Educational Series 16

Kansas Geological Survey

Windows to the Past–

A Guidebook to Common Invertebrate Fossils of Kansas

Liz Brosius

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Cover: Kansas fossils shown clockwise from upper left are echinoids (Permian rock, Manhattan, Riley County); brachiopods (Pennsylvanian Americus Limestone Member, Foraker Limestone, Chase County); ammonoid (Cretaceous Graneros Shale, Ellsworth County); and gastropods (Pennsylvanian Stanton Limestone, Elk County).

Title page: Brachiopod fossils in limestone slab from near Topeka, from the Coal Creek Limestone Member of the Topeka Limestone.

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Introduction

PICK UP A ROCK in many parts of Kansas and chances are good you will find a fossil. Kansas rocks are full of fossils, and these fossils all have a story to tell. From faint traces on a chunk of gravel to spectacular specimens in museum displays, Kansas fossils have contributed important information to the history of life on earth.

Over the millions of years recorded in the rocks at the surface in Kansas, a diverse array of plants and animals have flourished and waned in response to climate and other changes. These include creatures ranging from mastodons to giant dragonflies, saber-toothed cats to pterosaurs (large flying reptiles), and mosasaurs (enormous swimming reptiles) to tiny corals.

This guidebook focuses on a subset of the state's fossil record, the remains of creatures without backbones known as invertebrates. Familiar invertebrates living today include insects, clams, corals, and snails, to name a few. These and other types of invertebrates turn up as fossils in Kansas rocks.

Although fossil invertebrates have generally garnered less attention than their vertebrate counterparts (*T. rex* is far better known than *M. permiana*[1]), whatever invertebrates lack in drama, they make up for in sheer numbers. Invertebrate fossils are easy to find in Kansas rocks and far more common than vertebrate or plant fossils. Their small size makes them portable, and some well-preserved specimens have an almost sculptural appeal—from the graceful lines of a brachiopod shell to the simple geometry of a piece of a crinoid stem. Invertebrate fossils conjure visions of ancient life on crowded seafloors or in tropical swamps millions of years ago in Kansas.

Spiral-shaped gastropod, or snail.

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[1] Almost everyone is familiar with *Tyrannosaurus rex*, the fierce predator of the Cretaceous. *Meganeuropsis permiana*, on the other hand, is a well-kept secret. This giant dragonfly, with a 2-foot wingspan, dominated the skies in Kansas and elsewhere 250 million years ago.

What are Fossils?

Fossils are the remains or evidence of ancient life. Shells, bones, teeth, imprints, carbon traces, amber inclusions, footprints, and burrows—all these are fossils. Whether fragmented or complete, fossils provide vital information about the earth and its inhabitants millions, even billions, of years ago.


Pennsylvanian brachiopods.

Fossils are the basis of paleontology, the branch of science that studies ancient life. Paleontologists, like detectives, use clues to reconstruct past events—in this case what ancient plants and animals looked like and how they lived—and fossils are the clues. Fossils are also important in the related fields of geology and biology, where they are used to correlate rock layers from different parts of the world (see, for example, the discussion of ammonoids, p. 9-12), reconstruct ancient environments, or piece together the evolutionary history of life.

Fossilization

Although finding fossils is relatively easy, becoming a fossil is not. Only a minute fraction of the organisms that have lived are preserved as fossils. Following the death of any organism, many things can happen. The organism may be eaten, attacked by bacteria, fragmented, crushed, or worn away by movement of water and wind, to name some of the most common fates. Anatomy and chance play key roles in determining whether a given organism will be preserved as a fossil.

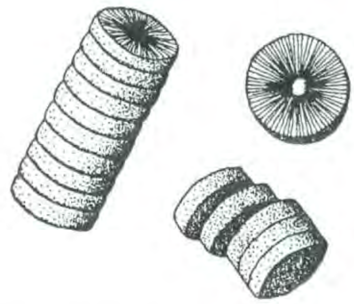
Among the attributes that favor fossilization, probably none is more important than the possession of hard parts—sturdy bones in vertebrates, thick shells in invertebrates, wood and seeds in plants—because hard parts hold up better to decay and destruction than such soft tissue as muscles and organs. Rarely, under just the right conditions, soft-bodied creatures are preserved (see box on Burgess Shale, p. 26). Usually, however, organisms without hard parts disappear without a trace. This explains why we find many more clams than worms in the fossil record.

Having hard parts is just the first requirement for fossilization. Rapid burial is another essential element. Rapid burial protects an organism from being eaten by scavengers, attacked by bacteria, or battered by wind or wave action. As a general rule, organisms that live in or fall into water have a better chance of being buried quickly when they die. They settle to the seafloor, lake bottom, or riverbed and are buried by the sediment that accumulates over time. This is one reason that aquatic organisms are far better represented in the fossil record than those that lived on land. Occasionally, however, mudslides and volcanic eruptions quickly bury land-dwelling animals and plants.

Once an organism is buried, it is then exposed to heat, pressure, and other physical and chemical processes that transform unconsolidated sediments into solid rock over millions of years. Although some fossils, particularly those whose hard parts were originally made up of calcite ($CaCO_3$) or silica (SiO_2), are apparently preserved with little alteration, most are affected to some degree by rock-forming processes such as replacement, permineralization, and recrystallization. In replacement, the original structural material is replaced, virtually atom-by-atom, with different minerals, commonly calcite or silica. Replacement is sometimes remarkably precise, preserving minute details and delicate structures. Another process affecting the preservation of fossils is permineralization, in which dissolved mineral material is added to the pores and cavities of bone, shell, or wood. Permineralization strengthens the fossil, increasing its chances of preservation. Recrystallization, as its name suggests, involves the rearranging of the internal physical structure on a molecular level and commonly destroys much of the organism's original structure, though the general appearance of the fossil is retained.

Once an organism becomes a fossil, it still may be subjected to compaction as additional sediments accumulate, to the upheavals of mountain building, or to exposure at the surface and erosion by wind and water—to name just a few of the ongoing geologic processes. If a fossil avoids destruction in these ways, it then becomes part of the fossil record. As this brief summary shows, there are many obstacles to becoming a fossil. Most organisms lived, died, and vanished without a trace. The fossil record of life is both incomplete and biased towards organisms with hard parts and that lived in or near the water.

Incomplete and biased as the fossil record may be, however, its value can hardly be overstated. Fossils tell us everything we know about prehistoric life. They truly are windows to the past.



Crinoid stem fragments and pieces.

Geologic Time

Any discussion of fossils forces us to think about time, long intervals of time. Geologists have determined that the earth is about 4.6 billion years old. Such long intervals of time are hard to grasp, especially in relation to human history.

One way to get a feel for the length of geologic time is to compress the 4.6 billion years of earth history into a single 12-month year. The first event in this imaginary year, the origin of the earth, takes place during the first second of the first minute of January 1. By mid-March, life (in the form of heat-loving, sulfur-eating bacteria that are still found in hot springs and volcanic vents) begins to take hold on the planet. At the end of March, photosynthetic bacteria start exhaling oxygen into the atmosphere. Then, in late November, animals with shells—trilobites, brachiopods, mollusks—begin to colonize the world's seas. Dinosaurs become dominant in mid-December but disappear the day after Christmas, about the same time that the Rocky Mountains are uplifted. On the evening of December 31, ancestral humans begin to walk upright, and a few seconds before midnight, an Italian sculptor named Michelangelo begins work on David. Clearly, the earth has a very long history, and human affairs, as geologists like to say, are barely "the blink of an eye" compared to geologic time.

Geologists manage the 4.6 billion years of earth history with the geologic time scale, which divides earth's history into a hierarchical series of units—eons, eras, periods, and epochs (fig. 1). These divisions are not arbitrary; they are based on major events in the history of life as recorded in the rocks. For example, the division between the Mesozoic and Cenozoic eras marks the extinction that killed off the dinosaurs, while the boundary between the Paleozoic and the Mesozoic eras marks the largest extinction event in life's history, the end-Permian mass extinction (see box on mass extinctions, p. 6-7). Similarly, the dividing line between the Paleozoic and Precambrian eras signifies the first flourishing of multicellular animals, an event often called the Cambrian explosion (the Cambrian is the earliest period in the Paleozoic Era).[2]

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[2] When the boundary was originally established, Cambrian fossils were the oldest ones known, and paleontologists believed they represented the beginning of life. Since that time, however, older fossils have been discovered, including the remains of microscopic bacteria that extended the origin of life back to 3.8 billion years ago, over three billion years before the start of the Cambrian. Despite the change in its meaning, however, the Paleozoic-Precambrian boundary still marks a clear-cut and important event recorded in the rocks, the rapid evolution of multicellular life on earth.

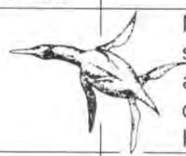
EON	ERA	PERIOD	EPOCH	DESCRIPTION	MILLION YEARS PAST
PHANEROZOIC	CENOZOIC	NEOGENE	QUATERNARY: HOLOCENE, PLEISTOCENE; TERTIARY: PLIOCENE, MIOCENE	 Glaciers moved into northeast Kansas at least twice, leaving behind red quartzite boulders and powdery silt called loess. Later the climate was dry. Sand dunes formed by wind in the west. Volcanic ash was blown in from California, New Mexico, and Wyoming. Fossils of Ice Age mammals found.	23
		PALEO-GENE	TERTIARY: OLIGOCENE, EOCENE, PALEOCENE	 Western third of the state covered by sand, gravel, silt, and "mortar beds" of the Ogallala Formation, which contains large quantities of ground water. No rocks deposited in eastern Kansas.	65
	MESOZOIC	CRETACEOUS		 Much of western Kansas covered by seas. Dakota Formation sandstones, "Fencepost" limestone (characterized by clam fossils), and Niobrara chalk (source of large, vertebrate marine fossils) deposited. Volcano-like kimberlites explode to surface in eastern Kansas.	145
		JURASSIC		Deposited in subsurface of western one-fifth of the state. Terrestrial (nonmarine) deposits mainly shale and sandstone.	199
		TRIASSIC		Found only in extreme southwestern Kansas, mostly in subsurface. Crops out at Point of Rocks, Morton County. Red sandstones and conglomerates, terrestrial deposits (nonmarine).	251
	PALEOZOIC	PERMIAN		 Shallow seas deposited limestone, shale, and chert that form Flint Hills in eastern Kansas. Invertebrate fossils common. Later, shale, siltstone, sandstone, dolomite, and gypsum—rocks that form the Red Hills in south-central Kansas—were deposited. Salt deposited, now mined in central Kansas. Subsurface rocks produce considerable oil, natural gas.	299
		CARBONIFEROUS: PENNSYLVANIAN subperiod		 Shallow seas, swamps, and river channels deposited shale, limestone, sandstone, chert, conglomerates, and coal found at the surface in eastern Kansas. Invertebrate fossils common. Two ridges of hills, the Nemaha uplift and the Central Kansas uplift, appeared; both now buried. Subsurface rocks source of oil.	318
		CARBONIFEROUS: MISSISSIPPIAN subperiod		Repeated layers of limestone, shale, and sandstone deposited in shallow seas, river channels. Outcrops in southeastern Kansas are oldest rocks at the surface of Kansas; elsewhere underground only. Once mined for lead and zinc in southeastern Kansas. Subsurface deposits source of large amounts of oil. Invertebrate fossils common.	359
		DEVONIAN		 Seas covered Kansas during much of the period. Limestone, shale, and sandstone deposits are underground only.	416
		SILURIAN		Seas covered Kansas, then the land was uplifted and seas disappeared. Limestone deposits are found only in the subsurface.	443
		ORDOVICIAN		 Seas covered parts of Kansas during much of the period. Dolomite and sandstone are underground only. Source of approximately one-third of oil produced in state.	488
		CAMBRIAN		Early, the climate was dry and many rocks eroded. Later, parts of Kansas were covered by seas, depositing dolomite, sandstone, limestone, and shales now in the subsurface.	542
PROTEROZOIC				Ancient rocks, mostly igneous and metamorphic, that lie beneath younger sedimentary deposits. Rift in the midcontinent, now in the subsurface of east-central Kansas, began, then stopped, about one billion years ago.	2,500
ARCHEAN					4,600?

FIGURE 1—Kansas geologic timetable (after Gradstein et al., 2004, and U.S. Geological Survey, proposed timetable in email communication, May 2006).

With Kansas rocks and fossils, we are primarily concerned with the late Paleozoic to Cenozoic, roughly the last 315 million years of geologic time (fig. 2). The oldest rocks at the surface, which occur in the extreme southeastern corner of the state, are Mississippian in age—they were deposited during the Mississippian subperiod, from about 340 to 320 million years ago. Most of the Kansas fossils discussed in this guidebook occur in rocks deposited during the Pennsylvanian subperiod and the Permian and Cretaceous periods.

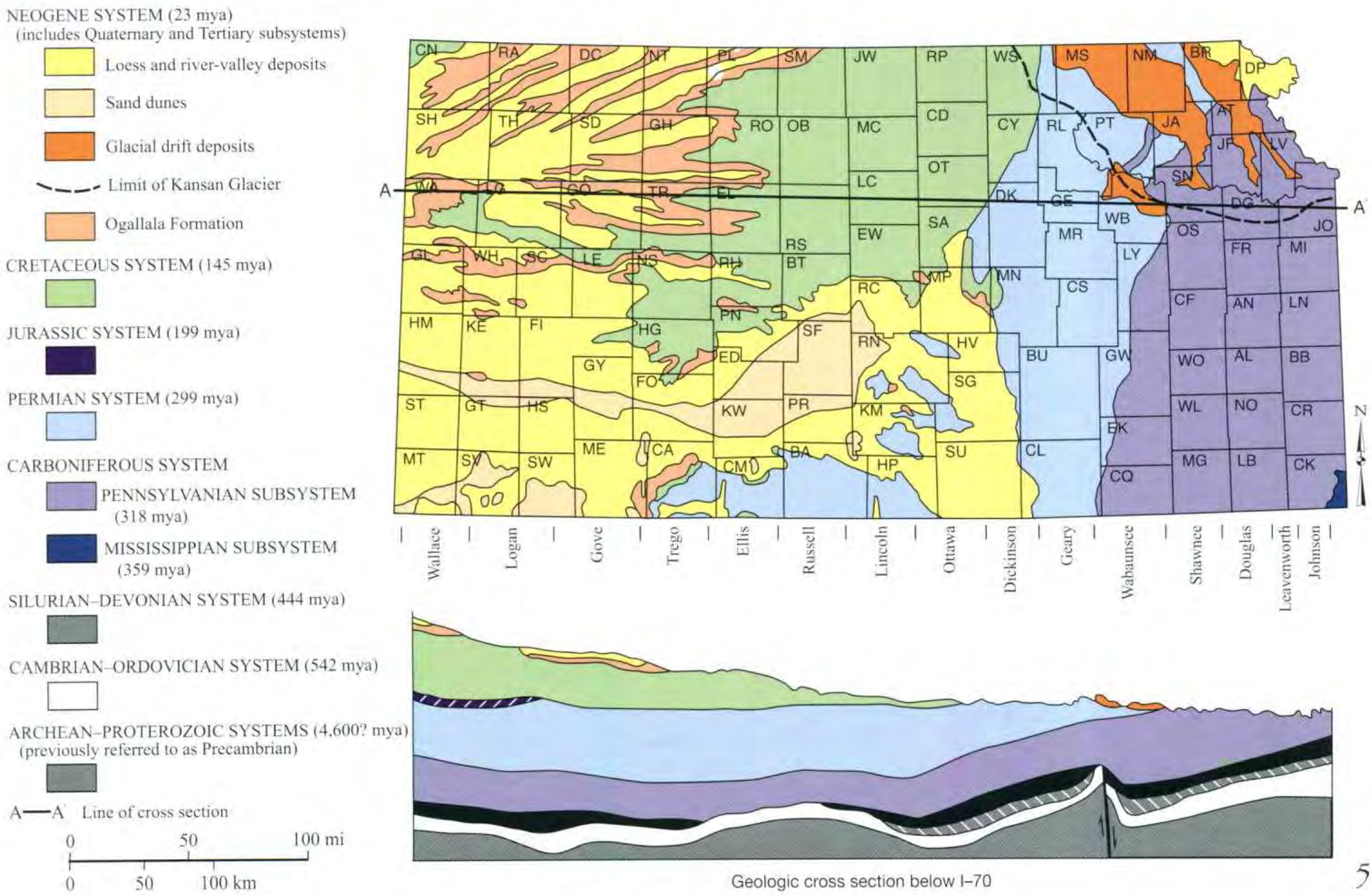
Fossils in Kansas Rocks

HERE IN KANSAS, we are fortunate to have plenty of fossil-bearing rocks at the surface. Almost all of these are what geologists call sedimentary rocks. The other two types of rocks, igneous and metamorphic, do not occur at the surface in Kansas, with a few rare exceptions. Sedimentary rock is made up of sediment, broken rock, and organic material that eventually (over millions of years) are transformed into solid rock by the weight of the accumulated sediments above them (compaction) or by mineral cementation (fig. 3). Limestone, sandstone, and shale are the most common sedimentary rocks at the surface in Kansas.

Limestone is composed mostly of the mineral calcite, or calcium carbonate ($CaCO_3$), which is secreted by various animals and plants—such as oysters, corals, and algae—that live in aquatic, mostly marine, environments. When these organisms die, they settle to the bottom of the sea, lake, or river (many of these actually lived at the bottom). The organic parts decay, and over millions of years the calcium carbonate accumulates to form limestone.

Sandstone and shale, on the other hand, are made up of sediment that has eroded from other rocks. Sandstone, as its name suggests, is made up of sand

FIGURE 2 (below)—Generalized geologic map of Kansas. The legend also shows the beginning time of each of the geologic systems (mya = million years ago).



Mass Extinctions

The history of life on earth is characterized by change—species evolve, thrive for a few million years, and then die out, making way for new species. This dying out, or extinction, of species is a normal part of evolution.

On the other hand, mass extinctions—the demise of vast numbers of species—are extraordinary events in evolutionary history. Mass extinctions are episodes in which more than half of the species living at a given time became extinct within a relatively short period of geological time (usually less than two million years).

Based on evidence in the fossil record, scientists have identified five major extinction events during the last 500 million years. These occurred at the end of the Ordovician (443 million years ago, or mya), near the end of the Devonian (359 mya), at the end of the Permian (251 mya), at the end of the Triassic (199 mya), and at the end of the Cretaceous (65 mya) periods.

Of these mass extinctions, undoubtedly the best known is the one that killed off the dinosaurs at the end of the Cretaceous Period, about 65 million years ago. Although the most celebrated, dinosaurs were by no means the only casualties—ammonoids (see p. 9), pterosaurs (flying reptiles), mosasaurs and other marine reptiles, and a host of other plants and animals either died out completely or suffered heavy losses in diversity. Other groups—mammals, birds, crocodiles, turtles, and redwood trees—were barely scathed by the events surrounding this extinction.

All in all, it is estimated that perhaps 60 percent of all species alive at the end of the Cretaceous became extinct. This abrupt change is recorded in the fossil record and provides a distinct marker, known as the K-P boundary, between late Cretaceous (K) rocks and the earliest Paleogene (P) rocks, or K-T boundary (Cretaceous-Tertiary).

Several theories have been proposed to explain what caused the end-Cretaceous mass extinction, including the much-publicized giant asteroid strike near the Yucatan peninsula. Scientists continue to research the causes of this mass extinction. Regardless of the cause, one thing is certain—the event marked a drastic change in life's history and set the stage for the rise of mammals.

Even more dramatic than the end-Cretaceous mass extinction, at least in terms of numbers of species lost, was the one that took place 251 million years ago at the end of the Permian Period. Scientists estimate that 96 percent of all marine species died out completely. Life on land was also devastated, with more than three-quarters of all vertebrate families lost. This is the largest extinction event in earth's history and marks not only the end of the Permian Period, but also the close of the entire Paleozoic and the beginning of the Mesozoic Era.

Marine animals living in reefs and shallow waters were especially hard hit during the end-Permian mass extinction. These included corals (see p. 22), some brachiopods (see p. 13) and bryozoans (see p. 16), and a variety of crinoids (see p. 25). Fusulinids (p. 32) and the last few trilobites (p. 43) died out completely, and ammonoids (p. 9) were decimated. On land, more than two-thirds of amphibian and reptile species and nearly one-third of insect species were wiped out. The demise of so many insects is noteworthy because insects tend to survive environmental changes. This is the only mass extinction insects have ever suffered and is evidence of the severity of the environmental changes at the end of the Permian.

The cause of this devastating mass extinction, like the end-Cretaceous extinction, remains a mystery. Probably several things contributed to the drastic environmental changes at the end of the Permian. A huge lava field in northern Asia, which dates back to the late Permian, is evidence of large-scale volcanic activity, and volcanoes were also active at that time in southern China. Scientists theorize that the volcanic gases released into the atmosphere may have produced deadly climate changes. Another piece of evidence is the sudden drop in sea levels at that time, which eliminated many shallow-water marine environments and may have caused periods of lethal low-oxygen levels in the ocean's waters. Whatever the cause, the mass extinction at the end of the Permian drastically affected the subsequent history of life.

Following each of the major mass extinctions, life rebounded. However, it took tens of millions of years of evolution for species diversity to be restored (see table 1). Current rates of species loss have convinced many scientists that we are in the midst of another mass extinction, caused mainly by human activities. The knowledge that it takes millions and millions of years for life to recover from mass extinctions should, Edward O. Wilson writes in *The Diversity of Life* (1992), "give pause to anyone who believes that what *Homo sapiens* destroys, Nature will redeem. Maybe so, but not within any length of time that has meaning for contemporary humanity."

Table 1—Mass extinctions of life on earth (Wilson, 1992, p. 31; mya = million years ago).

Mass Extinction	**Time Needed for Species to Rebound**
end-Ordovician (443 mya)	25 million years
late-Devonian (359 mya)	30 million years
end-Permian (251 mya)	100 million years
end-Triassic (199 mya)	
end-Cretaceous (65 mya)	20 million years

grains, bonded together by some natural cement. These grains can usually be seen by the naked eye. Shale, on the other hand, is composed of compacted clay particles that are too small to be seen without a microscope. It is a soft rock and often splits easily along its layers.

Most limestone (in Kansas and elsewhere) was deposited in warm, shallow seas, such as the ones that covered Kansas intermittently during the Pennsylvanian subperiod and the Permian and Cretaceous periods. These warm, shallow seas were not only good for making limestone; they were also good for preserving the organisms that lived in these seas. The calcium carbonate ooze that collected on the shallow seafloors made a perfect burial ground. Thus, Kansas limestone contains many fossils; indeed, some limestone formations are made up almost entirely of fossil fragments.

Sandstone and shale also formed in marine environments. During periods of erosion, sediments were washed from the land and carried into the sea by streams. The coarser sediment, such as sand, settled out first, while the finer-grained particles were carried farther out to sea. Thus, sandstone beds may indicate deposition on or very near shore, whereas layers of shale indicate deposition a little farther from shore. Limestone beds, as mentioned earlier, generally accumulated in quieter waters even farther from shore.

Although some limestone, sandstone, and shale were deposited in freshwater environments—that is, in rivers, streams, and lakes—most of the rocks in Kansas were deposited in marine environments. It is no surprise, then, that most of the invertebrate fossils in Kansas rocks are the remains of marine animals.

Fossils of marine invertebrates turn up throughout Kansas, but two regions are particularly rich in these fossils. The first, the Smoky Hills region of north-central and northwestern Kansas, is home to a variety of rocks that were deposited at the bottom of a broad, shallow sea that extended from Texas to Canada during the Cretaceous Period, about 80 million years ago. Three principal rock outcrops characterize the Smoky Hills—the sandstones of the Dakota Formation, the limestones of the Greenhorn Limestone, and the thick chalks of the Niobrara Chalk. The second region, the eastern third of Kansas, from the Flint Hills to the Missouri border—has even older rocks at the surface. These limestone, shale, and sandstone rocks were deposited in shallow seas that rose and fell over central North America many times during the Pennsylvanian subperiod and the Permian Period, from about 318 to 250 million years ago.

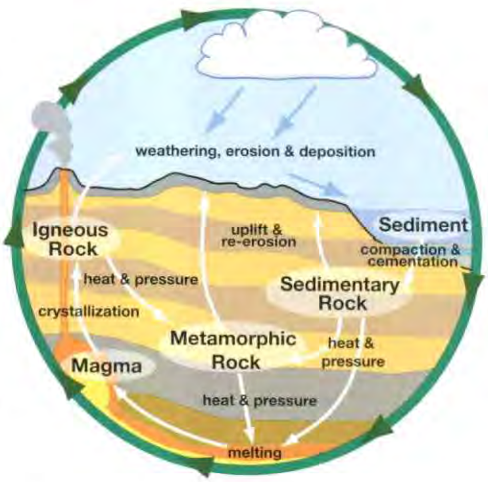


FIGURE 3—The rock cycle is one way to look at the relationships between the three major rock types—igneous, sedimentary, and metamorphic—and the earth's internal (generation of magma, or molten rock, and mountain building) and external processes (weathering, erosion, and deposition). **Igneous rock** is formed from the solidification (cooling or crystallization) of magma, or molten rock. **Sedimentary rock** results from the compaction and cementation of sediment. **Metamorphic rock** is formed from the alteration of igneous or sedimentary rock by heat and pressure beneath the earth's surface.

How to Use the Guidebook

As mentioned earlier, this guidebook focuses on invertebrates because they are the most common fossils in Kansas rocks. Specifically, we highlight 11 large groups of invertebrates, most of which occur frequently in Kansas rocks.

The guidebook is intended as a general introduction to Kansas invertebrate fossils, from ammonoids to trilobites. In addition to providing information about some of the interesting creatures that once made their home in Kansas, the guidebook should also help you figure out whether the fossil you have found is a clam or a crinoid—that is, it will help you place your fossil in one of the broad categories into which scientists divide life on earth. Beyond that, however, the guidebook is not intended to be used for identification because far more fossils occur than can be illustrated here (see Appendix 3 for additional resources for identifying fossils).

The section for each fossil group begins with a description of what these creatures looked like, how they lived, and where their fossils occur in Kansas. The descriptions are illustrated with photographs of fossils from Kansas rocks (with a few exceptions). In general, rather than photographing only the best-preserved, display-quality examples, we have pictured specimens that are representative of the fossils commonly seen in the field. Most of these fossils are housed in the Museum of Natural History and Biodiversity Research Center, Division of Invertebrate Paleontology, at the University of Kansas.

The discussion of each fossil group also includes its stratigraphic range. Strata are layers of sedimentary rock that are visually distinguishable from the layers above and below. The stratigraphic range indicates the worldwide distribution of fossils from a particular group in the sedimentary rock column. For example, the stratigraphic range of brachiopods is Lower Cambrian to Holocene: this means that brachiopod fossils have been found in rock layers, or strata, deposited during the early part of the Cambrian Period of geologic time and that brachiopods are still living today, in the Holocene Epoch of the Neogene Period (see fig. 1).

The final piece of information given for each fossil group is the taxonomic classification. This is a statement about where each fossil group belongs in the classification system of all living organisms. Such classification belongs to the branch of science called taxonomy, the analysis of an organism's characteristics for the purpose of assigning it to a taxon (plural: taxa), or group. This system, which continues to evolve as we learn more about life, currently classifies all organisms into five broad units called kingdoms—Bacteria, Protoctista (algae, protozoa, slime molds), Animalia, Fungi (mushrooms, molds, and yeasts), and

Table 2—Classification of two organisms (taken verbatim from Margulis and Schwartz, 1998, Table I-1, p. 4).

Taxonomic level	Humans	Garlic
Kingdom	Animalia	Plantae
Phylum (Division)[1]	Chordata	Anthophyta
Subphylum[2]	Vertebrata	
Class	Mammalia	Monocotyledoneae
Order	Primates	Liiales
Family	Hominoidea	Liiaceae
Genus	*Homo*	*Allium*
Species	*Homo sapiens*	*Allium sativum*

[1]Botanists use the term division instead of phylum.

[2]Intermediate taxonomic levels can be created by adding the prefixes "sub" or "super" to the name of any taxonomic level.

Plantae. (Based on distinctions at the cellular level, taxonomists have recently established two superkingdoms: the Prokarya, which includes the Bacteria, and Eukarya, which includes the four other kingdoms.) Below the level of kingdom, all life is further classified according to increasingly smaller units—phylum, class, order, family, genus, and species, the fundamental unit in the system (table 2). All the invertebrate groups discussed in this guidebook, with the exception of the fusulinids, belong to the kingdom Animalia.

Although the general descriptions provide some information about where particular invertebrate fossils commonly are found in Kansas, they do not provide specific fossil-collecting localities. Instead, figure 2 is a geologic map of Kansas showing the geographic extent of the rock units associated with the particular fossil groups. Appendix 1, an annotated list of Cretaceous, Permian, and Pennsylvanian stratigraphy in Kansas, provides more detail about the kinds of fossils found in specific rock units.

Finding fossils in Kansas is not difficult. Using this guidebook as a starting point, you should be able to track down some likely localities (see Appendix 2) and understand a bit more about the fossils you may find (see Appendix 3 for additional fossil resources). We hope this guidebook will encourage you to head outdoors and turn your attention to the rocks around you. There you will encounter the state's rich resource of invertebrate fossils, tangible relics of a distant past, part of the ongoing story of life in this place we call Kansas.

Ammonoids

Description: Ammonoids were squidlike creatures that lived inside an external shell. In fact, ammonoids are relatives of the modern squid, as well as the octopus and chambered *Nautilus,* all of which belong to the class of animals called cephalopods.

Ammonoids first evolved and appeared in the fossil record during the early part of the Devonian Period, about 415 million years ago. They died out about 65 million years ago, during the mass extinction at the end of the Cretaceous Period that killed the dinosaurs and many other kinds of land and sea animals. Their fossils are common in sedimentary rocks around the world and are fairly common in the Cretaceous rocks of western Kansas. They are also found in Pennsylvanian and Permian outcrops in the eastern part of the state (fig. 4).

Ammonoid shells were composed of calcium carbonate in the form of the mineral aragonite, which is relatively unstable and tends to dissolve or recrystallize to calcite, a more durable form of calcium carbonate. Recrystallization may destroy original structures in the shell, making for less than ideal preservation.

Most ammonoids had shells that were coiled in the same plane (like a cinnamon roll). Others had straight or erratically coiled shells (fig. 5). The external surface of the shells was ornamented in a variety of ways, with different color patterns, ribs, nodes, or spines. Depending on the state of preservation of individual fossils, this ornamentation is not always preserved.

Internally, ammonoid shells were divided into many chambers by a series of intricately folded walls. At times this folding was exceedingly complicated. The pattern of the folding can be seen in many specimens in which the outer shell has been removed. The junction between the wall and the outer shell produces a line called the suture, and these suture patterns are unique to each ammonoid species (fig. 6). Although paleontologists are not sure why the walls were folded in such elaborate and complicated ways, the folds would have strengthened the walls, making them able to withstand increased water pressure at greater depths.

The size of ammonoids varied greatly throughout their long history on earth. Most Paleozoic ammonoids were golf-ball sized or smaller. At the height of their diversity during the Cretaceous, however, many ammonoids were larger, and some with diameters up to 10 feet (3 meters) must have been formidable predators (fig. 7).

Because ammonoids are extinct, paleontologists look to the only shelled cephalopod alive today, *Nautilus,* for information about how ammonoids may have lived. Like *Nautilus,* most ammonoids were probably good swimmers, moving through the water by means of a kind of jet propulsion. Ammonoids

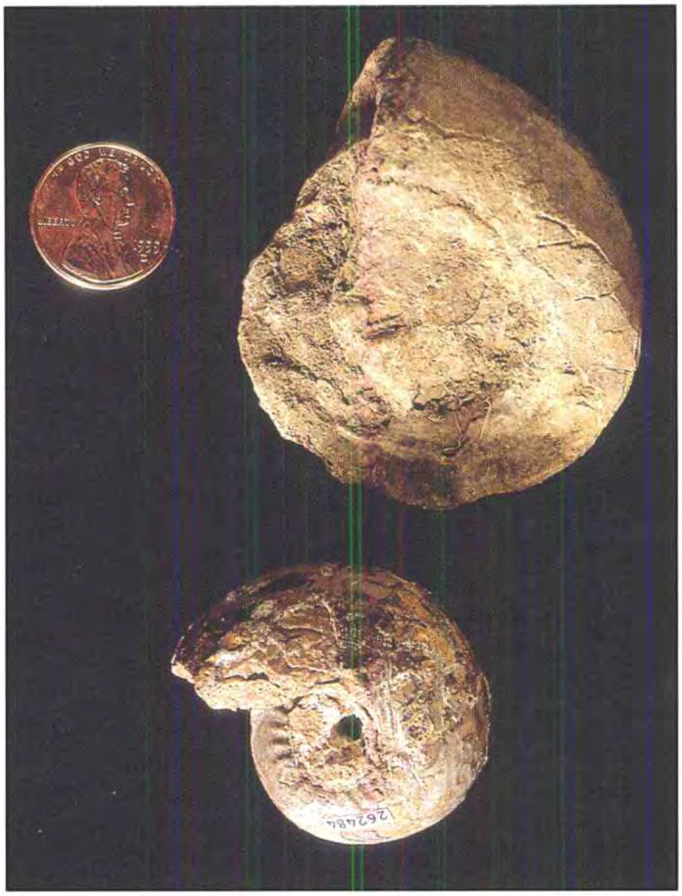


FIGURE 4—The two ammonoids shown here are from Pennsylvanian rocks in southeastern Kansas. The top specimen belongs to the genus *Goniatites* and was collected from the Eudora Shale Member (Stanton Limestone) in Montgomery County. The lower specimen is *Schistoceras missouriense,* collected from the Drum Limestone, about 6.5 miles northeast of Independence, Kansas.

FIGURE 5—*Baculites* is a common, straight-shelled ammonoid. These specimens are from the Pierre Shale of Logan County, Kansas. They are Late Cretaceous in age.

were important predators in the ancient oceans, eating fish, crabs, and other shellfish. The discovery of fossil ammonoids with bite marks tell us that ammonoids also were preyed upon by larger vertebrates, such as fishes, sharks, and mosasaurs.

The diversity of external shell form in ammonoids points to a wide range of adaptations to the marine environment. Some ammonoids may have spent part of their life on the ocean floor, while others spent their lives passively drifting with the currents through the water column. Others, especially those with smooth, streamlined shells, were probably energetic swimmers. The soft, squidlike animal lived in the front chamber; the other chambers, called buoyancy chambers, were used to regulate the ammonoid's position in the water column.

FIGURE 6—The convoluted sutures are easy to see in this fossil fragment of the genus *Baculites*, from the Beecher Island Shale Member of the Pierre Shale in Cheyenne County, Kansas. Note the relatively large size of this Cretaceous ammonoid.

FIGURE 7—*Acanthoceras* is a fairly large ammonoid from the Kansas Cretaceous. This specimen comes from Ellsworth County, from the upper part of the Graneros Shale.

Because of their rapid evolution, abundance in the fossil record, and swimming or floating lifestyles, ammonoids are extremely useful in correlating the ages of sedimentary rocks from different parts of the world. By matching ammonoid species contained within rock formations from different places, geologists can determine that the rocks were deposited at approximately the same time. In fact, because ammonoids evolved so quickly during the Triassic, Jurassic, and Cretaceous periods, their fossils can be used to establish zones that represent less than a million years. This is very fine resolution when compared to the 4.6 billion years of geologic time.

Although ammonoids are relatively common fossils in the Cretaceous outcrops of central and western Kansas, they are much less common in eastern Kansas, where smaller fossils occasionally are found in selected Pennsylvanian and Permian outcrops (fig. 8).

Stratigraphic Range: Lower Devonian to Upper Cretaceous.

Taxonomic Classfication: Ammonoids belong to the kingdom Animalia, phylum Mollusca, class Cephalopoda, order Ammonoidea.

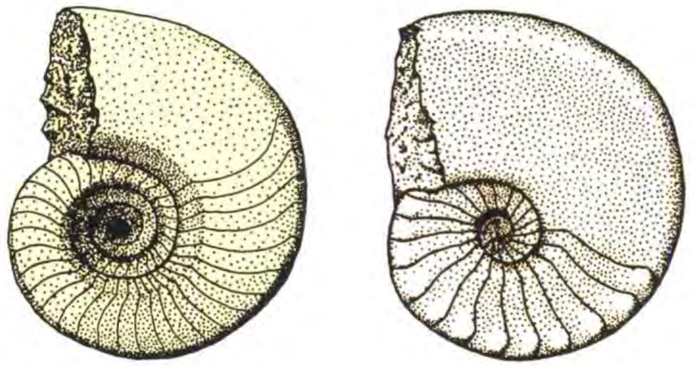


FIGURE 8—*Domatoceras* (left) and *Metacoceras* (right) can be found in Pennsylvanian and Permian rocks in eastern Kansas (drawings by Alan Kamb, KU Natural History Museum and Biodiversity Research Center, Division of Invertebrate Paleontology).

Brachiopods

Description: Brachiopods are marine animals that secrete a shell consisting of two parts called valves. Their fossils are common in the Pennsylvanian and Permian limestones of eastern Kansas (fig. 9).

Brachiopods have an extensive fossil record, first appearing in rocks dating back to the early part of the Cambrian Period, about 525 million years ago. They were extremely abundant during the Paleozoic Era, reaching their highest diversity roughly 400 million years ago, during the Devonian Period. At the end of the Paleozoic, however, they were decimated in the mass extinction that marks the end of the Permian Period, about 250 million years ago. This event, known as the Permian-Triassic mass extinction, may have killed more than 90 percent of all living species. It was the largest of all extinction events (larger than the major extinction at the end of the Cretaceous that killed off the dinosaurs).

Although some brachiopods survived the end-Permian extinction, and their descendants live in today's oceans, they never achieved their former abundance and diversity. Only about 300 to 500 species of brachiopods exist today, a small fraction of the perhaps 15,000 species (living and extinct) that make up the phylum Brachiopoda.

The name brachiopod comes from the Latin words for arm (*brachio*) and foot (*pod*) and refers to a paired, internal structure, which specialists initially thought was used for locomotion. This structure, called the lophophore, is actually used for feeding and respiration and is one of the features common to all brachiopods.

Another distinctive feature of all brachiopods is their bilaterally symmetrical valves—in other words, the right half is a mirror image of the left half (fig. 10). Humans and other mammals also are bilaterally symmetrical. This bilateral symmetry of each valve differentiates brachiopods from clams and other bivalved mollusks, with which they are sometimes confused (see fig. 21). Unlike

FIGURE 9—Slab containing numerous brachiopods belonging to the genera *Hystriculina* (H) and *Meekella* (M), from the Pennsylvanian Americus Limestone Member, Foraker Limestone, Chase County, Kansas.

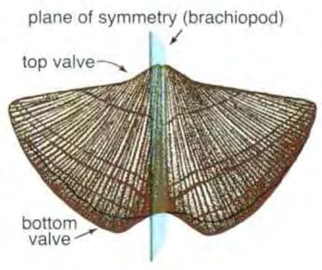


FIGURE 10—Bilateral symmetry of brachiopods (see fig. 21, for comparison with symmetry in clams).

brachiopods, clam valves are not bilaterally symmetrical; instead, the left and right valves are mirror images of each other.

Brachiopod shells come in a variety of shapes and sizes (fig. 11). Sometimes the bottom valve is convex like the top valve, but in many species the bottom valve is concave or occasionally conical. In some brachiopods (fig. 12), the top valve is concave and the bottom is convex. The outer surface of the valves may be marked by concentric wrinkles or radial ribs. Some brachiopods have prominent spines (fig. 13), but these are usually broken off and are found as separate fossils.

The shells of living brachiopods typically range in size from less than 0.25 inches (6.35 millimeters) to just over 3 inches (7.6 centimeters) in length or width. Fossil brachiopods generally fall within this same range, though some adults have shells that are less than 0.04 inches (1 millimeter) in diameter, and an exceptional few have shells that are 15 inches (38 centimeters) across.

Most brachiopods live in marine water, from relatively shallow environments up to about 650 feet (200 meters). Some species, however, have been found at depths of more than a mile. By studying living species, researchers can make inferences about how ancient brachiopods lived. Although they are mobile during their larval stage, many adult brachiopods are fixed to some object on the seafloor by a fleshy stalk that protrudes through an opening in the shell. Unable to move in pursuit of food, brachiopods use the lophophore to pump water through the interior cavity and recover food particles from it.

Brachiopods are one of most common fossils in the Pennsylvanian rocks in eastern Kansas (fig. 14). They are also common in the younger Permian rocks. However, in spite of their abundance in many Cretaceous rocks worldwide, brachiopods are almost never found in the Cretaceous rocks of Kansas.

Because of their worldwide abundance, diversity, and rapid evolution in the Paleozoic, brachiopod fossils are useful indicators of the ages of different rock layers. By matching the brachiopod species contained within rocks deposited in different locations, paleontologists can determine that the rock units were deposited at the same time.

Stratigraphic Range: Lower Cambrian to Holocene.

Taxonomic Classification: Brachiopods belong to kingdom Animalia, phylum Brachiopoda. The phylum is divided into three subphyla, the Linguliformea, Craniiformea, and Rhynchonelliformea.

FIGURE 11—These common Kansas brachiopod fossils display some of the group's variety (drawings by Alan Kamb, KU Natural History Museum and Biodiversity Research Center, Division of Invertebrate Paleontology).

FIGURE 12—Two specimens of the brachiopod genus *Reticulatia*, which has a concave top valve (left) and a convex bottom valve. These Pennsylvanian fossils are from the Americus Limestone Member of the Foraker Limestone in Greenwood County, Kansas.

FIGURE 13—(*left*) The exceptional preservation of the brachiopod fossil in the center of the photo (note the delicate spines still attached to the valve) indicates that the specimen was buried quickly in undisturbed sediments. This limestone slab was collected near Topeka, from the Coal Creek Limestone Member of the Topeka Limestone.

FIGURE 14—(*below*) Brachiopods commonly found in Kansas rocks: *Neospirifer,* Farley Limestone Member, Wyandotte Limestone, Johnson County; *Meekella,* collected near Beaumont, Butler County; *Derbyia,* Speiser Shale, Council Grove Group, Cowley County; *Crurithyris,* Beil Limestone Member, Lecompton Limestone, Douglas County; *Phricodothyris,* Lecompton Limestone, Douglas County; *Neochonetes,* Garrison Shale, Council Grove Group, Riley County; *Hustedia,* Topeka Limestone, Shawnee Group, Jefferson County.

Bryozoans

Description: Bryozoans are some of the most abundant fossils in the world. They are also widespread today, both in marine and freshwater environments, living at all latitudes and at depths ranging downward to at least 27,900 feet (8,500 meters).

Marine bryozoans show up in the fossil record in the early part of the Ordovician Period, roughly 470 million years ago. In Kansas, fossil bryozoans are common in the Pennsylvanian and Permian rocks of the eastern part of the state (fig. 15).

Freshwater bryozoans are virtually unknown as fossils because they did not have mineralized skeletons. Throughout their long history, marine bryozoans have been abundant and widely distributed geographically. They are the most abundant fossils in many limestones, calcareous shales, and mudstones. At least 3,500 living species and 15,000 fossil species are known.

Bryozoans are small animals (just large enough to be seen with the naked eye) that live exclusively in colonies. In fact, the phylum Bryozoa is the only animal phylum in which all known species form colonies. The name comes from two Greek words, *bryon* (moss) and *zoon* (animal), and bryozoans are sometimes called moss animals because some colonies resemble mosses.

Bryozoans are sometimes confused with corals, another colonial group of animals (see p. 22). Like corals, most bryozoans secrete external skeletons made

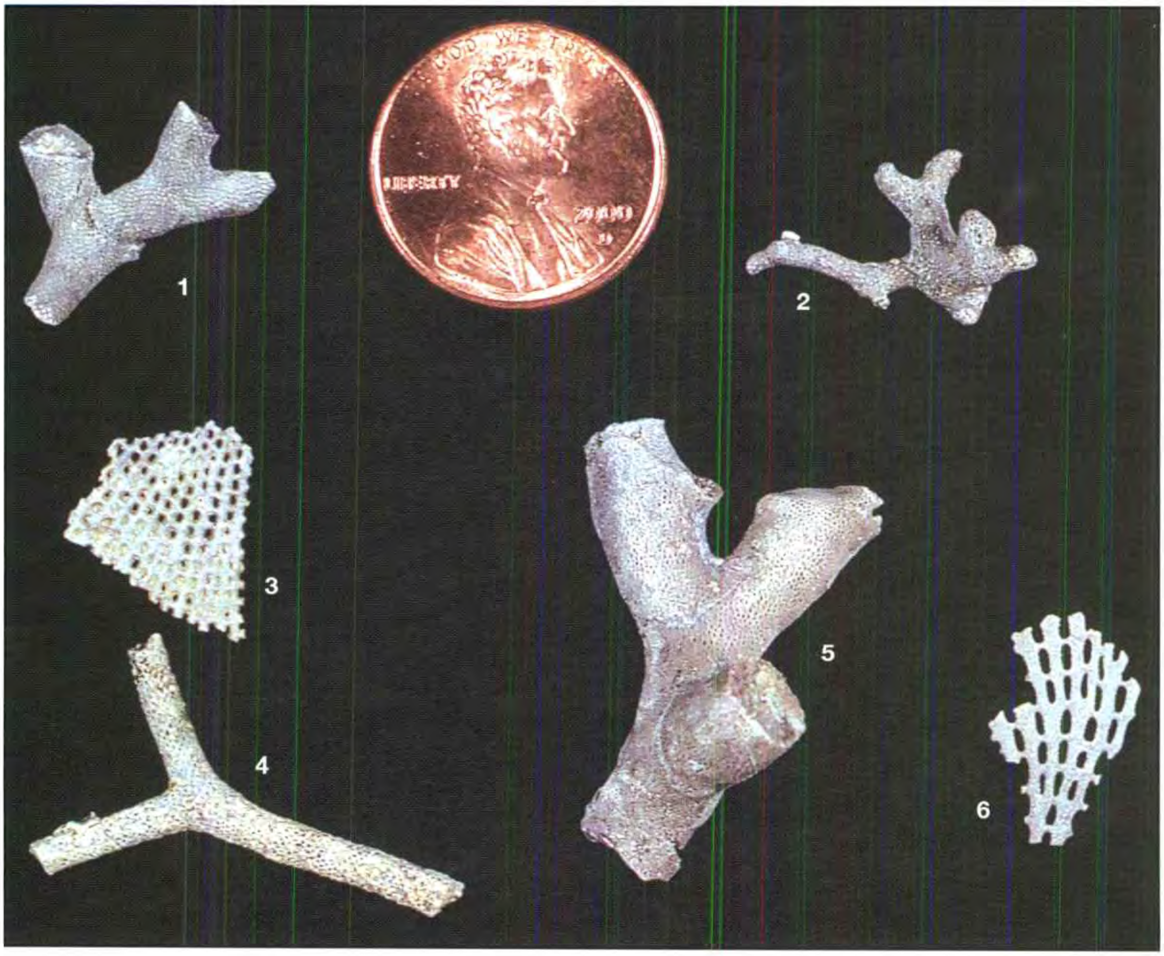


FIGURE 15—Bryozoan fossils from the Topeka Limestone. These fossils lived during the Pennsylvanian subperiod, about 300 million years ago, and illustrate the branching (1, 2, 4, 5) and netlike (3, 6) forms of some bryozoan colonies.

of calcium carbonate, which form the framework of the colony. Bryozoans, however, are more complex organisms than corals and generally do not build reefs.

Individual members of a bryozoan colony are called zooids. Although all zooids in the colony are physically connected, each lives in its own calcium carbonate compartment. Some or all zooids in a colony are feeding zooids, equipped with tentacle-bearing feeding organs. Bryozoans feed by projecting these tentacles into the water through openings in their external skeletons (fig. 16). The tentacles have tiny moving filaments called cilia, which create currents that draw microscopic organisms and plants into the mouth. Feeding zooids also have an alimentary canal, muscles, a nervous system, and a U-shaped digestive tract. Simple egg- and sperm-producing structures also are present in some zooids in every colony.

New bryozoan colonies start out with a single zooid, which may be produced either sexually or asexually (through budding) by the parent colony. As this original zooid begins feeding, it buds to form additional genetically identical zooids. These new zooids also bud, forming the colony. Large colonies may consist of hundreds of thousands or even millions of zooids.

Some bryozoans built colonies that grew from the seafloor in branching structures; these fossils look something like twigs. Other species erected netlike frameworks (fig. 17), while still others spread like a crust on shells, rocks, plants, and even other bryozoan colonies (fig. 18). Almost all the fossils are fragments of colonies; only rarely is an entire colony preserved.

FIGURE 16—Close-up drawing of *Rhombopora*, showing the openings in the external skeleton through which the individual zooids extended their tentacles for feeding. *Rhombopora* fossils are common in Pennsylvanian and Permian outcrops in Kansas (drawing by Alan Kamb, KU Natural History Museum and Biodiversity Research Center, Division of Invertebrate Paleontology).

FIGURE 17—*Septopora* is one of the netlike bryozoans found in Kansas rocks. This well-preserved specimen, although collected from the Kansas City Formation, near Kansas City, Missouri, is representative of fossils found in Pennsylvanian rocks of eastern Kansas.

In Kansas, the Florena Shale in Riley and Pottawatomie counties is an excellent place to find bryozoans. They are also common in the Plattsmouth Limestone Member (of the Oread Limestone), the Beil Limestone Member (of the Lecompton Limestone), and the Topeka Limestone. Bryozoans are less common in the Cretaceous rocks to the west.

Stratigraphic Range: Lower Ordovician to Holocene.

Taxonomic Classification: Bryozoans belong to kingdom Animalia, phylum Bryozoa. The phylum is divided into three classes, the Phylactolaemata (freshwater bryozoans), the Stenolaemata, and Gymnolaemata.

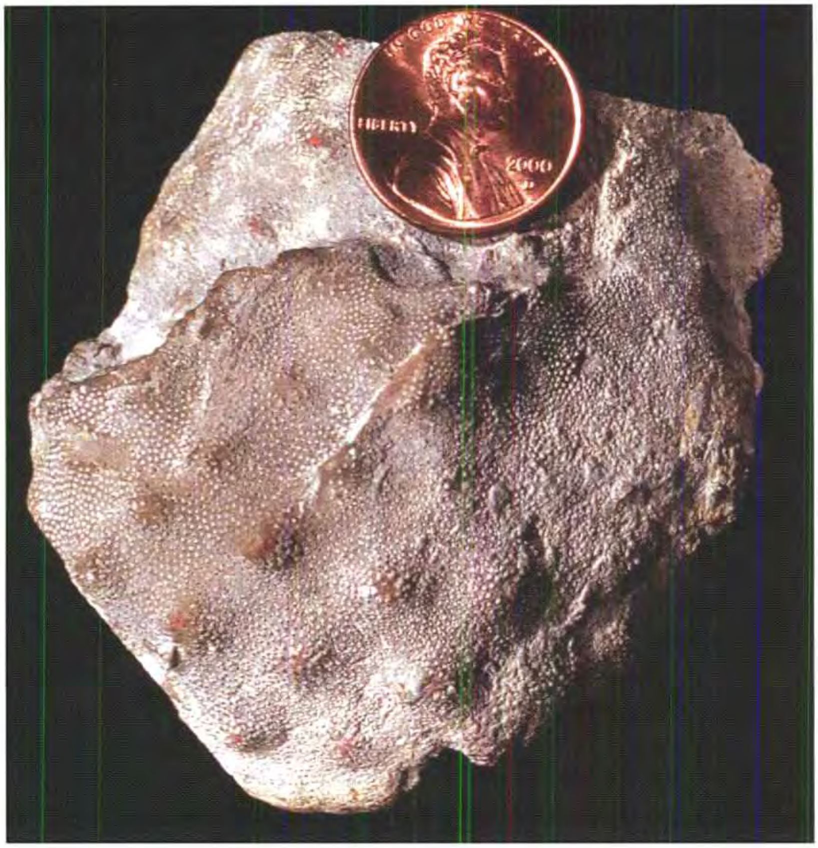


FIGURE 18—This specimen of *Fistulipora*, from the Argentine Limestone Member of the Wyandotte Formation in Wyandotte County, is an example of the encrusting form of bryozoan colonies.

Clams and Their Relatives

Description: Of the fossils commonly found in Kansas rocks, clams may be the easiest to recognize because they closely resemble clam shells scattered along modern seashores (fig. 19). Clams and their relatives (oysters, scallops, and mussels) are often called bivalves (or bivalved mollusks) because their shell is composed of two parts called valves.

Bivalves have a long history. Their fossils first appear in rocks that date to the middle of the Cambrian Period, about 510 million years ago. Although the group became increasingly abundant about 400 million years ago during the Devonian Period, bivalves really took off following the massive extinction at the close of the Permian Period.

Modern bivalves live in a variety of marine and freshwater environments, from the shallow, nearshore waters to great depths. Fossils indicate that bivalves have occupied most of these environments for more than 450 million years, but during the Paleozoic Era they were especially common in near-shore environments.

Inside the bivalve's hard shell, the body consists of two lobes, one lining each valve. A muscular structure called a foot, present in most bivalves, is used for locomotion and burrowing. Most bivalves feed on microorganisms suspended in the water, though some feed on the materials found in sediments of the seafloor and a few are even predatory.

Over their long history, bivalves have evolved a variety of lifestyles. Some live on the seafloor, attached to rocks and other objects or to the sediment. Oysters are an example of this mode of life. Other bivalves use their muscular foot to burrow into the substrate, sometimes quite deeply. These burrowing forms rely on tubelike structures that they can extend to the surface of the seafloor, allowing them to feed while remaining protected below the surface of the sediment. Some bivalves bore into rock and coral reefs and live in these cavities, and others simply lie on the substrate, unattached. A few unattached species such as scallops swim by clapping their valves together, propelled by the rapid expulsion of water.

Like their living descendants, fossil bivalves come in many different shapes and sizes. Externally, the valves have a wide range of markings (fig. 20). Typically the right and left valves are symmetrical (fig. 21), in contrast to the

FIGURE 19—Pennsylvanian bivalves in limestone, collected near Bonner Springs, Kansas (note bryozoan fragments on left side of photo).

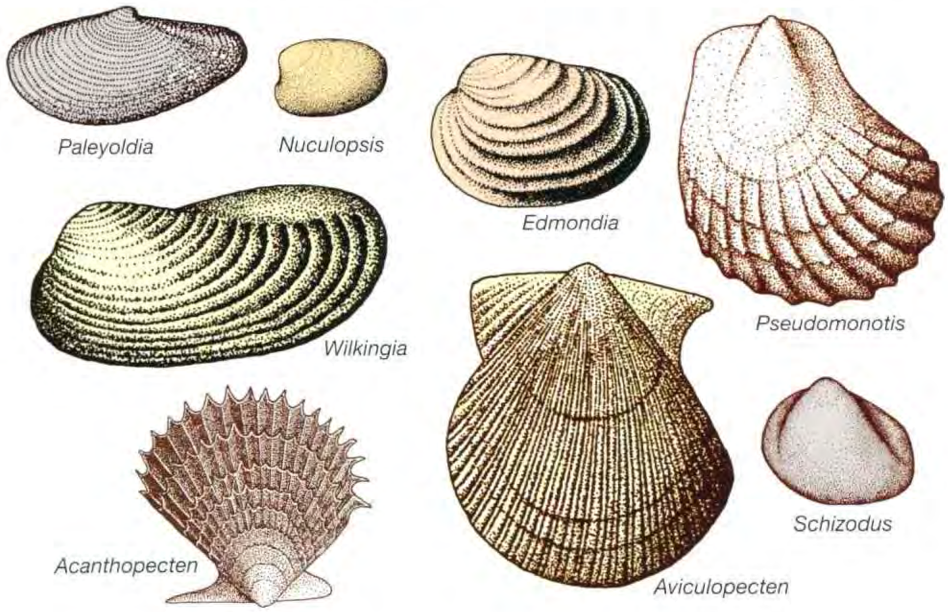


FIGURE 20—(*left*) These drawings of several Kansas fossil bivalves (approximately to scale) illustrate some of the variety in shape and ornamentation (drawings by Alan Kamb, KU Natural History Museum and Biodiversity Research Center, Division of Invertebrate Paleontology).

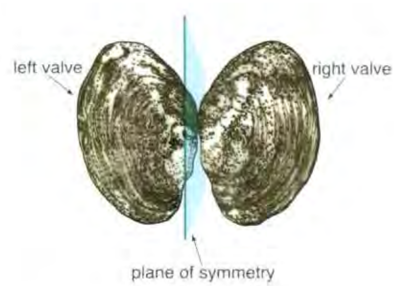
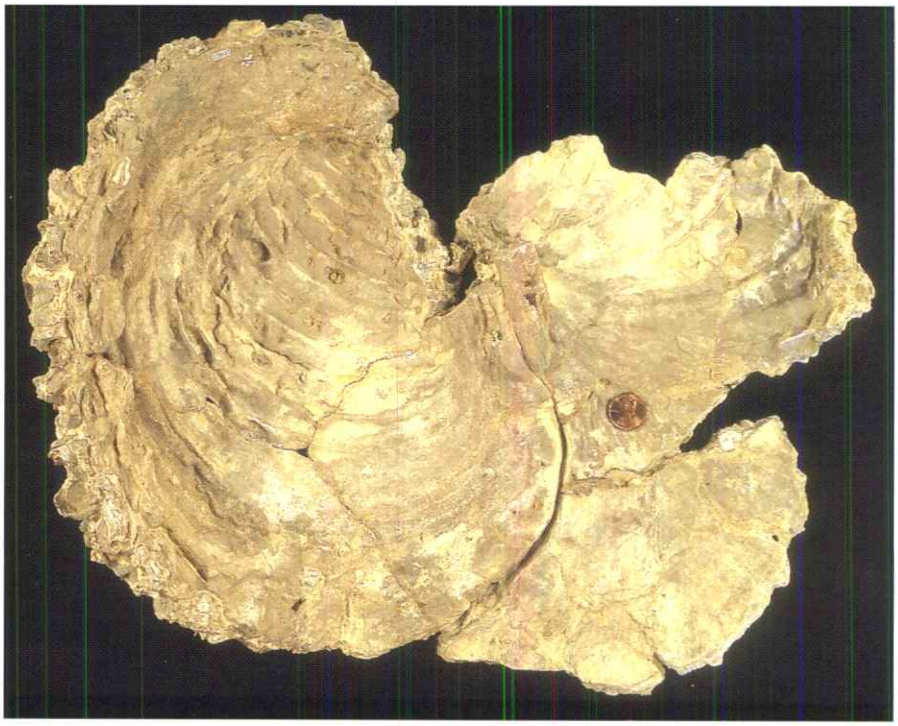


FIGURE 21—Symmetry of clams.

bilateral symmetry of individual brachiopod valves (see fig. 10). Some bivalves, such as oysters, do not have symmetrical valves.

The oldest fossil clams are generally the smallest; most Cambrian species are tiny, just large enough to see without magnification. Over time, larger species evolved. The largest—inoceramid clams from western Kansas—are as much as 6 feet (1.8 meters) in diameter. These extinct clams lived in groups on the seafloor of the shallow ocean that covered the interior of North America during the Cretaceous Period (from about 145 to 65 million years ago) and are preserved in great numbers in the rocks of the Niobrara Chalk. Some of these huge fossils are covered with encrusting oysters (fig. 22). Others have been found with a variety of fish fossils between their shells, indicating that the fish used the giant clam as a safe feeding place.



A

B

FIGURE 22—This fossil of *Platyceramus grandis* shows the larger sizes of some of the inoceramid clams from the Cretaceous (note penny for scale in each view). **A,** Interior view of valve; **B,** exterior view of valve, covered with fossils of encrusting oysters. This specimen is from the Smoky Hill Chalk Member, Niobrara Chalk, Trego County, Kansas.

In addition to the huge inoceramid clams, smaller clams and oysters are also common in the Cretaceous rocks of western Kansas, particularly in the Greenhorn Limestone (fig. 23). In the eastern part of the state, both marine and freshwater bivalves occur as fossils in Pennsylvanian and Permian limestones and shales (fig. 24).

Stratigraphic Range: Lower or Middle Cambrian to Holocene.

Taxonomic Classification: Bivalves belong to the kingdom Animalia, phylum Mollusca, class Bivalvia.

FIGURE 23—This smaller inoceramid clam, *Mytiloides mytiloides*, was collected from the Jetmore Chalk Member, Greenhorn Limestone, near Sylvan Grove in Lincoln County, Kansas. Inoceramids are among the most common fossils in central Kansas.

FIGURE 24—Several specimens of *Myalina*, a thick-shelled clam commonly found in the Pennsylvanian rocks of eastern Kansas. The middle specimen, showing the outside of the clam, is from the Stanton Limestone, Montgomery County; the other two, showing the interior of the shell, are from the Kanwaka Shale, Coffey County, Kansas.

Corals

Description: Corals are simple animals that secrete skeletons made of calcium carbonate. They are close relatives of sea anemones and jellyfish and are the main reef builders in modern oceans. Corals can be either colonial or solitary.

As fossils, corals are found worldwide in sedimentary rocks. Based on these fossils, we know the corals began their long evolutionary history in the Middle Cambrian, over 510 million years ago. In Kansas, they are fairly common in Pennsylvanian and Permian rocks, deposited from about 315 to 250 million years ago (fig. 25).

Corals are simple animals, characterized by their radial symmetry and lack of well-developed organs. The polyp, the soft part of the coral, is essentially a small digestive sack made up of an inner and outer wall, separated by a gelatinous layer (fig. 26). The mouth, surrounded by stinging tentacles, forms an opening through which food enters and waste products are expelled. The hard external skeleton is secreted by the polyp's outer wall. These calcium carbonate structures are the part of the animal most likely to be preserved as a fossil (fig. 27).

Corals live attached to the seafloor and feed by trapping small animals with their tentacles. They reproduce both sexually and asexually. Budding, a kind of asexual reproduction, occurs when the parent polyp splits off new polyps. Evidence of budding can be seen in fossil corals.

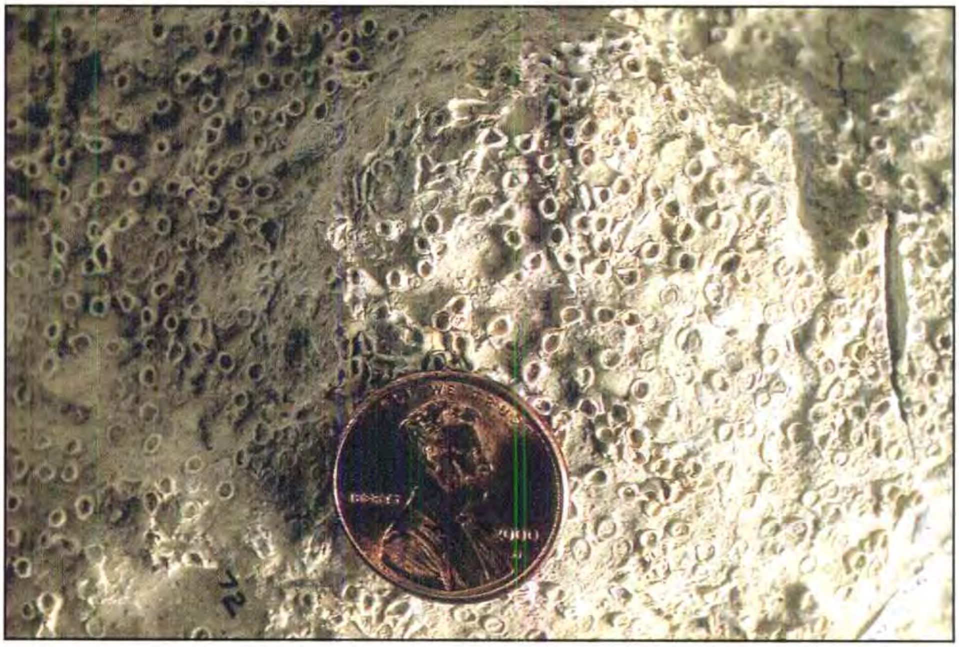


FIGURE 25—This sample of the colonial coral *Cladochonus* is from the Beil Limestone Member, Lecompton Limestone, Greenwood County. This limestone was deposited during the Pennsylvanian subperiod, about 300 million years ago.

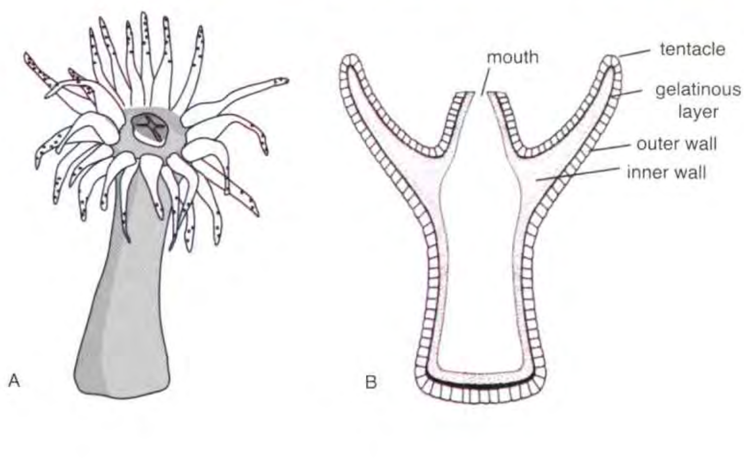


FIGURE 26—**A,** Generalized drawing of a coral polyp. **B,** Cross section of simple polyp.

Modern corals inhabit deep-water environments as well as shallow reefs. Based on evidence from the rocks, scientists have determined that the Pennsylvanian and Permian corals of Kansas lived in warm, shallow, sunlit waters where the bottom was firm enough to offer a secure point of attachment.

Although corals are the main reef builders in modern oceans, not all corals build reefs. In addition to the corals, which are called framework organisms, other organisms contribute to the formation of reefs. For example, modern reefs are inhabited by binding organisms (such as encrusting algae) and filler organisms (such as snails, bivalves, and sponges), whose skeletons fill in the spaces in the reef after death.

Two groups of corals were important inhabitants of the Pennsylvanian and Permian seas—tabulate and rugose corals. Tabulate corals were exclusively colonial and produced calcium carbonate skeletons in a variety of shapes: moundlike, sheetlike, chainlike, or branching (figs. 28, 29). Tabulate corals get their name from horizontal internal partitions known as tabulae. Some tabulate corals were probably reef builders, but not in Kansas.

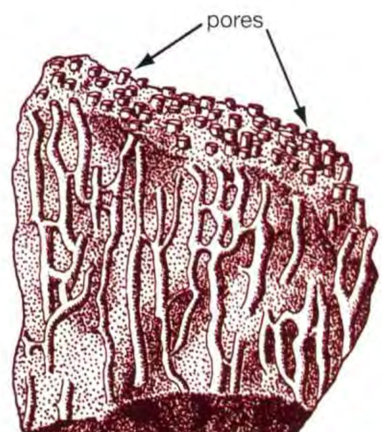
A common characteristic of rugose corals, from which they get their name, is the wrinkled appearance of their outer surface. (Rugose comes from the Latin word for wrinkled.) Rugose corals may be either solitary or colonial. Because solitary rugose corals are commonly shaped like a horn, these fossils are sometimes called horn corals (fig. 30).

Both tabulate and rugose corals died out in the major extinction that occurred at the end of the Permian Period, roughly 250 million years ago. This extinction marked the end of the Paleozoic Era. The corals that inhabited the post-Paleozoic seas differ significantly from the earlier corals. Because of this, specialists agree that these later corals are not closely related to the Paleozoic corals.

Tabulate and rugose corals are common in eastern Kansas. Rugose corals are especially common in the Beil Limestone Member of the Lecompton Limestone in the vicinity of Sedan, Kansas.

FIGURE 27—The tabulate coral *Syringopora* shows the structure of the hard parts that protected the individual polyps and formed the framework of the colony. **A,** Side view of colony, in which the pores are not visible; specimen collected from the Plattsmouth Limestone Member, Oread Limestone, Douglas County. **B,** The drawing shows the pores on the surface (see arrows), from which the polyps extended their tentacles to feed (Alan Kamb, KU Natural History Museum and Biodiversity Research Center, Division of Invertebrate Paleontology).

A



B

FIGURE 28—The Pennsylvanian tabulate coral *Thamnoporella* illustrates the branching structure of some colonies. These corals were collected from the Bethany Falls Limestone Member, Swope Limestone, in Labette County, Kansas.

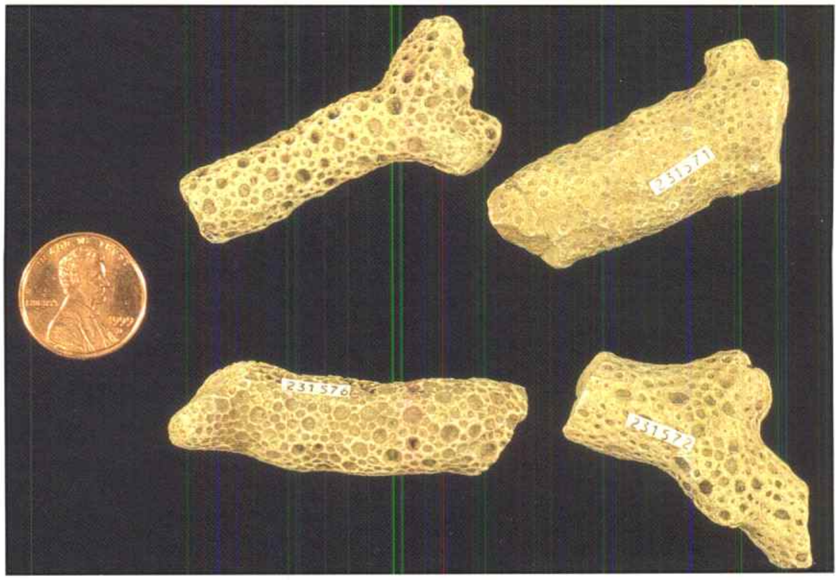


FIGURE 29—Another tabulate coral, *Syringopora,* is an example of a moundlike structure. This sample is from the Spring Branch Limestone Member, Lecompton Limestone, Woodson County, Kansas.

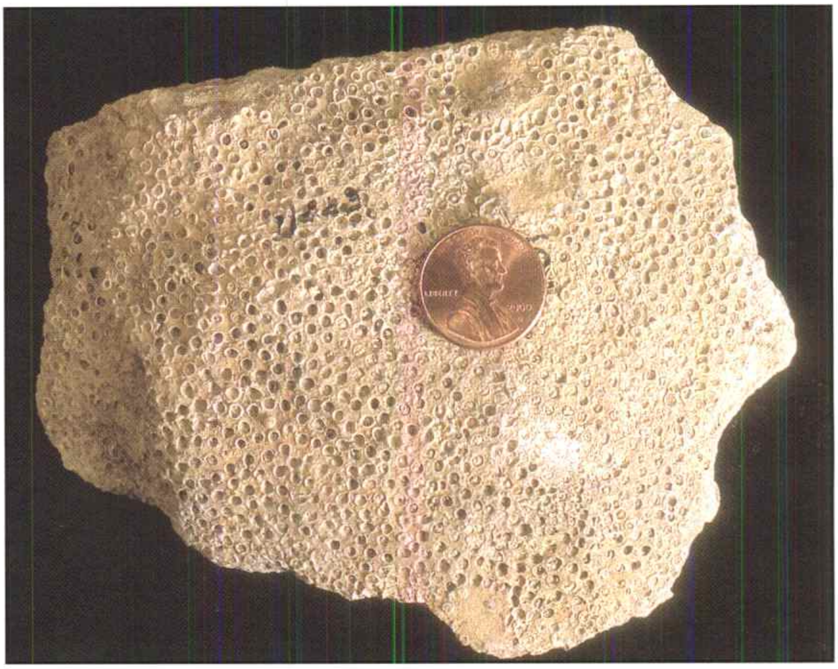
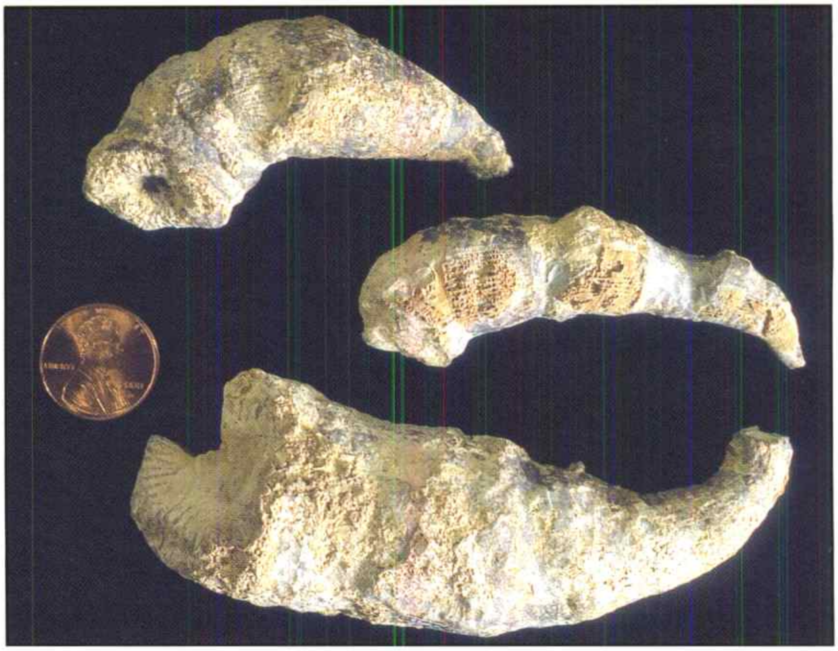


FIGURE 30—These Pennsylvanian rugose corals, *Caninia torquia,* are from the Beil Limestone Member, Lecompton Limestone, Douglas County, Kansas.



Stratigraphic Range: Middle Cambrian to Holocene.

Taxonomic Classification: Corals belong to the kingdom Animalia, phylum Cnidaria, class Anthozoa, subclass Zoantharia. The subclass is divided into six orders, two of which—the Rugosa and Tabulata—are common Kansas fossils. Most living and post-Paleozoic fossil corals belong to a third order, the Scleractinia, the earliest fossils of which are from the middle part of the Triassic Period, about 14 million years after the mass extinction at the end of the Permian.

Crinoids

Description: Because many crinoids resemble flowers, with their cluster of waving arms atop a long stem, they are sometimes called sea lilies. But crinoids are not plants. Like their relatives—starfishes, sea urchins, sea cucumbers, and brittle stars—crinoids are echinoderms, animals with rough, spiny surfaces and a special kind of radial symmetry based on five or multiples of five.

Crinoids have lived in the world's oceans since at least the beginning of the Ordovician Period, roughly 490 million years ago. They may be even older. Some paleontologists think that a fossil called *Echmatocrinus*, from the famous Burgess Shale fossil site in British Columbia, may be the earliest crinoid. The Burgess Shale fossils date to the Middle Cambrian, well over 500 million years ago. Either way, crinoids have had a long and successful history on earth (fig. 31).

FIGURE 31—Stem fragments from assorted Pennsylvanian crinoids show some of the variation in the fossils found in Kansas rocks.

The Burgess Shale

The Burgess Shale is one of a handful of exceptional fossil sites worldwide where soft parts—soft-bodied animals and soft tissues—are preserved along with the hard parts. Located in the Canadian Rockies, in Yoho National Park, the Burgess Shale of eastern British Columbia has produced spectacularly well preserved fossils of over 100 kinds of organisms, including trilobites, sponges, seaweed, brachiopods, jellyfish, wormlike creatures, and a number of bizarre life forms that may not be related to recognized animal groups.

The dark shales that give the Burgess Shale its name were deposited in the Middle Cambrian, roughly 505 million years ago, not so long after the Cambrian Explosion, the name given to the rapid burst of multicellular life. Because of their exceptional preservation, the Burgess Shale fossils provide precious clues about these early multicellular creatures—from the contents of a worm's gut to the delicate trilobite antennae—information that could never be deduced from hard parts alone.

The fossils also provide clues about the world these creatures inhabited and the events that killed them. The animals of the Burgess Shale lived on and around a vast reef submerged in a warm, shallow sea. (In early Cambrian times, the North American continent was positioned just south of the equator.) At that time, all life was restricted to the world's oceans; the continents were bare and subject to erosion. Now and then, mudslides rolled off the barren continents into the seas, burying the plants and animals living there. At the Burgess Shale site, periodic avalanches of fine mud swept animals from the reef top and buried them, along with any other living thing in its path, at the base of the reef roughly 500 feet below. The fine mud buried the organisms so quickly and completely that the animals died instantly and were entombed in an oxygen-free environment that saved them from destruction by both larger scavengers and bacteria.

The ancient environment of the Burgess Shale furnished two essential ingredients for soft-part preservation: rapid burial in undisturbed sediment and deposition in an oxygen-free environment. Thus, the organisms were saved from immediate destruction and decay. That the fossils somehow withstood 500 million years of heat, pressure, fracturing, and erosion (not to mention the mountain-building forces that brought them to their current position high in the Canadian Rockies), and then were discovered by Charles Walcott of the Smithsonian Institute in 1909, is nothing short of a miracle. It's no wonder that in 1981, UNESCO designated the Burgess Shale as a world heritage site.

For more information on the Burgess Shale, see the following books and web sites:

Gould, Stephen J., 1989, Wonderful Life—The Burgess Shale and the Nature of History: New York, Norton, 347 p.

Smithsonian National Museum of Natural History, 2002, Burgess Shale: www.nmnh.si.edu/paleo/shale/preef.htm (July 12, 2002).

University of California Museum of Paleontology, 2000, Localities of the Cambrian: The Burgess Shale (written by Erin Scott, Lara Kirkner, Jane Shin, Veeral Desai, James Chan): www.ucmp.berkeley.edu/cambrian/burgess.html (July 12, 2002).

Yoho-Burgess Shale Foundation, 1997-2002, The History of the Burgess Shale: www.burgess-shale.bc.ca/history/history.htm#505 (July 12, 2002).

Crinoids flourished during the Paleozoic Era, carpeting the seafloor like a dense thicket of strange flowers, swaying this way and that with the ocean currents. They peaked during the Mississippian subperiod, when the shallow, marine environments they preferred were widespread on several continents. Massive limestones in North America and Europe, made up almost entirely of crinoid fragments, attest to the abundance of these creatures during the Mississippian. Mississippian rocks crop out only in the extreme southeast corner of Kansas, but crinoid fossils are common in Pennsylvanian and Permian rocks in the eastern part of the state.

Crinoids came close to extinction towards the end of the Permian Period, about 250 million years ago. The end of the Permian was marked by the largest extinction event in the history of life (see box on mass extinctions, p. 6-7). The fossil record shows that nearly all the crinoid species died out at this time. The one or two surviving lineages eventually gave rise to the crinoids populating the world's oceans today.

In general, crinoids have three main body parts. The first, the stem, attaches the animal to the ocean floor and consists of disk-shaped pieces stacked on top of each other. These stem pieces come in a variety of shapes—round, pentagonal, star-shaped, or elliptical—and each stem piece has a hole in its center (fig. 32). At the top of the stem is the cuplike calyx, which contains the mouth, the digestive system, and the anus. The lower part of the calyx is made up of rigid, five-sided plates, arranged radially in rows of five (fig. 33). These

FIGURE 32—Individual stem pieces are common fossils in Kansas rocks. These samples of different Pennsylvanian crinoid species are from the Stanton Limestone, Woodson County, Kansas.

FIGURE 33—This calyx of the Pennsylvanian crinoid *Ulocrinus* shows the radial arrangement of the five-sided plates (outlined in white); arrow indicates where the stem would attach. This specimen is from the Iola Limestone, Allen County, Kansas.

plates form the base of the third part, the food-gathering arms. The arms, which are also segmented, have grooves with cilia, or tiny hairs, that capture suspended food particles and direct them back towards the mouth. The number of arms varies from five, common in primitive species, to as many as 200 in some living species, always in multiples of five (fig. 34).

Based on the fossil record of crinoids, especially the details of the plates that made up the arms and calyx, experts have identified hundreds of different crinoid species. Though most crinoids had stems, not all did. Today, stemless crinoids live in a wide range of ocean environments, from shallow to deep, whereas their relatives with stems normally live only at depths of 300 feet (91 meters) or more. These modern crinoids are an important source of information about how the many different extinct crinoids lived.

Rarely are crinoids preserved in their entirety: once the soft parts of the animal decayed, sea currents generally scattered the skeletal segments. By far the most common crinoid fossils are the stem pieces. These are abundant in eastern Kansas limestones and shales. Only occasionally is the cuplike calyx found. Kansas, however, is home to a spectacular and rare fossil crinoid called *Uintacrinus,* which was preserved in its entirety. These fossils, which were discovered in the Niobrara Chalk of western Kansas, lived during the later part of the Cretaceous Period, roughly 75 million years ago (fig. 35). *Uintacrinus* is a stemless crinoid, and specimens of these beautifully preserved crinoids from

FIGURE 34—(*above*) This plaster cast of the Pennsylvanian crinoid *Delocrinus* preserves the segmented arms sitting on top of the calyx. The fossil's resemblance to a flower bud illustrates why crinoids have been called sea lilies. The original specimen was found west of Emporia, Kansas.

A

B

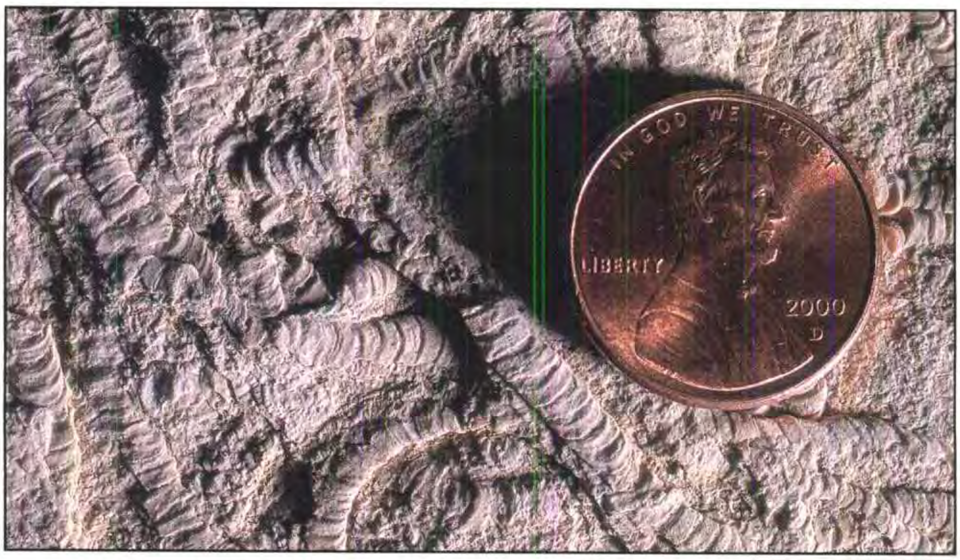


FIGURE 35—*Uintacrinus socialis* is a stemless crinoid that lived in the shallow Cretaceous sea that covered much of North America roughly 70 million years ago. **A,** Among the numerous arms preserved in this slab, a segmented calyx is also visible (see arrow). **B,** In this close-up of another specimen, the individual arm segments are easy to see. These specimens were collected from the Niobrara Chalk, Gove County, Kansas.

Kansas are on display in many of the major museums of the United States and Europe.

Stratigraphic Range: Ordovician (or possibly Middle Cambrian) to Holocene.

Taxonomic Classification: Crinoids belong to the kingdom Animalia, phylum Echinodermata, subphylum Crinozoa, class Crinoidea.

Echinoids

Description: Echinoids are a distinctive group of marine animals that includes the familiar sea urchins and sand dollars. Like crinoids, echinoids are members of the phylum Echinodermata and have a skeleton of calcite with warty or spiny projections (*echinodermata* means spiny-skinned). This skeleton is usually made up of tightly interlocking plates that form a rigid structure called the test, which houses the animal's soft parts.

The fossil record of echinoids began in the Late Ordovician, about 450 million years ago. Echinoids evolved slowly throughout the Paleozoic, becoming more diverse though never really abundant during the early part of the Mississippian subperiod. Although decimated by the massive extinction at the end of Paleozoic (see p. 6-7), echinoids survived into the Triassic Period. By the Late Triassic, echinoids had begun the rapid evolution that continued throughout the Mesozoic and Cenozoic eras. They remain a diverse and abundant part of today's oceans.

Echinoids are often divided into two groups, the regular and irregular echinoids. Regular echinoids have a nearly perfect pentameral (five-part) symmetry, like crinoids (see p. 27), whereas the irregular echinoids are essentially bilaterally symmetrical. Regular echinoids include all the extinct Paleozoic forms (fig. 36) as well as modern sea urchins and pencil urchins (cidaroids). Irregular echinoids, which evolved from a regular ancestor during the Triassic Period, include the sand dollars, sea biscuits, and heart urchins common in today's oceans. (Sand dollars originated during the Paleocene Epoch, roughly 60 million years ago.)

FIGURE 36—The five-part symmetry of the Paleozoic echinoids is visible in these disarticulated plates collected from Permian rock in Manhattan, Riley County, Kansas. Such fragmented spines and plates are common fossils in the Pennsylvanian and Permian rocks of eastern Kansas.

In the Late Triassic, irregular echinoids underwent major changes—including the flattening and elongation of the test, repositioning of the anus, and reduction in size and increase in number of spines. These changes allowed echinoids to live buried in the sediment, in contrast to their Paleozoic precursors, which were restricted to life on the seafloor. This expansion of their habitat possibilities no doubt fueled the evolutionary burst that occurred in the Mesozoic and Cenozoic.

All echinoids, whether regular or irregular, have movable spines attached to their tests. In regular echinoids like the sea urchins, these spines are typically long and prominent; in irregular echinoids like sand dollars and heart urchins, they are shorter and more numerous. The spines in regular echinoids are typically used for protection from predators and for walking. In irregular echinoids, in addition to being used for locomotion, spines protect the animal from abrasion and help maintain space for water to circulate between the test and the burrow.

Echinoids developed different ways of living—on the seafloor (sea urchins), slightly buried (sand dollars), and deeply buried in the sediment (heart urchins). By studying the types of rock in which echinoid fossils are found, specialists know that Paleozoic echinoids generally lived in quiet environments near the shore. During the Mesozoic and Cenozoic eras, echinoids expanded into a wide range of marine environments. The fossil record shows that echinoids were gregarious, occurring in large associations; this is also true of living species. Today echinoids are found in all marine environments, from shoreline to the deep ocean but are most common in shallow, warmer seas.

Echinoids are active predators and scavengers. Many echinoids eat algae; others feed on higher plants as well as animal matter. Regular echinoids use their teeth and jaws to rasp or scoop up drifting plant matter, organic detritus, and small invertebrates. Irregular echinoids, on the other hand, swallow large quantities of sediment in bulk and extract the tiny organic particles, expelling the cleaned sediment through the large anus. Echinoids are preyed upon by fish, some gastropods, sea stars, sea otters, and even other echinoids.

Echinoid fossils are much more common in post-Paleozoic rocks. While this suggests that echinoids were much less abundant in the Paleozoic than in the Mesozoic, the regular echinoids of the Paleozoic had delicate tests that were less likely to be preserved. The combination of more rugged tests and burrowing lifestyle makes irregulars better candidates for fossilization. The regular echinoids of the Paleozoic lived on the substrate where predators and turbulence could break up their tests.

In Kansas, echinoid spines and plates are common in Pennsylvanian and lower Permian rock (fig. 37). Complete echinoids are rare because the skeletons are easily disarticulated and scattered, though occasionally more intact fossils are found (fig. 38). Echinoid spines are common in the Topeka Limestone, the lower Cresswell Limestone Member of the Winfield Limestone, the Florena Shale Member of the Beattie Limestone, and the Hughes Creek Shale Member of the Foraker Limestone. In Franklin County, they are also found in the Raytown Limestone Member of the Iola Limestone, the Spring Hill Limestone Member of the Plattsburg Limestone, and the Stoner, Captain Creek, and the South Bend Limestone Members of the Stanton Limestone.

Stratigraphic Range: Upper Ordovician to Holocene.

Taxonomic Classification: Echinoids belong to the kingdom Animalia, phylum Echinodermata, subphylum Eleutherozoa, class Echinoidea.

FIGURE 37—Scattered spines and plates of a Permian echinoid can be seen on the surface of this small piece of limestone from the Winfield Limestone, Dickinson County, Kansas.

FIGURE 38—This flattened specimen retains the general shape of the echinoid test with some of its plates and long spines more or less in life position. This Permian fossil was probably collected from the Florena Shale Member of the Beattie Limestone near Beattie, Kansas.

Fusulinids

Description: Fusulinids were small, marine organisms that were common inhabitants of the world's seas during the Pennsylvanian subperiod and the Permian Period, from about 315 to 250 million years ago. The earliest fusulinids occur in rocks deposited during the late Mississippian subperiod, about 320 million years ago. Fusulinids became extinct during the mass extinction at the end of the Permian Period, about 250 million years ago (see box on mass extinctions, p. 6-7).

Fusulinids were single-celled organisms, about the size and shape of a grain of wheat. In fact, the common Kansas fusilinid *Triticites* gets its name from the Latin word for wheat (fig. 39). Unlike multicellular animals, which accomplish basic life functions (such as locomotion, feeding, digestion, and reproduction) through a wide range of specialized cells, fusulinids and other single-celled organisms have to carry on these same functions within the confines of a single cell. As a result, the cell is highly complex.

In fusulinids, this complexity is evident in the structure of the hard calcium carbonate shells, called tests. Internally, the tests are divided into a series of chambers (fig. 40). By studying living relatives of the fusulinids (a group called the foraminifera), scientists know that the tests were secreted by the protoplasm, the living material within the cell. As fusulinids grew, the test coiled around itself, adding chambers along its longitudinal axis.

The earliest fusulinids were smaller than the head of a pin and somewhat spherical. During their 70 million years on earth, fusulinids evolved rapidly, typically becoming progressively longer and narrower. By the late Permian Period, some forms were over 4 inches (10 centimeters) long, an amazing size for a single-celled organism.

As fusulinids evolved, the internal test walls also became increasingly complex, with more ornate subdivisions of their internal chambers. Fusulinids look fairly similar from the outside. In order to identify them, scientists usually examine a cross section of the fossil test using a microscope (fig. 41).

Because of their rapid evolution and their occurrence in the rocks from around the world, fusulinids are extremely useful in correlating the ages of sedimentary rocks from different parts of the earth. By matching the kinds of fusulinids contained within sedimentary rock formations, geologists can show that far-flung rock strata—as widely separated as Kansas and Russia—were deposited at approximately the same time.

By studying the rocks in which fusulinids are found, geologists can determine what kind of environment they lived in. Apparently, fusulinids preferred a clear-water environment and may have been reef dwellers, though not in Kansas. The mass extinction at the end of the Permian Period decimated the world's reefs and their occupants.

Fusulinid fossils are found on all continents except Antarctica and are common in the Permian and Pennsylvanian rocks of eastern Kansas (fig. 42).

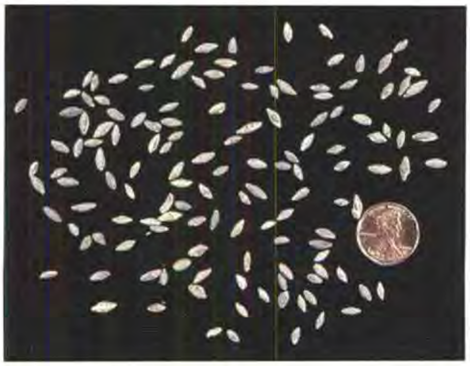


FIGURE 39—These Pennsylvanian fusulinids belong to the genus *Triticites*, which gets its name from the Latin word for wheat. *Triticites* is a common fossil in Kansas rocks.

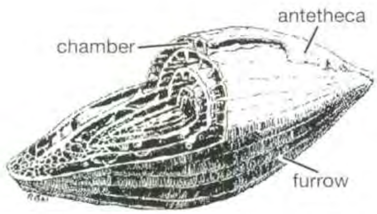


FIGURE 40—This cutaway view of a fusulinid test shows the complex structure of these single-celled organisms. The prominent line on the outside of the test, the antetheca, was the growing surface, where new chambers were added (drawing by Roger B. Williams, KU Paleontological Institute).

FIGURE 41—Cross section of the common fusulinid *Triticites*, showing the distinctive internal structure of its chambers (drawing by Alan Kamb, KU Natural History Museum and Biodiversity Research Center, Division of Invertebrate Paleontology).

FIGURE 42—*(right)* Fusulinids cover this limestone slab, collected from the Beil Limestone Member of the Lecompton Limestone in Chautauqua County, Kansas.

In fact, some Kansas limestones—for example, the Cottonwood Limestone Member of the Beattie Limestone, the Tarkio Limestone Member of the Zeandale Limestone, the Beil Limestone Member of the Lecompton Limestone, and the Americus Limestone Member of the Foraker Limestone—are made up almost exclusively of fusulinid fossils.

Stratigraphic Range: Upper Mississippian to Upper Permian.

Taxonomic Classification: Fusulinids belong to the kingdom Protoctista, phylum Protozoa, order Foraminiferida, suborder Fusulinina.

Insects

Description: Insects were the first animals on earth to develop flight, which is probably one reason they have been so successful. In sheer numbers, insects dominate the animal kingdom, with over 750,000 living species described. This is more than all the other living animal species combined, and scientists estimate that there are perhaps at least a million more insect species that have not yet been described.

Insects were probably similarly abundant in the past, but the fossil record of insects is limited, with only about 7,000 species known. The scarcity of insect fossils (compared to their present and probable past diversity) is a consequence of their relative fragility, lack of hard parts, and the fact that they lived on land. Rapid burial is essential for preservation, and this is more likely to happen in and around water than on land (fig. 43).

The oldest fossil insects are primitive, wingless insects (similar to modern silverfish and springtails) that lived during the early part of the Middle Devonian Period, roughly 395 million years ago. These primitive insects are known only from a few fragmentary specimens found in rocks from Scotland, New York, and Quebec. Nonetheless, these fragments have led experts to agree that insects must have originated millions of years earlier, perhaps at the end of the Silurian Period, about 415 million years ago.

The first substantial record of insects is in Pennsylvanian-age rocks, deposited from about 315 to 300 million years ago. By the Pennsylvanian,

FIGURE 43—This Permian fossil, *Dunbaria fascipennis*, preserves details of the veins and traces of colored bands on the wings that characterized members of this genus. This specimen, which has a wingspan of about 1.25 inches (3.2 centimeters), comes from the fossil insect site near Elmo, in Dickinson County (photograph by Michael Engel, KU Ecology and Evolutionary Biology).

insects had evolved wings and a variety of other specialized structures. Between the scarce Devonian fossils of primitive forms and the abundant and diverse Pennsylvanian fossils, there is a huge gap in the fossil record. So far, no fossil insects are known from Mississippian rocks, most of which were deposited in marine environments. Thus, both the origin of insects and the evolution of wings remains a mystery.

Insects are arthropods (*arthro* means jointed and *pod* means foot). Like other arthropods—shrimps, lobsters, crabs, spiders, scorpions, and the extinct trilobites—insects have a hardened outer covering, the exoskeleton, and jointed appendages used for feeding and movement.

The basic insect body plan is fairly simple, consisting of a head with two antennae, a middle section called the thorax, and an abdomen usually made up of 10 or 11 segments. The thorax has three segments, each of which bears a pair of jointed legs. The thorax generally has two pairs of wings, though some insects have lost one or both pairs.

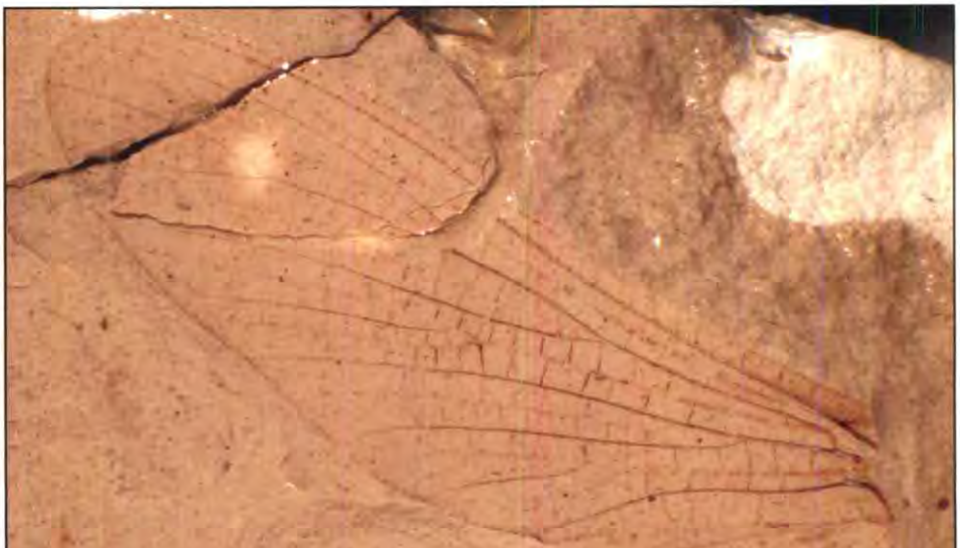
Insect wings contain a network of veins that serve as blood vessels and aid respiration. Because the wings are more resistant to deterioration than the rest of the body, they are the part most commonly fossilized. Although insect wings look delicate, their flat surface holds up better to compression than the rest of the body, and the wing is strengthened by its network of veins. In addition, predators prefer the body to the wings, another reason why about half of all described species of fossil insects are known from their wings alone (fig. 44).

Although fossil insects are not common in most Kansas rocks, the state is home to the Elmo fossil site, one of the world's richest sources of Permian insects, those that lived from about 300 to 250 million years ago. Located near the town of Elmo, south of Abilene in Dickinson County, the fossil site has yielded thousands of well-preserved specimens (fig. 45).

During Permian times, the Elmo site was a swampy, forested lowland around a freshwater lake, an oasis in an otherwise arid landscape. This ancient environment accounts for the excellent preservation of the Elmo fossils: insects probably became mired in the muddy swamp and were quickly buried by fine-grained sediments before they could be consumed by scavengers or microbes.

Among the numerous specimens recovered from the Elmo site was a giant dragonfly-like insect, *Meganeuropsis permiana*. With a wingspan of 29 inches (0.73 meter or 73.6 cm), *Meganeuropsis* is the largest insect ever known and

FIGURE 44—Insect fossils from Elmo, such as this delicate forewing of *Protereisma permianum*, were discovered in 1899. The first insect fossils from the Permian Period to be found anywhere in the world, they provided important information on the insects that lived 250 million years ago and filled an important gap in the record of insects' evolution.



must have been a formidable predator (fig. 46). By the end of the Permian Period, however, *Meganeuropsis* and many other Permian insects became extinct in the world's largest mass extinction, a catastrophe that killed off roughly 90 percent of all species (see mass extinctions, p. 6-7).

Fossil insects have also been found in the Pennsylvanian and other Permian rocks of eastern Kansas, most notably the Hamilton quarry, another famous fossil site, in Greenwood County. The 295-million-year-old limestones at the Hamilton quarry include fossils of dragonflies, crickets, and cockroaches (fig. 47).

Stratigraphic Range: Lower Pennsylvanian to Holocene.

Taxonomic Classification: Insects belong to kingdom Animalia, phylum Arthropoda, superclass Hexapoda, class Insecta. Insects that cannot fold their wings next to the body when at rest are grouped into the subclass Palaeoptera, while those that can fold their wings against their body are assigned to the subclass Neoptera.

FIGURE 45—Insects belonging to the genus *Lemmatophora* are relatively common fossils at the Elmo site. This dime-sized specimen preserves the body, wings, and parts of the legs, antennae, and segmented appendages called the cerci (see arrows).

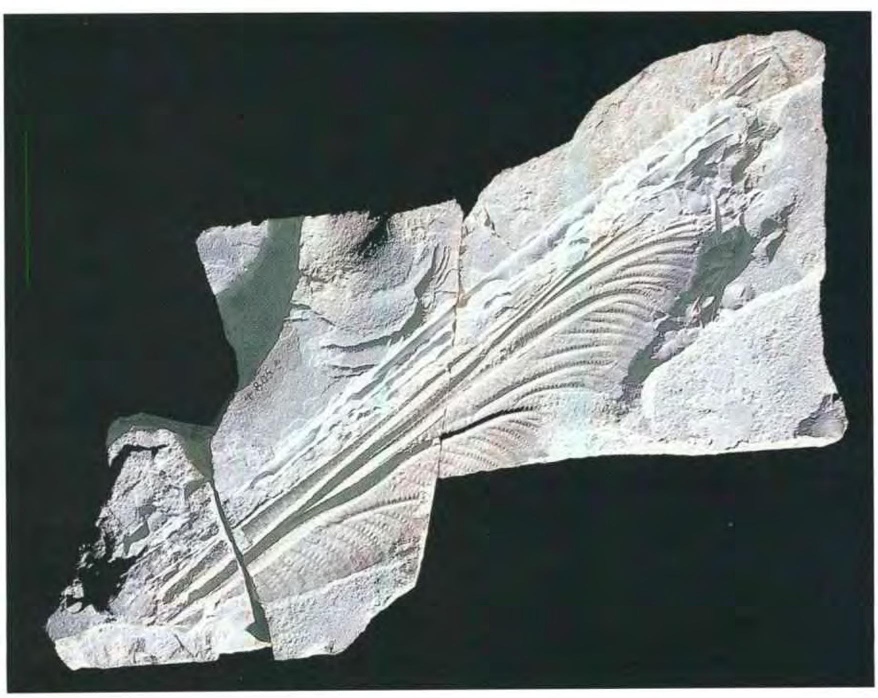


FIGURE 46—(*below left*) This wing belonged to the largest known insect, *Meganeuropsis permiana*, a dragonfly-like insect with a 29-inch wingspan, first discovered in the Permian limestones of the Elmo fossil site (photo by Chris Becker, EARTH magazine).

FIGURE 47—Cockroach wing fragments are somewhat common fossils at the Hamilton quarry site in Greenwood County. These fossils are from the rocks deposited during the Late Pennsylvanian subperiod, about 295 million years ago.

Snails and Other Gastropods

Description: Gastropods are the most diverse and abundant type of mollusks, with nearly 35,000 living and 15,000 fossil species identified so far. The group includes snails, slugs, conchs, whelks, and limpets. Like the familiar snail, most gastropods have a single coiled shell (slugs being a notable exception). A variety of fossil gastropods occur in the Pennsylvanian and Permian rocks of eastern Kansas (fig. 48).

The earliest undisputed gastropods date from the Late Cambrian Period, around 500 million years ago. Some paleontologists think gastropods are even older, based on a small, shelly fossil called *Aldanella,* known from Lower Cambrian rocks, but others think *Aldanella* is a worm. Either way, by the end of the Cambrian, gastropods were abundant and diverse, and they continue to be so up to the present day.

In a typical shelled gastropod, such as the snail, the soft body parts include those that normally extend outside the shell—the head and foot—and those that remain inside—the mantle and visceral mass. Because the fossil record of gastropods is based almost exclusively on the shells, paleontologists rely on living gastropods for information about the anatomy of their ancient relatives.

The gastropod head bears the most obvious sensory organs, at least one pair of hornlike tentacles that are generally located above the mouth. Most also have two eyes, situated along or near the base of the tentacles. The mouth is usually located on the underside of the head or at the end of a long retractable snout. Inside the mouth is a feeding structure called the radula, made up of numerous tiny teeth (as many as 250,000) that scrape against a horny plate in the upper part of the mouth to shred food.

The foot is typically a broad, tough, muscular structure with a flattened base; it moves along a surface by means of small undulations. In land snails or slugs, the foot contains mucous glands that secrete a slimy substance that facilitates progress over a dry surface; a similar kind of lubricating substance is also secreted by some marine snails.

Inside the shell, the mantle is a heavy fold of tissue that covers the visceral mass and lines the inside of the gastropod shell. The mantle also secretes the

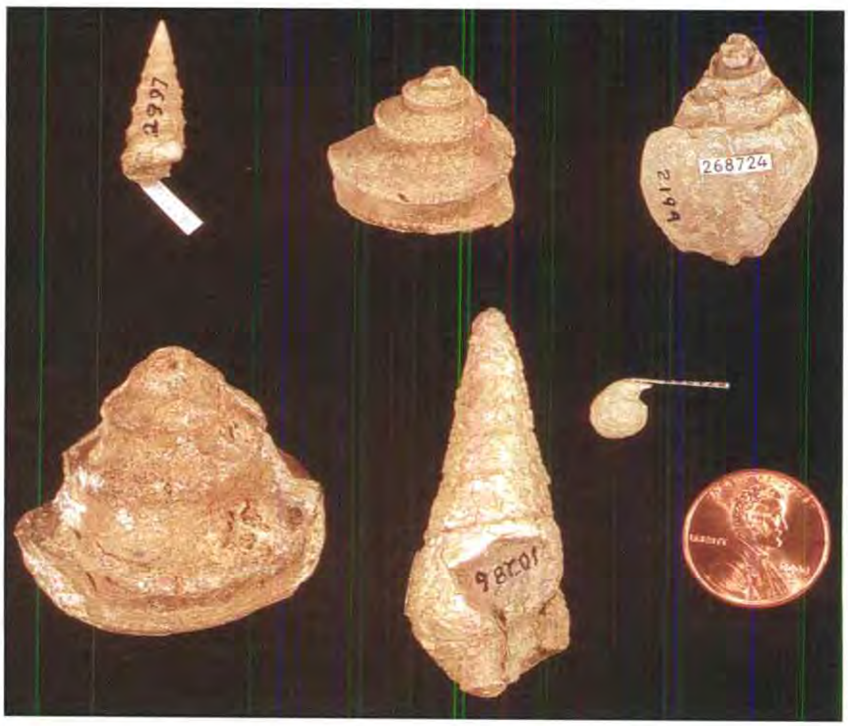


FIGURE 48—These common Kansas fossil gastropods show some of the variation in size, shape, and external markings. From left to right, top: *Turritella* (base of the Church Limestone Member of the Howard Limestone, Pennsylvanian, Marion County); *Worthenia* (shale below the Stanton Limestone, Pennsylvanian, Elk County); *Soleniscus* (Florena Shale Member of the Beattie Limestone, Permian, Cowley County); and left to right, bottom: *Baylea* (Shawnee Group, Pennsylvanian, Jefferson County); *Meekospira?* (Stranger Formation, Pennsylvanian, Douglas County); *Bellerophon* (Lawrence Shale?, Pennsylvanian, Douglas County).

shell. The visceral mass fills the shell cavity (which can be a very long, narrow, twisted space) and contains the heart, gonad, digestive gland, liver, kidney, and excretory organs.

The gastropod shell forms a hollow, twisted or coiled cone that increases in width from its initial point, called the apex, to the opening from which the head and foot protrude. In many gastropods, a platelike cover, the operculum, is attached to the foot and closes the shell opening when the head and foot are retracted within the shell.

The shells of different gastropods vary enormously, and these variations are used to distinguish one species from another. Most gastropod shells are coiled. This coiling may be in one plane, similar to the shells of coiled ammonoids (fig. 49). Other gastropod shells may be coiled in such a way as to produce spires of varying heights (fig. 50; see also fig. 51). The outer surface of the shells may be ornamented with ridges, grooves, bumps, spines, or other markings (fig. 51).

The earliest gastropods were exclusively marine, but by the Mesozoic Era, about 250 million years ago, many had adapted to terrestrial and freshwater environments. During their long history, gastropods have developed many different ways of obtaining food. Some are carnivores, while others are herbivores, omnivores, deposit feeders, scavengers, suspension feeders, and parasites. Some carnivorous gastropods use their radula to rasp through the shells of other gastropods or bivalves, drilling a neat, round hole, through which they inject a muscle relaxant. Fossil shells with drill holes are evidence of gastropod predation, probably dating back to the Devonian Period (416 to 359 million years ago).

The long fossil record and present-day abundance and diversity of gastropods attests to their evolutionary success. Over time, they have withstood a number of major extinction events that wiped out other creatures.

In Kansas, fossils of marine snails are common in the Pennsylvanian and Permian rocks of the eastern part of the state (fig. 52) and in the Cretaceous rocks farther west (fig. 53). Fossils of terrestrial and freshwater snails also are common in some Pleistocene deposits in northwestern and northeastern Kansas.

Stratigraphic Range: Upper Cambrian to Holocene.

Taxonomic Classification: Gastropods belong to the kingdom Animalia, phylum Mollusca, class Gastropoda.

FIGURE 49— The Pennsylvanian gastropod *Bellerophon* illustrates the coiling of the shell in one plane. This fossil was collected from the Lecompton Limestone in Osage County.

FIGURE 50—This Pennsylvanian gastropod, which probably belongs to the genus *Meekospira*, has a shell with a very high spire. It was collected from the Leavenworth Limestone Member of the Oread Limestone in Douglas County.

FIGURE 51—A series of raised bumps spiraling out from the apex distinguishes these three specimens of *Trepospira*, collected from the shale below the Stanton Limestone in Elk County.

FIGURE 52—*Straporallus (Amphiscapha)* is a common fossil in the Pennsylvanian rocks of eastern Kansas. This specimen is embedded in a chunk of limestone taken from the Drum Limestone of Montgomery County.

FIGURE 53—*Bellifusus willistoni* is a Cretaceous gastropod from the Blue Hill Shale Member of the Carlile Shale. The two fossils on the left are from Smith County; the smaller one on the right is from Ellis County.

Sponges

Description: Sponges, members of the phylum Porifera, are one of the simplest kinds of multicellular animals living today. They are also among the oldest, with a fossil record extending back to the last part of the Precambrian, about 550 million years ago. Fossil sponges are known from around the world. In Kansas, fossil sponges can be found in the Pennsylvanian and Permian rocks in the eastern part of the state (fig. 54).

Unlike most larger multicellular animals, sponges lack tissues, organs, and respiratory or circulatory systems. Instead, they rely on specialized cells to perform the different functions necessary for survival. Some cells, for example, equipped with flexible tails, or flagella, create one-directional currents that draw nutrient- and oxygen-bearing water into the sponge and help eliminate waste products. Other cells perform tasks associated with support, reproduction, or protection.

Sponges come in many different colors, shapes, and sizes. Some sponges have irregular shapes or look like encrusting sheets, while others take the form of mounds, tubes, or even a series of spheres reminiscent of beads on a necklace. They range in size from 1 centimeter to more than 2 meters. Many of the differences in size and shape are due to environmental factors, such as temperature, salinity, turbulence, and the amount of sediment in the water. This means that members of a single sponge species may look very different from each other.

In spite of differences in appearance, sponges have the same basic body plan (fig. 55). All sponges are characterized by numerous pores on their external surface (*porifera* means pore bearer). Water is drawn through these pores, flows through tubular or chamberlike canals, and passes out through one or more large openings, each called the osculum (figs. 56, 57). Sponges circulate a vast amount of water each day, as much as 20,000 times their own volume.

Sponges reproduce both sexually and asexually. Most sponges that reproduce sexually produce eggs and sperm at different times, with the sperm being broadcast into the water to fertilize eggs in an individual of the same species. The fertilized eggs develop into larvae, which attach and develop into new sponges. Budding is the simplest method of asexual reproduction, in which a branch grows off the parent sponge, constricts, and separates at its base,

FIGURE 54—*(below left)* This Pennsylvanian sponge, belonging to the genus *Maeandrostia*, is an example of a branching form; note also the raised pores on the surface of the branches. These fossils were collected from the Hickory Creek Shale Member of the Plattsburg Limestone in Wilson County, Kansas.

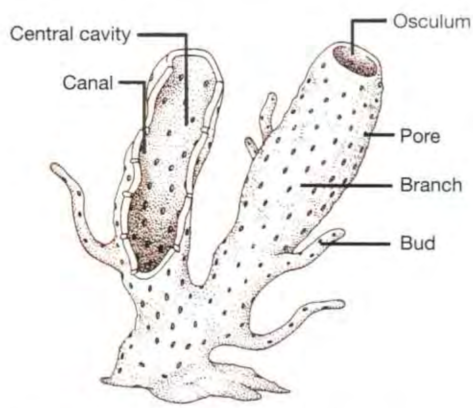


FIGURE 55—Generalized simple sponge showing basic features (adapted from Boardman and Cheetham, 1987).

thus becoming an independent organism. Sponges have remarkable powers of regeneration and are generally able to produce fully developed animals from small fragments.

All sponges live in water, attached to rocks, shells, or bottom sediments. Although some live in freshwater habitats, most sponges live in the oceans. Their bodies are supported by a skeletal framework, which may be composed of calcium carbonate layers, needlelike spicules, or organic fibers called spongin. The spicules are made up either of calcium carbonate or silica; spongin is the material of natural bath sponges that humans have used for centuries.

One group of sponges, the hypercalcified sponges, secrete a basal skeleton of calcium carbonate and also contain spicules in the soft tissue associated with this basal skeleton. Modern members of this group live in underwater caves associated with coral reefs; ancient members include specialized sponges known as archaeocyathids, stromatoporoids, and chaetetids. Chaetetids are fairly conspicuous in several limestone beds in southeastern Kansas forming reef-like masses in some instances (fig. 56).

The approximately 5,000 species of living sponges dwell at various depths in the world's oceans. Sponges from the Paleozoic and earliest Mesozoic, however, lived mostly in shallow water and were, at times, important reef builders.

Even though sponges have a long fossil record, they are not common fossils. This is partly due to their relatively delicate skeletons and to the low-sediment environments that ancient sponges seemed to prefer (which precluded the quick burial necessary for preservation). Most fossil sponges are known solely from mineralized spicules and are differentiated by the chemical composition of these spicules.

In the Pennsylvanian and Permian rocks of eastern Kansas, chaetetid sponges are found in Labette, Crawford, Bourbon, and Neosho counties (see fig. 58). They are locally common in the Pennsylvanian Hickory Creek Shale Member of the Plattsburg Limestone in Wilson County and the Hartford Limestone Member of the Topeka Limestone in Greenwood County (fig. 59).

Stratigraphic Range: Upper Precambrian to Holocene.

Taxonomic Classification: Sponges belong to the kingdom Animalia, phylum Porifera. The phylum is divided into several classes based on the composition of the skeleton: the classes Demospongea, Hexactinellida, and Calcarea.

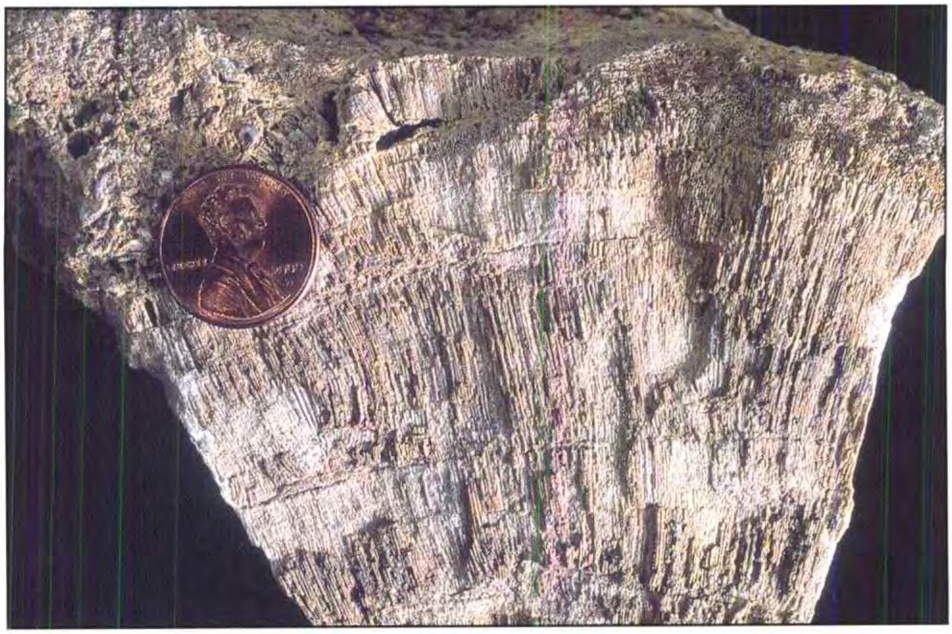
FIGURE 56—The donut-like shapes on this limestone slab are cross sections through the branches of a tubular Pennsylvanian sponge, *Amblysiphonella*. The central cavity (the donut hole) is clearly visible. The fossil was collected in the upper part of the Avoca Limestone Member of the Lecompton Limestone in Greenwood County, Kansas.

A

B

FIGURE 57—Two specimens of *Heliospongia*, a Pennsylvanian sponge, illustrate (**A**) the openings, or oscula (arrows), through which water passed out from the sponge and (**B**) the central cavity (see cross section), as well as the pores (circled) on the external surface. Both fossils were collected in the Hickory Creek Shale Member of the Plattsburg Limestone in Wilson County.

FIGURE 58—Chaetetid sponges from Pennslvanian limestones of eastern Kansas. **A,** Note the tubular canals in this side view of a specimen from the Laberdie Limestone Member of the Pawnee Limestone in Linn County, Kansas. **B,** This magnified (x5) top view shows the honeycomb pattern of the tubes; this fossil was collected from the Higginsville Limestone Member of the Fort Scott Limestone in Bourbon County, Kansas.



A

B

FIGURE 59—In this specimen of *Amblysiphonella* (from the Hartford Limestone Member, Topeka Limestone, at the Hamilton quarry in Greenwood County), the individual chambers (arranged like beads on a necklace) and central cavity are clearly visible. *Amblysiphonella* is believed to have been a branching form, and the two branches may have been connected.

Trilobites

Description: Trilobites were some of the first multicellular animals to live in the world's oceans. Their fossil record extends back approximately 530 million years to the early part of the Cambrian Period and indicates that trilobites evolved rapidly in the shallow seas of this time. In fact, trilobite fossils are so common in Cambrian rocks that the Cambrian Period is sometimes called the age of trilobites (fig. 60).

Although trilobite diversity decreased about 440 million years ago, following the major extinction event at the end of the Ordovican Period (see mass extinctions, p. 6-7) and again during a series of extinctions in the Middle to Late Devonian Period, trilobites have one of the most extensive fossil records of any group of animals. Thousands of species are known from rocks around the world, leading some to call trilobites the beetles of the Paleozoic.

Trilobite fossils are fairly rare in the Pennsylvanian and Permian rocks that crop out in eastern Kansas, a testament to the decline in their diversity during the later Paleozoic. The very last trilobites appear to have died out completely near the end of the Permian Period, just before another huge extinction that marked the end of the Paleozoic Era.

Like the insects, trilobites are classified as arthropods, animals with jointed legs. Their closest living relative is the horseshoe crab *Limulus*.

Trilobites had a hard external skeleton, called a carapace, which is convex and approximately oval-shaped. The carapace is divided lengthwise into three lobes (hence, the name trilobite): a prominent central axis and two flatter lobes (fig. 61). The carapace consists of a head, the cephalon, which is typically crescent shaped; a middle region called the thorax, made up of a number of overlapping segments (anywhere from 2 to 61); and a tail, the pygidium, in which the segments were fused (fig. 62). Complete trilobite carapaces can be found in rocks that were deposited in quiet-water environments, but generally the skeletal parts were scattered by currents, scavengers, or other processes.

Whether scattered or whole, trilobite skeletal parts were hard enough to have a decent survival rate. Their carapaces were probably made of chitin, an organic material akin to horn, that were reinforced with calcium carbonate, or calcite. In addition, trilobites molted—that is, they periodically shed their external skeletons as they grew. Thus, each individual typically discarded several carapaces, increasing the chances that one of these parts might be preserved as a fossil.

Trilobite limbs, on the other hand, were not covered with calcium carbonate and are only rarely preserved as fossil impressions. From these rare fossils, we know that trilobites possessed numerous jointed limbs, one pair per segment, as well as a pair of antennae. On the thorax, each limb was divided into a walking appendage and a branch of feathery gills. Experts think that in addition to locomotion, trilobite limbs were used like a broom to sweep debris from the seafloor into suspension where it could then be drawn into the mouth and eaten.

Trilobite eyes are the oldest example of a visual system known. Trilobites had compound eyes, made up of many lenses (like those of modern insects)—and each lens was a rod made of calcite. The calcite lenses were oriented so that light passed through in straight lines, unrefracted by the transparent crystals. Trilobites undoubtedly used their eyes to elude predators and possibly to locate food and mates (fig. 63).

Another way many trilobites avoided being eaten was to roll themselves up into a tight ball, with their vulnerable soft parts safely tucked away inside. Some trilobites were preserved in this position, rolled up like modern pill bugs, commonly known as roly-poly bugs (fig. 64).

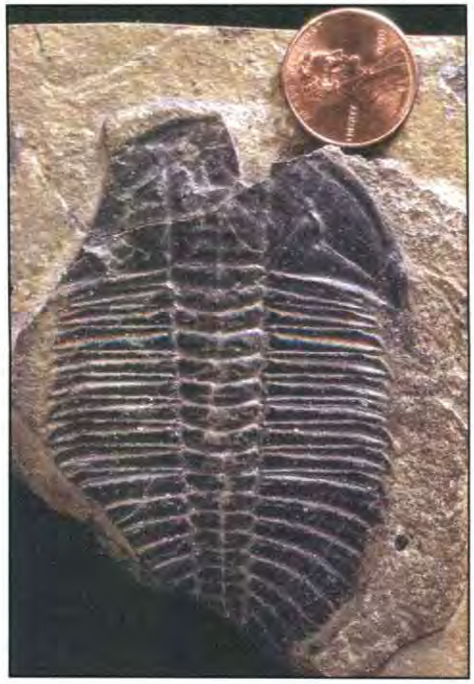


FIGURE 60—*Ogygopsis* was one of the trilobites that abounded in the seas of the Cambrian Period (no Cambrian rocks are at the surface in Kansas). This specimen was collected from the world-famous Burgess Shale locality in eastern British Columbia (see Burgess Shale, p. 26).

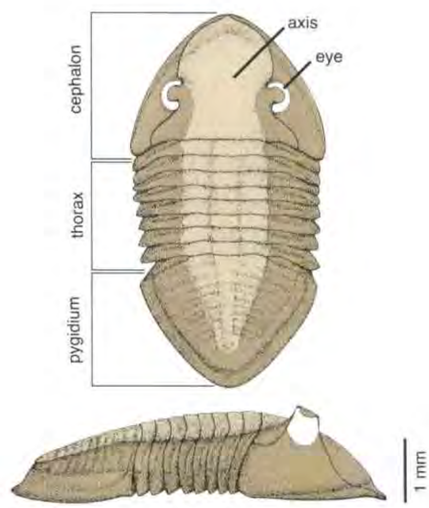


FIGURE 61—Two views of the Ordovician trilobite *Isotelus*, showing the basic divisions of the carapace, or external skeleton (adapted from Whittington, 1997, fig. 157).

During their long history, trilobites evolved a multitude of forms. Some trilobites were spiny; some were smooth. Some had enormous eyes; others were blind. Some were tiny, about the size of a ladybird beetle; others were the size of a large serving platter, though most were about 1 to 3 inches (2.5 to 7.5 centimeters) in length.

Trilobites also adapted to a wide range of habitats within the world's oceans, from shallow environments near the shore to deep ocean. Some were swimmers,

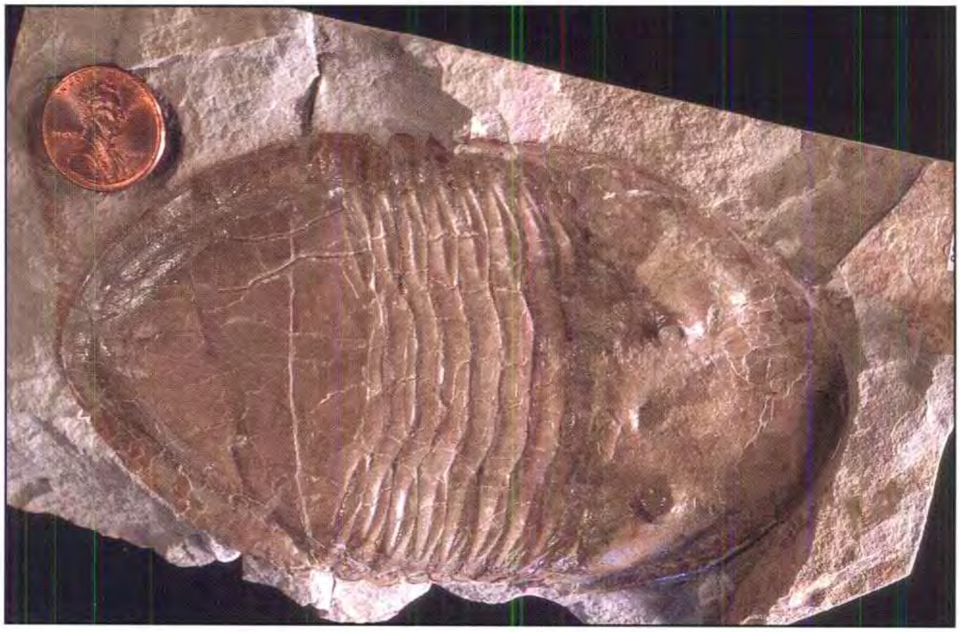


FIGURE 62—This Ordovician trilobite, *Isotelus iowensis,* is from the Maquoketa Shale, near Bowling Green, Missouri. *Isotelus* was a relatively large trilobite, common in the late Ordovician seas (no Ordovician rocks are at the surface in Kansas). The basic body parts are easy to see on this specimen: the cephalon on the right, the thorax of eight segments in the middle, and the pygidium on the left.

FIGURE 63—The crescent-shaped eyes are clearly visible on this cephalon, or head, of the Pennsylvanian trilobite *Ameura.* This fossil is from the Wyandotte Limestone of Kansas City, Missouri.

FIGURE 64—This fossil of *Phacops rana milleri,* a Devonian specimen from the Silica Shale in Ohio, shows the trilobite in its enrolled form.

some merely floated in the water, and others spent their lives scuttling along the seafloor. Some fed on organic matter trapped in the seafloor sediments or on plankton, while others preyed on small wormlike animals.

Human fascination with trilobites apparently has a long history. Archeologists have found trilobites associated with ancient human remains. At Arcy-sur-Cure, in France, a Silurian trilobite was found along with 15,000-year-old human remains. A hole made in the fossil suggests that it was worn as a necklace. In the western United States, Ute Indians made amulets out of fossil trilobites, which they named *timpe khanitza pachavee* (little water bug like stone house in).

In Kansas, the oldest rocks that crop out at the surface are from the last part of the Paleozoic, when trilobite numbers had dwindled greatly. Thus, trilobites are not common fossils in Kansas, though they are sometimes found in Pennsylvanian and Permian rocks of eastern Kansas. These Kansas fossils are records of some of the last trilobites (figs. 65, 66).

Stratigraphic Range: Lower Cambrian to Upper Permian.

Taxonomic Classification: Trilobites belong to the Kingdom Animalia, Phylum Arthropoda, Class Trilobita.

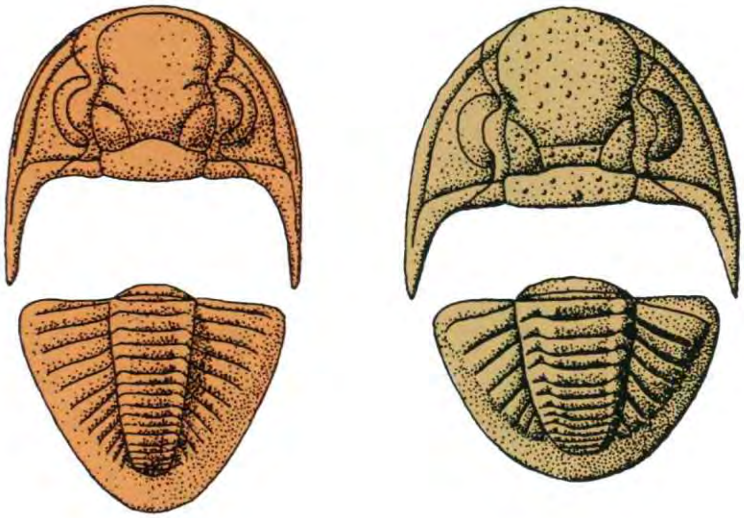


FIGURE 65—These drawings illustrate the details of the cepahlon (head) and pygidium (tail) of the two common Kansas trilobites, *Ameura* (left) and *Ditomopyge* (right).

FIGURE 66—Trilobite fossils found in Kansas rocks often consist of the pygidia (the tail) of either *Ameura* or *Ditomopyge*. This specimen of *Ameura* was collected from the Pennsylvanian Drum Limestone of Independence, Kansas.

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Appendix 1—Cretaceous to Pennsylvanian Stratigraphic Succession in Kansas, with Common Fossils

This annotated listing of the stratigraphic succession combines the fossils noted in Zeller (1968) with the updated version of the stratigraphic succession approved by the Kansas Geological Survey.

Cretaceous System
Upper Cretaceous Series
Montana Group
Pierre Shale – ammonoids
Beecher Island Shale Member
unnamed shale member
Salt Grass Shale Member
Lake Creek Shale Member
Weskan Shale Member
Sharon Springs Shale Member
Colorado Group
Niobrara Chalk
Smoky Hill Chalk Member – large inoceramid clams, oysters, ammonoids
Fort Hays Limestone Member – large inoceramid clams
Carlile Shale
Codell Sandstone Member
Blue Hill Shale Member – bivalves, ammonoids
Fairport Chalk Member – inoceramid clams, oysters, ammonoids; bryozoans in middle part of member
Greenhorn Limestone
Bridge Creek Limestone Member
Pfeifer Shale Member – inoceramid clams
Fencepost limestone bed
Jetmore Chalk Member – small inoceramid clams, ammonoids
Shellrock limestone bed
Hartland Shale Member – inoceramid clams
Lincoln Limestone Member – inoceramid clams
Graneros Shale – oysters, inoceramid clams
Dakota Formation
Lower Cretaceous Series
Janssen Clay Member
Terra Cotta Clay Member
Rocktown channel sandstone
Kiowa Shale
Longford Shale
Champion shell bed
Cheyenne Sandstone
Jurassic System
Upper Jurassic Series
Morrison Formation
Triassic System
Upper Triassic Series
Dockum Group
Permian System
Upper Permian
Leonardian Series
Nippewalla Group
Big Basin Formation
Day Creek Dolomite
Whitehorse Formation
Kiger Shale Member
unnamed member
Relay Creek(?) Dolomite Member
Marlow Sandstone Member
Dog Creek Formation
Blaine Formation
Haskew Gypsum Member
Shimer Gypsum Member
Necatunga Gypsum Member
Medicine Lodge Gypsum Member
Flower-pot Shale
Cedar Hills Sandstone
Salt Plain Formation
Crisfield sandstone bed
Harper Sandstone
Kingman Sandstone Member
Chikaskia Sandstone Member
Stone Corral Formation
Runnymede Sandstone
Sumner Group
Ninnescah Shale
Wellington Formation – brachiopods (*Lingula, Derbyia*), mollusks, ostracodes, corals
Milan Limestone Member
Hutchinson Salt Member
Carlton Limestone Member
Geuda Springs shale
Hollenberg Limestone Member
Pearl shale
Wolfcampian Series
Chase Group
Nolans Limestone
Herington Limestone Member – mollusks
Paddock Shale Member – mollusks
Krider Limestone Member
Odell Shale
Winfield Limestone
Luta limestone bed
Cresswell Limestone Member – echinoid spines and other fossils plentiful in lower massive limestone
Grant Shale Member
Stovall Limestone Member
Doyle Shale
Gage Shale Member
Towanda Limestone Member
Holmesville Shale Member
Barneston Limestone
Fort Riley Limestone Member
Oketo Shale Member

Florence Limestone Member – brachiopods, mollusks, bryozoans, fusulinids

Matfield Shale

Blue Springs Shale Member

Kinney Limestone Member

Wymore Shale Member

Wreford Limestone

Schroyer Limestone Member

Havensville Shale Member

Threemile Limestone Member

Council Grove Group

Speiser Shale

Funston Limestone

Blue Rapids Shale

Crouse Limestone

Easly Creek Shale

Bader Limestone

Middleburg Limestone Member

Hooser Shale Member

Eiss Limestone Member – abundant, small, high-spired gastropods

Stearns Shale

Beattie Limestone

Morrill Limestone Member – algal limestone

Florena Shale Member – brachiopods, mollusks, trilobites; also ammonoids from SE Kansas

Cottonwood Limestone Member – abundant fusulinids

Eskridge Shale – mollusks

Grenola Limestone – ammonoids

Neva Limestone Member – ammonoids in uppermost part; fusulinids, brachiopods abundant

Salem Point Shale Member

Burr Limestone Member – ostracodes abundant in some parts; mollusks and other fossils locally abundant

Legion Shale Member

Sallyards Limestone Member

Roca Shale

Red Eagle Limestone

Howe Limestone Member – tiny mollusks, gastropods, ostracodes, and foraminiferids

Bennett Shale Member – brachiopods, echinoderms, corals, and algae

Carboniferous System

Pennsylvanian subsystem

Glenrock Limestone Member – brachiopods, algae, gastropods, abundant fusulinids and smaller foraminiferids

Johnson Shale

Foraker Limestone

Long Creek Limestone Member

Hughes Creek Shale Member – abundant fusulinids and brachiopods

Americus Limestone Member – crinoids, brachiopods, bryozoans, mollusks, fusulinids, algae

Virgilian Series

Admire Group

Janesville Shale

Oaks shale bed

Houchen Creek limestone bed

Hamlin Shale Member

Five Point Limestone Member – fossiliferous

West Branch Shale Member

Falls City Limestone – mollusks, bryozoans, brachiopods

Onaga Shale

Hawxby Shale Member

Aspinwall Limestone Member – sparsely fossiliferous; mollusks and brachiopods

Towle Shale Member

Indian Cave sandstone bed

Wabaunsee Group

Richardson Subgroup

Wood Siding Formation

Brownville Limestone Member – large fusulinids, brachiopods, crinoids, bryozoans, and trilobites (rare)

Pony Creek Shale Member – brachiopods, bryozoans in upper part of some outcrops

Grayhorse Limestone Member – large bivalves (*Myalina*)

Plumb Shale Member – *Myalina*, small snails, bryozoans, fusulinids in SE Kansas

Nebraska City Limestone Member – brachiopods, bryozoans, algae, mollusks

Root Shale

French Creek Shale Member

Lorton coal bed

Jim Creek Limestone Member

Friedrich Shale Member – mollusks, sparse bryozoans, and brachiopods

Stotler Limestone

Grandhaven Limestone Member – abundant brachiopods and bryozoans, some mollusks, large fusulinids

Dry Shale Member – abundant marine fossils in upper part; ammonoids

Dover Limestone Member – mollusks, brachiopods, algae, fusulinids

Pillsbury Shale

"Nyman" coal bed

Zeandale Limestone

Maple Hill Limestone Member – crinoids, bryozoans, brachiopods, mollusks, fusulinids common at some localities

Stormont limestone bed

Wamego Shale Member

Tarkio Limestone Member – abundant large fusulinids (*Triticites*)

Nemaha Subgroup

Willard Shale

Emporia Limestone

Elmont Limestone Member – brachiopods (*Derbyia* and *Chonetes*) in gray shale; small fusulinids, algae, brachiopods, and crinoids in dense, blue-gray limestone

Harveyville Shale Member

Reading Limestone Member – fusulinids characteristic of persistent bluish-gray limestone

Auburn Shale

Bern Limestone

Wakarusa Limestone Member – large fusulinids, algae, brachiopods, and bryozoans

Soldier Creek Shale Member

Burlingame Limestone Member – fusulinids

Sacfox Subgroup
  Scranton Shale
    Silver Lake Shale Member
    Rulo Limestone Member – brachiopods, bryozoans
      Elmo coal bed
    Cedar Vale Shale Member
    Happy Hollow Limestone Member – large fusulinids
    White Cloud Shale Member
  Howard Limestone
    Utopia Limestone Member – algae, fusulinids, bryozoans, brachiopods, mollusks
    Winzeler Shale Member
    Church Limestone Member – crinoids, brachiopods
    Shanghai Creek Shale Member
    Wauneta Limestone Member
      Nodaway coal bed
    Aarde Shale Member
    Bachelor Creek Limestone Member
  Severy Shale
Shawnee Group
  Topeka Limestone
    ***Coal Creek Limestone Member – fusulinids abundant**
    ***Holt Shale Member – brachiopods, bryozoans, mollusks, crinoids, and trilobites (rare)**
      *Hwys 4 and 24, Topeka (see appendix 2)
    Du Bois Limestone Member – mollusks and brachiopods
    Turner Creek Shale Member
    Sheldon Limestone Member
    Jones Point Shale Member
    Curzon Limestone Member – bryozoans in upper layers; fusulinids in lower to middle parts; brachiopods
    Iowa Point Shale Member
    Hartford Limestone Member – fusulinids, sponges
  Calhoun Shale
  Deer Creek Limestone
    Ervine Creek Limestone Member – corals, echinoids, crinoids, bryozoans, brachiopods, mollusks
    Larsh and Burroak Shale Members
    Rock Bluff Limestone Member – fusulinids common
    Oskaloosa Shale Member
    Ozawkie Limestone Member – fusulinids and other marine fossils abundant in some outcrops
  Tecumseh Shale
      Ost limestone bed
  Lecompton Limestone
    Avoca Limestone Member – large fusulinids
    King Hill Shale Member
    Beil Limestone Member – abundant fossils, especially horn corals, fusulinids, bryozoans, brachiopods
    Queen Hill Shale Member
    Big Springs Limestone Member – fusulinids abundant
    Doniphan Shale Member – fusulinids plentiful in basal part in some exposures
    Spring Branch Limestone Member – fusulinids abundant in most outcrops
  Kanwaka Shale
    Stull Shale Member
    Clay Creek Limestone Member – fusulinids locally abundant; crinoids in upper part
      Elgin sandstone bed
    Jackson Park Shale Member
      Waverly flags
  Oread Limestone
    Kereford Limestone Member
    Heumader Shale Member – well-preserved mollusks common
    Plattsmouth Limestone Member – fusulinids, corals, bryozoans, brachiopods, mollusks
    Heebner Shale Member – numerous gastropods, brachiopods
    Leavenworth Limestone Member – fusulinids, brachiopods, gastropods
    Snyderville Shale Member – marine fossils, especially brachiopods, abundant
    Toronto Limestone Member – fusulinids, corals, small brachiopods
Douglas Group
  Lawrence Formation
      Upper and lower Williamsburg coal bed
    Amazonia Limestone Member – sponges common locally in Atchison Co., fusulinids in southern Kansas
    Ireland Sandstone Member
    Robbins Shale Member
  Cass Limestone
    Shoemaker Limestone Member
    Little Pawnee Shale Member
    Haskell Limestone Member
  Stranger Formation
    Vinland Shale Member
      Upper Sibley coal
    Westphalia Limestone Member – upper part contains fusulinids, mollusks
      Lower Sibley coal
    Tonganoxie Sandstone Member (Stalnaker Sandstone)
    Iatan Limestone Member – crops out in Leavenworth County only; fusulinids, brachiopods, bryozoans, crinoids, corals, and *Arachaeolithophyllum*
      "Ottawa" coal
    Weston Shale Member
Missourian Series
Lansing Group
  South Bend Limestone
    Kitaki Limestone Member
    Gretna Shale Member
    Little Kaw Limestone Member
  Rock Lake Shale
  Stanton Limestone
    Stoner Limestone Member
    Eudora Shale Member
    Captain Creek Limestone Member
      Benedict limestone bed
  Vilas Shale
  Plattsburg Limestone
    Spring Hill Limestone Member
    Hickory Creek Shale Member – in southern Kansas contains abundant crinoids, sponges, and bryozoans

Merriam Limestone Member – in central and northern outcrops in eastern Kansas, characterized by mollusks, brachiopods (*Composita*)

Kansas City Group

Zarah Subgroup

Lane Shale

Bonner Springs Shale Member

Farley Limestone Member

Island Creek Shale Member

Wyandotte Limestone

Argentine Limestone Member – ammonoids

Quindaro Shale Member

Frisbie Limestone Member

Liberty Memorial Shale

Iola Limestone

Raytown Limestone Member

Muncie Creek Shale Member

Paola Limestone Member

Linn Subgroup

Chanute Shale

Cottage Grove sandstone bed

Thayer coal bed

Noxie sandstone bed

Dewey Limestone – horn coral (*Caninia*) characterizes upper part in NE Kansas

Cement City Limestone Member

Quivira Shale Member

Nellie Bly Formation

Cherryvale Formation (north)

Westerville Limestone Member

Wea Shale Member

Block Limestone Member – fusulinids are generally common; in places *Hystriculina wabashensis* is abundant

Fontana Shale Member (south)

Drum Limestone Member

Middle Flaggy Limestone Member

Lower Shale member

Bronson Subgroup

Dennis Limestone

Winterset Limestone Member – marine invertebrates abundant; in places well-preserved mollusks; in SE Kansas algal mounds in upper part

Stark Shale Member

Canville Limestone Member

Galesburg Shale (Coffeyville Group equivalent)

Cedar Bluff coal bed

Dodds Creek sandstone bed

Mound Valley Limestone (south)

Ladore Shale (south)

Swope Limestone (Tacket Formation equivalent)

Bethany Falls Limestone Member

Hushpuckney Shale Member

Middle Creek Limestone Member

Elm Branch Shale

Hertha Limestone

Sniabar Limestone Member – corals locally abundant

Mound City Shale Member – contains 2-inch bed of crinoidal limestone in Linn and Bourbon counties

Pleasanton Group

Shale Hill Formation

Guthrie Mountain Shale Member

Critzer Limestone Member – gastropods characteristic of massive facies; brachiopods and corals plentiful in thin beds

Mantey Shale Member

Exline Limestone Member

Hepler Formation

South Mound Shale Member (Checkerboard Limestone Member equivalent)

"Hepler" coal bed

Desmoinesian Series

Marmaton Group

Holdenville Subgroup

Lost Branch Formation

Cooper Creek Limestone Member (north)

Glenpool limestone bed (south)

Nuyaka Creek black shale bed

Sni Mills Limestone Member (north)

Memorial Shale

Upper member

Dawson coal bed

Lenapah Limestone

Idenbro Limestone Member

Perry Farm Shale Member – locally abundant brachiopods and mollusks in middle and lower parts

Norfleet Limestone Member

Nowata Shale

Walter Johnson Sandstone Member

Altamont Limestone

Worland Limestone Member – brachiopods and locally abundant fusulinids

Lake Neosho Shale Member

Amoret Limestone Member

Bandera Shale

Bandera Quarry Sandstone Member

Mulberry coal bed

Pawnee Limestone

Laberdie Limestone Member – fusulinids and other marine fossils plentiful locally

Frog Cemetery limestone bed

Mine Creek Shale Member – abundant brachiopods

Joe shale bed

Myrick Station Limestone Member

Anna Shale Member

Childers School Limestone Member

Labette Shale

Lexington coal bed

Englevale Sandstone Member

Fort Scott Limestone

Higginsville Limestone Member – scattered, unusually large crinoids; fusulinids; isolated corals and chaetetids

Little Osage Shale Member

Summit coal bed

Morgan School shale bed

Houx limestone bed

Blackjack Creek Limestone Member
Excello Shale Member
Cherokee Group
Banzet formation
Bevier member
Lagonda member
Mulky member
Cabaniss Formation
Mulky coal bed
Breezy Hill Limestone Member
Bevier coal bed
Verdigris Limestone Member
Croweburg coal bed
Fleming coal bed
Mineral coal bed
Scammon coal bed
Chelsea Sandstone Member
Tiawah limestone bed – gastropods and brachiopods abundant
Tebo coal bed
Weir–Pittsburg coal bed
Krebs Formation
Seville Limestone Member
Bluejacket Sandstone Member
Dry Wood coal bed
Rowe coal bed
Neutral coal bed
Warner Sandstone Member
Riverton coal bed
McLouth sand
Atokan Series
Atokan Group
Morrowan Series
Kearny Formation

Appendix 2—Collecting Fossils in Kansas

Fossil collecting in Kansas does not require special equipment or training. You are likely to find fossils in the gravel of a driveway, in the rocks that crop out at roadcuts, or any other place that rock is exposed at the surface.

Before setting out to collect fossils, it is important to take safety and legal issues into consideration. If you're planning to look for fossils along roadcuts, be sure to pick a place where you can park safely and collect a safe distance off the roadway. Stops along the Kansas Turnpike are prohibited. Of course, as with any other outdoor activity in Kansas, you need to obey laws related to trespass and private property. You must obtain permission from the landowner before entering private property to search for fossils. Obtaining permission is particularly important in western Kansas, where commercial fossil collecting—finding and restoring fossils for resale to private buyers and museums—is more common and is regulated by Kansas law. Some landowners in this area have signed lease agreements with fossil collectors, in essence giving those collectors exclusive right to take fossils from their property.

As mentioned in the introduction, many Kansas outcrops contain invertebrate fossils, and those in the Smoky Hills region of north-central and northwestern Kansas and in the eastern third of Kansas, from the Flint Hills to the Missouri border, are especially fossiliferous (see p. 7). Using the annotated list in Appendix 1 and county-level geologic maps available from the Kansas Geological Survey (see **http://www.kgs.ku.edu/General/Geology/index.html**), you can target some likely places to hunt for specific kinds of fossils.

Specific fossil-collecting sites are described in various guidebooks published by the Kansas Geological Survey. A listing of these guidebooks can be accessed from the KGS online bibliography (**http://www.kgs.ku.edu/Magellan/Bib/index.html**) or by contacting the Publications and Sales office (785-864-3965). Online guidebooks also are available on the KGS web site (**http://www.kgs.ku.edu/Extension/fieldtrips.html**). The site described below is extracted from these online guidebooks and offers easy access to numerous invertebrate fossils.

Fossil Site—Northeast Kansas

The recently constructed interchange at the junction of K-4 and US-24 northeast of Topeka provides good exposures for collecting Pennsylvanian-aged invertebrate fossils. To get to the best collecting site, approach the interchange from the south on K-4. As you are driving north, pull off to the right side of the road immediately past the first exit ramp, but before you come to the overpass. If the ground is dry, follow the dirt road that will take you safely away from the highway; park near the underpass.

The rocks exposed immediately to the east can be accessed easily by walking north down to the end of the exposure and then walking back on the flat bench that has been excavated into the cut. The fossils occur in the 6- to 7-foot exposure of rock above this bench. Two rock units are exposed in this outcrops, the Holt Shale and Coal Creek Limestone Members of the Topeka Limestone. The Holt Shale Member is a dark-gray, layered siltstone, about 2 feet thick. The Coal Creek Limestone Member, which sits directly above the Holt Shale Member, is a light-gray or olive, silty limestone, about 4 feet thick.

Though the fossils at this site tend to be small, they are generally well preserved and give an idea of the variety of life that inhabited the Pennsylvanian seas roughly 300 million years ago. Brachiopods, bryozoans, and crinoids are abundant at this site. Small trilobite fossils, though less common, also occur.

Appendix 3—Additional Resources

Museums

The state's museums are a great place to view spectacular specimens and learn more about all kinds of fossils from Kansas and elsewhere.

Sternberg Museum, Fort Hays State University

Adjacent to Interstate 70 on the northeast edge of Hays, the newly remodeled Sternberg Museum is a great place to learn more about what life was like at the edge of the Cretaceous sea that covered western Kansas, roughly 80 million years ago. The Sternberg Museum, a part of Fort Hays State University, is named after a famous fossil-hunting family that collected extensively from the Kansas Cretaceous. In addition to impressive displays of vertebrate and invertebrate specimens, the museum features a life-sized walk-through diorama of Late Cretaceous times, complete with *Tyrannosaurus rex*.

Sternberg Museum
600 Park Street
Hays, KS 67601-4099
785-628-3478
http://www.fhsu.edu/sternberg/

Natural History Museum and Biodiversity Research Center, University of Kansas

Located in Dyche Hall on KU's main campus in Lawrence, the Natural History Museum has displays of both invertebrate and vertebrate fossils, including the skeleton of a mosasaur, a giant swimming lizard that swam in Kansas' Cretaceous seas. The museum also has a good collection of mammalian fossils from the Paleogene Period, such as mastodons collected along the Kansas River.

The University of Kansas
Natural History Museum and Biodiversity Research Center
1345 Jayhawk Blvd.
Lawrence, KS 66045-7163
http://nhm.ku.edu/

Johnston Geology Museum, Emporia State University

Located in Cram Science Hall on the ESU campus in Emporia, the Johnston Geology Museum has fossil specimens ranging from mosasaurs to ammonoids. The museum also contains other geological specimens predominantly from Kansas.

Johnston Geology Museum
Earth Sciences Department, Division of Physical Sciences
Emporia State University
Emporia, KS 66801
620-341-5330
http://www.emporia.edu/earthsci/museum

Fick Fossil and History Museum

Famous for its unique fossil displays, the Fick Fossil and History Museum in Oakley features fossils from the Cretaceous Period from the personal collection of Earnest and Vi Fick. Most of their fossils were collected within a 50-mile radius of Oakley. Their unique collection includes sharks' teeth, skeletons of 15-foot-long Cretaceous fish, inoceramid clams, and other invertebrates.

Fick Fossil and History Museum
700 West Third St.
Oakley, KS 67748
785-672-4839
http://www.discoveroakley.com/Document.aspx?id=1353

Museum of Geosciences, University of Missouri–Kansas City

The Geosciences Museum is located in Room 271, Flarsheim Hall, on the UMKC campus in Kansas City, Missouri. Among its specimens are excellent displays of Pennsylvanian crinoid fossils collected in the early part of the last century.

Museum of Geosciences
University of Missouri-Kansas City
Department of Geosciences
Room 271, Robert H. Flarsheim Hall
5110 Rockhill Road
Kansas City, MO 64110
816-235-1334
http://cas.umkc.edu/geo/resources.html

Books

Numerous books have been published about fossils and fossil collecting. The following books are a starting point for learning more about fossils, vertebrates as well as invertebrates.

- *National Audubon Society Field Guide to North American Fossils,* by Ida Thompson, 1982, Knopf, Inc., New York, NY.
- *Smithsonian Handbooks: Fossils,* by Cyril Walker and David Ward, 2002, Gem Guides Book Company, Baldwin Park, CA.
- *Fossils: A Guide to Prehistoric Life,* by Frank H. T. Rhodes, Paul R. Schaffer, Herbert S. Zim, and Raymond Perlman, 1962, Golden Press, New York, NY.
- *Where to Find Dinosaurs Today,* by Daniel Cohen and Susan Cohen, 1992, Cobblehill Books, Dutton, New York, NY.

In addition to these books, you can get help identifying fossils by contacting any of the museums or university departments listed above, as well as the geology or earth science departments of your local college or university.

Kansas Geological Survey
The University of Kansas
1930 Constant Ave
Lawrence, KS 66047