THE GEOLOGY OF THE TALLGRASS PRAIRIE PRESERVE, OSAGE COUNTY, OKLAHOMA

AN INTRODUCTION AND FIELD-TRIP GUIDE

Oklahoma Geological Survey
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AN INTRODUCTION AND FIELD-TRIP GUIDE

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Prepared for a Meeting of the
Legacy Club Members
Oklahoma Chapter, The Nature Conservancy

Tallgrass Prairie Preserve, Oklahoma
April 1, 2000

PHYSIOGRAPHY OF THE TALLGRASS PRAIRIE PRESERVE

Perhaps the most immediate and striking features of The Nature Conservancy's Tallgrass Prairie Preserve, particularly in the winter when the vegetation doesn't draw the visitor's attention, are its landforms. The gently rolling hills, peaked to flat-topped ridges, broad valleys, and meandering streams are major factors that influence greatly the kinds of vegetation (and therefore, animal life) in the area. The topography (or physiography), in turn, reflects the geology of the preserve.

On a broad scale, Osage County and most of north-central Oklahoma and south-central Kansas are in what is called the Osage section (more commonly called the Osage Plains) of the Central Lowland Physiographic Province of the U.S. (Fenneman, 1938). (A physiographic province is defined as "a region whose pattern of relief features or landforms differs significantly from that of adjacent regions" [Glossary of Geology, 1997, published by the American Geological Institute]. It is also "a region of which all parts are similar in geologic structure and climate and which has consequently had a unified geomorphic history.") The Osage Plains are "a plain of low relief, interrupted at intervals by east-facing escarpments which indicate the presence of stronger strata in a great mass of relatively weak rocks dipping gently west or northwest" (Fenneman, 1938, p. 605). All of the rocks in the Osage Plains are Pennsylvanian (323 to 290 million years old) or Permian (290 to 245 million years old) in age and consist of limestone and sandstone, which are relatively resistant to erosion and tend to form the tops of ridges and hills, and shale, which is easily eroded and tends to form slopes and valleys.

In detail, however, Osage County is in two relatively distinct physiographic "sub-provinces" - the Eastern Sandstone Cuesta Plains to the east and the Northern Limestone Cuesta Plains to the west (Johnson and others, 1972, p. 3) (Fig. 1). Most of The Nature Conservancy's Tallgrass Prairie Preserve is in the Eastern Sandstone Cuesta Plains. As one might guess, the eastern cuestas are formed mostly by sandstone beds and the western cuestas by limestone beds, and, indeed, most of the ridges and hills in the Preserve are capped by sandstone. (A cuesta is a hill or ridge with a gentle slope on one side and a steep slope on the other; commonly, the gentle slope conforms to a tilted resistant bed and the steep slope is capped by the resistant bed but forms on the less resistant rocks beneath it. See figure 2.) To a remarkable degree, the boundary between the sandstone and limestone plains follows a major drainage divide separating streams that flow generally east into the Caney or Verdigris Rivers (e.g., Buck, Sand, Bird, and Hominy Creeks) and those that flow generally south into the Arkansas River (e.g., Salt, Gray Horse, and Sycamore Creeks) (Fig. 1). The topography and vegetation of northern Osage County also reflects the two different plains; in general, the Northern Limestone Cuesta Plains are gently rolling, grass-covered hills, whereas the Eastern Sandstone Cuesta Plains are more rugged and typically covered with oak trees. However, because much of the Preserve is located along the western edge of the sandstone plains, it reflects many of the characteristics of the limestone plains.

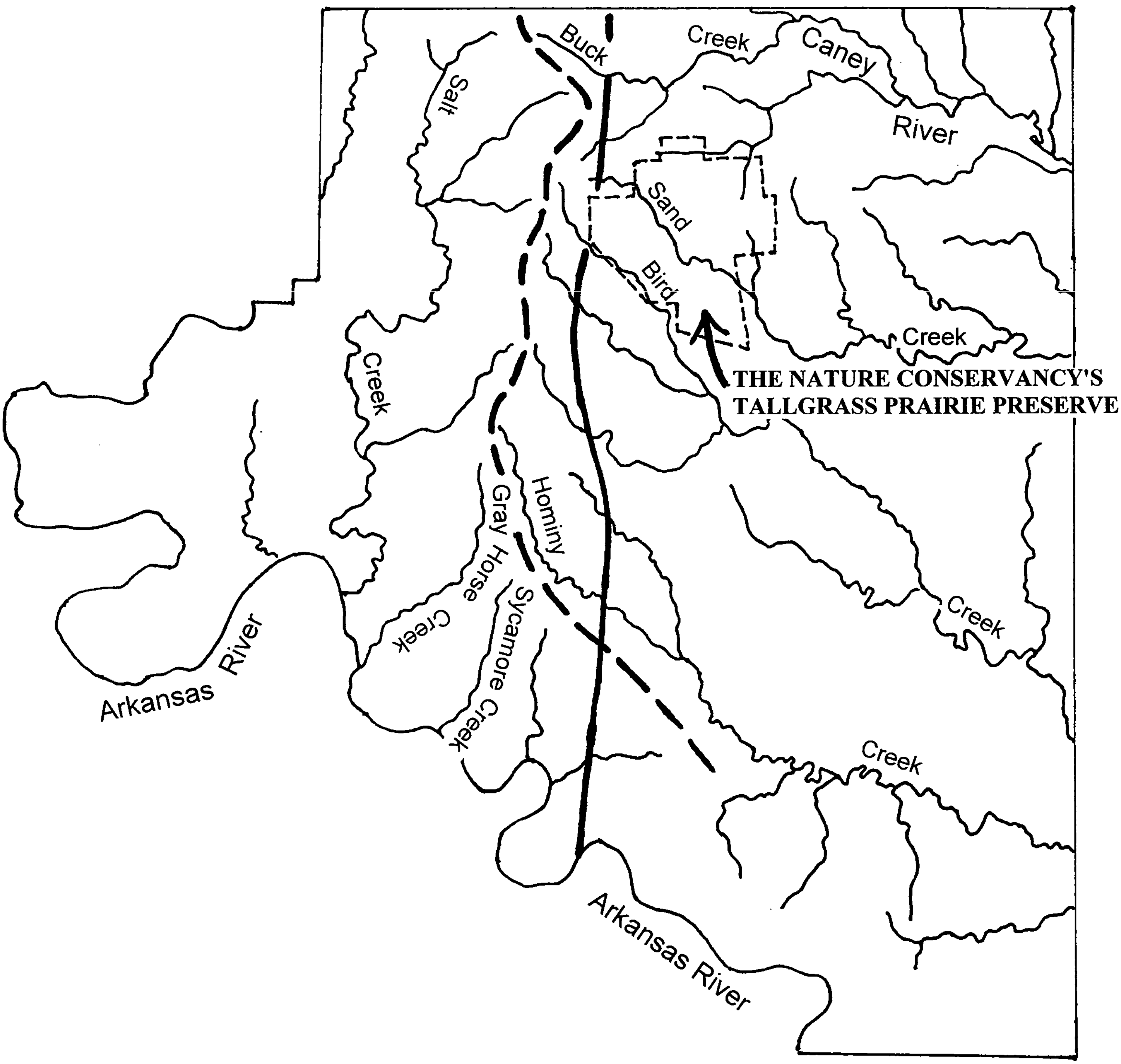


Figure 1. Map of major streams and rivers, Osage County. Heavy dashed line is divide between Arkansas River drainage on west and Caney/Verdigris Rivers drainage on east. Heavy solid line separates Northern Limestone Cuesta Plains to west and Eastern Sandstone Cuesta Plains to east. Approximate outline of The Nature Conservancy's Tallgrass Prairie Preserve shown in northern part of county.

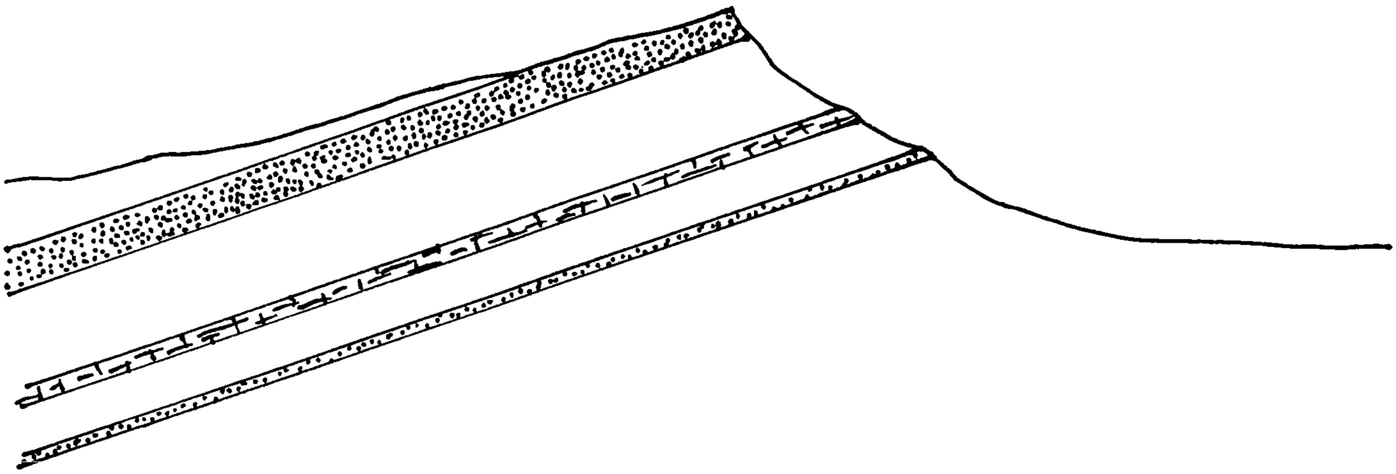


Figure 2. Cross-section sketch of cuesta. A relatively thick sandstone bed (stippled pattern) that resists erosion forms the top of the cuesta and much of the gentle slope to the left. Most of the steep slope beneath and capping sandstone is underlain by soft, easily eroded shale (unmarked). The two small "bumps" on the steep slope are caused by outcrops of thin limestone (top, brick pattern) and sandstone (bottom, stippled pattern) beds.

The western part of the Northern Limestone Cuesta Plains subprovince, if extended north into Kansas, would partly overlap the famous Flint Hills. The Flint Hills are so named because the limestone beds in the area contain abundant flint (chert), blocks of which remain on the surface long after the limestone in which they are found is eroded. Although the same limestone beds that occur in the Flint Hills also are present in Oklahoma, they contain less chert; hence, the "Flint" Hills gradually disappear southward. The rocks of the Kansas Flint Hills and the equivalent rocks in Oklahoma are Permian; as such, they are younger than those found in the Tallgrass Prairie Preserve. These younger formations are present west of the preserve because the strata are tilted to the west.

An interesting physiographic feature of Osage County identified by Ham (1939) is the Pawhuska Rock Plain. (Dr. William E. Ham is one of Oklahoma's preeminent geologists; his geologic work on the Arbuckle Mountains is still the standard for that area.) In his master's thesis at the University of Oklahoma, Ham (1939) noted that many of the hill-tops throughout much of eastern Oklahoma and southeastern Kansas have a remarkably similar elevation of about 1000 feet. He interpreted this planar feature as a relatively young (less than about 2 million years) erosion surface that developed on widely different types and ages of rocks. He suggested that the erosion surface developed between two (of the four) Pleistocene glacial periods and that it was originally remarkably smooth, but has since been dissected. To my knowledge, the existence of an extensive Pleistocene erosion surface in Oklahoma has not been addressed since Ham's 1939 thesis.

GEOLOGY OF THE TALLGRASS PRAIRIE PRESERVE

STRATIGRAPHY

As stated above, all the rocks in the Tallgrass Prairie Preserve are Pennsylvanian in age (323 to 290 million years old). A more precise age of the rocks is Virgilian (the most recent of five subdivisions of the Pennsylvanian), which lasted from about 298 to 290 million years ago. The most detailed studies of the geology of the Tallgrass Prairie area are White (1922), Beckwith (1928), Carter (1954), and Shannon (1954). Other studies (cited below) focus on particular aspects of the geology of the area, for example, the structure (folds and faults). The most recent moderately detailed geologic map of the area is by Bingham and Bergman (1980); however, that map is mostly a compilation of earlier maps and contains several controversial stratigraphic correlations. All these studies agree in a general way on the stratigraphy and structure of the Tallgrass Prairie area; they differ slightly in the way they name certain limestone beds and the way they group different limestone and sandstone beds into formations and groups (Fig. 3). For the purposes of this report, these slight differences in names and groupings are not important and, for convenience and uniformity, the terminology used by Carter (1954) and Shannon (1954) will be followed.

The oldest geologic unit in the Tallgrass Prairie Preserve is the Elgin Sandstone (Stop 7), which is at or near the top of the Vamoosa Formation (Shawnee Group) (Fig. 3). Exposures of the Elgin Sandstone are present in the southernmost part of the preserve along Little Sand Creek.

The next youngest formation is the Pawhuska Formation (also Shawnee Group) (Stops 5 and 6), which consists of a series of interbedded unnamed shale and sandstone beds and named limestone beds (Fig. 3). The limestones are, from oldest to youngest, the Lecompton, Plummer, Deer Creek, Little Hominy, Pearsonia, and Turkey Run Limestones. In places, the Lecompton is subdivided into three units: the Beil Limestone at the base, King Hill Shale in the middle, and Avoca Limestone at the top. These limestones and shales crop out in the eastern part of the preserve.

The youngest geologic unit is the Wabaunsee Group (Fig. 3) (Stops 1, 2, and 3). Although Carter (1954) subdivided the underlying Shawnee Group into formations (e.g., the Vamoosa and Pawhuska), for some reason he did not divide the Wabaunsee into individual formations. The Wabaunsee, like the Pawhuska, consists largely of interbedded shale, sandstone, and limestone beds; unlike the Pawhuska, however, the shale beds in the Wabaunsee are named and locally contain coal. From oldest to youngest, the Wabaunsee consists of the Severy Shale (including the Nodaway coal), Bird Creek Limestone (Stops 1 and 2), White Cloud Shale, Happy Hollow Limestone, Cedarvale Shale (including the Elmo coal), Rulo Limestone, an unnamed shale (locally divided into the Silverlake Shale, Burlingame Limestone, and Soldier Creek Shale), Wakarusa Limestone (Stop 3), Auburn Shale, and the Stonebreaker Limestone (divided into the Reading Limestone, Harveyville Shale, and Elmont Limestone). The upper part

WHITE (1922)		BECKWITH (1928)		CARTER (1954), SHANNON (1954)			BINGHAM AND BERGMAN (1980)	
				WABAUNSEE GROUP		Upper Virgil	VANOSS GROUP	
						Elmont Limestone		Elmont Limestone
	Stonebreaker Limestone	BUCK CREEK FORMATION	Stonebreaker Limestone			Harveyville Shale (inc. coal)		Stonebreaker Shale
						Reading Limestone (inc. coal)		Reading Limestone
					STONEBREAKER LS.	Auburn Shale		Auburn Shale
	Cryptozoon-bearing Limestone		Cryptozoan-bearing Limestone			Wakarusa Limestone		Wakarusa Limestone
						Soldier Creek Shale		
						Burlingame Limestone		unnamed shale
						Silverlake Shale		
						Rulo Limestone	ADA GROUP	Rulo Limestone
						Cedarvale Sh. (inc. Elmo coal)		unnamed shale
						Happy Hollow Limestone		Happy Hollow Limestone
						White Cloud Shale		unnamed shale and sandstone
	Bird Creek Limestone		Bird Creek Limestone			Bird Creek Limestone		Bird Creek Limestone
						Severy Sh. (inc. Nodaway coal)		Severy-Aarde Shale
	Turkey Run Limestone		Turkey Run Limestone	SHAWNEE GROUP	PAWHUSKA FORMATION	Turkey Run Limestone		Turkey Run Limestone
PAWHUSKA LIMESTONE		PAWHUSKA FORMATION				unnamed shale		unnamed shale
	"Red Lime"		Red Limestone			Pearsonia Limestone		Pearsonia Limestone
						unnamed shale		unnamed shale
	Little Hominy Limestone		Little Hominy Limestone			Little Hominy Limestone		Little Hominy Limestone
						unnamed shale		unnamed shale
	Deer Creek Limestone		Deer Creek Limestone			Deer Creek Limestone		Deer Creek Limestone
						unnamed shale		unnamed shale
	Plummer Limestone		Plummer Limestone			Plummer Limestone		Plummer Limestone
						unnamed shale		
						Avoca Limestone } Lecompton Limestone		
	Lecompton Limestone		Lecompton Limestone			King Hill Shale } Lecompton Limestone		
			Okey Limestone			Beil Limestone } Lecompton Limestone		Beil Ls. Mbr. of Lecompton Ls.
	Elgin Sandstone		Elgin Sandstone		VAMOOSA FM.	Kanawaka Shale		unnamed shale and sandstone
						Elgin Sandstone at top		

Figure 3. Correlation chart of Upper Pennsylvanian strata exposed in The Nature Conservancy's Tallgrass Prairie Preserve.

of the Wabaunsee consists of a unit Carter (1954) called the Upper Virgil, but he did not study it in any detail.

Despite the array of names and complicated (in detail) stratigraphy, the single overwhelming feature of the geology of the preserve is the monotonous repetition of shale, limestone, and sandstone beds, with only minor variations, like coal, thrown in to make things interesting. This repetition is reflected in the topography of much of the preserve: a succession of low sandstone-capped hills and cuestas whose smooth slopes underlain by easily eroded shale are locally broken by small "bumps" underlain by limestone or thin sandstone beds (Fig. 2). The repetition of shale, limestone, and sandstone beds throughout the Tallgrass Prairie Preserve is a feature of the geology of much of the midcontinent, albeit with some variations. The term *cyclothem* was coined to describe this cyclic repetition of geologic strata and recently has been used in the context of global climate change and worldwide glaciation.

CYCLOTHEMS AND THE CONCEPT OF SEQUENCE STRATIGRAPHY

Pennsylvanian-aged rocks throughout the world are characterized by a certain degree of repetitiveness, in other words, a particular sequence of rock types that repeats itself vertically. The repetitive character of Pennsylvanian-aged rocks in the midcontinent of North America was first recognized almost 90 years ago and the term *cyclothem* was coined in 1932 for the kind of sequence of rocks that occurred there. Geologists have long recognized that the deposition of cyclothems resulted from a peculiar set of circumstances that coincided in the midcontinent during the Pennsylvanian, but have disagreed on exactly what those circumstances are.

Cyclicity of geologic events occurs on many scales. Perhaps the largest scale (representing the longest period of time) was first recognized by Sloss (1963), who identified six major periods of deposition of sediments in North America (Fig. 4). These major periods of sediment deposition (from oldest to youngest, the Sauk, Tippecanoe, Kaskaskia, Absaroka, Zuni, and Tejas) are represented by thick accumulations of sedimentary rocks, particularly on the east and west coasts. There, the periods are separated by five relatively brief intervals of non-deposition; i.e., rocks of certain ages are not present in the geologic record in certain areas. In the middle of the continent, in contrast, the periods of non-deposition are relatively long and are separated by brief periods of deposition. Figure 4 shows that the Pennsylvanian was one of the time periods when sediments were deposited in the midcontinent; Sloss (1963) called these rocks part of the Absaroka sequence. These sedimentary sequences (or cycles of deposition) last about 60 to 140 million years and are believed to be caused by changes in the volume of mid-ocean ridges and/or seafloor spreading rates. As such, the "Sloss sequences" are fundamentally tectonic (i.e., related to periods of mountain building, albeit submarine) and are controlled by plate-tectonic processes.

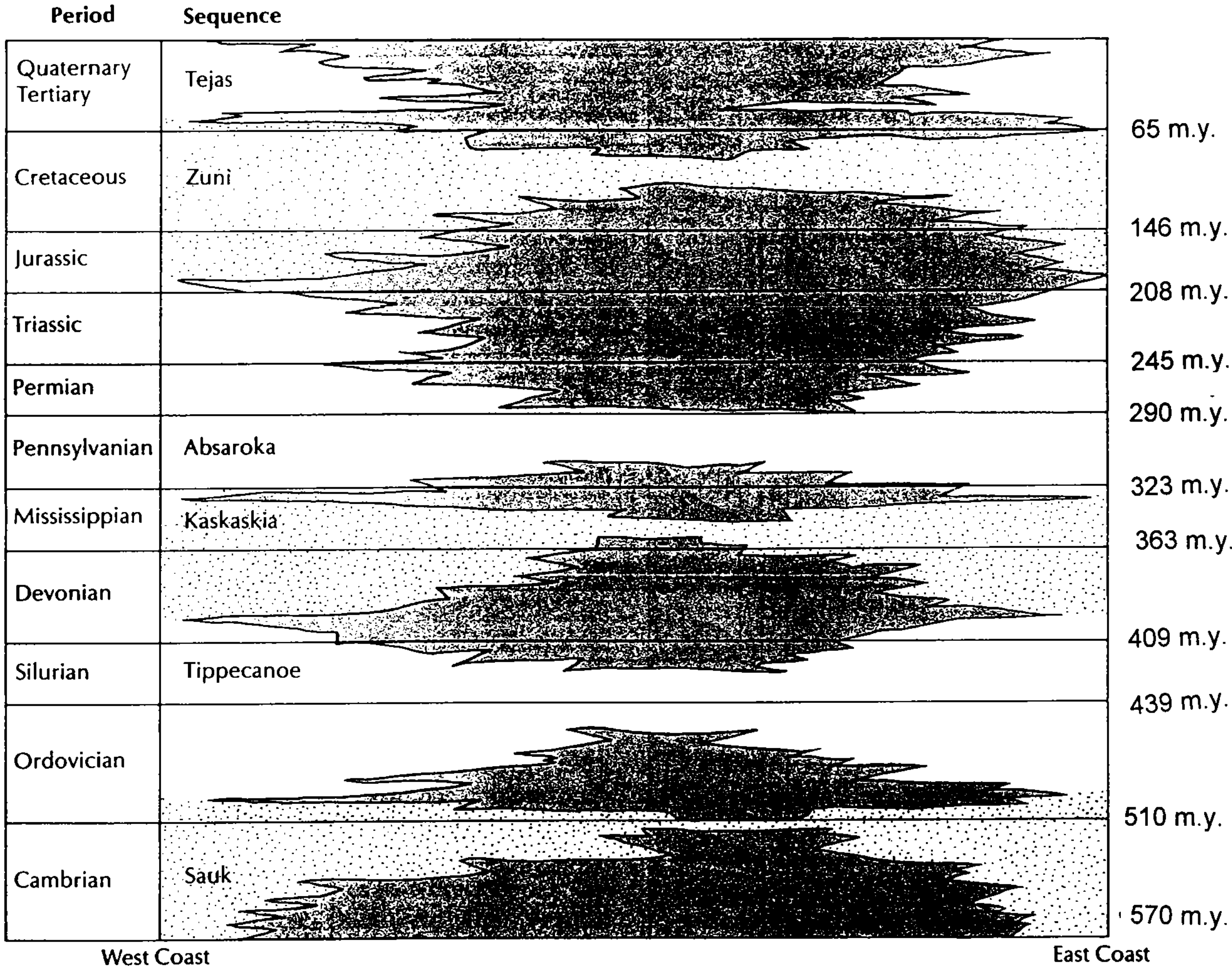


Figure 4. Major sedimentary sequences of North America (Sloss, 1963). Sedimentary rocks on the west coast are represented on the left side of the diagram; sedimentary rocks on the east coast are on the right; and those of the mid-continent are in the center. Dark areas represent large gaps in the geologic record caused by either nondeposition of sediments or deposition and subsequent erosion. This diagram shows that sedimentation has been almost continuous for the last 570 million years on the tectonically active east and west coasts, but interrupted for significant periods of time on the stable continental interior. These "Sloss sequences" also occur in South America and Russia.

Note that the outlines of the "Sloss sequences" on figure 4 are not smooth; they are, in fact, very jagged lines. This indicates that boundary between areas of deposition and non-deposition did not progress uniformly and without interruption from the Rockies and Appalachians to the midcontinent; rather, the oceans (sites of deposition) advanced inland (high area - site of non-deposition) for a while, only to retreat briefly before recommencing their advance inland. During the Pennsylvanian, the midcontinent was covered by ocean and sediments were deposited there. Throughout the Permian and Triassic, the sea retreated (albeit sporadically readvancing), leaving the midcontinent entirely by the end of the Triassic. These sporadic smaller-scale advances and retreats of the ocean each last about 0.5 to 7 million years and are called "third-order cycles" according to modern terminology. (Modern concepts of geologic cyclicity are largely based on the work of a group of Exxon researchers. Vail and others (1977) is probably the seminal work in this field of research. The "Sloss sequences" are "second-order cycles" in the Exxon scheme; we have ignored the still-larger-scale "first-order cycles".)

Figure 5 is a refinement of the Sloss sequence diagram showing how sea level has changed throughout the Paleozoic. As sea level rises ocean water, which "always" covers the deep ocean basins, advances across the shelf. (This advance is referred to as "coastal onlap".) For example, the period of time from the Early to Late Devonian was marked by a relatively steady advance of the sea across the shelf (rising sea level) and was followed by an unsteady retreat (falling sea level) throughout the Mississippian. The Devonian and Mississippian shelf deposits left behind are the Kaskaskia sequence of Sloss (1963) (Fig. 4). The carefully drawn "spikes" on the Devonian - Mississippian sea-level curve are third-order sea-level rises and falls.

As one might guess, "fourth-order cycles" of ocean advance and retreat are superposed on the "third-order cycles". The "fourth-order cycles" last between 0.2 and 0.4 million years and are called cyclothems which, as stated above, are the fundamental Pennsylvanian stratigraphic unit in the midcontinent. Geologists generally agree that the repetitive or cyclic character of sedimentary rocks in the midcontinent is caused by sea-level fluctuation - certain kinds of sediments are deposited when an area is inundated by the sea; different kinds of sediments are deposited in a shoreline environment; and still others accumulate in a river-delta setting (Figs. 6A and B). (And none are deposited in the highlands away from the ocean.)

Although several different ideas have been proposed in the past to explain the cyclic nature of midcontinent sedimentation (e.g., widespread gentle uplift followed by subsidence; "delta-switching"), most geologists now agree that the rise and fall of sea level were caused by the decay and growth of continental ice sheets. When the Earth's climate cools, so much water is trapped in the form of glaciers that sea level lowers. (During the maximum extent of the Pleistocene glaciers, sea level was about 300 feet lower than it is now.) When the climate warms, the glaciers melt and sea level rises. Thus, the repetition of shale, limestone, and sandstone layers in the Pawhuska Formation and Wabaunsee Group on the Tallgrass Prairie Preserve (like other cyclothem formations throughout much of the midcontinent) are evidence for sea-level fluctuation (Fig.7) which, in turn, was probably caused by repeated periods of glaciation about 295 million years ago. (In northern Osage County, the simple rise and fall of sea level probably was complicated somewhat by periodic "invasions" of deltas.)

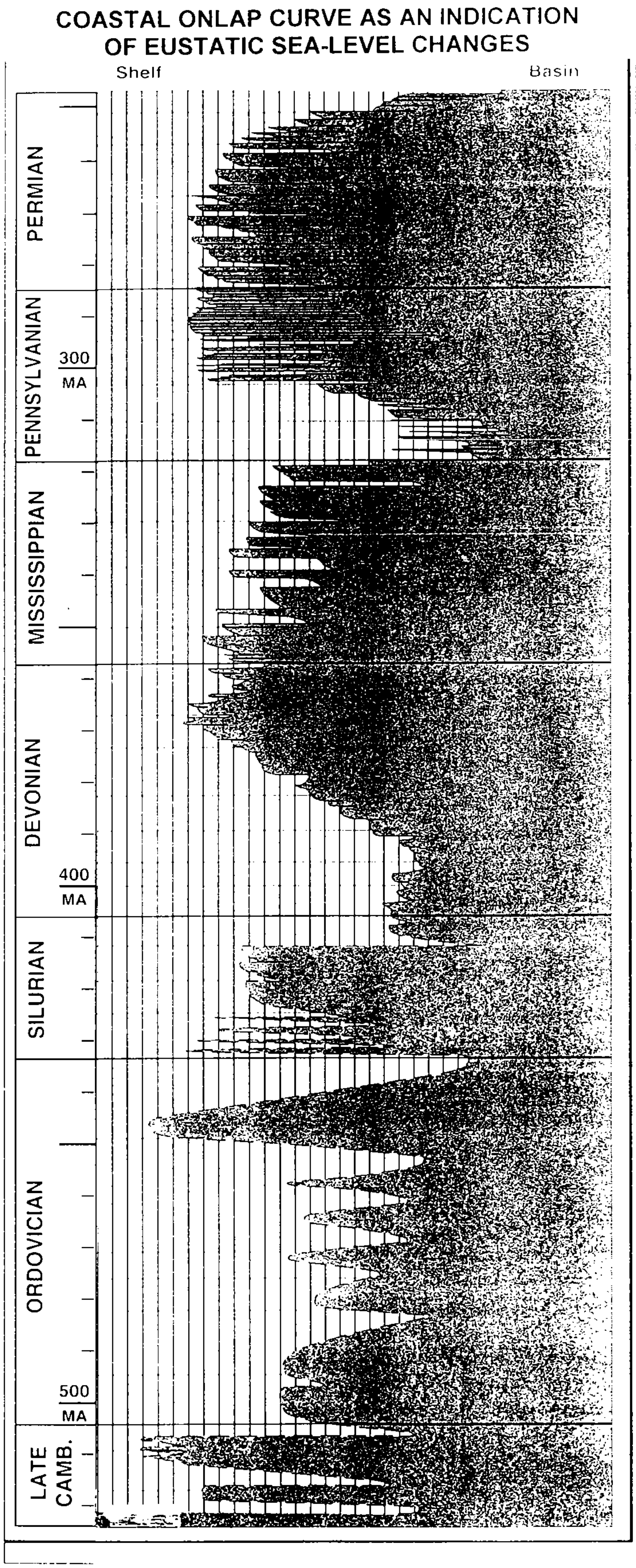


Figure 5. Coastal onlap curve for the Paleozoic (modified from Shelton and Gerken, 1995; based on other authors). Sea-level rise (marine advance) is shown on this diagram as a "finger" of dark gray (representing presence of ocean water and deposition of sedimentary rocks) extending to the left from the ocean basin to the shelf. Note the numerous and rapid advances and retreats in the Pennsylvanian.

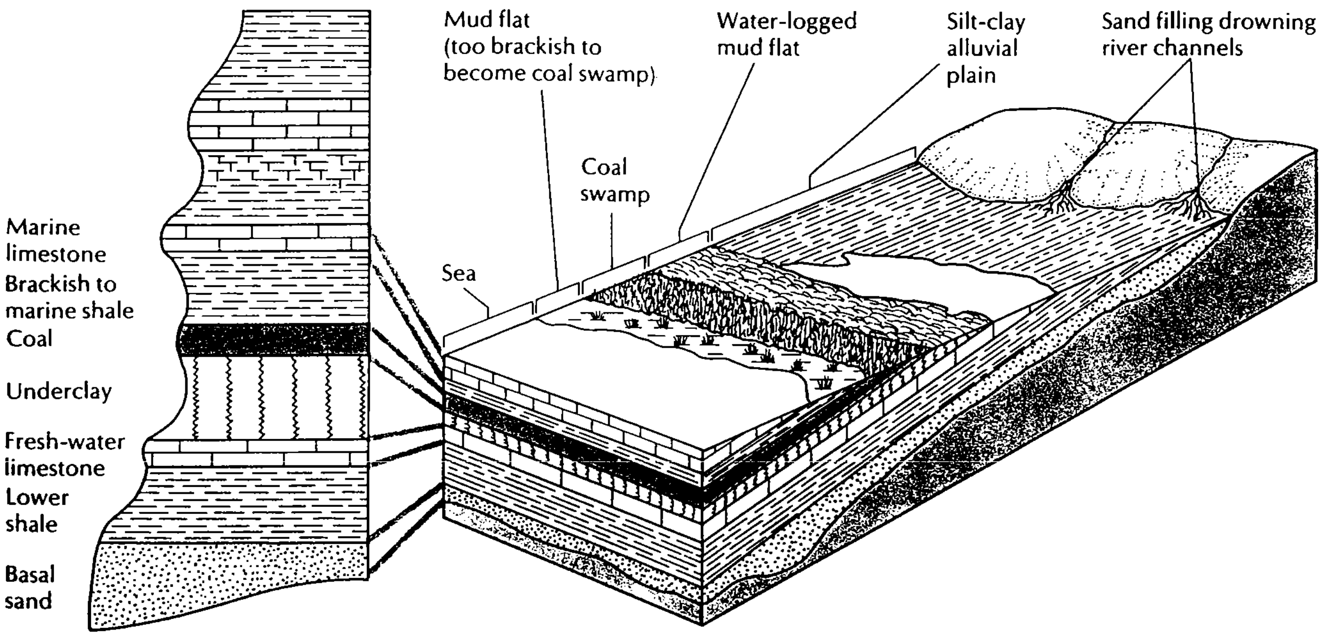


Fig. 6A. Idealized relation of rock types in "classic" cyclothem to sedimentary environment (from Prothero, 1990). If sea level rises, all the environments will "march" landward and, for example, marine limestone will overlie the coal. If sea level falls, the environments will "retreat" seaward and coal will overlie marine limestone. The cyclic repetition of rock types represent the rise and fall of sea level (Fig. 6B).

The primary cause of the Pennsylvanian temperature variations probably is changes in the amount of sunlight received by the Earth. These changes, in turn, are caused by variations in the Earth's orbital geometry which affect its orientation to and distance from the sun. The variations in orbital geometry are called *Milankovitch cycles* and it was the geologic effect of Milankovitch cycles on worldwide sedimentary sequences over the last 550 million years of geologic time that was the focus of the Exxon research described above. An incredible effort!

There are three reasons the concept of cyclothems was developed in the midcontinent. 1) The Pennsylvanian was a time of multiple continental-scale glaciations. 2) The middle of North America was flat and very low; hence, small changes in sea-level had far-reaching effects. 3) The midcontinent was tectonically stable and far from any mountain ranges. Factors 1) and 2) allowed the effects of glaciation to be exceptionally well preserved. Factor 3) eliminated a complicating effect. Crustal movement can interrupt the regular pattern of marine retreat and advance.

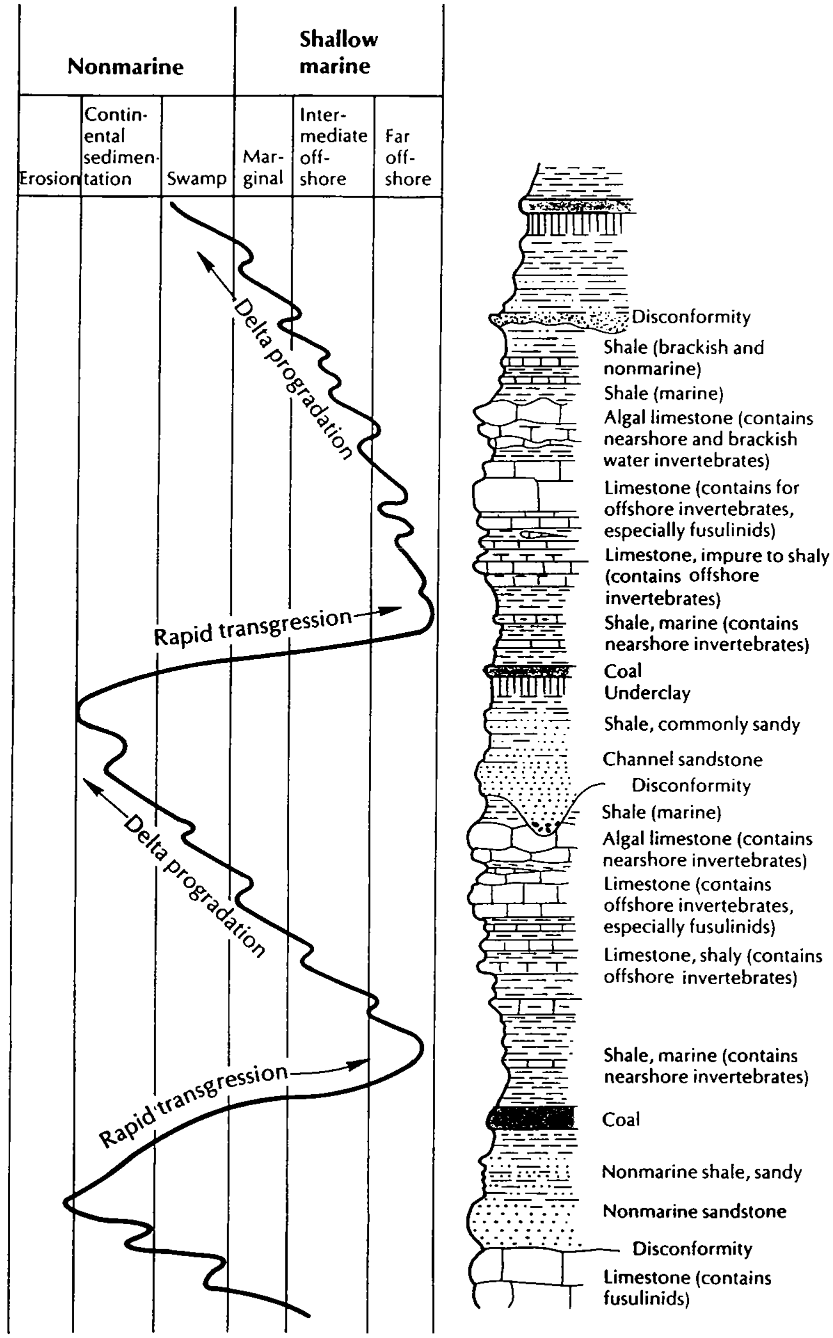


Fig. 6B. Relation of rock types to sea level in "classic" cyclothem (modified from Prothero, 1990). "Rapid transgression" means rise of sea level; delta progradation is equivalent to fall of sea level. Alternating limestone, shale, and sandstone of the Pawhuska Formation cyclothems probably record far-offshore to marginal-marine conditions. Coal in the Wabaunsee Group is evidence for shallower conditions (swamp).

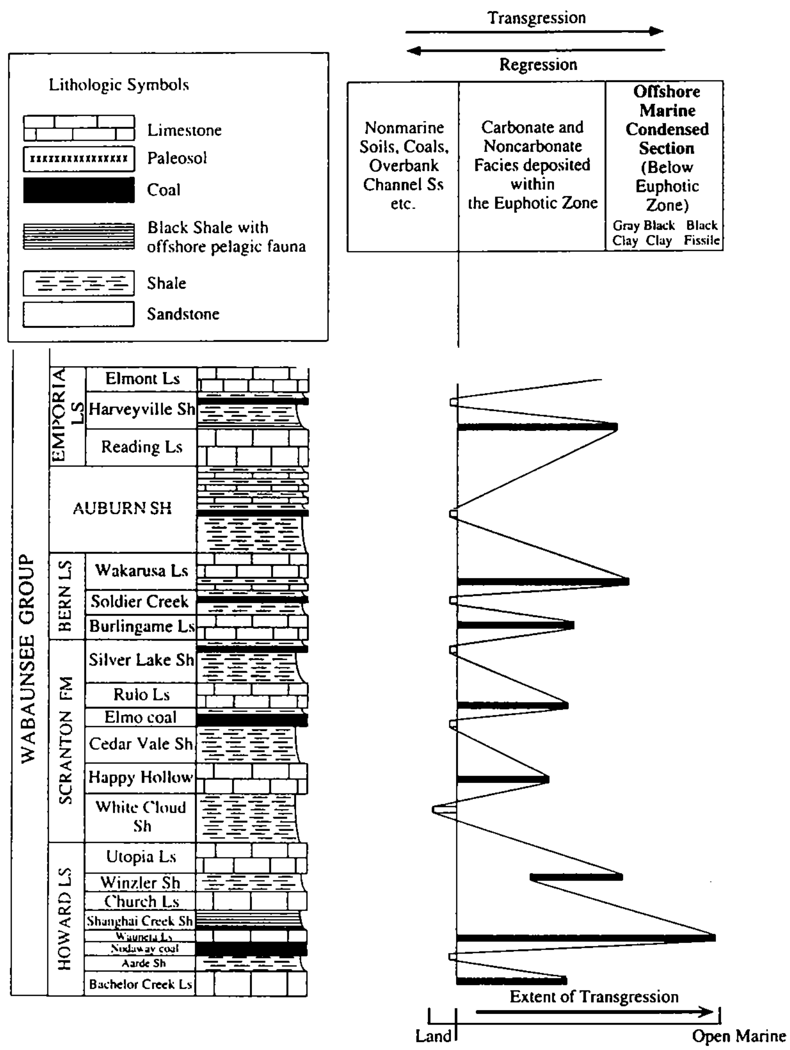


Fig. 7. Relation of sea level and strata of the Wabaunsee Group (modified from Boardman and others, 1995). (The additional formation names are Kansas terminology.)

STRUCTURE AND PETROLEUM PRODUCTION

As most visitors to the Tallgrass Prairie Preserve are aware, oil and gas have played a major role in the development of Osage County (Fig. 8) (Stop 4). Franks (1980) has described early petroleum industry activity in the county and Smith (1996) has described some of the triumphs and tragedies of the people who lived and worked there. This brief report will not attempt to repeat the history of oil and gas exploration and development in Osage County; rather, it will describe how the surface geology is related to the oil and gas fields and what subsurface formations produce petroleum and why.

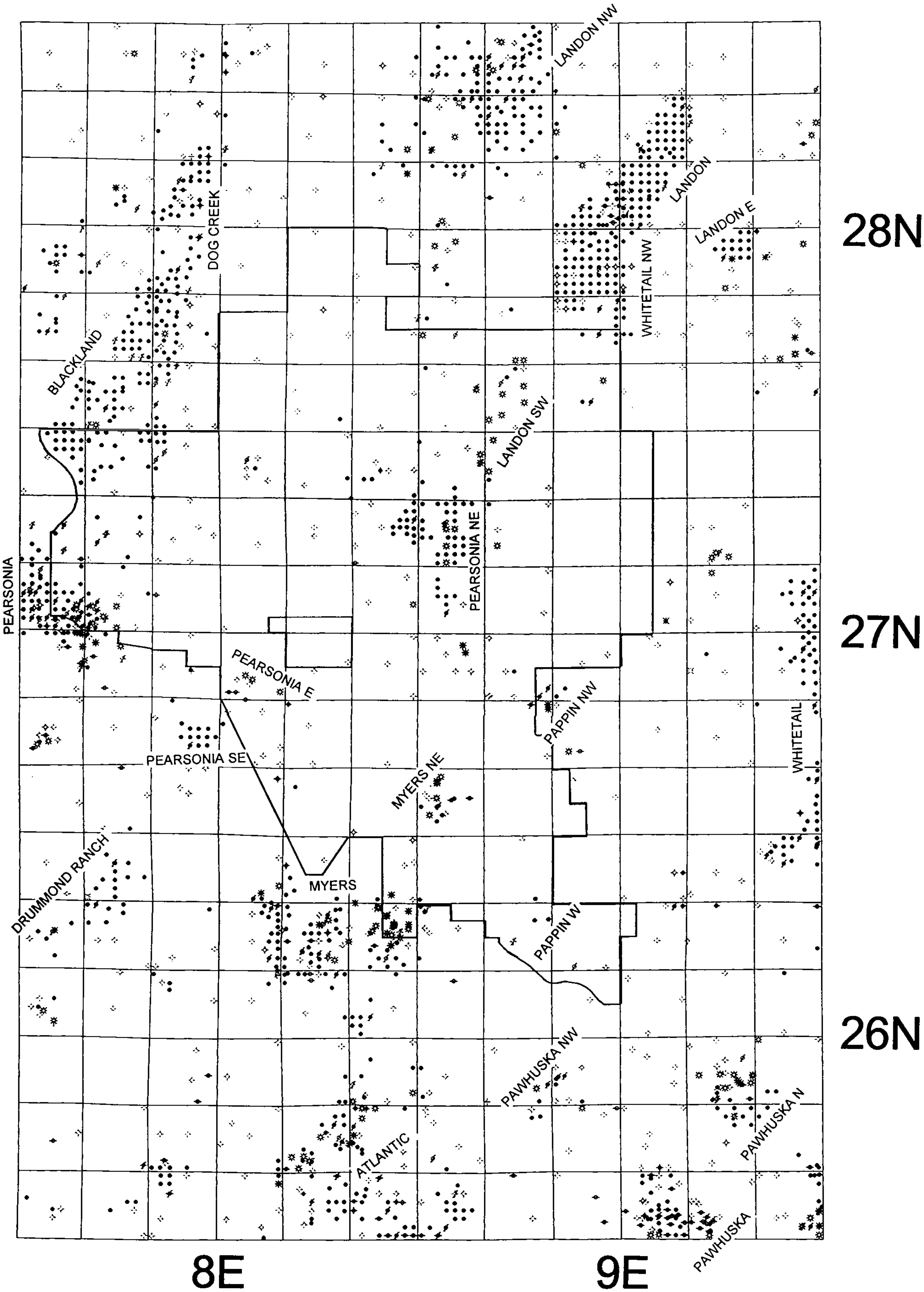


Figure 8. Map of oil, gas, dry and abandoned, and other kinds of petroleum wells in the Tallgrass Prairie Preserve and vicinity. The name of some of the larger oil and gas fields are also shown.

The first oil well in Osage County (then the Osage Reservation) was drilled in 1896, but reported only a show of oil. Exploration continued, albeit sporadically; and by 1901, there were only five producing wells in the county. Oil discoveries and production began to increase dramatically in 1903 and in 1905, almost 2 million barrels of oil were produced (Franks, 1980).

The first public geologic studies of the Osage Reservation were conducted by the U.S. Geological Survey. The introduction to the published results of this work (White and others, 1922) gives the reasons why the USGS was interested in the area:

"Responding to the imperative need for increasing to the utmost the petroleum supply of the United States, the Geological Survey, since we entered the war, has largely concentrated its investigations of oil fields in the most promising undeveloped territory, such as Wyoming and the midcontinent-Texas region, and especially in the Osage Reservation in Oklahoma.

"The Osage Reservation demands particular attention at this time because (1) it contains a great acreage of unleased oil lands; (2) the productivity of the developed areas is high and well sustained; (3) anticlines and domes are numerous in the greater part of the area, and the development and tests indicate that most of the structurally favorable folds will yield oil; (4) the oil is of paraffin grade, ,,, yielding about 23 per cent of gasoline in present practice but capable of producing over 50 per cent by the best methods; (5) pipe lines and refineries are already at hand; and (6) the Office of Indian Affairs, which administers the lands, held in common by the Osage Indians, is offering leases of hundreds of quarter sections to openly competitive bidders on advertised dates. ...

"A review of the bonuses paid shows a most regrettable lack of information as to the relative values of the tracts on the part of some of the bidders and suggests that many of them had little if any geologic guidance. ... The loss of the driller in bonuses, labor, equipment, supplies, and transportation and even his loss of time and opportunity through fruitless boring in an area of distinctly unfavorable structure constitute an economic waste that affects the military efficiency of the Nation." (p. ix-x)

In summary, the presence of numerous oilfields in Osage County, the possibility of discovering more, and the war effort was the impetus for the USGS mapping.

At the time, accurate maps of the Osage Reservation did not exist. This, in addition to the very subtle folds that the USGS was trying to identify, led White (1922) to say the following about the geologists who studied the area:

"... The field work, which included plane-table mapping with telescopic alidade under many hardships in addition to those of the severe winter, was carried forward with splendid teamwork and with gallant and indefatigable emulation. In recording his admiration for the esprit and high standard of this war work, done by geologists in professional civil service, the writer believes he expresses the appreciation not only of the Geological Survey but of the oil operators as well." (p. x)

The geologic formations in the Tallgrass Prairie Preserve and throughout Osage County appear almost horizontal; in fact, they are tilted very gently about 35 to 40 ft/mi to the west. In addition to the regional tilt, the rocks are folded into numerous low-amplitude anticlines (upfolds) and domes. The presence and location of these folds (Fig. 9) was one of the major discoveries made by the USGS. Brown (1928) identified 151 domes in Osage County and Millikan (1920) noted that most of them occurred in the east half of the county (Fig. 10). (The line dividing the "folded" from "little-folded" parts of the county runs almost northeast-southwest through the middle of the Preserve.) The domes are very subtle; in some cases, they rise vertically only 10-20 ft over a horizontal distance of a mile. Clearly, to identify such subtle features attests to the accuracy of the USGS work.

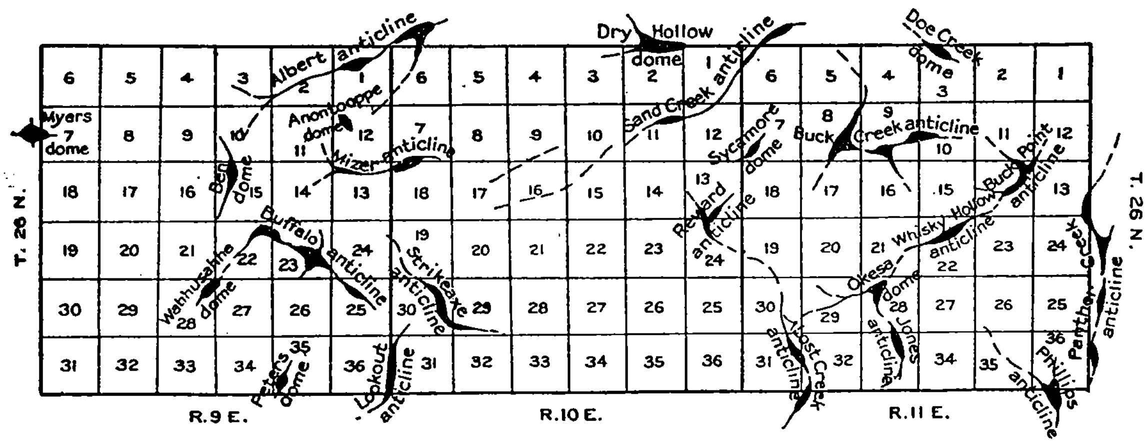


Figure 9. Sketch map from original USGS publication (White, 1922, fig. 21) showing approximate location of anticlines in T. 26 N., Rs. 9, 10, and 11E. The southern part of the Tallgrass Prairie is in the northwestern quarter of T. 26 N., R. 9 E.

The origin of the folds is controversial. Brown (1928) summarizes many of the ideas on the origin of the folds and concluded that they were caused by compressive stresses acting equally in all directions; this idea was strongly criticized by Kitson (1928). Most geologists familiar with the midcontinent would probably agree that the folds observed on the surface (and that extend into the subsurface) are related in some way to the basement[1], but exactly how is debateable.

footnote: (1) Geologists define "the basement" as the crust of the Earth below the sedimentary deposits, usually granitic or metamorphic rocks. The depth to basement is about 2500 ft on the east side of Osage County and 4500 ft on the west side.

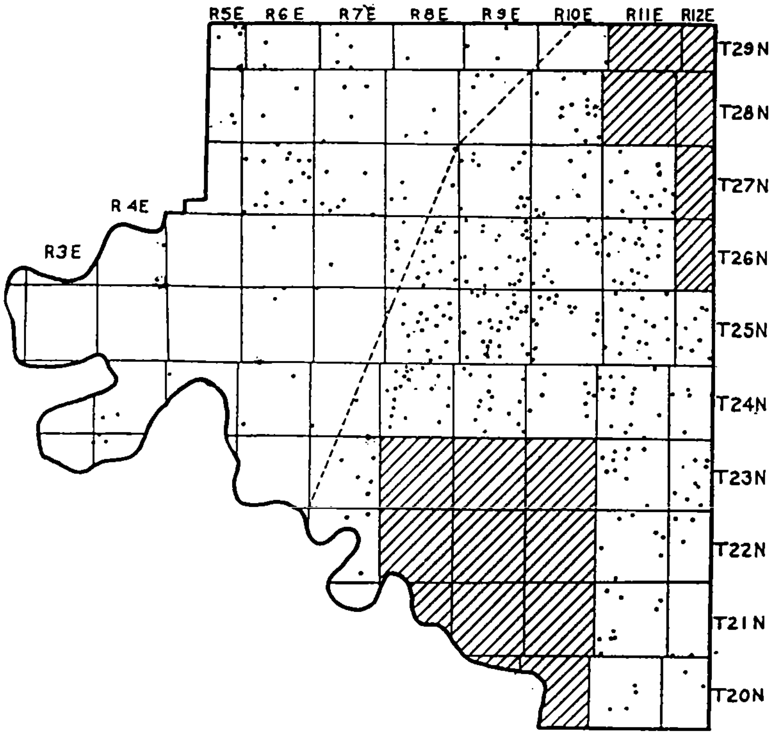


Figure 10. Map showing predominance of folds in eastern part of Osage County compared to western part (Millikan, 1920, fig. 1). Dots represent domes and doubly-plunging anticlines.

A detailed description of the geology of the oilfields of Osage County is beyond the scope of this brief report. It is probably safe to say that most of the oil and gas fields in Osage County are "related to but not necessarily controlled by" domes and anticlines (Beckwith, 1928, p. 39). In other words, the reservoir quality of a potential petroleum-bearing formation can be as important a factor as that formation's position on a fold. The exploration for and development of many of these fields has shown that the folds extend to considerable depth.

Most of the petroleum reservoirs in Osage County are between 500 and 3000 ft deep - relatively shallow by industry standards. The formations that produce oil and gas are older than those exposed at the surface in the Preserve; they include, from youngest to oldest, several Pennsylvanian sandstones and limestones (especially the Bartlesville and Burgess Sandstones and Ft. Scott Limestone), limestone of Mississippian age, and cherty limestone (Arbuckle Group) of Ordovician age.

PALEONTOLOGY

The limestones that make up cyclothems contain abundant and varied invertebrate fossils representing a number of different phyla. Many fossils are too small to be seen without a microscope; others, which typically are of more interest to visitors and collectors, can be seen easily with the naked eye. The most primitive visible fossil in the Pennsylvanian formations of the Tallgrass Prairie Preserve is the single-celled fusulinid foraminiferan *Triticites (sp.)* (Fig. 11). The fusulinids are among the largest of the "forams", which are related to the modern, soft-bodied amoeba. Forams are marine organisms that secrete a skeleton composed of calcite ($CaCO_3$) and consisting of a series of tiny chambers, the shape and arrangement of which defines the species. The chambers of the fusulinids are elongate and arranged in a coiled fashion, resulting in an overall shape resembling a wheat grain or very, very small football.

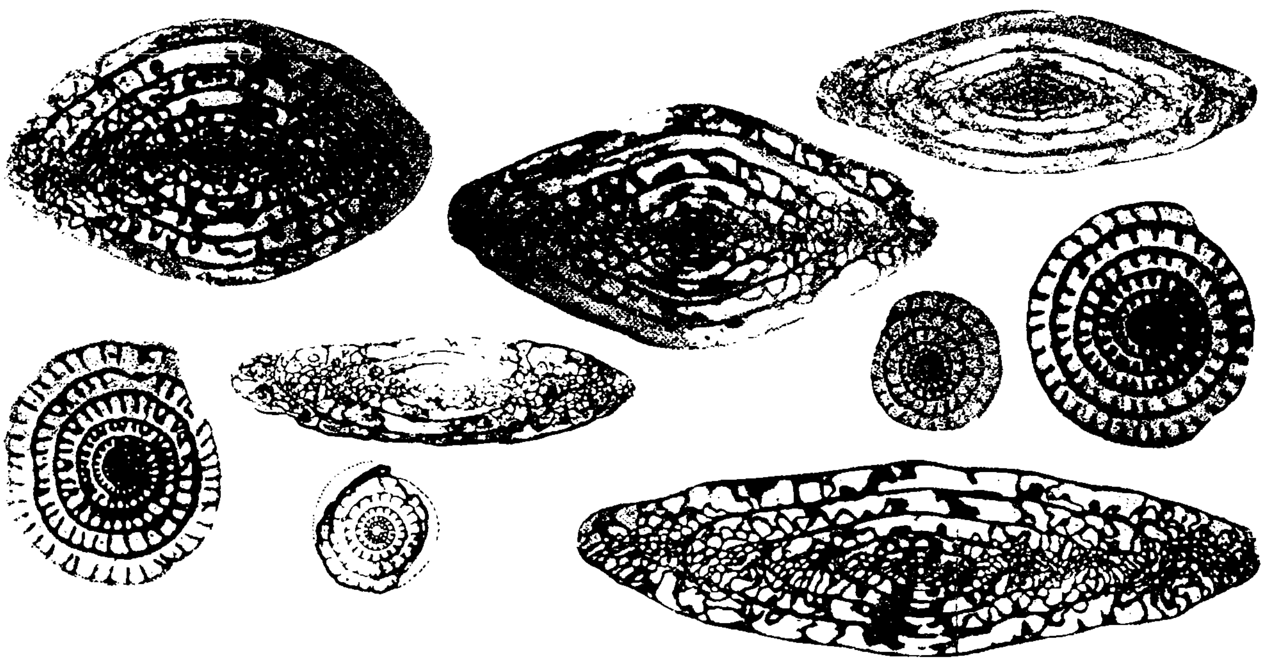


Figure 11. Variety of different species of the fusulinid foraminiferan *Triticites* (magnification approximately 10x). From Shimer and Shrock (1944).

Fossils in the phylum Porifera (sponges) are present, but uncommon, in the limestones of the Tallgrass Prairie Preserve. Figure 12 is an example of a fossil sponge. Perhaps one reason sponge fossils are not common is that sponges do not have a well-defined, rigid skeleton; rather, they are composed of spicules (small, needlelike structures) that are bound together in a variety of ways. As a result, when the sponge dies and falls to the sea floor, it collapses and the spicules are scattered about, rarely leaving the shape of the living sponge. Individual sponge spicules can be seen in some of the limestones.

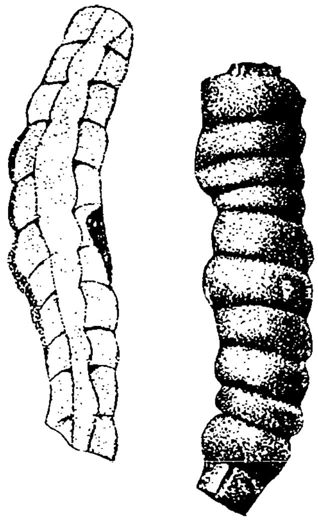


Figure 12. The fossil sponge *Amblysiphonella prosseri* (1x). *Amblysiphonella sp.* has been identified in several units in the Pawhuska Formation. From Shimer and Shrock (1944).

The phylum Cnidaria (formerly part of the phylum called Coelenterata) includes a variety of marine animals such as sea anemones, jellyfish, and corals. Because corals have hard parts, they represent most of the cnidarians in the fossil record. The most common coral found in the cyclothem limestones is a solitary, conical variety (Fig. 13), as opposed to colonial or encrusting varieties.

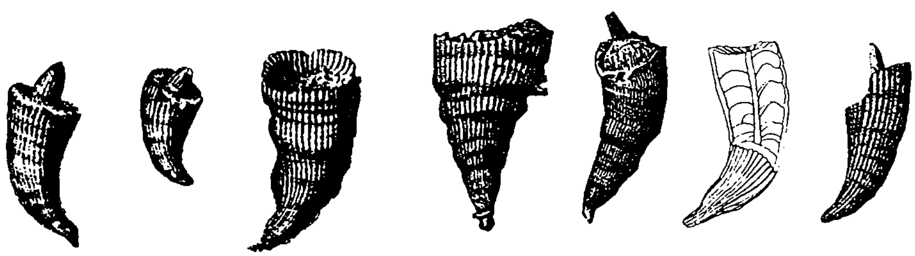


Figure 13. Example of the genus *Lophophyllidium* (1x). Pictured is *L. proliferum*; *L. asarcum* occurs in several units in the Preserve. From Shimer and Shrock (1944).

A colonial marine animal that many people mistake for a plant are members of the phylum Bryozoa. Modern bryozoans (or "sea fan") occur in both marine and fresh water, but only the marine varieties have hard skeletons composed of calcite; therefore, only the marine bryozoans are well-represented in the fossil record. Bryozoans may form encrusting mats or dome- or fan-shaped colonies consisting of hundreds of individuals and measuring several feet across. Two genera have been identified in the limestone beds of the Tallgrass Prairie: *Fenestrellina* (Fig. 14A) and *Rhombopora* (Fig. 14B). These can be distinguished by the arrangement of openings in the "fans". The openings in the *Fenestrellina* are aligned vertically, whereas those of the *Rhombopora* are aligned diagonally.

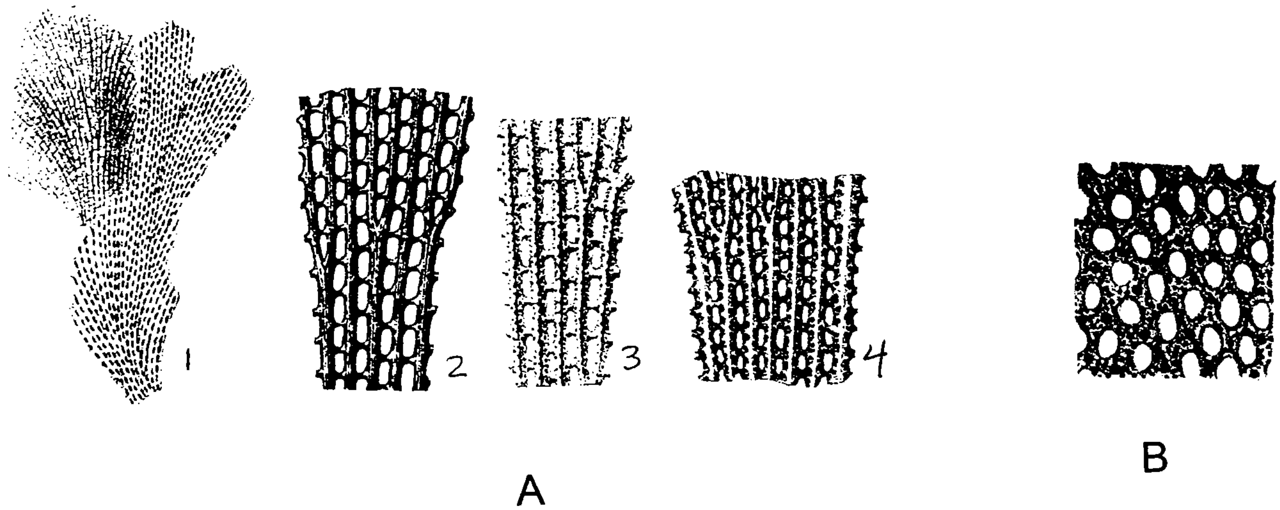


Figure 14. Examples of bryozoans found at the Tallgrass Prairie Preserve. A. Variety of different species of the genus *Fenestrellina*. No. 1 is 1x, nos. 2 and 3 are 6x, no. 4 is 18x. B. *Rhombopora lepidodendroides* (18x). From Shimer and Shrock (1944).

A large group of diverse marine animals that are common as fossils is the phylum Mollusca. In the modern marine environment, the mollusks include clams, oysters, scallops, snails, squids, octopuses, and the pearly nautilus. Clams and snails can also be found in fresh water and some snails live in a terrestrial environment. Three classes of the phylum Mollusca can be found as fossils on the Tallgrass Prairie - the Pelecypoda (clams), Gastropoda (snails), and Cephalopoda (nautilus). The shell of a pelecypod consists of two valves that are joined at a hinge (Figs. 15 A, B, C, and D). In some respects, it is similar to a brachiopod (described below), but the two shells of a complete pelecypod are mirror-images of each other, whereas the two shells of a brachiopod are different. In addition, the shell of a pelecypod is not symmetrical, whereas that of a brachiopod is. Gastropods are single-shelled animals in which the skeleton consists of a hollow, conical, generally coiled tube with a spiral shape similar to that of a corkscrew (Figs. 16 A, B, C). In some cases, the shell forms a very high spire; in others, the shell is coiled in a single plane. Thus, gastropods can vary greatly in shape. Probably the least common mollusk found in the rocks of the Tallgrass Prairie are cephalopods. The shell of a cephalopod can be coiled similar to that of a gastropod (Figs. 17A), or it may be straight or slightly curved (Fig. 17B). However, unlike most gastropods, the shell of a cephalopod is segmented into chambers so that the living animal lives only in the outermost, widest part of the cone. Although relatively unspectacular as fossils here, coiled ammonites (a variety of cephalopod) as large as 2 ft in diameter are common in parts of Marshall County in southern Oklahoma.

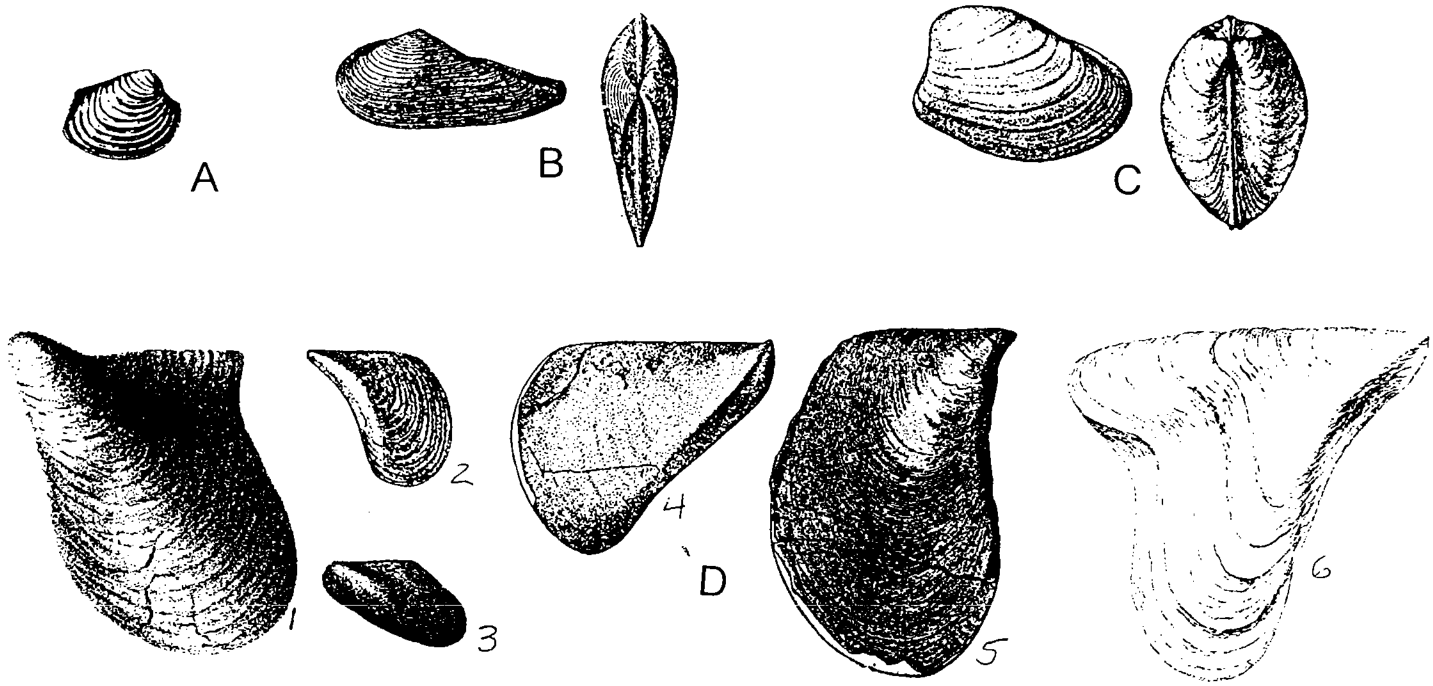


Figure 15. Examples of pelecypods found in some of the units on the Tallgrass Prairie Preserve. A. *Astartella* vera (1x). B. *Phestia bellistriata* (1.2x). C. *Nucula girtyi* (2x). D. Nos. 1 - 6. Several different species of the genus *Myalina*. (Nos. 5 and 7 0.5x; others 1x). From Shimer and Shrock (1944).

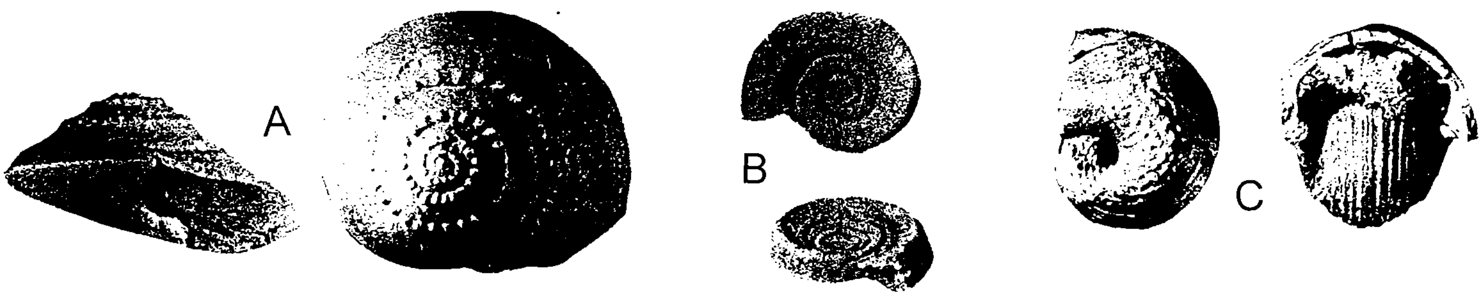


Figure 16. Examples of gastropods found in some of the units on the Tallgrass Prairie Preserve. A. *Trepospira discoidalis* (1x). B. *Straparolus catilloides* (2x). C. *Euphemites vittatus* (1x). From Shimer and Shrock (1944).

A large group of well-represented and common fossils (not only here but throughout Oklahoma and maybe even the world!) are the brachiopods (phylum Brachiopoda). These solitary marine animals, like the pelecypods, are bivalves; but unlike the pelecypods, each shell is symmetrical. The size, shape, and ornamentation of brachiopod shells vary widely. At the center of the hinge that joins the shells is a feature called a pedicle opening which allows a fleshy stalk (the pedicle) to extend out of the shell and attach itself to the sea floor. This is another difference between the brachiopods and pelecypods - brachiopods could not move about (i.e., are sessile), whereas pelecypods could (i.e., are mobile) using a fleshy foot that extends out from between the shells. Figures 18 A, B, C, D, E, F, and G show some of the more common brachiopods that occur in the limestones of the area.

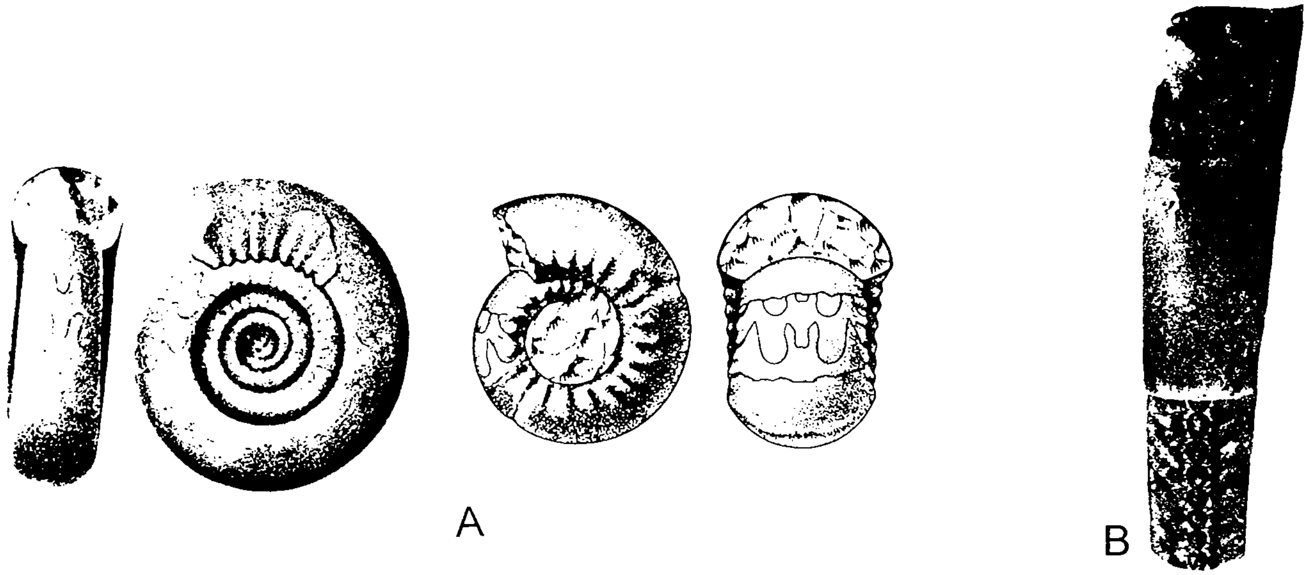


Figure 17. Examples of cephalopods found in the Preserve. A. Two different species of the genus *Gastrioceras* (1x), a coiled cephalopod. B. *Pseudorthoceras knoxense* (1x), a straight cephalopod. From Shimer and Shrock (1944).

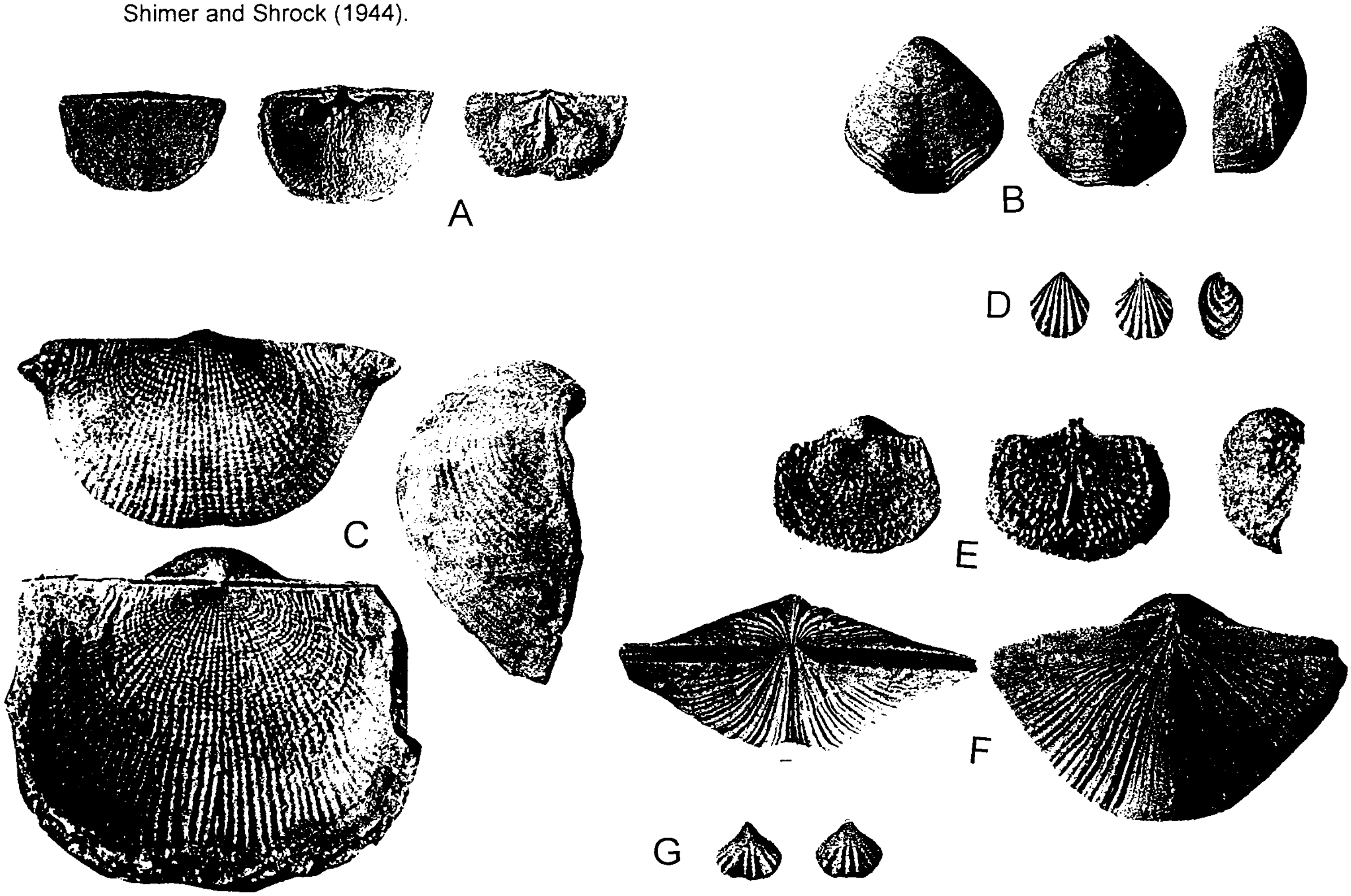
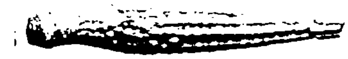


Figure 18. Brachiopods of the Nature Conservancy's Tallgrass Prairie Preserve. A. Neo*chonetes granulifer* (1x). B. *Composita subtillita* (1x). C. *Dictyoclostus americanus* (1x). D. *Hustedia mormoni* (1x). E. *Juresania nebrascensis* (1x). F. *Neospirifer dunbari* (1x). G. *Wellerella osagensis* (1x). From Shimer and Shrock (1944).

Another phylum of marine invertebrates that has not been identified to the genus or species level are the echinoderms (phylum Echinodermata) (e.g., starfishes, sea urchins, sand dollars, crinoids). Echinoid spines (Fig. 19) and crinoid columns (Fig. 20) are present and in some places common.

Figure 19. Echinoid spine (2x). From Shimer and Shrock (1944).



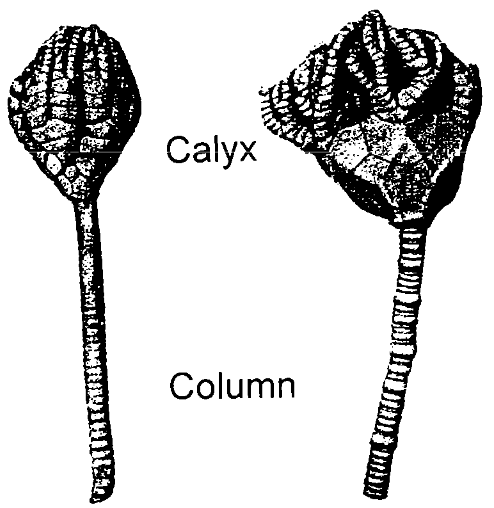


Figure 20. Drawing of upper part of crinoid showing calyx (head) (very rarely preserved as fossil) and column (stem or stalk) (common). Crinoid columns occur as fragments as long as several inches or a small round or star-shaped columnals (individual segments of the column). From Shimer and Shrock (1944).

Fossil algae (a plant) (often referred to as Cryptozoon or Cryptozoan) is present in much of the limestone of the Tallgrass Prairie. The algae consists of irregular, concentric bands of limestone of extremely variable thickness (Fig. 21).

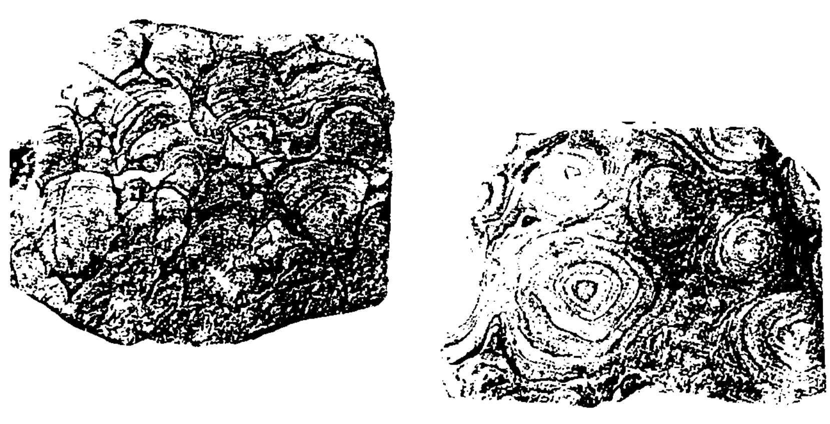


Figure 21. One example of Cryptozoon algae, *Cryptozoon undulatum* (0.45x). From Shimer and Shrock (1944).

Fossils are useful to geologists because they allow geologists to date and correlate widely separated outcrops and formations. If the same fossils are found in a formation in Oklahoma and Idaho, there's a good chance they are the same age.

Of equal importance to geologists are fossil assemblages, that is, groups of fossils found in the same formation in the same place. Fossil assemblages enable geologists to interpret paleo-marine ecosystems. The marine invertebrate assemblages in Osage County have not been been studied; therefore, a detailed paleo-environmental picture of Late Pennsylvanian northern Oklahoma cannot be described. However, Moore (1964), in his study of the Pennsylvanian and Permian cyclothems of Kansas, provides some clues as to how geologists use fossils to determine paleo-environment.

On the Beil-type assemblage:

"Specimens are exceptionally well preserved, few if any forms showing abrasions such as might be caused by being moved about by currents. Fragile bryozoans and delicate small brachiopods are unbroken; fine surface ornamentation ... generally is intact. Collections commonly contain perfect specimens best suited for museum display." (p. 315). "The paleobiotope represented by the Beil-type assemblage is thought to be one that existed in clear sunlit shallow waters (estimated less than 20 m on the average) far from the nearest shores (probably 50 to 100 miles distant)." (p.318).

On the Tarkio-type (*Triticites*) assemblage:

"The most common marine ecologic assemblage of organisms found ... consists predominantly, in many places almost exclusively, of fusulinid foraminifers. (p. 319). "*Triticites* is not a marker of deepest parts of invading ... seas but presumably of intermediate to greatest distances from sea margins." (p. 323).

On the Wakarusa-type assemblage:

"Main observed features are moderately large specimens of (a certain brachiopod), partly to almost entirely incrusted (sic) by laminated algal-foraminiferal colonies typically representative of *Ottonosia* (same as Cryptozoon) (whose) growths ... are quite variable in thickness, in different colonies or parts of the same colony. ... A tendency toward maximum coverage and thickness of the colonies on upper surfaces of their support indicates growth on shells fairly well stabilized in position on the sea floor and consequently an absence of strong currents or wave-induced turbulence." (p. 327). "The geographic variations reported must have paleoecological significance, ... indicating that the Wakarusa-type assemblage of northern Kansas, with abundant *Triticites* and relatively few *Ottonosia*, represents a paleobiotope in a far offshore location, whereas the presumably contemporaneous *Ottonosia*-dominated, fusulinid-lacking assemblage in the Wakarusa Limestone of Osage County, Oklahoma, denotes a paleobiotope located comparatively nearshore, possibly less than 30 miles or so from a strand line to the south." (p. 330).

From Moore's (1964) work, it is clear that paleoenvironmental interpretation requires not only determining the assemblage of fossils at a particular site, but the condition of the fossils and how the assemblage and condition change over a large area.

CONCLUSIONS AND FURTHER WORK

Geologists have a working knowledge or framework of the geology of northern Osage County and the area of The Nature Conservancy's Tallgrass Prairie Preserve. Much needs to be done, however, not the least of which is an accurate and detailed geologic map of the area. The base maps used by the USGS in the early part of the 20th century and those used by the OU students in the 1950's are inadequate by today's standards. Remapping would present a more detailed and complete picture of the surface geology.

In addition, the distribution of some of the more discontinuous units (especially the sandstones) is poorly known. Many of the units bear Kansas names, but few have been physically mapped into Kansas and connected with the formations there. Given the poor nature of outcrops in northern Osage County, shallow core holes would clearly add to our understanding of the nature of the cyclothems in the late Pennsylvanian strata of northern Oklahoma, particularly, the relation between sea-level changes and the introduction of deltaic sandstones, presumably from highlands to the east. Many advances have also been made in the field of biostratigraphy and the environmental significance of assemblages of fossils. A restudy (and renaming) of the fossils in these late Pennsylvanian rocks would clearly give us a better picture of what things were like in this part of Oklahoma nearly 300 million years ago.

ROAD LOG

INTRODUCTION

This road log starts at the parking lot of the Preserve headquarters and mostly proceeds south along the main road toward Pawhuska. Incremental mileages are shown first with cumulative miles shown in parantheses. Many of the rock units exposed in the Tallgrass Prairie Preserve can be examined in roadcuts or with short walks off the road along this route. A couple of notes of caution:

1. Several of the stops are not at scenic overlooks. Park your car as far to the side of the road as possible without driving into the bar ditch. Be aware that if the road is wet it is also slippery, and sliding off into the bar ditch with little effort on your part becomes more likely.

2. The bison in the Preserve are wild. If they are grazing on one of the outcrops you'd like to visit, visit the outcrop later. Do not try to shoo the bison off the outcrop - they have priority.

3. The Nature Conservancy prohibits collecting rocks, minerals, and fossils on Preserve land. Look, touch, pick it up, examine, photograph, and taste (if you want to), but please do not take it with you. The same formations and fossils are exposed in roadcuts outside the Preserve, and collecting is permitted there along county roads.

ROAD LOG

0.0 (0.0) Parking lot of Headquarters. Drive southwest to intersection with road to north. Continue southwest across Sand Creek to nature trail parking lot.

0.3 (0.3) Park in parking lot on right. Stop 1 is a couple of hundred yards up the road.

STOP 1. LIMESTONE, SHALE, AND SANDSTONE OF THE BIRD CREEK LIMESTONE

Although both Carter (1954) and White and others (1922) mapped the ridge-capping unit as the Bird Creek Limestone, the rock type that caps the ridge (and, in fact, most of the ridges throughout the Preserve) is sandstone. The reason the different units throughout the Preserve are named "limestone" is because the limestone beds are more continuous and mappable than the sandstones. Although this outcrop is at first glance quite unspectacular, it provides us with the opportunity to examine all the rock types found in the Preserve. More importantly, the outcrop exposes the one rock type that probably is the most common in the Preserve, but is very rarely exposed. That rock is shale.

Exposed in the bar ditch and on the north side of the road are the following (from bottom to top, or oldest to youngest): shale, 1.5-ft-thick limestone, about 20-ft-thick shale, blocks of sandstone (near top of outcrop). Examine the thick shale carefully. Dig through the weathered material on the surface to expose a relatively fresh sample of the shale. Note that the shale is relatively soft. Shale is easily eroded (compared to the limestone and sandstone) and hence, tends to form the slopes on the sides of the hills throughout the Preserve. Because it is soft, soils tend to be thicker on shales than other rock types and thus shale outcrops tend to be few and far between. Roadcuts and streamcuts typically are the only places where shales can be observed.

Break off a fresh (and small) piece of the shale and grind it between your teeth. Note the gritty sensation. There is a small amount of silt mixed in with the mud that makes up this shale. If this were a pure shale (mud made into rock) there would be no gritty sensation. Like M&Ms, the rock would dissolve in your mouth.

Note also the abundant small, rounded, rust-colored fragments littering the surface of the shale. Some of these show a concentric color-banding. These fragments are known as concretions, which form as a result of differential cementation of the shale. Because they are better cemented, the concretions are slightly harder and more resistant to weathering than the surrounding shale. Concretions come in a wide variety of shapes and sizes and are sometimes mistaken for dinosaur eggs or a number of other kinds of fossils. They are common in shales and have a non-organic origin.

Return to parking lot and continue on road away from Headquarters.

1.1 (1.4) Intersection with road to left (south) to Pawhuska. Turn left.

0.3 (1.7) Cross small stream. Outcrop of sandstone on left (east) side is cross-bedded and ripple-marked.

0.4 (2.1) Large blocks of Wakarusa Limestone on left (east) side of road just before ridge top.

0.4 (2.5) Scenic turnout on left.

0.8 (3.3) Intersection with road to Pawhuska to left (east) and Foraker to right (west). Turn right.

0.6 (3.9) Cross Hickory Creek. Park just west of creek and walk up hill to large outcrop a couple hundred yards to the north.

STOP 2. BIRD CREEK LIMESTONE

Walk up the hill towards the large outcrop. Note that the surface of the ground is littered with blocks, slabs, and "flagstones" of sandstone. Many of the hills throughout the Preserve are similarly covered with brownish-colored sandstone fragments; generally these occur on the slopes below a ridge or hill that is capped by sandstone. Break open one of the sandstone fragments. The brown to tan color is caused by a thin iron-oxide coating on some of the sand grains. The sandstone is fine grained and many pieces are poorly sorted, which means that there is a fair variation in the size of the sand grains. Well-sorted sandstones have a uniform grain size. Some of the sandstone fragments show internal laminations known as bedding planes. Some of the bedding planes are parallel whereas those on other specimens are tilted; this is known as cross-bedding. Very small carbonized plant fragments are present on many of the bedding planes.

A distinctive feature of many sandstone fragments are the numerous holes. Most likely these are burrows left by long-vanished marine organisms. (Because the remnants [fossils] of the animals aren't present, such burrows and trails are known as trace fossils.) Some of the holes are filled with mud, as though the organism back-filled his/her burrow as he/she dug through the sediment. Most of the burrows appear to be vertical, i.e., the animal dug down through the sediment. Some burrows, however, are on the surfaces of some of the sandstone slabs, indicating that the animal was moving along the surface of the sediment. Some geologists use the abundance of vertical over horizontal burrows to indicate a harsh environment for the organism, such as an environment dominated by waves and/or currents.

The sandstone outcrop is about 10 ft thick and highly lichen-covered. Most of the sandstone is unstratified; some weathers into flagstones.

The reason this unit is called the Bird Creek Limestone can be found by returning to the road and walking up it (away from the creek) about a hundred feet. A poorly exposed limestone is visible on the right side of the road and in the small creek on the right. The limestone contains crinoid fragments, echinoid spines, brachiopods, and corals. Most are small and broken. Note that the sandstone overlies the limestone (and is perhaps separated from it by an unexposed shale); we will see this relation elsewhere.

Return to cars and continue driving on same road.

0.4 (4.3) Road intersection. Turn right (west).

0.4 (4.7) Park carefully on right side of road and walk up hill to right to large gray limestone slabs.

STOP 3. WAKARUSA LIMESTONE

Although one is not sure if any of these limestone blocks are in place, they probably haven't moved too far from the outcrop and therefore this line of gray limestone boulders marks the outcrop pattern of the Wakarusa Limestone. The Wakarusa was called "Cryptozoon-bearing limestone" by the USGS workers in the area, for reasons that will become immediately apparent.

Most caverns in the world are formed in limestone. (Important and significant exceptions are those in northwestern Oklahoma, including Vickery Cave in Woodward County [a Conservancy registry site], which form in gypsum.) The reason for this is that limestones are subject to chemical weathering, resulting in dissolution and reprecipitation of calcite (the primary mineral in limestone). Note that many of the Wakarusa Limestone boulders here assume some unusual and fantastic shapes; this is due to slow but continuing chemical action of rainwater.

The Wakarusa at this locality is very fossiliferous. Small crinoid fragments are especially abundant and solitary corals can also be found. I found one fenestrate bryozoan. The most conspicuous fossil, however, are the numerous, slightly darker gray, concentrically banded, 1- to 4-inch diameter algal heads. These are the cryptozoon algae that the USGS used to map this particular limestone throughout the area. Note that some of the algal heads appear to surround crinoid and coral fragments. Note also that some of the algal heads appear to be broken, as though they were relatively firm and hard while growing, but were "ripped up" and redeposited by current or wave action. The fragmented nature of the crinoids is further evidence for deposition in other than quiet water.

After examining the Wakarusa Limestone, walk toward the top of the hill. Note the abundance of sandstone fragments similar to those seen at Stop 2 (Bird Creek Limestone). The sandstone over (unexposed shale? over) limestone is a pattern that repeats itself and is part of the reason these kinds of rock sequences are called cyclothems.

Return to cars and continue driving on same road.

0.4 (5.1) Just after driving over low pass, park on right side of road for overview of Stop 4.

STOP 4. SPILL SITE AND PEARSONIA OIL FIELD

The western part of the Tallgrass Prairie Preserve seems dominated by pumpjacks, a far cry from the apparent wildness and solitude of much of the Preserve. The oil wells in this area are part of the Pearsonia oilfield. Most of the wells in the field vary in depth from 800 to 2400 feet deep. Oil (and natural gas) have played and continue to play a significant role in the economy of Osage County and livelihood of many of the people who live here. To date, 6 million barrels of oil and 9 trillion cubic feet of natural gas have been produced from 320 wells on the Preserve. At present, there are 107 active wells on the Preserve (Bryan Tapp, written commun.).

Note the unusual drainage pattern in the valley on the left (south) side of the road. This was caused by a spill of produced oilfield brine. The wells near the heads of the drainages were drilled in the 1920s, and the unusual topography is evident on the USGS topographic map of the Pearsonia quadrangle published in 1973. Clearly, the spill occurred between the 1920s and 1973.

Dr. Bryan Tapp of the Dept. of Geosciences, University of Tulsa, is currently studying the origin of this spill as well as several others that occurred on the Tallgrass Prairie Preserve prior to The Nature Conservancy acquiring the property. This area is his Site 5. It covers about 0.25 square miles and brine is present at the surface. Tapp has researched historical aerial photographs of the area and determined that the spill was visible on photos taken on June 17, 1937. His work also determined that a significant amount of topsoil has been removed from the area as a result of the spill. Through his work and that of his colleagues and students at the University of Tulsa, he has recommended that complete remediation of this site would require that the topsoil be replaced and the original drainage be reestablished.

Return to cars and reverse direction.

1.8 (6.9) Road intersection. Continue straight ahead toward Pawhuska.

1.1 (8.0) Main road bears left (due east), dirt road to right (south). Continue on main road.

0.6 (8.6) Main road turns right (south), private road to left (east). Continue on main road.

0.2 (8.8) Scenic turnout on left (east). Note all the sandstone blocks scattered around on the ground. These are at about the same stratigraphic position as the sandstone at Stop 2 (Bird Creek Limestone), but no limestone crops out in the slope below the turnout. Is the limestone still present (probably) but unexposed (probably) or was it never deposited (unlikely)?

In general, the limestone beds are remarkably persistent and widespread throughout the area of cyclothem deposition, but poorly exposed. The sandstones, by contrast, tend to thicken and thin and are relatively discontinuous but, where present, are well exposed.

0.4 (9.2) Small outcrop and large blocks (remnants of road-building) of Bird Creek Limestone on left (east) side of road. Limestone is locally abundantly fossiliferous, including abundant echinoid spines and rare brachiopods, crinoids, corals, and branching bryozoans. Fossils are more easily seen on the weathered tops of some of the limestone blocks. Most are small and broken.

1.7 (10.9) Carefully park on right side of road next to limestone outcrop on right.

STOP 5. PEARSONIA (OR LITTLE HOMINY?) LIMESTONE

The Pearsonia and Little Hominy Limestones are very close at this locality according the Carter's (1954) map. The fossils observed more closely resemble the Little Hominy, but the geologic relations here compared to those at the next stop suggest this outcrop is Pearsonia.

Two very different limestone beds are present at this locality. The upper and more conspicuous limestone shows the same kind of fantastic weathering that characterized the Wakarusa Limestone at Stop 3. Note, however, that algal heads are not present. Shells, probably those of pelecypods, as long as 6 inches are present. Coiled cephalopods as large as 4 inches in diameter also occur. Note the abundant sandstone blocks eroding down the slope from the top of the hill. This relation (sandstone over limestone) was noted at the Bird Creek (Stop 2) and the Wakarusa (Stop 3) Limestones.

The lower limestone is very distinctive and locally contains very abundant fusulinids. The fusulinids are the foraminifera *Triticites* and look like large striped grains of wheat. In places they constitute 100% of a layer in the limestone. Other fossils in this lower limestone include abundant brachiopods and lesser amounts of bryozoans and crinoids.

Return to cars and continue on main road.

0.4 (11.3) Low ridge capped by Little Hominy Limestone. Powerline immediately to south.

0.6 (11.9) Intersection with road to left (east). Continue on main road.

0.3 (12.2) Conspicuous limestone (Little Hominy) outcrop on left (east). Carefully park on right side of road.

STOP 6. LITTLE HOMINY AND PEARSONIA LIMESTONES

This outcrop and that at Stop 5 illustrate how a geologist might map this area. It also illustrates why careful observation and correlation of units can be critical in determining the structural geology (folds and faults) of an area which, in turn, can (or used to) lead to oil discoveries.

Carter (1954) clearly maps the limestone just above road level as the Little Hominy Limestone and shows the top of the hill just above it to be capped by Pearsonia Limestone. Walk up to the top of the hill.

The top of the hill is capped by sandstone. Immediately underlying the sandstone is a distinctive echinoid-spine-bearing limestone. Underlying this limestone and separated from it by about 15 ft of unexposed shale(?) is a fusulinid-bearing limestone; this may be the same fusulinid-bearing limestone as was exposed at Stop 5. This limestone is separated from the Little Hominy just above road level by about 25 to 30 ft of unexposed shale(?). A likely grouping of these different rock units would be to combine the hill-capping sandstone and two closely underlying limestones into the Pearsonia (another sandstone over limestone sequence) and make the distinct limestone just above the road the Little Hominy. If this is accepted and the two limestones near the top of the hill are the same as the two at Stop 5, then those at Stop 5 are Pearsonia.

Alternatively, there may be more than one fusulinid-bearing limestone and those at Stop 5 and here are not the same. In addition, it appears that the ridge-capping sandstone at Stop 5 is higher above its immediately underlying limestone than the hill-capping sandstone here is above its limestone. Either the shale(?) beneath the sandstone is thicker at 5 than 6 OR the capping sandstones are different. Either or both explanations are possible.

Repeated careful observations all around this hill and at several places on the ridge to the northwest would be necessary to exactly correlate individual beds at the two localities. Depending on what the elevations of the individual beds are on the hill compared to those on the ridge, the geologic strata may be flat or tilted in a particular direction. Depending on the direction of tilt, an anticline (upfold), indicating a possible oil accumulation in the subsurface, would be indicated either generally to the north or south of here. These very subtle differences in stratigraphy and careful measurements of elevation give one an appreciation for the work done by USGS geologists in the late 19teens and early 19twenties.

Return to cars and continue south and then east on main road.

0.6 (12.8) Intersection with road sharply back to right (west). Continue straight ahead (east).

0.1 (12.9) Outcrop of Little Hominy Limestone.

0.7 (13.6) Entrance monument to The Nature Conservancy's Tallgrass Prairie Preserve. Monument reads:

> The Tallgrass Prairie Preserve
>
> "You stand at the south edge of the largest unplowed, protected tract which remains of the 142 million acres of tallgrass prairie grassland that once stretched from Canada to the Gulf of Mexico. Today, less than ten percent still exists, found mostly in the Flint and Osage Hills regions of Kansas and Oklahoma.
>
> In an increasingly crowded and noisy world, what you see is an oasis of space and silence. Here you can experience the same beautiful views that greeted the earliest human hunters and gathers many thousands of years ago.
>
> This area is indeed a national treasure. Please treat it with respect.
>
> For additional information about this preserve and its unique history, visit the Preserve Headquarters gift shop and nature room, another 10 miles north on this road. This preserve is owned and managed by The Nature Conservancy, a private, nonprofit organization."

Road to right (south) goes to Pawhuska. Continue straight ahead.

0.2 (13.8) Small outcrop of Beil Limestone on left side of road. Sandstone, limestone, and a sandstone-limestone mix are present.

0.9 (14.7) Large outcrop on left (north). Carefully park on right.

STOP 7. ELGIN SANDSTONE

This is perhaps one of the best, most instructive, but overlooked outcrops in the entire Tallgrass Prairie Preserve. Unlike all the other outcrops in this roadlog, it is 1) very well exposed and 2) is not associated with limestone. Note also the very distinctive change in topography starting about a half-mile back. This area is characterized by much steeper hills and deeper valleys compared to most of the Tallgrass Prairie, which is characterized by relatively subdued hills and broad, open valleys. This area also is heavily forested; the open grasslands so characteristic of most of the preserve are not present here. No doubt there are many other differences in the vegetation of the two areas, which means there are probably many differences in the animals that populate the two areas. We are now well within the Eastern Sandstone Cuesta Plains physiographic subprovince, having left behind topography more characteristic of the Northern Limestone Cuesta Plains.

The Elgin Sandstone is the oldest mapped unit in the Tallgrass Prairie Preserve. It is in the Vamoosa Formation of Carter (1954).

The Elgin Sandstone at this locality varies from massive and unstratified to very well stratified. Most of the bedding planes are parallel-stratified, but cross-bedding is present locally. Ripple marks are abundant and conspicuous on the tops of some of the sandstone beds on the south side of the road. Some of the sandstone beds are discontinuous; they do not extend the length of the outcrop. Some beds contain small hollows that probably once were shale pebbles that have since eroded out.

Some of the sandstone beds have extremely irregular bases. These are in the form of bulbous masses that appear to protrude downward as much as a foot into the underlying sedimentary rocks. These are known as load casts. Load casts typically form when a bed of sand is deposited in a relatively short amount of time and the weight of the sand presses down into the underlying still-soft sediment. Load casts are a kind of soft-sediment deformation feature - the beds are deformed, but not due to any kind of tectonic activity. Rather, the beds are deformed because they moved while they were still soft. The key interpretation to be made is that beds that exhibit load casts are deposited in a single event, like a flood. They underwent no reworking, as might occur in a shallow marine environment by wave action.

Look at the shale and siltstone underlying the sandstone at the bottom of the outcrop. Look carefully at the bedding planes. Unlike the silty shale observed at Stop 1, there is abundant carbonized organic debris on the bedding planes. This suggests that a source of abundant organic debris (forest, swamp, marsh?) was relatively nearby. Such a concentration of organic debris is unlikely to occur in a marine environment.

The abundance of organic debris in the siltstone/shale and single-event sandstones in the Elgin are evidence that this unit probably was deposited in a river delta and not in the ocean. Thus, the origin of the Elgin Sandstone is very different from those units in the Pawhuska Formation and Wabaunsee Group, which have a dominant to overwhelming marine component. This, in turn, suggests a sea-level rise following the deposition of the Elgin Sandstone.

End of field trip. Return to cars and leave via Pawhuska or return to Preserve Headquarters.

ACKNOWLEDGMENTS

I would especially like to thank Keven Colbert of the Oklahoma Chapter of The Nature Conservancy for suggesting doing a guidebook on the Tallgrass Prairie Preserve. Bryan Tapp (University of Tulsa) generously shared his work on Site 5. Jim Chaplin and Tom Stanley (Oklahoma Geological Survey) reviewed early versions of this paper and made many useful suggestions.

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