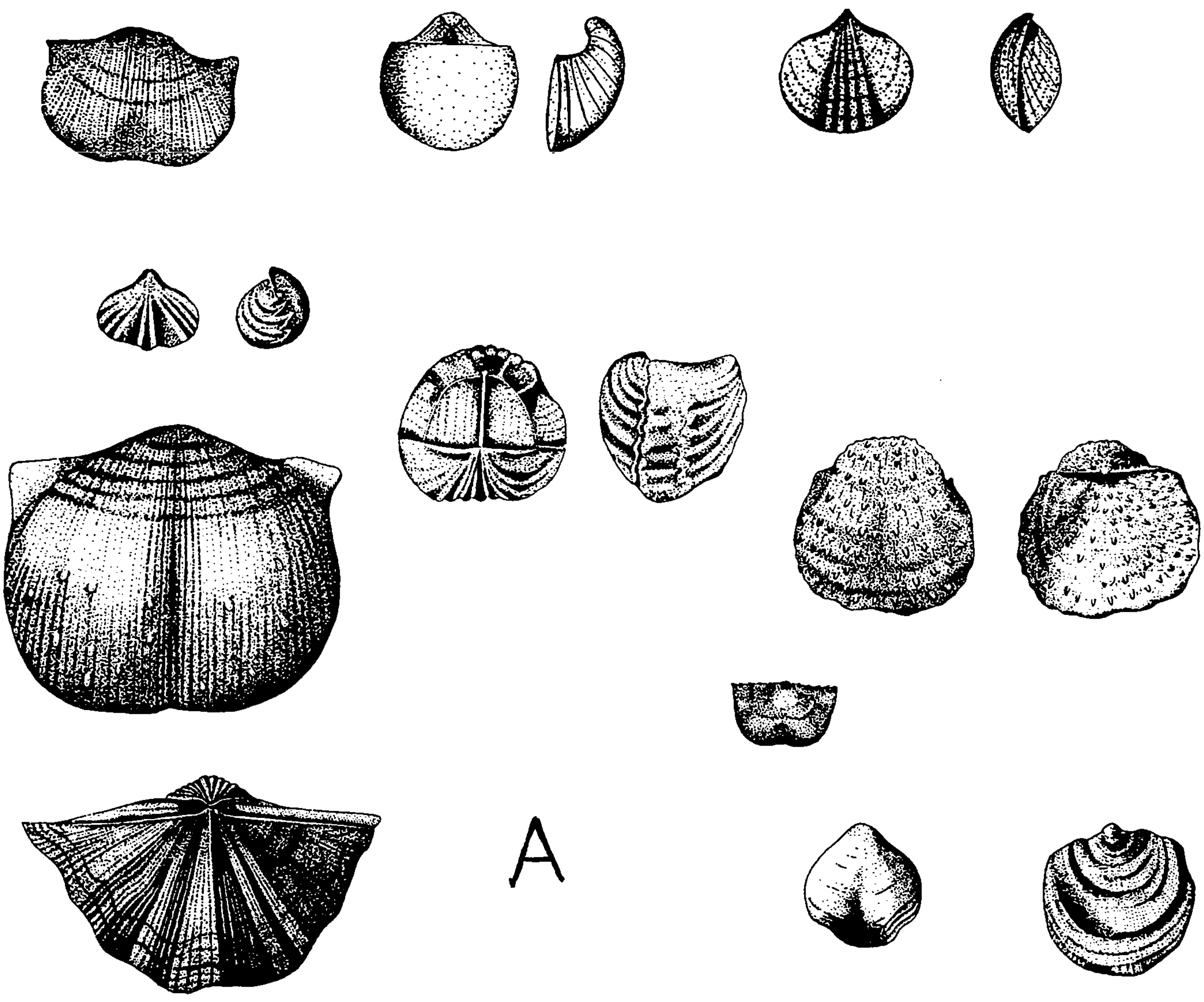

Figure 16. Common Pennsylvanian fossils of Oklahoma. A. Brachiopods. B. Gastropods. C. Pelecypods. D. Horn Coral E. Bryozoans.

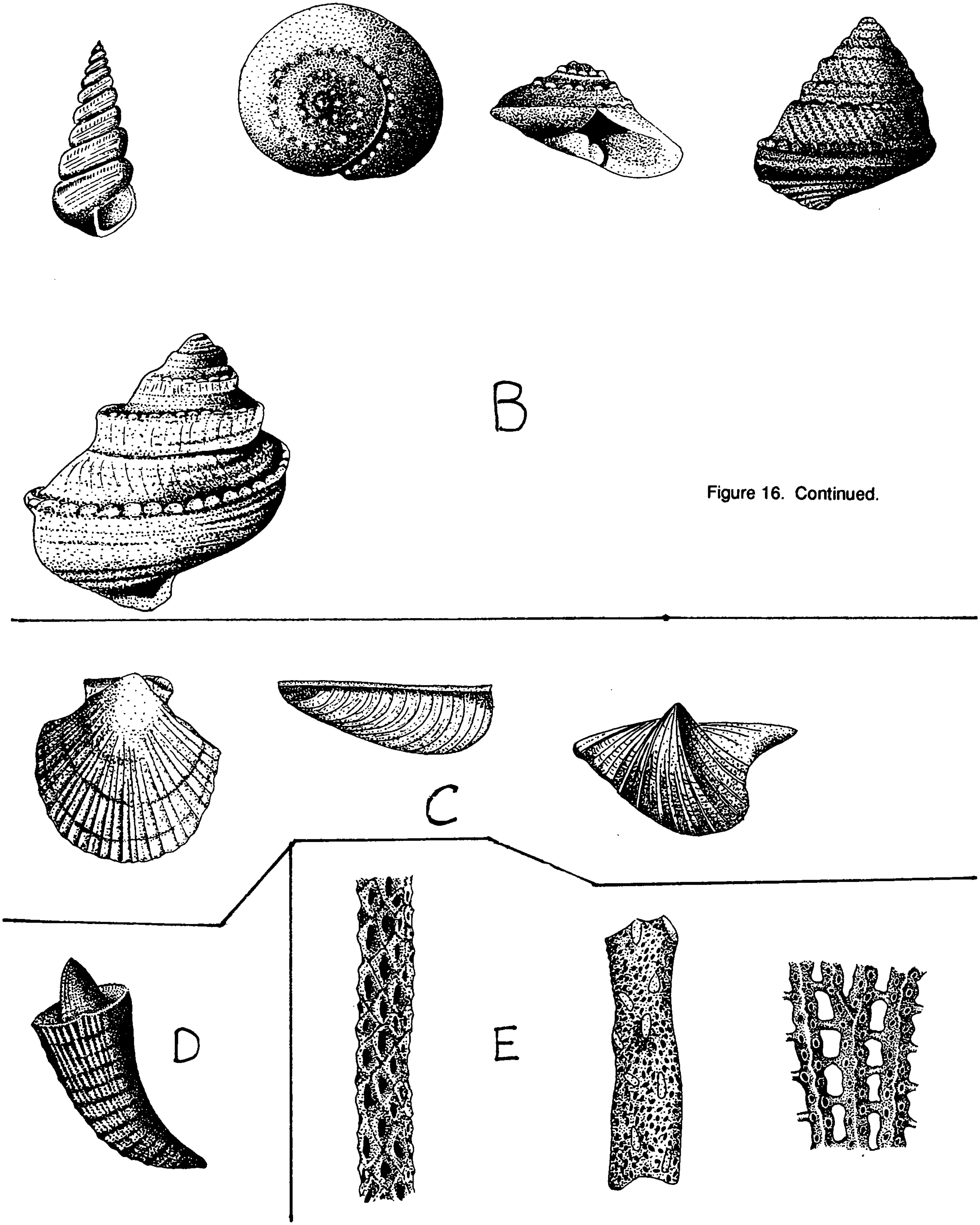

Figure 16. Continued.

Return to cars. Before we leave, look at the big rock that serves as a barrier to the parking lot. What do you think is the origin of all those irregular patterns?

Continue south on Hwy. 77s about 3.8 miles to the intersection with the road to the Lodge. The road follows a number of low ridges that are underlain by different members of the Deese Group. Turn left towards the Lodge. Drive .4 miles, passing the swimming pool. As you enter the Lodge parking lot, turn left again toward the marina. Park. We will follow the shoreline from the marina toward the Lodge.

STOP 2. ROCKY POINT CONGLOMERATE MEMBER (DEESE GROUP)

Like the Natsy, the Rocky Point Member (Fig. 4) is also Desmoinesian in age. Given the relatively short time interval represented by the Desmoinesian (about 2 million years), it is remarkable that so much sediment accumulated in this part of the Ardmore Basin. The Desmoinesian strata in Lake Murray State Park are 8,000 ft thick. Geologists would conclude that the Ardmore Basin was rapidly subsiding at this point in its history, but erosion of nearby highlands provided an abundant supply of sediment to keep it filled. There is little evidence that sedimentation was not able to keep up with subsidence, because few of the rocks appear to have been deposited in deep water. Similarly, the basin does not appear to have filled, because unconformities, or periods of nondeposition, are not present, at least within the Desmoinesian.

As we walk around the small points of land jutting into the lake, look at the rocks. What kind of rock makes up the points of land? Why do you think this particular rock type forms these small points? Look at the outcrops at all scales. Stand back and see if you can identify some sedimentary structures other than parallel bedding planes. Look more closely and try to find some fossils and/or pebbles. Break off a fresh piece, look at it with a hand lens, and describe what you see. Would you call it a coarse, medium, or fine sand, or silt?

On the first point of land, you might be able to identify the following sedimentary structures: cross-stratification (both high- and low-angle) (Fig. 17), soft-sediment deformation features, dish-and-pillar structures (Fig. 18), channelling. All these features indicate this sandstone was deposited relatively quickly in an active environment (i.e., the water was <u>not</u> still).

On the second point of land (where the Frisbee course is located), note that the grain size is distinctly coarser. This suggests the current was even stronger than it was for the sandstone on the first point of land. The pebbles are mostly angular pieces of chert; evidently, they did not suffer a great deal of erosion or their edges would be worn off. Also, the chert fragments appear to be "floating" in the sandstone; this suggests to geologists that the sandstone was deposited as some sort of debris flow, rather than being deposited inch by inch at the bottom of a current. Like we observed on the first point of land, soft-sediment deformation features and dish-and-pillar structures are common.

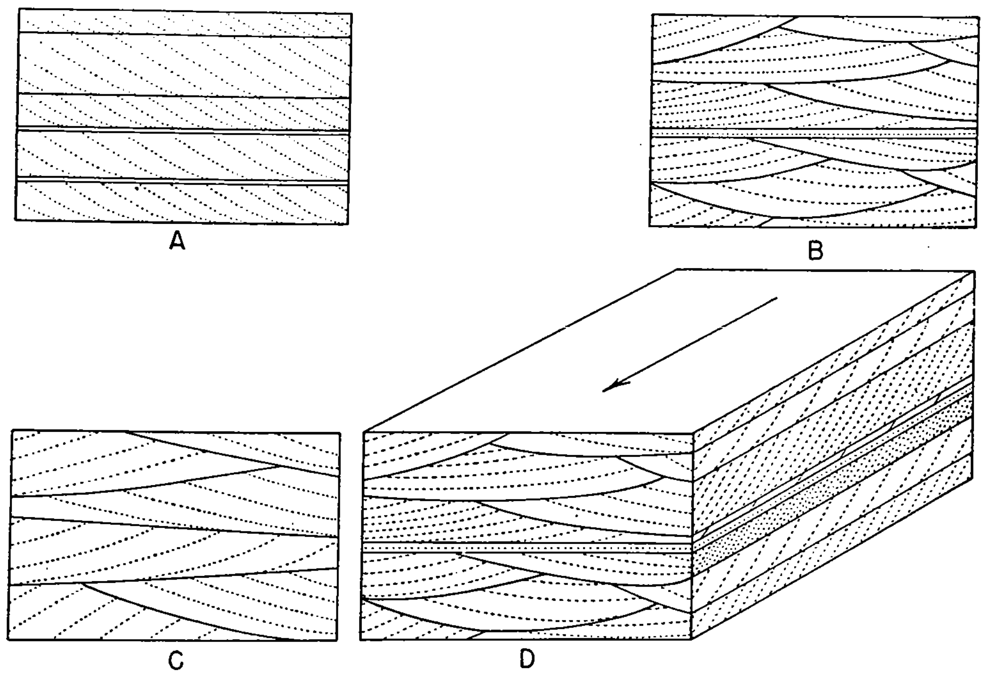

Figure 17. Different kinds of cross-stratification. A. Tabular. B. Lenticular. C. Wdge-shaped. D. Block diagram showing relation between tabular and lenticular; arrow shows direction of current.

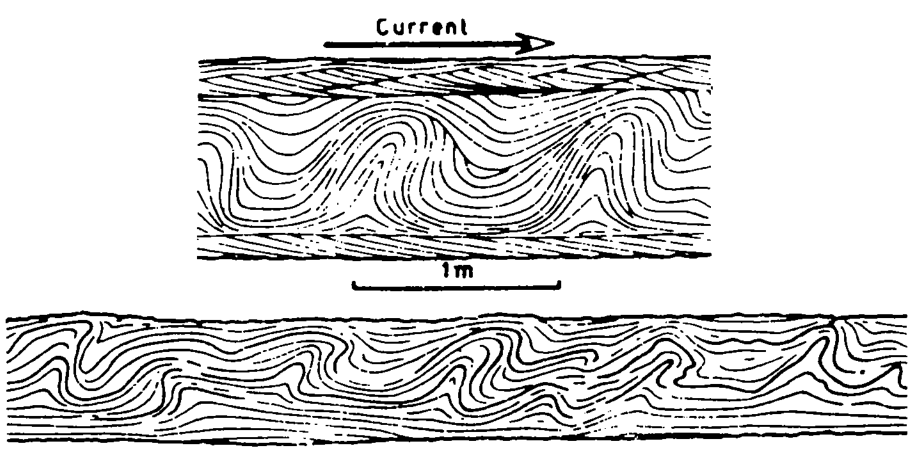

Figure 18. Dish and pillar structures formed by rapid deposition of sand followed by dewatering. "Pillars" are water-escape structures.

Return to cars and drive back to the intersection with Hwy. 77s. Turn left (south) toward Tucker Tower Nature Center.

For the next several miles, the road crosses a number of northwest-trending ridges and valleys. The ridges tend to be underlain by the named members of the lower part of the Deese Group and the upper part of the Dornick Hills Group. The valleys tend to be underlain by poorly exposed shales that separate the named members.

Drive 3.4 miles and turn left toward Tucker Tower. The road intersection is on the Pumpkin Creek Member. Drive to end of road and park. We will spend most of our time visiting Tucker Tower where there are some excellent geology displays. We will also spend some time looking at the rocks that Tucker Tower is built on.

STOP 3. TUCKER TOWER NATURE CENTER AND UPPER DEVILS KITCHEN CONGLOMERATE MEMBER (DEESE GROUP)

The following description of the geology exhibits at Tucker Tower is from a recent OGS publication by Neil H. Suneson, "Guide to Resources for Earth Science Information in Oklahoma" (OGS Educational Publication 5).

"Exhibits include representative fossils from the following groups: fish (Devonian), pelecypods, cephalopods, ammonites, brachiopods, gastropods, trilobites, echinoids, coelenterates, bryozoans, crinoids, various ferns and trees (Carboniferous), minerals of Oklahoma (rose rocks, etc.), various concretions, and five wax exhibits pertaining to the Ordovician, Devonian, Pennsylvanian, Permian, and Cretaceous time periods. A large (288-pound) meteorite that fell approximately 90 million years ago, a mastodon skull, and a tooth from a saber-toothed cat from the Pleistocene also are displayed. The center conducts paleontology programs for the public and has an audiovisual program titled 'Fossils - Clues to the Past' from the National Geographic Society."

At the time this booklet was being written, the center was undergoing extensive renovation, and the displays may be different than what is described above.

Now let's look at the rocks. The unit exposed here is the upper part of the Devils Kitchen Conglomerate Member of the Deese Group (Fig. 4). It forms a very distinct ridge throughout much of Lake Murray State Park; in fact, it was a break in this ridge that was dammed to form Lake Murray.

More conglomerates! What can you say about the grain size of the pebbles and cobbles in the conglomerate? What's the largest you can find? Given the relatively large size of the "grains" that make up the conglomerate, how active do you think the water was that deposited this conglomerate? How rounded or angular are the pebbles and cobbles? Again, the more angular the clasts, the closer you are to the source.

Now look at the what the pebbles and cobbles are made of. Do you see any limestone? Geologists who have studied the Devils Kitchen noted that the pebbles and cobbles in the Devils Kitchen get larger to the southeast and the proportion of conglomerate relative to sandstone gets greater to the southeast. This suggests a source area for the conglomerate to the southeast, but that area is now buried by younger rocks. A guess as to a source terrane for the Devils Kitchen Conglomerate

Member is the Ouachita Mountains (Fig. 10). Lots of chert is exposed in the western part of the Ouachitas, for example, near the town of Atoka. A southeastern source is corroborated by the fact that there is no conglomerate in the Devils Kitchen to the north near the flank of the Arbuckle Mountains.

How these coarse sediments got here can be deduced by looking at the sedimentary structures in the outcrop. Large- and small-scale crossbeds (Fig. 19) indicate a very active sedimentary environment. The "nested" (one on top of the other) channels with eroded tops are probably marine, but barely so. Some of the conglomerates are debris flows, but the presence of pebbles layers indicate that "traction" flow (layer upon layer) was also active. Burrows (trace fossils) appear on the base of the some of the beds.

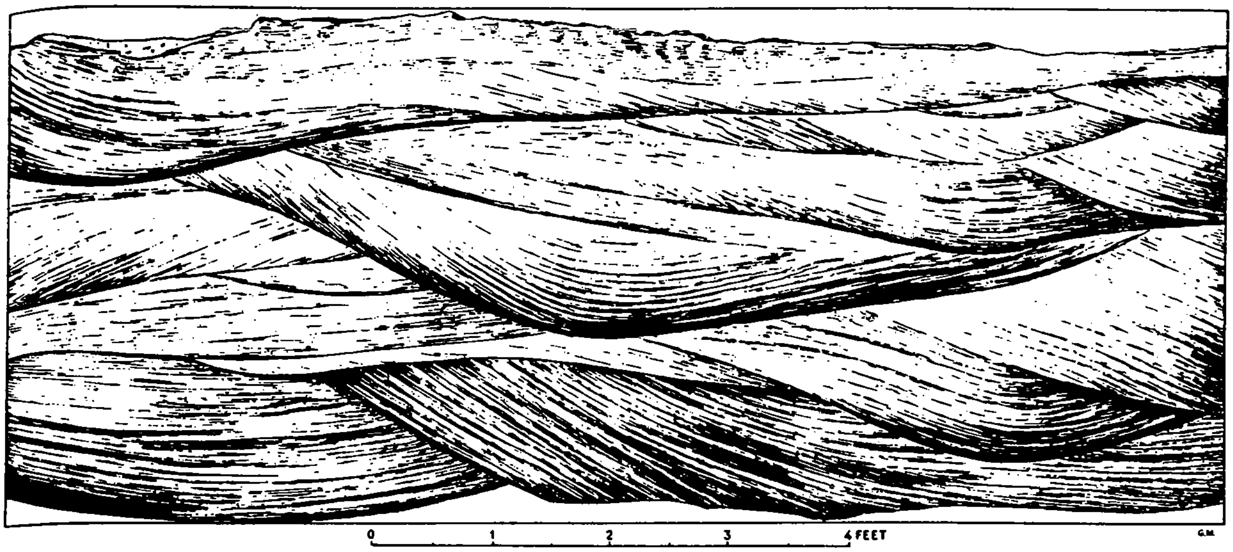

Figure 19. Large-scale cross-bedding and channeling similar to that observed in the Devils Kitchen Conglomerate. Note scale.

Return to cars and drive back out to Hwy. 77s. At the intersection, turn left (south) and drive 0.7 miles to the emergency spillway to Lake Murray.

STOP 4. LOWER DEVILS KITCHEN CONGLOMERATE MEMBER (DEESE GROUP)

The Upper Devils Kitchen that we looked at at Tucker Tower is the same as the ridge just north of the road. As you can see, the ridge holds in Lake Murray. We will look at some magnificent exposures below the conglomerate, but that are still part of the Devils Kitchen. Here, floods have swept clean the outcrops and many features that typically are not visible are exposed for our examination.

This part of the Devils Kitchen consists of a series of interbedded conglomerates, sandstones, siltstones, shales, and limestones. We will start by looking at the rocks in the spillway above the road, then those below the road.

The conglomerates and sandstones above the road consist of a thick sequence of stacked, very lenticular beds that appear to thicken and thin over short distances (Fig. 19); the extreme lenticularity suggests the sediments were deposited in channels. This is confirmed by the presence of crossbeds (flowing water).

Immediately beneath the riprap that was used to shore-up the road is a 1.5-ft-thick limestone and immediately above it is a shale with abundant crinoids. The top of the limestone is highly burrowed (Fig. 20). What does the presence of crinoids tell you about the environment of deposition of these rocks? Immediately beneath the limestone is a gray shale with scattered brachiopods. Does the presence of brachiopods confirm or conflict with what the crinoids tell you about the depositional environment? (Note that some of the mud eroded from the shale may be mud-cracked. The mud cracks are not part of the rock record, rather, are a recent feature.)

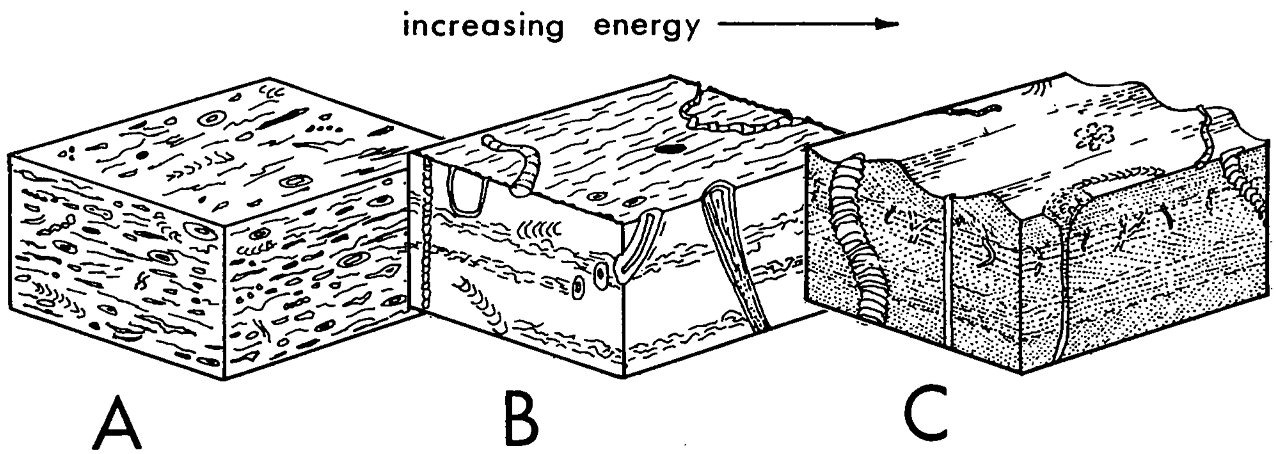

Figure 20. Different kinds of trace fossils (also known as bioturbation) as a function of increasing energy in the depositional environment.

Beneath the gray shale is red shale. Dig into the red shale and note that many of the red shale chips have a "streaked" appearance; some of the streaks have a certain sheen to them. What do you think may have caused the alternation from gray to red shale? Is it possible that some of the iron minerals in the shale were oxidized? What does this mean? Some geologists see red and think exposure to the atmosphere. The shiny streaks in the red shale resemble what geologists call "slickensides" which form on rock surfaces adjacent to faults where two rock masses have moved by one another. The streaks in this red shale resemble those observed in paleosols (ancient soil horizons). If this red shale is, in fact, a paleosol, it suggests an extremely rapid rising of sea level in order to form the immediately overlying gray, marine shale. There is evidence from other parts of the world that the Pennsylvanian period was characterized by drastic changes in sea level; could we be seeing evidence for this in this outcrop?

Below the red shale is a gray siltstone with an unusual, concave-up stratification. This resembles a type of deposit (hummocky cross-stratification) that forms in relatively shallow marine water that is only affected by large, storm-generated waves.

Below the gray siltstone is another red shale (paleosol?) and another limestone (marine).

So, reviewing what we've seen and proceeding upsection (oldest rocks to youngest rocks), we see

1. marine limestone
2. red shale (paleosol?)
3. gray siltstone (storm deposits)
4. red shale (paleosol?)
5. gray marine shale (fossils)
6. limestone and crinoid-rich shale
7. interval covered by riprap
8. stacked channel deposits of sandstone and conglomerate

We are clearly seeing evidence for a variety of depositional environments. Are we also seeing evidence for drastic rising and falling of sea level? I don't know.

Below this point the canyon gets very narrow and depending on how much standing water is present, may be difficult to examine. The rocks consist of a relatively thick sequence of alternating sandstones, siltstones, and shales. Many features typical of Ardmore Basin sedimentary rocks are present, including:

1. Burrows, also called "trace fossils" (Fig. 20).
2. Ripple marks (Fig. 15).
3. Cross beds (Fig. 17).

How many of these features can you identify in the rocks?

Return to cars. Continue driving south on Hwy. 77s around Lake Murray. Drive for 1.7 miles to the fork in the road and the sign to "Off Park Services". Stay right (leaving Hwy. 77s). Drive 0.3 miles and turn right (due south). Drive 0.7 miles and turn left (due east). Drive 0.7 miles, cross small creek, and park just on the other side of the creek.

STOP 5. PUMPKIN CREEK LIMESTONE MEMBER (BIG BRANCH FORMATION, DORNICK HILLS GROUP) AND ANTLERS SANDSTONE

Although the outcrops here may not look like much, they record a significant period of the Earth's history in this part of Oklahoma. The Pumpkin Creek Limestone Member is Pennsylvanian or, more specifically, Desmoinesian (Fig. 4), and is about 310 m.y. old. The Antlers is Lower Cretaceous, or about 125 m.y. old. Dinosaurs roamed this part of Oklahoma during the Cretaceous and, in fact, nearly complete skeletons of the carnivore Acrocanthosaurus have been found in the Antlers Sandstone near the towns of Atoka and Broken Bow. By way of contrast, dinosaurs hadn't yet evolved in the Pennsylvanian.

Look at the rather poor outcrops of the Pumpkin Creek in the bar ditch on the south side of the road. Despite the fact they are mostly sandstone, they are still part of the Pumpkin Creek Member. Are they tilted or flat lying? Now look at the Antlers on either side of the road just up the hill. Is it tilted or flat lying? Also compare the hardness of the Pumpkin Creek rocks and the Antlers "rocks". Which formation contains real rocks and which contains "barely rocks"?

Geologists call the boundary betweeen steeply tilted rocks and less steeply tilted rocks an angular unconformity (Fig. 21). Unconformities represent a period of time in the Earth's history when no sediments were deposited at a particular locality. In this particular case, a slightly more detailed history can be worked out:

1. Deposition of sand and lime in a marine environment about 310 m.y. ago.
2. Deep burial of the sand and lime, which eventually compress and harden to form sandstone and limestone.
3. Tilting (probably due to folding and faulting) of the sandstone, limestone, and surrounding beds.
4. Uplift and erosion
5. Deposition of pebbly sand on the tilted limestone about 125 m.y. ago.
6. Erosion to form the present exposures.

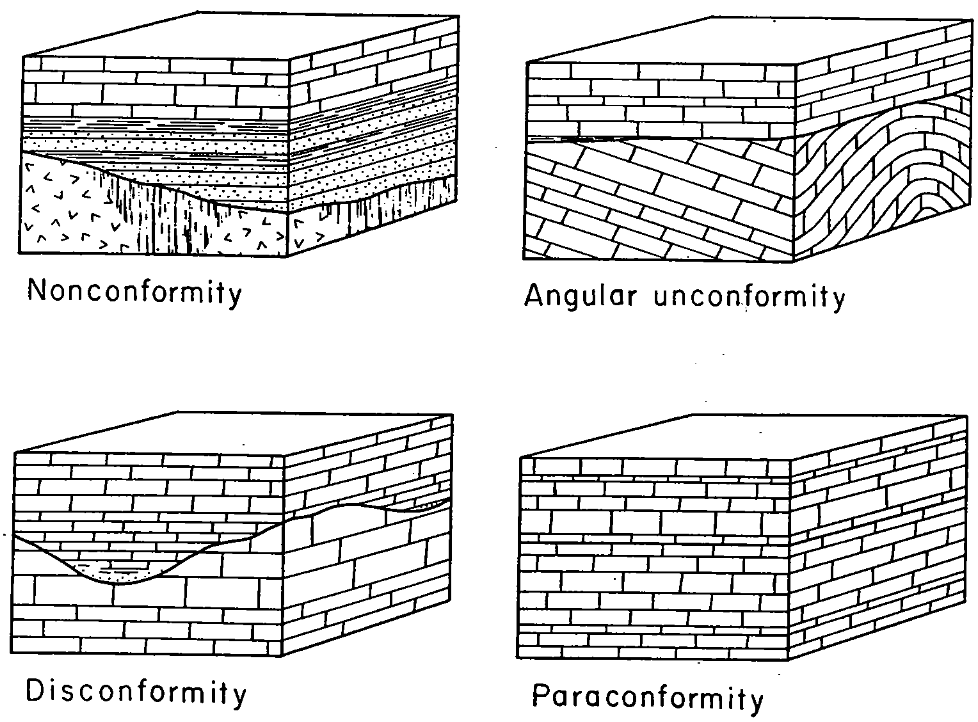

Figure 21. The four types of unconformities, each of which represents a significant erosional gap in the rock record. A *nonconformity* occurs between sedimentary rocks and older plutonic and/or metamorphic rocks. An *angular unconformity* occurs between folded and/or otherwise tilted sedimentary rocks and less tilted rocks. The bedding planes above and below a *disconformity* are parallel but there is an irregular erosional surface separating the two. A *paraconformity* is a simple bedding plane, but one that marks a significant period of non-deposition.

From this outcrop, we cannot say how long events 2, 3, and 4 took. Event no. 3 was, in fact, associated with a major period of mountain building and tectonism in this part of Oklahoma, but the evidence for the timing of that event is found elsewhere. Similarly, we cannot say how much sand or what other rocks may have been deposited on the tilted sandstone and limestone starting about 125 m.y. ago or how long it took to eroded to the present outcrop.

We can say, however, that sometime between 310 m.y. ago and 125 m.y. ago, this part of Oklahoma suffered a serious period of mountain building and erosion. That period of mountain building is called the Arbuckle orogeny and is described in the preceding section.

An interesting weathering phenomenon are the gypsum crystals weathering out of the Anters Sandstone.

End of road log.

Return to cars. To head back to camp, return to Hwy. 77s, turn right, and continue around the lake for about 1.5 miles. Turn west (left) to Group Camp 3.

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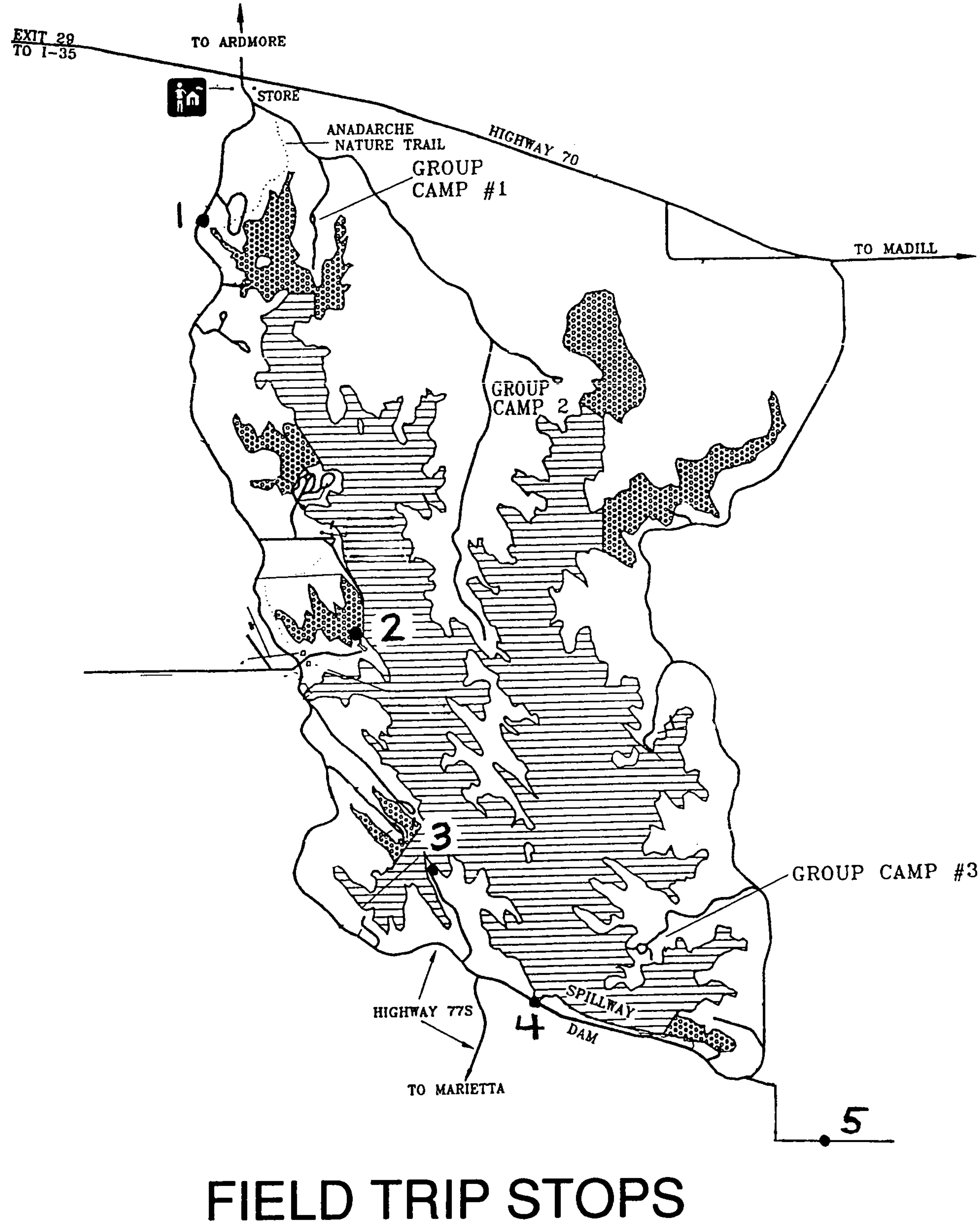

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