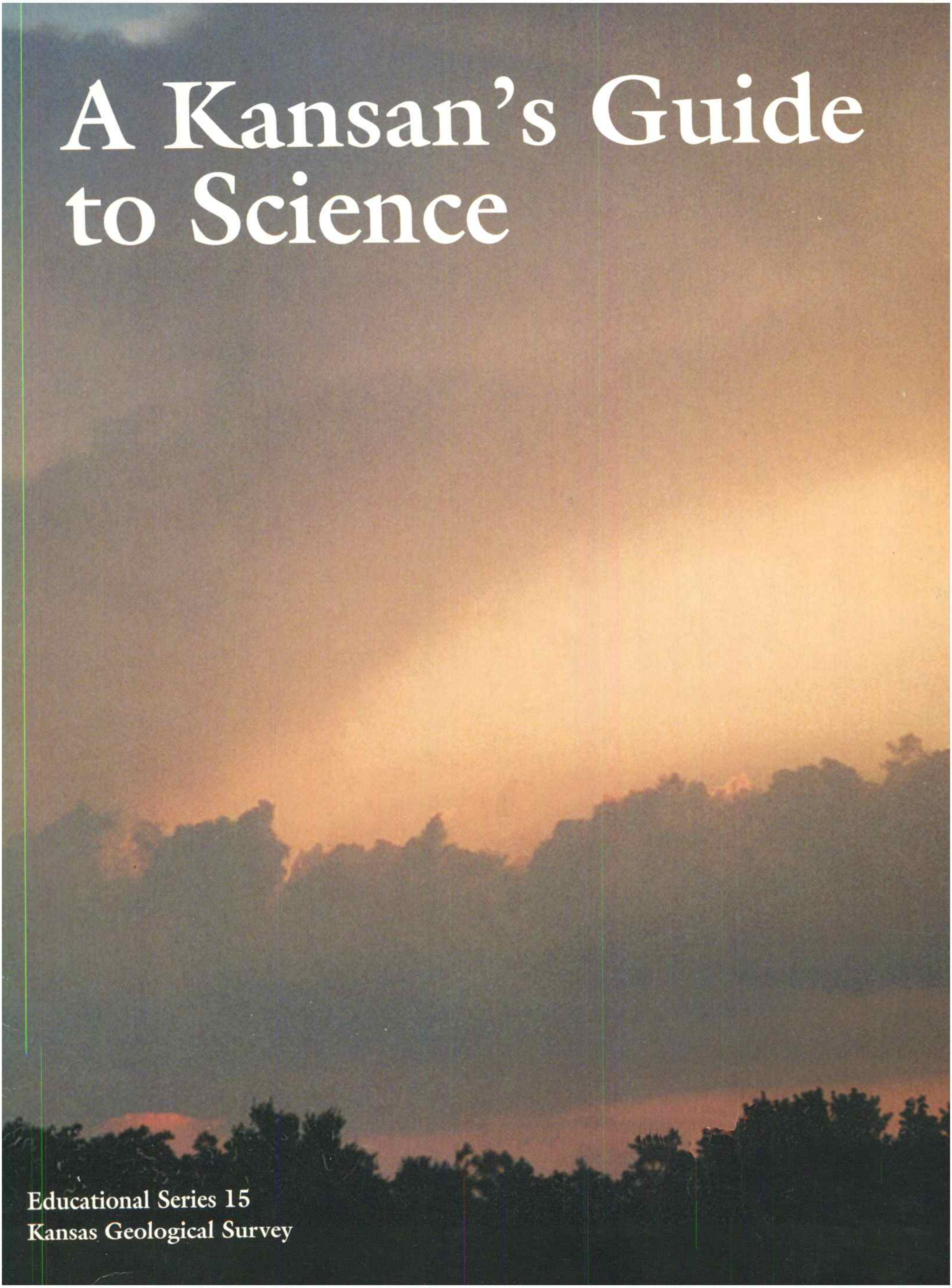
A Kansan's Guide to Science



Educational Series 15
Kansas Geological Survey

A Kansan's Guide to Science

An introduction to evolution and the nature of science, including origins of the universe and the Earth and the history of life

Contributing Authors

Paulyn Cartwright
Division of Biological Sciences

Roger L. Kaesler, Department of Geology,
Paleontological Institute, Natural History Museum

Bruce S. Lieberman
Department of Geology, Department of Ecology and Evolutionary Biology

Adrian L. Melott
Department of Physics and Astronomy

University of Kansas, Lawrence, Kansas 66045

Educational Series 15
Kansas Geological Survey
2000

Editors: Marla Adkins–Heljeson and Liz Brosius
Designer: Jennifer Sims
Cover photograph: Jennifer Sims

Printed at The University of Kansas Printing Service on recycled paper with soy-based ink

ISBN: 1-58806-317-8

Preface

Modern scientific inquiry has provided us with a wealth of insight into the workings of the natural world, and this will in turn lead to great technological advances as we enter the new century. In this high-tech era, it has become more imperative that average citizens, not just scientists, be equipped with a basic understanding of scientific discoveries and the scientific process. The authors of this booklet all are scientific researchers and educators from Kansas with a real interest in the scientific literacy of the people of this state. This interest became concern when, in the summer of 1999, the Kansas State Board of Education (BOE) voted to adopt a new set of standards for the teaching of science in Kansas public schools. The Board voted six to four to approve public-school science standards that downgrade the teaching of accepted scientific concepts: specifically, they de-emphasized or deleted references to geologic time, evolution, and the origin of the universe. We are concerned for several reasons. First, excellent evidence that life has evolved is all around us. Similarly, evidence for the nature and extent of geologic time can be found in rocks under foot in the state of Kansas; many of these rocks are under active study by Kansas geologists. Furthermore, scientists also are watching the Kansas skies to uncover clues to the origin of the universe. Finally, all the challenges to the immensity of geologic time, the nature of evolution, and the origin of the universe that motivated the BOE decision were based on pseudoscientific approaches or qualified as junk science, ideas not backed up by any actual data.

Our concerns motivated us to write this booklet. In the booklet we pose a set of questions that were chosen because they address topics that were most under attack by supporters of the Kansas BOE decision and most misunderstood by the general public. It is our intent to reach all Kansas citizens who wish to learn more about the nature of science, geologic time, evolution, and the origin of the universe from a Kansas perspective.

Contents

Table

Figures

The Nature of Science

What is science and the scientific method?

Science is a way of learning about the universe. It provides a way of understanding and explaining our observations of the natural world. Science deals with observed phenomena and seeks to explain the way the world works by employing natural, orderly relationships. Science pursues truth within very narrow limits. Some of humanity's most profound questions pertain to meaning, purpose, and morality. Their answers lie beyond the reach of science.

A crucial part of the scientific method involves making hypotheses. A **hypothesis** (boldface words are included in the glossary at the end of the book) is an idea that explains observations about the world. In most areas of science, a useful hypothesis is one that makes predictions about the results of future experiments or of future observations from the natural world. These can then be tested against new observations and the hypothesis modified or rejected if necessary.

A hypothesis that has been tested repeatedly and never found to be false is likely to be accepted. If it survives many tests and if it covers a range of topics, it may be referred to as a theory. Thus, in science the term **theory** has a precise meaning, different from its use in everyday life. A scientific theory is "a statement of what are held to be the general laws, principles, or causes of something known or observed" (Oxford English Dictionary). The important thing is that it is testable. Some well-known theories are the theory of gravitation and the atomic theory of matter. An idea—a theory or hypothesis—that cannot be tested is not interesting to scientists. They refer to such ideas that are outside the realm of science as being unfalsifiable. For example, many ideas about religion are unfalsifiable by the methods of science and thus lie outside the realm of science.

A common misunderstanding about the work of scientists has to do with proof. Although hypotheses or theories can be disproved by the methods of science, they cannot be proved. No scientific theory can be proved in the sense of a mathematical or logical proof. Any accepted scientific theory is simply the best existing explanation of the observations already made, an explanation that has not been shown to be false. This is as true for astronomy, geology, and evolutionary biology as it is for the nonhistorical sciences of physics and chemistry. It is important to realize that some theories are held in higher regard than others. Those that explain a wide range of observations and that generate many fruitful and testable hypotheses are held with greater confidence. Evolution is one such theory. It has been incredibly fruitful for research in medicine, developmental biology, genetics, ecology, paleontology, and geology.

Besides being testable and falsifiable, a scientific idea is most useful if it answers more questions than it raises. The idea that the Earth revolves around the sun is a good scientific idea because it explains the progression of the seasons upon which much of our economy is based. No one has ever seen the Earth move around the sun, and no one will ever do so because there can be no stationary platform in space from which to make such observations. Similarly, no one has seen an electron, touched a thermometer to the sun to learn that it is very hot, or watched *Tyrannosaurus rex* stalk its prey. In spite of this, these scientific ideas are considered useful and reasonable interpretations of the evidence.

The general field of science can be divided into two groups—historical science and experimental science. Experimental science includes physics, chemistry, genetics, and some branches of astronomy. Experimental scientists probably fit the popular conception of scientists as people in white lab coats pouring chemicals or watching dials. Experimental scientists are interested in making predictions about the future. Ultimately, their goal is to derive scientific laws from hypotheses and theories. **Laws** are statements, such as the law of gravity, that always apply.

Geology, paleontology, evolutionary biology, and some branches of astronomy are said to be historical sciences. A useful way of thinking about those sciences is to realize that the experiments have already been run by nature, sometimes millions of years ago. The job of the historical scientist is to determine what happened in the past—what experiment nature conducted. A hypothesis in the historical sciences is an explanation of these past events, an explanation that can be tested.

A historical scientist can make observations and statements about the past and develop hypotheses from evidence left from nature's past experiments. For example, at numerous times in the distant past the temperature at the Earth's surface was much lower than it is today. At each of these episodes of cooling, we can study how the animal and plant life evolved, migrated, and went extinct. This enables us to say how life has been affected by these events. We can use this information to make statements about past events and predictions of the future.

Hypotheses in the historical sciences are continually being tested by new observations. If the ideas in a hypothesis are contradicted by new observations, then that hypothesis is rejected. Like all sciences, the historical sciences proceed by an almost continual process of hypothesis development and testing. Many ideas about the historical sciences that were developed in the past have been discarded with the accumulation of new observations and the development of new ideas that provide better explanations. Evolutionary theory remains powerful because it continues to generate fruitful and testable hypotheses and has not been contradicted by evidence from the natural world and because it best explains our observations.

Evolutionary biologists, from paleontologists to molecular geneticists, try to determine the precise sequence of life's history and which species are most closely related to one another. Thus, the study of evolution involves historical science. Evolutionary biologists, however, also try to determine the mechanisms that govern how life evolves. These mechanisms include natural selection, chance factors, and various constraints on the way life evolves. That is why the study of evolution also involves experimental science. We can test some of the mechanisms of evolution in the lab by studying bacteria, flies, or mice over many generations and watching how they evolve over months or years in controlled experiments. Many similar natural experiments have been conducted over many millions of years, and their results are recorded in the fossil record of ancient life.

Isn't creation science a type of science?

In spite of its name, creation science is not science at all but is in fact pseudoscience, much like astrology or alchemy. Pseudoscience does not restrict itself to natural explanations of the physical world but often involves supernatural explanations. Creation science is a branch of creationism that is based on the literal interpretation of the Bible and holds that the origin of living species and the Earth occurred as a single event a few thousand years ago. Creation science, unlike legitimate sciences, does not seek to derive explanations through observations and testing of the natural world but instead begins with a belief system and then seeks to find evidence to support this view. Therefore, by its very nature, creation science is not a science because it is not testable and falsifiable.

Understanding Evolution

What is evolution?

Biological evolution is the theory that life on Earth has developed gradually from a common ancestor. This is sometimes described as descent with modification. Since life's origin some 4 billion years ago, life has changed in numerous ways as it branched out into different lineages, with adaptations to different environments and changes in genetic makeup. Some major changes include the evolution of plants and animals and, among the animals, some major groups became extinct. The evolution of life can be thought of as a tree with different lines splitting off. Some branches were cut short by extinction, while others are represented by species living in the modern world.

It is inaccurate, for example, to view the evolution of the hominids, as a straight-line transformation from some apelike form into transitional forms and eventually with humans at the pinnacle. Humans did not evolve from chimpanzees or gorillas, but instead humans and modern apes share a common ancestor that lived at some time in the past, probably about 6 million years ago.

Is evolution a fact or a theory?

Evolution is not just a fact and not just a theory; it is both! Evolution is a fact because there is overwhelming scientific evidence that evolution has happened in the past and continues to happen. No reputable scientist questions evolution. That is, all scientific data support the fact that the Earth is more than 4.5 billion years old, that cellular life appeared before 3.5 billion years ago, and that all modern life is descended from a common ancestor. Sometimes people ask scientists and teachers, in the interest of fairness, to present the evidence against evolution. Scientists and teachers do not present such evidence because there simply is no such evidence against evolution. True, there are things we do not yet know, but no one has found any scientific evidence to suggest that evolution does not occur, or that it does not explain all aspects of biology.

When people say that evolution is just a theory, they are partly correct; but they are confused about what it means for an idea to be a scientific theory. The scientific usage of **theory** is different from its meaning in everyday usage. In everyday language, a theory is a hunch or a guess. In science a theory is defined as "a statement of what are held to be the general laws, principles, or causes of something known or observed" (Oxford English Dictionary). Thus, when scientists refer to evolutionary theory, they are talking about the *mechanisms* of evolution, not about some vague idea of whether evolution has happened or not. Evolutionary theories are a way of explaining the fact of evolution. Scientists have suggested many mechanisms of evolution. Some we accept; some we no longer accept. For example, the theory of natural selection, put forward by Darwin and Wallace in 1858, is still considered an accurate explanation of this mechanism of evolution. On the other hand, we no longer accept the theory of inheritance of acquired characters, which was proposed early in the 19th century by the French biologist Lamarck. Among other things, for example, Lamarck had the idea that successive generations of giraffes inherited ever longer necks because their parents stretched their necks to reach higher branches.

In all sciences, debate about theories exists, but that does not change the facts. For example, just because we cannot always predict where a thunderstorm will happen, this does not mean that thunderstorms do not occur. Similarly, today biologists and paleontologists sometimes debate the importance of different evolutionary mechanisms such as natural selection. These debates do not detract from the fact of evolution; they only demonstrate that evolution is a complex process, like the weather, and that the work of science is not yet finished.

What is the evidence that evolution has actually happened?

The theory of evolution is supported by evidence from experimentation and from the fossil record. In the laboratory, scientists have shown how fruit flies, bacteria, and many other types of organisms adapt and change evolutionarily, even over the short time scales of human experimentation. Similarly, scientists have observed populations evolving in the wild, both in Kansas and elsewhere. The development of resistance to antibiotics by various disease-causing bacteria, including the bacteria responsible for tuberculosis, is one well-known and unfortunate example of evolution.

Outside the laboratory, evidence for evolution also comes from the fossil record. The evolution of organisms shown by the geological record is consistent the world over. That is, through time the fossil species follow the same order of appearance everywhere. Moreover, that order of evolution and first appearance of fossil species is consistent with everything we know about the relationships among fossils. For example, the fossil record of vertebrates has the following order of first appearances: jawless fishes → fishes with jaws → lobe-finned fishes → amphibians → highly terrestrial amphibians → reptiles → mammal-like reptiles → mammals → hoofed mammals → horses. Similar sequences can be reconstructed for virtually every other living group of organisms. In addition, numerous examples of transitional fossil species are known. A transitional species possesses a mixture of traits that are characteristic of both ancestral and descendant organisms, indicating that it represents an intermediate form. Some examples include the evolutionary transition between fish and amphibians, reptiles and mammals, terrestrial reptiles and birds, and hoofed mammals and whales (fig. 1). Each of these evolutionary transitions involved several distinct species that were intermediate in character between their ancestors and their descendants.

Several Kansas fossils are key transitional species. One example is the Pennsylvanian-aged reptile *Petrolacosaurus*, which has features of early reptilian groups as well as later reptiles like crocodiles and the dinosaurs (figs. 4 and 5). *Edaphosaurus* (fig. 6), also known from a Pennsylvanian-aged lagoon in Kansas, is a transitional link between early reptiles and other groups more closely related to modern mammals. The mosasaurs, which must have terrified the occupants of Kansas seaways in the Cretaceous, are a link between lizardlike groups and snakes (fig. 8). The Cretaceous-aged *Parahesperornis*, an early bird, is another important evolutionary transitional form between reptiles and modern birds (fig. 11). Like extinct and modern reptiles, *Parahesperornis* had bones that were not hollow and a mouth filled with teeth, yet it had a birdlike skull, wings, feet, and body, making it a transitional form. Finally, a more recent example is *Pliohippus*, a relative of the modern horse that roamed the grassy plains of Kansas within the last few million years. Like the modern horse that served the native peoples and early settlers of Kansas so well, *Pliohippus* was well adapted to the ancient environments of Kansas. About the size of a modern pony, *Pliohippus* had a single toe or hoof, and is a transitional link between the older, small horses with many toes, which are extinct and only known as fossils, and the modern large draft horse that populates Kansas.

What is the difference between microevolution and macroevolution?

Many people wonder whether the small-scale evolution that scientists observe in the laboratory and in the wild (**microevolution**) is distinct from the large-scale evolutionary trends that scientists observe, say, in the fossil record (**macroevolution**). What seems to separate microevolution from macroevolution is the act of speciation—that is, the process in which a new species is formed. Changes can occur within a single species as it adapts to its local environment; changes that are referred to as microevolution. Antibiotic resistance in bacteria is a good example of microevolutionary change. In adapting to an environment of antibiotics through natural selection, bacteria have evolved resistance to the drugs. If there is microevolutionary change within a species but that species does not split off a new descendent species, then there is unlikely to be any visible evolutionary change over long time scales.

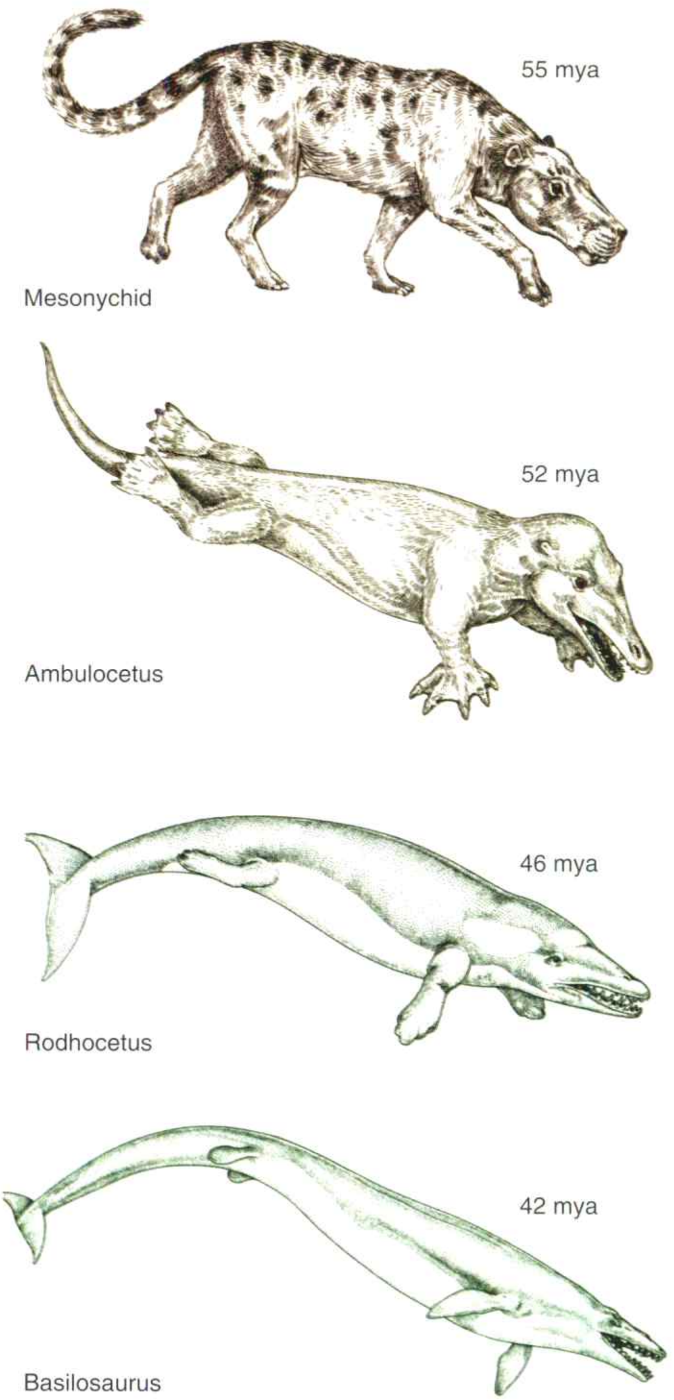


FIGURE 1—Evolutionary sequence depicting the transition between terrestrial mammals and whales (mya = million years ago). After drawings by N. Haver © Sinauer Associates; *in*, Purves et al. (1998).

Major or macroevolutionary changes are tied to speciation, the origin of new species, which usually occurs when populations of a species are isolated from one another over long periods of time. A small, isolated population can then undergo its own independent microevolutionary changes as it adapts to local environments. With sufficient evolutionary divergence, a new species evolves, and microevolutionary changes are translated to macroevolution. Thus, microevolution and macroevolution are not distinct processes. They are related, and macroevolution results when such situations as the geographical isolation of small populations occur. This makes it more likely that microevolutionary changes will add up to macroevolution.

The evolution of horses provides an example of how new species form following geographic isolation. North America was home to the earliest known horse, *Hyracotherium*, which was about the size of a small dog, with a curved back, unspecialized teeth, and three and four toes on the back and front hooves respectively, whereas modern horses have only one toe on each of their four hoofs. In the Miocene, about 35 million years ago, as extensive grassy prairies evolved for the first time, *Merychippus*, a three-toed horse that descended from *Hyracotherium*, evolved high-crowned teeth that allowed it to feed on grass. Its large size enabled it to run fast to escape the predators that were evolving at the time, especially sabertoothed cats and wolves.

Descendants of *Merychippus* migrated from North America to the Old World where, in isolated populations, new species evolved that soon went extinct. Meanwhile, in North America isolated populations of *Merychippus* evolved into the one-toed *Pliohippus* in the Pliocene and into *Equus* in the Pleistocene. Shortly after early humans came to North America, *Equus* went extinct on this continent, but the populations of *Equus* that had migrated to the Old World thrived and again, as isolated populations, evolved into the six species of *Equus* we know today as well as several that are known only from the fossil record. Today's species include three separate species of zebra, the onager of Asia, the donkey, and *Equus caballus*, the modern horse. Domestication of the modern horse began some 2,500 years ago, and they were taken by humans to North America some time around 1500 AD.

What is natural selection?

Natural selection happens when some individuals in a population survive and reproduce more successfully than others because of their inherited traits. Because these traits enable the individuals to reproduce more successfully, over time the traits will appear more frequently and begin to accumulate in the population. The outcome of this microevolutionary process is **adaptation**. That is, over time through natural selection, individuals in a population will come to possess traits that lead to their being well adapted to their environment. In fact, Darwin's ideas on how natural selection works are really rather simple, and they are exactly the same as the procedure animal breeders have used for thousands of years to develop new breeds of animals. Animals vary, and some of the variation is inherited. Animals have more offspring than can possibly survive. On average, other things being equal, animals will tend to survive if they have inherited traits that are favored by the environment to lead to survival and reproduction. In this way, favorable, adaptive traits accumulate in a population of organisms, and traits that are not adaptive are weeded out. Such principles are being applied today to Kansas livestock and crop species.

Is natural selection the best explanation of evolution?

Natural selection is often described as the best explanation of how evolution happened, and numerous examples demonstrate that it is an important force controlling evolution. Polar bears offer one example. They hunt in the snowy arctic; they sneak up on their prey; and they are, after all, white. Thus they appear to be well adapted to their environment. Many features in the history of life, however, suggest that chance has played a very important role in evolution, too. For example, several times in the history of life, mass extinctions have occurred—events so severe that they eliminated most of the species on Earth. Such a mass extinction ended the dinosaurs' reign at the end of the Cretaceous Period. Prior to the mass extinction, dinosaurs were large and dominated the world, whereas mammals were small and nocturnal, sneaking around in the dinosaurs' world. It was not until the dinosaurs went extinct that the mammals could take over and flourish. The mechanism that caused this extinction was a massive asteroid striking the Earth. This example points out that natural selection alone is insufficient to explain the history of life. No matter how well adapted an animal is, it may not survive a catastrophe like a collision with a five-mile-wide asteroid.

The History of the Earth and the History of Life

How old is the Earth, and what is the evidence for the Earth's age?

Scientists have determined that the Earth is about 4.5 billion years old. This is older than the oldest rocks native to Kansas, which are buried deep beneath the surface and can be recovered only by drilling. Even older rocks, however, have been found in the state. These are meteorites, rocks that have literally fallen from the sky. Because meteorites differ so much from the rocks geologists typically find in Kansas, they are relatively easy to identify, and they provide one clue to the age of the Earth. Meteorites are found all over the world. Because all parts of the solar system are thought to have formed at the same time, meteorites must be the same age as the Earth. Meteorites have been dated to about 4.5 billion years old. The oldest rocks that formed on the Earth are 4 billion years old.

The way scientists can date ancient rocks like Kansas meteorites is through the use of **radioactive isotopes**. These are atoms that decay at predictable and constant rates into other stable atoms. The relative concentrations of some of these isotopes within a rock can be used with considerable accuracy to determine the age of that rock. Using this technique, scientists have shown that very old rocks—3.5 million years or older—occur on all the continents and that meteorites and moon rocks are about 4.5 to 4.6 billion years old.

How do geologists talk about geological time?

Geologists have divided the 4.5 billion years of geological time into smaller parts using the geological time scale (table 1). As we have discussed, geologists have determined the age of the Earth by studying the concentrations of radioactive isotopes in certain rocks. Only certain types of rocks, however, can be dated using radioactive isotopes. In many cases, the best way to determine a rock's age is to look at the fossils contained within that rock. Many of the rocks in Kansas, like those found along many of our state highways and in stream banks, have abundant fossil remains. Geological time is divided into a number of **eras** and **periods**, each characterized by a specific set of **fossils**, the remains of organisms that lived in those remote geological times.

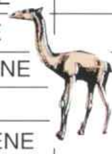
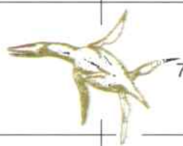
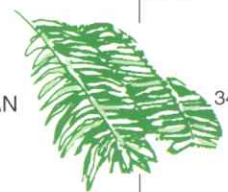
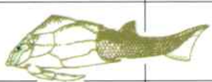
The oldest rocks, which were formed before large animals had evolved, are termed Precambrian rocks. Precambrian rocks do not contain many fossils, and most of the fossils that occur in them are rather small—in fact, most are microscopic in size. On top of the Precambrian rocks, which are older than about 540 million years, lie the Cambrian rocks. The term Cambrian comes from the Roman word (*Cambria*) for *Cymru*, which is the Welsh word for their native land. Thus Cambrian rocks were first described from Wales in the United Kingdom, but they have since been found on all the continents. The rocks outside Wales are recognized as Cambrian rocks because they contain the same kinds of fossils as the Cambrian rocks in Wales.

The process of determining the ages of rocks and relating them to each other is called *correlation*. Correlation involves looking for similar types of fossil organisms in rocks from different parts of the world. Sometimes a single key fossil species may reveal a rock's age. This is like dating a historical event by the presence of a key person in a particular place. For example, if we know that a house in Kansas was once occupied by John Brown, we know that house must have been in existence in the 1850's. Other times, a rock's age will be revealed by the presence of several key species. In Kansas the Reagan Sandstone, which lies deeply buried below the surface, was deposited during the Cambrian Period. On the basis of the fossils it contains, which were recovered from drilling, it can be correlated to other sequences of Cambrian rocks, both in Wales and elsewhere. Because some of the rocks containing Cambrian fossils are closely associated with rocks that can be dated using radioactive isotopes, we can date the fossil-bearing rocks to around 500 million years. In Kansas, it turns out that Cambrian rocks supply an important part of the oil and gas produced in the state of Kansas, not a bad heritage. Furthermore, the Reagan Sandstone lies directly on top of the even older Precambrian rocks that are present beneath the surface everywhere in Kansas.

The geologic history of the Earth is divided into major segments but not all of that history is preserved here in Kansas (see table 1). There were prolonged periods during which rocks were deposited, but there were also long times when no rocks were deposited in Kansas, although rocks of those ages are present in the other parts of the country. The oldest rocks preserved at the surface in Kansas are from the Mississippian Period, which lasted from about 360 to 320 million years ago. These rocks are found in the southeastern part of the state. In eastern Kansas, the alternating sandstone, shale, and limestone beds were deposited during the Pennsylvanian and Permian Periods, which lasted, respectively, from about 320 to 285 million and from about 285 to 245 million years ago. To the west are rocks that were deposited during the Cretaceous Period, from about 145 to 65 million years ago, most notably the Niobrara Chalk beds. Still farther west on the High Plains of Kansas is the Ogallala Formation, which was deposited during the Tertiary Period and is less than about 5 million years old (fig. 2).

KANSAS GEOLOGIC TIMETABLE

(Not scaled for geologic time or thickness of deposits)

ERAS	PERIODS	EPOCHS	EST. LENGTH (YEARS)*	DESCRIPTION	MILLION YEARS PAST
CENOZOIC	QUATERNARY	HOLOCENE 	10,000+	Early, the land was stable with some erosion. Glaciers moved into the northeast at least twice. Later the climate was dry. Sand dunes were formed by wind in the west. Volcanic ash was blown in from California, New Mexico, and Wyoming.	
		PLEISTOCENE	1,590,000		1.6
	TERTIARY	PLIOCENE 	3,700,000	Rocks found are part of the Ogallala Formation (sand, gravel, and porous rock), which contains a large quantity of ground water and occurs only in the western third of the state. No rocks were formed in eastern Kansas.	
		MIOCENE	18,400,000		
		OLIGOCENE	12,900,000		
		EOCENE	21,200,000		
		PALEOCENE	8,600,000		66.4
MESOZOIC	CRETACEOUS		77,600,000	Much of the western half was covered by seas. Limestone, sandstone, and chalk formed from sea deposits. Fossils can be found in these rocks, which crop out in central and western Kansas.	144
	JURASSIC		64,000,000	Most rock in Kansas is underground in the west. A few small outcrops are found in the southwest corner.	208
	TRIASSIC		37,000,000	No rocks have been found in Kansas.	245
PALEOZOIC	PERMIAN		41,000,000	Much of Kansas was covered by several seas. As they rose and fell, limestone, shale, and chert were deposited. The Flint Hills were formed. When the seas dried up, salt and gypsum were left behind. Salt, now underground, is mined in central Kansas. The Red Hills were formed from deposits of shale, siltstone, sandstone, gypsum, and dolomite.	286
	PENNSYLVANIAN		34,000,000	For much of the period the land was flat. Seas and swamps came and went; coal formed in swamps from dead plants. Shale, limestone, sandstone, chert, and conglomerates were deposited. Two ridges of hills, the Nemaha uplift and the Central Kansas uplift, appeared; both are now buried. Pennsylvanian rocks are found at the surface in eastern Kansas.	320
	MISSISSIPPIAN		40,000,000	Repeated layers of limestone, shale, and sandstone indicate that seas rose and fell. Mississippian rocks are the oldest found at the surface and are in the southeast corner; elsewhere these rocks are only underground.	360
	DEVONIAN		48,000,000	Seas covered Kansas during much of the period. Limestone, shale, and sandstone deposits are only underground.	408
	SILURIAN		30,000,000	Land was uplifted and seas disappeared. Limestone deposits are found only underground.	438
	ORDOVICIAN		67,000,000	Seas covered parts of Kansas during much of the period. Dolomite and sandstone are only underground.	505
	CAMBRIAN		65,000,000	Early, the climate was dry and many rocks eroded. Later, parts of Kansas were covered by seas. Dolomite, sandstone, limestone, and shale are now underground.	543
PRECAMBRIAN			3,930,000,000	These rocks are the oldest on earth. In Kansas, they are only found deep below the surface and not much is known about them. Many are igneous and metamorphic and have gone through many changes.	4,500?

Eons not shown

* Decade of North American Geology, 1983 Geology Time Scale, Geological Society of America

TABLE 1—Kansas geologic timetable.

What evidence do we have for the history of life?

Fossils are our best evidence of past life. **Fossils** are the remains of long-dead organisms preserved in rocks. For an animal or plant to become a fossil, it has to be buried soon after it dies. After burial, the enclosing material may slowly harden, sometimes over many millions of years, and be transformed into rock. The remains of the organism also undergo chemical changes. The final product is a chemically altered form that preserves the original animal or plant to a greater or lesser degree. The fossil record provides an excellent chronicle of life's history, so that we now understand it quite well. Of course, not all animals are perfectly preserved, so the fossil record is far from perfect.

Incidentally, although many ancient organisms have been preserved as fossils, other ancient organisms are the source of the oil that powers our cars and the coal that drives our power plants. The state of Kansas is particularly well endowed with rich reserves of oil and coal derived from ancient life, much of which lived more than 100 million years ago. Conservative estimates suggest that Kansas has oil reserves measured in billions of barrels, a quantity that provides both a reasonable idea of the number of organisms that lived in the past and also tangible evidence of the contributions of these ancient organisms to the state's economy (fig. 3). Coal reserves in Kansas also are significant, although less important economically at the present time. Coal is derived from the remains of ancient swamps and forests that once covered Kansas. These forests contained a wide variety of now-extinct plant groups. Millions of tons of coal are known to occur in Kansas, especially in the southeastern part of the state. These are a further testament to the wealth of past life.

When did life first appear?

Early in its history, the Earth was a molten, volcanically active sphere that was inhospitable to any kind of life. Moreover, at that time, the Earth was bombarded by many more meteorites and asteroids than in more recent times. Just over 4 billion years ago, the Earth began to cool somewhat, and some of the earliest rocks from this time period bear chemical traces of life. Thus,

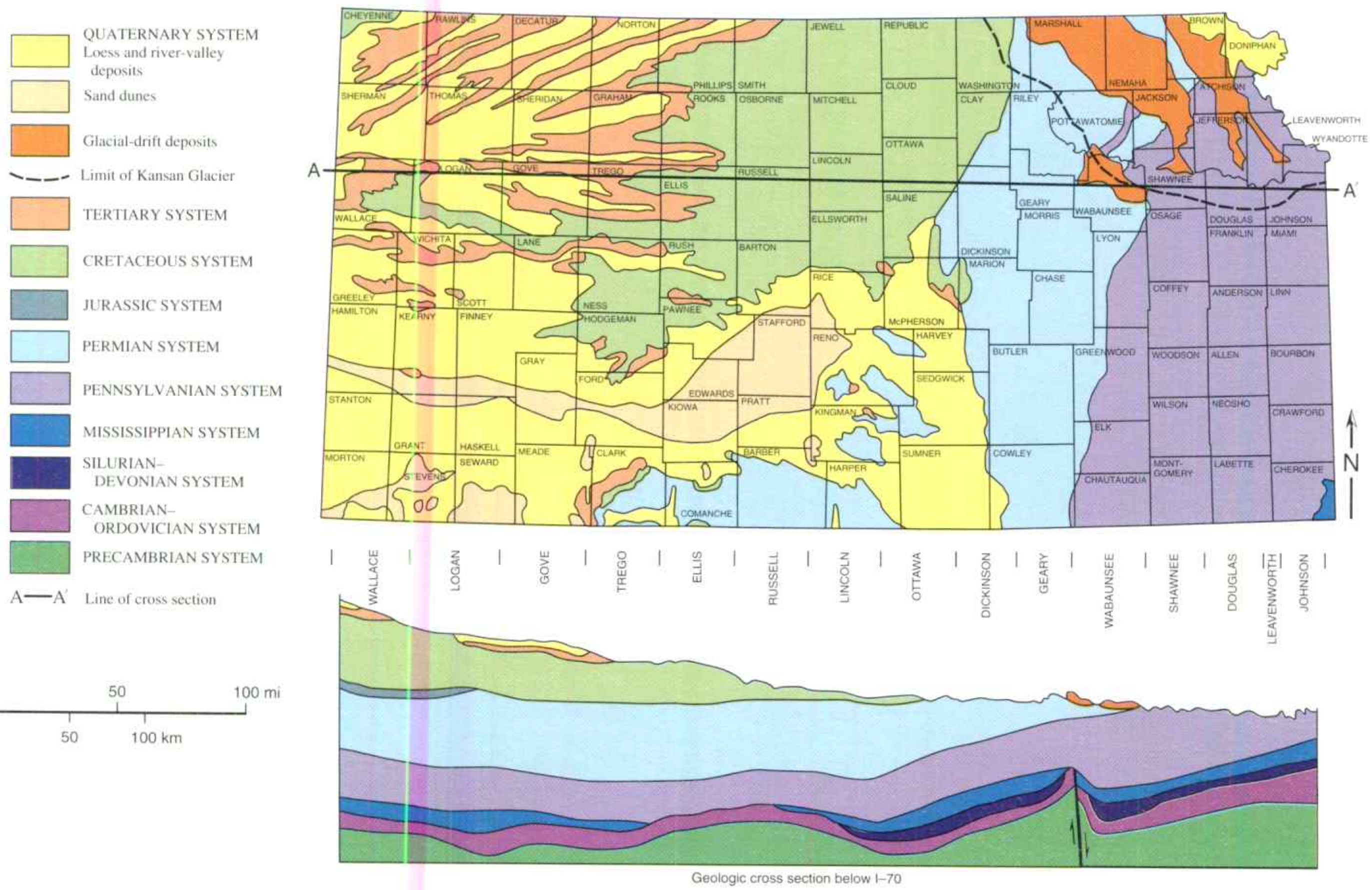


FIGURE 2—Generalized geologic map of Kansas.

shortly after the Earth cooled, life had already begun to evolve. The oldest fossils known are simple, microscopic organisms. These single-celled organisms, resembling modern pond scum, date from roughly 3.5 billion years ago. Although these earliest organisms were exceedingly simple, we owe them at least one great debt. They helped generate the oxygen in the atmosphere that our early animal ancestors needed. For nearly all of the next 3 billion years (the period called the Precambrian), single cells were the only life that existed. Eight hundred million years ago the first multicellular organisms appeared. These were a type of algae resembling modern-day seaweeds. Near the end of the Precambrian, by 550 million years ago, the world's oceans were populated by such multicellular animals as sponges, jellyfish, snail-like organisms, and a variety of wormlike organisms together with unusual flattened organisms called the **Ediacara**. The rocks containing these early multicellular organisms are exposed in many parts of the world, but unfortunately cannot be found in Kansas.

What was the Cambrian explosion?

Roughly 540 million years ago a key event occurred, sometimes referred to as the Cambrian explosion. Early in the Cambrian Period, abundant, complex animals began to evolve. Over a period of about 30 million years, the ancestors of nearly all the major groups of animals living today appeared in the fossil record. Many kinds of early animals are now extinct, and we know them only through the study of fossils. Some of the extinct forms were truly bizarre. Others of the early animals are intermediate between the different modern animal groups. That is, their overall form is close to what we would predict for the ancestors of each of these great groups of animals. Others, while primitive, clearly belong to familiar modern groups: clams, snails, arthropods (the group that contains today's spiders, lobsters, and insects), and our own group, the vertebrates. Although these ancestral species are now extinct, their descendants are still with us today and comprise the groups of animals with which we are familiar in the modern world.

We do not know what caused the Cambrian explosion, but it is being actively researched by a number of geologists and paleontologists who are developing a good understanding of those events that occurred so long ago..

The Cambrian explosion is important for several reasons. The organisms did not appear all at once, but over 30 million years, an extremely long period of time from our point of view. Thus, it was not an instantaneous event. Compared to the long, Precambrian interval when only single-celled organisms dominated the Earth, however, the pace of this evolution seemed to be quite explosive indeed. The Cambrian explosion is an excellent example of how the rate of evolution has varied in the long history of life. Sometimes evolutionary change occurs quickly; at other times it moves slowly. This is analogous to human history and the history of nations. Witness the relatively sudden toppling of the Communist regime in the former Soviet Union. It happened in a few years, relatively quickly compared to the previous 70 years of that regime's stability. Thus, the Cambrian explosion does not contradict the fact that evolution has happened. Instead, it shows that the rate at which evolution occurs is not constant. Although, as mentioned above, no Cambrian rocks are found at the surface in Kansas, rocks dating from shortly after the Cambrian explosion are found buried deep beneath the surface.

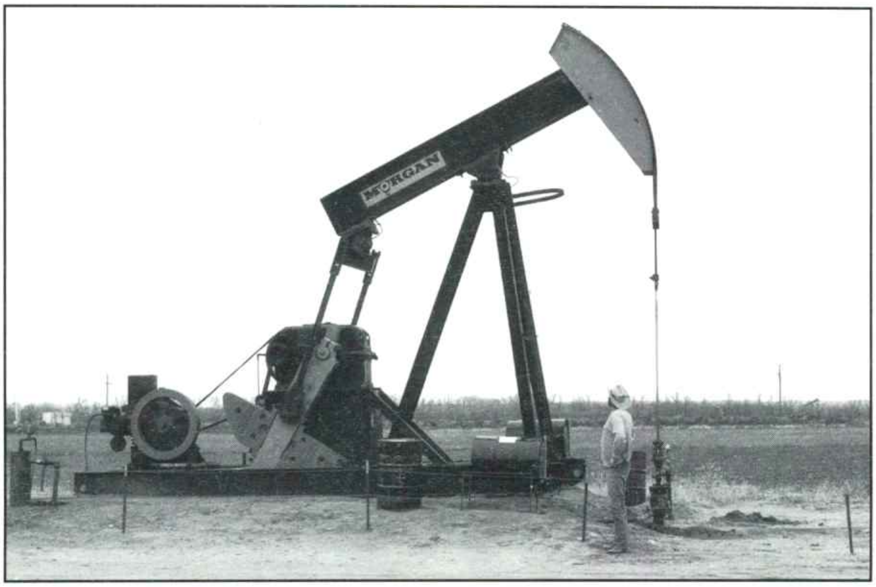


FIGURE 3—Oil is a byproduct of fossil remains. This oil well in Comanche County, Kansas, is one of many found throughout the state (Evans, 1988).

What happened after the Cambrian explosion?

The next key event in the history of life was the evolution of plants and their invasion of land, roughly 420 million years ago during the Silurian Period. Within a few tens of millions of years, forests covered large parts of the Earth's surface that was above sea level. Shortly thereafter, our own group, the vertebrates, invaded the land. Fish had lived in the oceans for nearly 100 million years and were extremely diverse. New species eventually evolved that had the ability to move onto land, although they returned to the water to mate and lay their eggs, just as modern-day amphibians do—the frogs, toads and salamanders. Eventually, tens of millions of years later, some vertebrates evolved to become fully terrestrial, laying their eggs on land. The animals that evolved this ability are the ones we now refer to as reptiles. Kansas has one of the best fossil records of these early reptiles, which lived in the Pennsylvanian and Permian Periods. They have been recovered from Garnett, Kansas, in rocks that preserve what was once an ancient lagoon. Several kinds of early reptiles lived in this lagoon, including *Petrolacosaurus* (figs. 4, 5). This Kansas reptile is close to the ancestral form of the reptile group that spawned the dinosaurs, crocodiles, and birds. Also living in that 300-million-year-old Kansas lagoon in close association with *Petrolacosaurus* was another early reptile called *Edaphosaurus* (fig. 6). It was part of a separate lineage that gave rise to modern mammals.

Not all the periods are represented in the Kansas geological record. This is partly because sea level has varied dramatically throughout earth history. Sometimes the continents have been flooded by shallow seaways. At other times the continents have been largely exposed as they are today. During times of inundation, sediments were deposited on the sea floor. Over millions of year, these accumulated sediments formed massive layers of limestones, shales, and sandstones. In general, when the land is above sea level, rocks are not deposited. Thus, in the future, Kansas will have relatively few rocks that preserve a record of the present day.

Shortly after the plants evolved, sea level rose and fell periodically across the North American continent. In Kansas, as sea level rose and fell, the surface environment alternated between shallow swamps and shallow oceans. It was at this time, during the Pennsylvanian Period, that much of the coal in Kansas was formed, in large swamps teeming with plants. After the plants died, they were covered by water and mud and sand. As layers of sediment accumulated, the decaying plant material was compacted, eventually forming coal. At other times, when the water level rose, shallow seas covered Kansas and much of the rest of the country as well. During this time, limestone was deposited. This limestone is now exposed as the yellow-brown rocks that crop out along the side of many highways and country roads in eastern Kansas. Later, during the Permian Period in Kansas, the seas began to dry up. As the seawater evaporated, it left behind thick layers of salt. This salt now is mined commercially, especially near Hutchinson, Kansas.

Still later, to the west, after a long interval during which the land was above sea level, the water level once again rose, covering much of the continent in the Cretaceous Period. Chalks and sandstones from this time period occur throughout central and western Kansas. (The sandstones are a rich source of water for Kansas, and wells are often drilled into these rocks.) The Cretaceous chalks formed because the Kansas sea also contained tiny microorganisms. As these small organisms died, their skeletons rained down onto the seafloor and over millions of years formed the extensive chalks that crop out throughout much of western Kansas. The white cliffs of Dover in England are a similar type of chalky rock that was deposited in the same type of environment and at the same time. The Cretaceous rocks contain very different organisms from those found in Pennsylvanian rocks. The Cretaceous chalk contains large clams that evolved to look completely different from those that lived during the Pennsylvanian Period. The chalk also contains ammonoids, which are now extinct but were relatives of modern-day squids and octopuses (fig. 7). The ammonoids also lived during the Pennsylvanian Period, but the ones that lived at those times were much more primitive and had much simpler shells than the Cretaceous forms. The most noteworthy fossils in the Cretaceous rocks of Kansas, however, are the fossils of animals with backbones. Among these were the giant mosasaurs, great meat-eating marine reptiles that in Kansas grew up to 20 feet long (fig. 8). Giant predatory fish and sharks as much as 15 feet long also roamed the Kansas seas (fig. 9).

The skies above the Kansas Cretaceous seas also were rich in life. Pterosaurs, some of them giants with wing spans reaching almost 20 feet, glided through Kansas skies, scooping fish from the water (fig. 10). These reptiles, close relatives of the dinosaurs, evolved flight independently from the modern feathered birds. Along with these pterosaurs, however, birds flew through Kansas skies and fed on ancient Kansas fish; these were true, feathered birds. Several species of these early birds are known from Graham County, Kansas. Some of these were flightless species, such as *Hesperornis* and its close relative *Parahesperornis* (fig. 11), stood nearly 5 feet tall and had large feet, like modern diving birds, such as the loon, which migrates through Kansas in the spring and autumn. Unlike the loon and other modern birds, it had teeth set in its mouth, and its bones were not hollow. These were characters inherited from reptilian ancestors that had not yet been lost in the early evolution of birds.

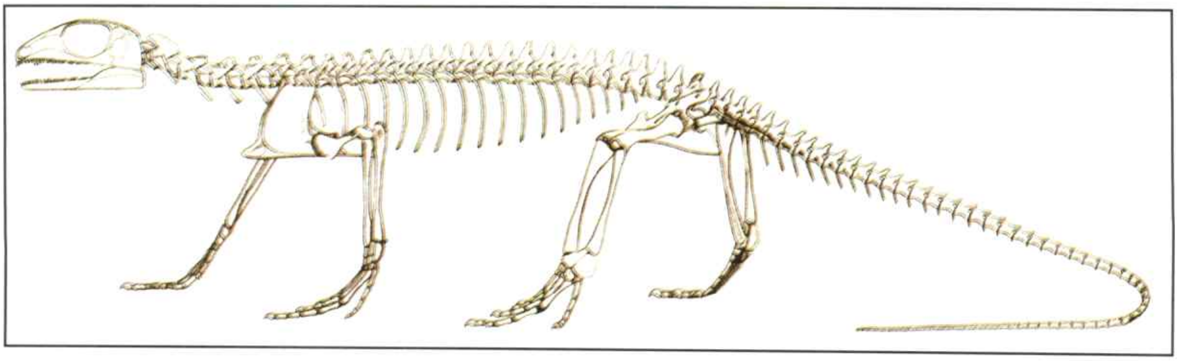


FIGURE 4—Skeleton of *Petrolacosaurus*, an early reptile from the Pennsylvanian of Kansas (University of Kansas, Museum of Natural History, Special Publications, Reisz, 1981).

FIGURE 5—Reconstruction of Pennsylvanian-aged lagoon in central Kansas (University of Kansas Paleontological Contributions, Peabody, 1952).

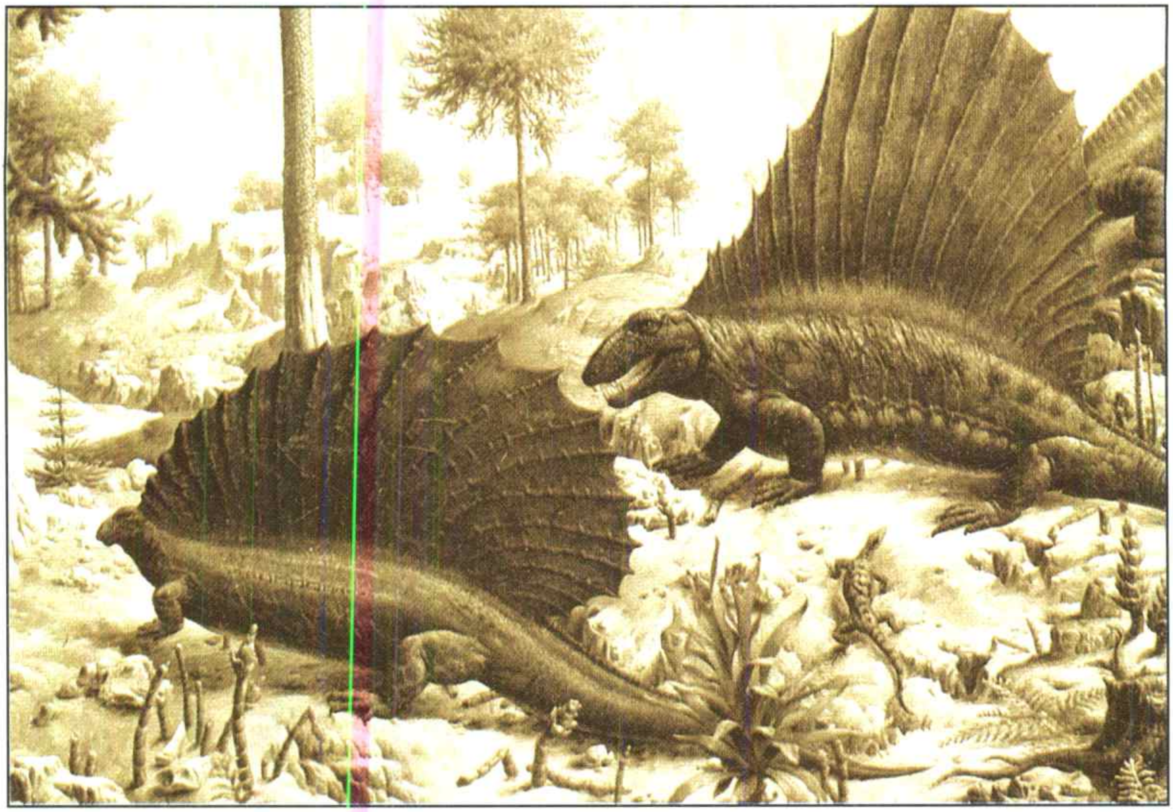


FIGURE 6—*Edaphosaurus* (left) from the Pennsylvanian of Kansas is a transitional link, along with it close relative *Dimetrodon* (right), between early reptiles and other groups more closely related to modern mammals (The Age of Reptiles, a mural by Rudolph F. Zallinger, Peabody Museum of Natural History, 1989, used with permission).

Why do scientists describe the history of life as a branching tree?

Playing out over these immense time scales are two distinct phenomena. First, life was continually evolving, casting out new branches representing new lineages of organisms like a great tree. At the same time, however, many lineages went extinct as if nature were pruning the tree of life. The kinds of animals and plants that populate the Earth have been changing continually. Truly cataclysmic events often led to mass extinctions, some of them eliminating more than three quarters of all life on Earth. Recovery was slow, but it always occurred. Often the survivors of these extinction events were kinds of organisms that had not been especially important before the mass extinction. Part of the reason that Kansas fossils from the Pennsylvanian Period differ from those of the Permian Period is because a time of extinction separates these two intervals. In addition, these fossils differ because evolutionary change had occurred.

FIGURE 7—The fossil ammonoid *Aegoceras*, a marine predator with a spiral shell went extinct along with the dinosaurs 65 million years ago (University of Kansas, Paleontological Contributions, Donovan and Forsey, 1973).

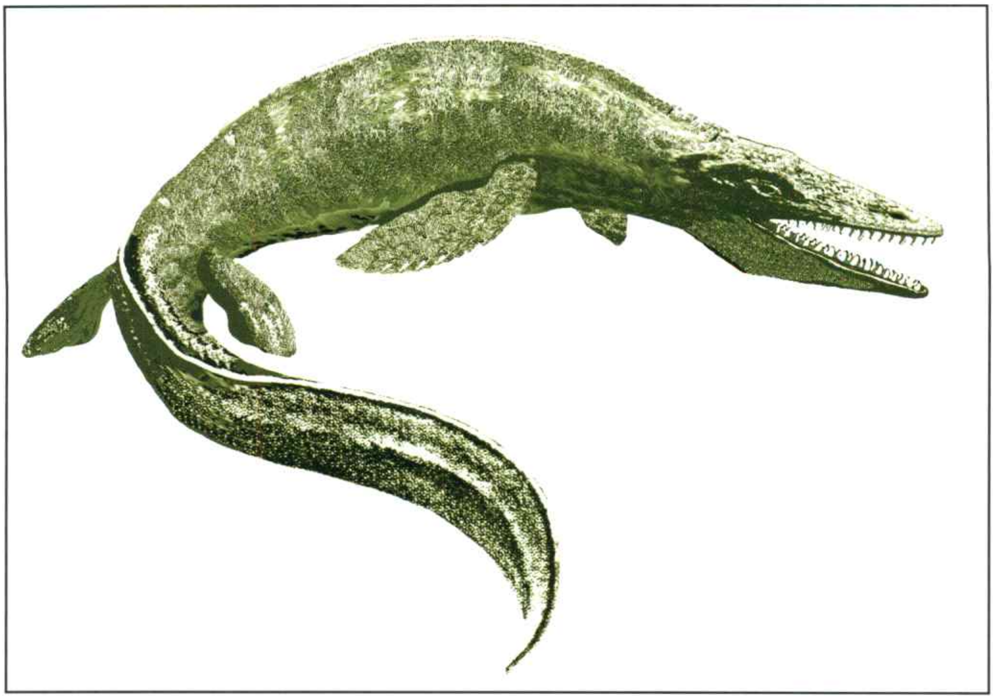


FIGURE 8—The mosasaur *Platecarpus* was a giant marine reptile that grew up to 20 feet long. Species like *Platecarpus* were abundant in Kansas seas 70 million years ago. They are close relatives of modern-day snakes (Kansas Geological Survey, Educational Series 6, Evans, 1988).

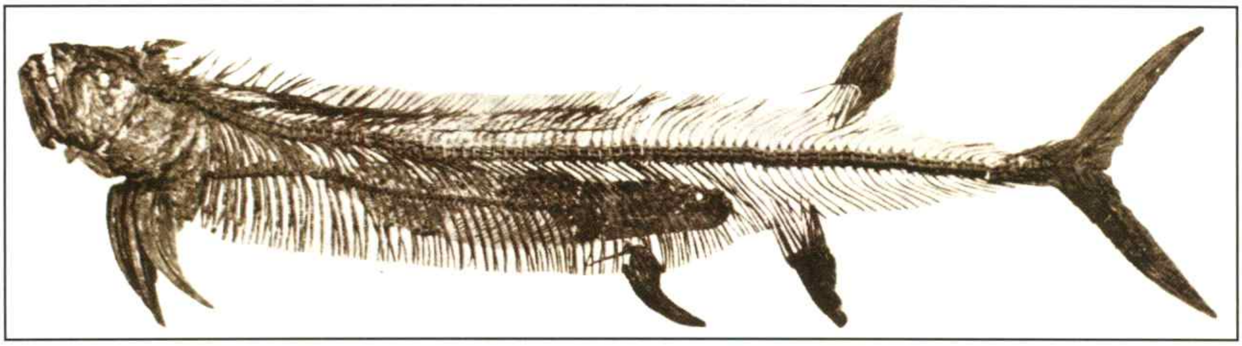


FIGURE 9—Fifteen-foot-long fossil fish *Xiphactinus* from the Cretaceous of western Kansas, with a smaller fossil fish *Gillicus* preserved inside its abdominal cavity (University of Kansas, Paleontological Contributions, Bardack, 1965).

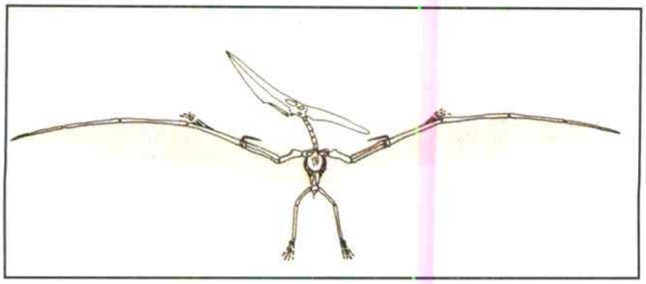


FIGURE 10—Reconstruction of *Pteranodon*, a species of pterosaur, a winged reptile from the Cretaceous of Kansas (University of Kansas, Paleontological Contributions, Brower and Veinus, 1981).

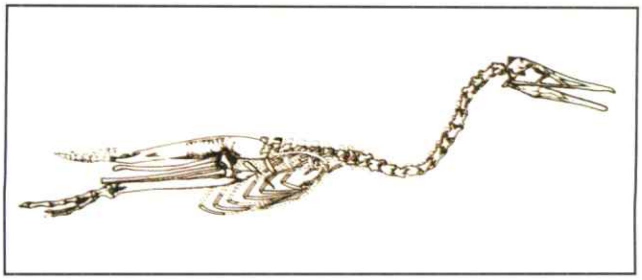


FIGURE 11—*Parahesperornis*, an early fossil bird from the Cretaceous of western Kansas (L. Martin, Transactions of the Kansas Academy of Science, 1984, v. 87).

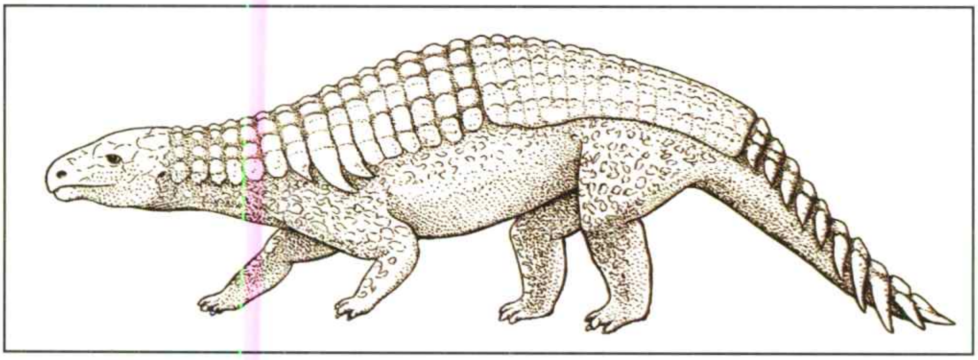


FIGURE 12—*Silvisaurus*, an armored dinosaur from the Cretaceous of Kansas (University of Kansas, Paleontological Contributions, Eaton, 1960).

What happened in Kansas during the Cretaceous–Tertiary mass extinction?

The Cretaceous Period ended 65 million years ago, and the Tertiary Period began. The boundary between the two periods is marked by the Cretaceous–Tertiary mass extinction. Before the extinction occurred, dinosaurs were the dominant terrestrial organisms of their day. Three distinct species of plant-eating dinosaurs, two with thick bony armor on their backs and one with a broad duck bill, are known to have roamed the state of Kansas (fig. 12). The largest Kansas dinosaurs grew up to 20 feet in length. During the Cretaceous the mammals, the group that includes our own species, were small and rodentlike, but even more primitive than today's rodents. Fossil mammals are found rarely in Cretaceous rocks, and they probably were of marginal importance in the dinosaurs' world. Seemingly overnight, this all changed. A large meteorite roughly 5 miles across struck the Earth near what is now the Yucatan peninsula of Mexico. The catastrophic impact and ensuing darkness eliminated the large terrestrial dinosaurs and many other kinds of animals as well. The small mammals, arguably less well adapted than the dinosaurs, somehow survived. Within a few million years after the mass extinction event, they had evolved into a diverse array of animals, including bats, whales, and horses. Our own lineage, the primates, also evolved shortly after the extinction event. From the start of their evolution, the primates were distinguished from the other mammals by their relatively large brains and good eyesight.

We also can see evidence of the Cretaceous–Tertiary mass extinction transition on a more narrow scale in Kansas. Before the mass extinction, several types of giant marine reptiles, including the mosasaurs (fig. 8), swam in the shallow seas that covered parts of Kansas. These mosasaurs went extinct along with the dinosaurs, and the seas they lived in have since retreated, but their close cousins, the snakes, populate what is now the prairie of Kansas. The skulls and backbones of snakes are very similar to those of mosasaurs: they share many anatomical features because they share a close common ancestor. Mosasaurs can best be thought of as the close evolutionary kin of the snakes that were very well adapted to the Kansas environments of 70 million years ago. Similarly, snakes, including the rattlesnake, are well adapted to the modern-day prairie environment.

An evolutionary continuity stretches across the 70-million-year transition from sea to prairie in Kansas. The history of life and its evolution as shown in the fossil record now are well understood and full of variety. The tree of life is a diversely branching tree that has been populated by millions of species, almost all of which are now extinct. Some of the major branches of this tree have vanished through the incessant processes of extinction; other major branches are still with us today.

How did our relatives, the primates, evolve from swinging in trees to walking the plains?

From our perspective, another key evolutionary transition occurred roughly 4 million years ago in Africa. Primates originally were tree dwellers and had a stooped posture. Some primates from this time show profound similarities to chimpanzees in the structure of their face and hands and in the size of their brains, but their hips show clearly that they walked with an upright, erect posture—much like that of modern humans. These are the first known fossil **hominids**, the narrowly defined group of organisms that includes modern humans and several other extinct species. The evolutionary transition happened during a time when the climate in Africa and in much of the rest of the world was becoming cooler and drier. Patches of trees were becoming more widely spaced, requiring longer travel times to move between them, a situation that favored an upright gait.

We can identify some fossils as being links in the evolutionary chain between a living animal and its older ancestors in the fossil record. We expect such links to have a combination of features intermediate between an ancestor and its descendants. The earliest hominid fossils fulfill this expectation. In fact, a series of transitional links forms a chain from the earliest primates to the most primitive hominids and from these earliest hominids to our modern species of humans (fig. 13). The general trends are the evolution of larger brains and such specializations of the hands and limbs as our opposable thumb, which enables us to manipulate tools. Within the hominid family tree, some branches do not lead to humans at all. Some of the so-called australopithecine hominids developed large teeth and jaws, probably for crushing plants. The australopithocines went extinct more than a million years ago. Hominids are known from rocks in Africa, Asia, and Europe. We have no record of these evolutionary transitions here in Kansas because the group was evolving elsewhere.

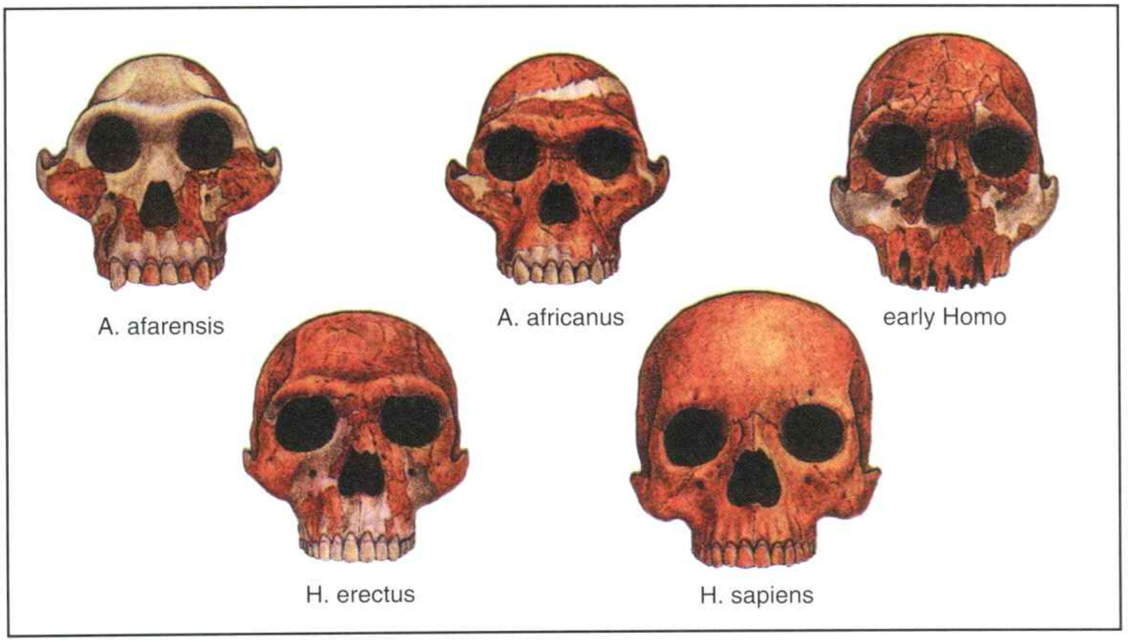


FIGURE 13—Hominid skulls showing evolutionary transitional forms. The earliest *Australopithecus* have a combination of apelike, humanlike, and intermediate features. The earliest species of *Homo* have intermediate features between *Australopithecus* and modern humans. All skulls show an overall trend towards larger brain size; used with permission of artist Darwen Hennings, National Academy of Science, 1999.

The Origin of the Universe

What does science say about the origin of the universe?

Scientific evidence points to an origin sometime between 10 and 20 billion years ago. The Big Bang theory is universally accepted by those who do research on the development of the universe, galaxies, and stars as the cause of the origin of the universe. The **Big Bang theory** says that the universe has developed by expanding from a hot dense state with everything exploding away from everything else. What caused this explosion is not part of the Big Bang theory. It must be regarded as unknown at this time, although there are many ideas about the cause.

How do we know the universe is expanding?

The evidence indicates that as the Big Bang occurred, everything in the universe was an expanding mass of hot gas. As this mass of gas expanded, it cooled. Knots of matter formed that became the objects we see—including galaxies, stars, and planets such as our Earth. These objects continue to move away from one another even today, and, thus, our knowledge that the universe is expanding is based on observation. Evidence for the expanding universe comes from a phenomenon referred to as the **redshift**. When objects move apart rapidly, the light emitted by one and received by the other changes in a specific way. The light of an object moving rapidly shifts to the red end of the visible spectrum, and a redshift occurs. In the 1920's, scientists discovered that distant galaxies are moving away from us. Moreover, the farther away galaxies are, the faster the motion is relative to us and the greater the observed redshift. It happens that this kind of expansion is predicted by Einstein's general theory of relativity. This aspect of Einstein's theory has been tested by a number of experiments, and no test has been able to falsify the hypothesis. Over the years, many other scientific hypotheses have been introduced to explain the redshift without invoking an expanding universe. None of these hypotheses has a simple and direct connection with effects we can measure in the laboratory. It also is true that nearly all of them make other kinds of predictions about light that are not observed, so these hypotheses are no longer taken seriously.

Is there any other evidence for the Big Bang?

Three other major pieces of evidence indicate that the Big Bang occurred. The first is called the **cosmic microwave background radiation (CMBR)**, which is a weak form of radiation that comes from the sky and is energy that is left over from the very early universe (fig. 14). The

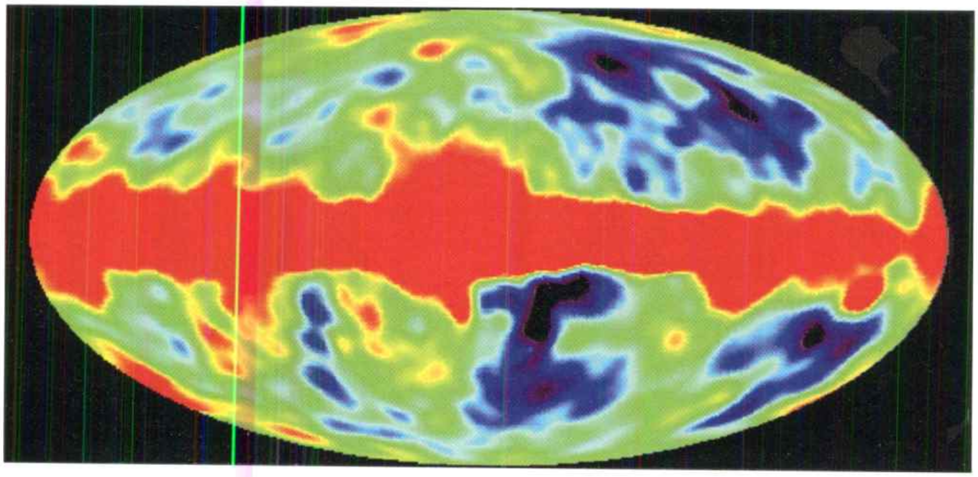


FIGURE 14—The cosmic microwave background is the afterglow radiation left over from the Big Bang. Shown here are cosmological fluctuations in the microwave background temperature made by the Cosmic Background Explorer (COBE) satellite (Spergel et al., 1999). Although extremely uniform all over the sky, tiny temperature variations can offer great insight into the origin, development, and initial structure of the universe.

CMBR was predicted during World War II, and in the 1960's it was detected for the first time. Since then, it has been measured and remeasured and now ranks as the most precise scientific measurement ever made. The second major piece of evidence concerns the fraction of various kinds of atoms in the universe. Scientists have calculated the amount of helium and other light atoms that should have been formed in the first few minutes after the Big Bang. The predictions agree remarkably well with what is observed. The third piece of evidence comes from our own eyes. Telescopes currently in use in Kansas and elsewhere allow us to see faraway galaxies as they appeared close to the time of the Big Bang because light takes so long to reach us from such distant objects. The observations continue to fit our interpretation of a universe that was very different early in its history. At the present time, we do not understand everything about the development of the universe. The work of science is not finished. We do not yet know how it started or what the **dark matter** is. We are, however, very confident that, in general, the Big Bang model is correct, and many physicists and astronomers are now working to fill in the details.

Where did the Earth come from?

Most of the matter in the universe consists of such light elements as hydrogen and helium, plus an additional kind of unknown cold dark matter that is not yet well understood. Such heavier elements as carbon, oxygen, and silicon that are needed to form rocks and living organisms formed in earlier generations of stars that exploded, scattering the elements across the galaxy. These elements, sometimes referred to as ashes, were part of the matter that clumped together to form our solar system. Planets like our Earth are made primarily of the heavier elements. The Earth is known to be about 4.5 billion years old; the universe is at least three times older. A lot had to happen before the Earth could form!

What will happen to the universe in the future?

Scientists believe there are two possible scenarios. One is that the universe may collapse again into sort of a reverse of the Big Bang. The other is that it may continue to expand forever, eventually growing cold and dark. At present, the weight of evidence seems to indicate that it will expand forever. Our understanding of the nature of the cold dark matter, a subject being actively investigated by many scientists, may help us answer the question of the ultimate fate of the universe. If cold dark matter is sufficiently abundant, it could halt and possibly even reverse the universe's expansion.

Acknowledgments

We would like to thank Keith Miller, Charles Higginson, and Helen Alexander for comments on earlier versions of this booklet. Thanks go also to The Kansas Citizens for Science.

References

Bardack, D., 1965, Anatomy and evolution of chirocentrid fishes: University of Kansas, Paleontological Contributions, v. 10, p. 1–87.

Brower, J. C., and Veinus, J., 1981, Allometry in pterosaurs: University of Kansas, Paleontological Contributions, v. 105, p. 1–32.

Darwin, C., and Wallace, A. R., 1858, On the tendency of species to form varieties; and on the perpetuation of varieties and species by natural means of selection: Journal of the Proceedings of the Linnean Society of London, Zoology, v. 3, p. 53–62.

Donovan, D. T., and Forsey, G. F., 1973, Systematics of Lower Liassic Ammonitina: University of Kansas, Paleontological Contributions, v. 64, p. 1–24.

Eaton, T. H., Jr., 1960, A new armored dinosaur from the Cretaceous of Kansas: University of Kansas, Paleontological Contributions, v. 8, p. 1–24.

Evans, C. S., From sea to prairie—A primer of Kansas geology: Kansas Geological Survey, Educational Series 6, 60 p.

Martin, L., 1984, A new hesperornithid and the relationships of the Mesozoic birds: Kansas Academy of Science, Transactions, v. 87, p. 141–150.

National Academy of Sciences, 1999, Science and creationism—A view from the National Academy of Sciences, 2nd ed.: Washington, D.C., National Academy Press, p. 24.

Peabody, F. E., 1952, *Petrolacosaurus kansensis* Lane, a Pennsylvanian reptile from Kansas: University of Kansas, Paleontological Contributions, v. 1, p. 1–41.

Purves, W. K., Orians, G. H., Heller, H. C., and Sadava, D., 1998, LIFE: The Science of Biology, 5th Edition: Sunderland, Massachusetts, Sinauer Associates, p. 438.

Reisz, R., 1981, A diapsid reptile from the Pennsylvanian of Kansas: Museum of Natural History, University of Kansas, Special Publication, v. 7, p. 1–74.

Spergel, D. N., Hinshaw, G., and Bennett, C. L., 1999, Introduction to Cosmology: NASA, http://map.gsfc.nasa.gov/html/fluct.html, accessed October 15, 1999.

Zallinger, R. F., 1989, The age of reptiles: Peabody Museum of Natural History, mural.

Glossary

Adaptation—A trait that is particularly suited to an environment. It is the result of natural selection.

Big Bang Theory—The most supported explanation for the formation of the universe. All matter and energy in the universe came from a condensed hot mass that exploded and expanded in all directions.

Cambrian Explosion—An important event in the history of life that began around 540 million years ago and concluded around 510 million years ago. During this interval nearly all the major types of organisms now known on Earth, as well as several novel extinct types, appeared in the fossil record.

Cosmic Microwave Background Radiation (CMBR)—Radiation left over from the Big Bang. Fluctuation in the distribution of this energy is evidence of the structure of the universe right after the Big Bang.

Dark Matter—Invisible material in the universe that may mean that the universe is sufficiently heavy that it will not expand forever.

Ediacaran—A term used to describe the earliest known multicellular organisms, which appeared about 600 million years ago and largely went extinct just before the Cambrian explosion.

Evolution—Evolution is change through time. Biological evolution means change that has accompanied descent from a common ancestor.

Fossils—Any evidence of past life preserved in rocks.

Geologic Era—A long interval of geologic time recognized by the origination and extinction of a large number of plant and animal species. The boundaries usually correspond to times of major environmental change that lead to extinction and also spur evolutionary change. An example is the Mesozoic Era, when the large terrestrial dinosaurs lived. The average duration of an era is on the order of tens to hundreds of millions of years. We currently are in the Cenozoic Era, which began 65 million years ago.

Geologic Period—A long interval of geologic time, but shorter than an era, and again, defined by the origination or extinction of a large number of species. The number of species that evolve and go extinct at period boundaries, however, is less than at era boundaries. The boundaries also usually correspond to times of major environmental change, although not as major as those changes occurring at era boundaries. An example is the Cambrian Period, when animal life first appears in abundance in the fossil record. The average duration of a period is on the order of tens of millions of years. We currently are in the Quaternary Period which began 10,000 years ago.

Hominids—A group of primates that includes humans and several extinct species such as *Homo erectus* and the Neanderthals that all shared an upright posture.

Hypothesis—An explanation for observed phenomena. A hypothesis is used as a basis for further observations or experiments.

Law—A scientific statement that always applies, such as the law of gravity.

Macroevolution—Evolutionary changes that involve the production of new species. These occur over time scales of thousands of years. They are produced by a series of microevolutionary changes, but not all microevolutionary changes lead to macroevolution.

Microevolution—Evolutionary changes that occur within species. These occur over a range of time scales, from months to millions of years.

Natural Selection—Greater survival or reproductive success among some members of a population due to inherited traits that confer an advantage in the environment in which the population lived.

Radioactive Isotopes—Chemical elements that differ in their number of neutrons. For any radioactive isotope, the rate of decay into other elements is constant and therefore can be used to measure geologic time.

Red Shift—Light from an object that is moving away from an observer is shifted toward the red or longer wavelength end of the spectum relative to the light emitted at the source of the object. The fact that stars inside and outside of our galaxy predominantly show a red shift is evidence that the universe is expanding.

Species—A group of organisms that can interbreed with each other and produce fertile offspring. It is the fundamental unit of biological evolution.

Theory—An explanation for natural events that is based on a large number of observations and has been tested repeatedly.

Suggested Readings and Educational Resources

Publications on Evolution

Eldredge, Niles, 1999, The Pattern of Evolution: New York, W. H. Freeman.

Fortey, Richard, 1998, Life—A Natural History of the First Four Billion Years of Life on Earth: New York, Alfred P. Knopf.

Tattersall, Ian, 1998, Becoming Human: New York, Harcourt Brace.

Longair, Malcolm S., 1996, Our Evolving Universe: New York, Cambridge University Press.

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

Dawkins, Richard, 1986, The Blind Watchmaker: New York, W. W. Norton.

Eldredge, Niles, 1985, Time Frames: Princeton, N. J., Princeton University Press.

Gould, Stephen Jay, 1977, Ever Since Darwin—Reflections in Natural History: New York, W. W. Norton.

Publications on the Nature of Science, the Relationship Between Science and Religion, and Creationism

Gould, Stephen Jay, 1999, Rock of Ages: New York, Harmony Books.

National Academy of Sciences, 1999, Science and Creationism, A View from the National Academy of Sciences, 2nd Ed.: Washington, D.C., National Academy Press.

Godfrey, Laurie (editor), 1983, Scientists Confront Creationism: New York, W. W. Norton.

Eldredge, Niles, 2000, The Triumph of Evolution and the Failure of Creationism: New York, W. H. Freeman.

Web Sites

Kansas Citizens for Science—www.kcfs.org

Kansas Geological Survey—www.kgs.ukans.edu

NASA—http://map.gsfc.nasa.gov/html/web_site.html

National Academy of Sciences—http://www4.nationalacademies.org/opus/home.nsf

National Center for Science Education—www.nacensciedu.org

Public Education Facilities

University of Kansas, Natural History Museum and Biodiversity Research Center, Lawrence, Kansas

Sternberg Museum of Natural History, Hays, Kansas

Other Publications of Interest Available from the Kansas Geological Survey

Educational Series

Ancient life found in Kansas rocks (common fossils of Kansas), by *R. B. Williams*, 1975, Kansas Geological Survey, Educational Series 1, 44 p.

Kansas rocks and minerals, by *L. L. Tolsted* and *A. Swinford*, revised and reprinted 1986, Kansas Geological Survey, Educational Series 2, 64 p.

Kansas clays for the ceramic hobbyist, by *D. A. Grisafe* and *M. Bauleke*, 1977, Kansas Geological Survey, Educational Series 3, 35 p.

Kansas geomaps, by *D. W. Steeples* and *R. C. Buchanan*, revised and reprinted 1984, Kansas Geological Survey, Educational Series 4, 30 p.

Kansas landscapes: a geologic diary, by *F. W. Wilson*, Kansas Geological Survey, Educational Series 5, 1978, 50 p.

From sea to prairie: a primer of Kansas geology, by *Catherine S. Evans*, 1988, Kansas Geological Survey, Educational Series 6, 60 p.

Petroleum: a primer for Kansas, by *D. L. Baars*, *W. L. Watney*, *D. W. Steeples*, and *E. A. Brostuen*, 1989, Kansas Geological Survey, Educational Series 7, 40 p.

A guide to finding Kansas maps, by *Catherine S. Evans*, 1990, Kansas Geological Survey, Educational Series 8, 80 p.

Caves in Kansas, by *James Young* and *Jonathan Beard*, 1993, Kansas Geological Survey, Educational Series 9, 50 p.

Kansas ground water: An introduction to the state's water quantity, quality, and management issues, compiled by *Rex Buchanan* and *Robert W. Buddemeier*, 1993, Kansas Geological Survey, Educational Series 10, 44 p.

Wichita's building blocks—A guide to building stones and geological features, by *L. H. Skelton*, 1996, Kansas Geological Survey, Educational Series 11, 32 p.

Climate and weather atlas of Kansas, by *D. G. Goodin*, *J. E. Mitchell*, *M. C. Knapp*, and *R. E. Bivens*, 1995, Kansas Geological Survey, Educational Series 12, 24 p.

Primer on industrial minerals for Kansas, by *D. A. Grisafe*, 1999, Kansas Geological Survey, Educational Series 13, 32 p.

An atlas of the Kansas High Plains aquifer, by *J. A. Schloss*, *R. W. Buddemeier*, and B. *B. Wilson*, eds., 2000, Kansas Geological Survey, Educational Series 14, 92 p.

Public Information Circulars

A user's guide to well-spacing requirements for the Dakota aquifer in Kansas, by *P. A. Macfarlane* and *R. S. Sawin*, 1995, Kansas Geological Survey, Public Information Circular 1, 4 p.

Salt contamination of ground water in south-central Kansas, by *R. W. Buddemeier*, *R. S. Sawin*, *D. O. Whittemore*, and *D. P. Young*, 1995, Kansas Geological Survey, Public Information Circular 2, 4 p.

Earthquakes, by *D. W. Steeples* and *L. Brosius*, 1996, Kansas Geological Survey, Public Information Circular 3, 6 p.

Geologic mapping in Kansas, by *R. S. Sawin*, 1996, Kansas Geological Survey, Public Information Circular 4, 5 p.

Hugoton Natural Gas Area of Kansas, by *T. Carr* and *R. S. Sawin*, 1997, Kansas Geological Survey, Public Information Circular 5, 4 p.

Sand, gravel, and crushed stone: Their production and use in Kansas, by *D. A. Grisafe*, 1997, Kansas Geological Survey, Public Information Circular 6, 4 p.

The Dakota aquifer system in Kansas, by *P. A. Macfarlane*, 1997, Kansas Geological Survey, Public Information Circular 7, 5 p.

Water-supply-suitability areas of the Dakota aquifer in Kansas, by *P. A. Macfarlane*, 1997, Kansas Geological Survey, Public Information Circular 8, 6 p.

Safe yield and sustainable development of water resources in Kansas, by *M. Sophocleous* and *R. S. Sawin*, 1997, Kansas Geological Survey, Public Information Circular 9, 6 p.

Information resources for ground-water exploration in the Dakota aquifer, by *P. A. Macfarlane*, *D. O. Whittemore*, and *J. H. Doveton*, 1998, Kansas Geological Survey, Public Information Circular 10, 6 p.

Kansas springs, by *R. C. Buchanan*, *R. S. Sawin*, and *W. Lebsack*, 1998, Kansas Geological Survey, Public Information Circular 11, 6 p.

Measuring water levels in Kansas, by *R. D. Miller*, *R. Buchanan*, and *L. Brosius*, 1999, Kansas Geological Survey, Public Information Circular 12, 4 p.

Landslides in Kansas, by *G. Ohlmacher*, 1999, Kansas Geological Survey, Public Information Circular 13, 6 p.

Nitrate in Kansas ground water, by *M. A. Townsend* and *D. P. Young*, 1999, Kansas Geological Survey, Public Information Circular 14, 4 p.

The Data Resources Library at the Kansas Geological Survey, by *Daniel R. Suchy*, 1999, Kansas Geological Survey, Public Information Circular 15, 4 p.

Kansas kimberlites, by *P. Berendsen*, *T. Weis*, and *K. Dobbs*, 2000, Kansas Geological Survey, Public Information Circular 16, 4 p.

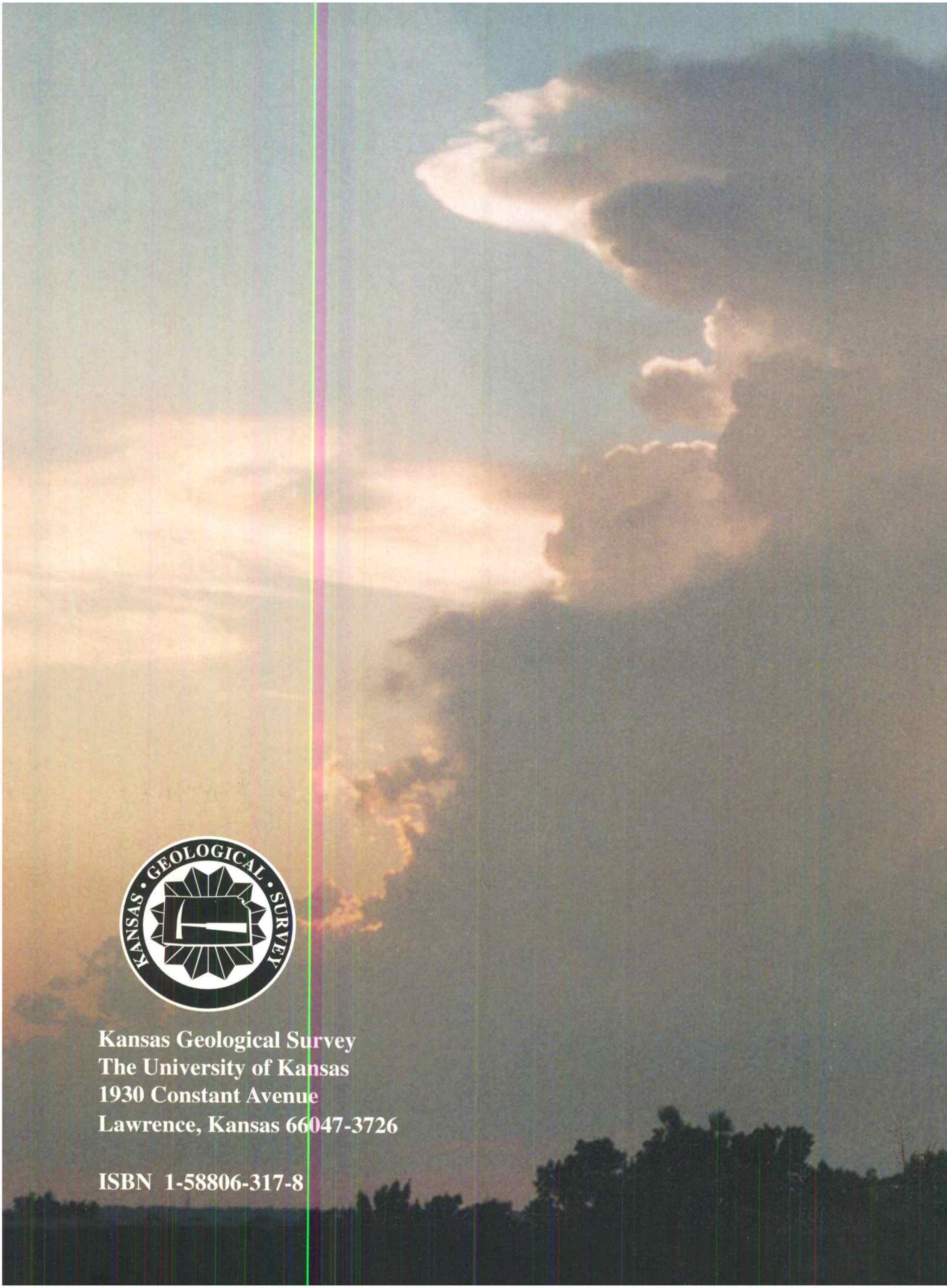
Also Available:

Roadside Kansas—A traveler's guide to its geology and landmarks, by *R. C. Buchanan* and *J. R. McCauley*, reprinted 1990, University Press of Kansas, 379 p.

Kansas geology—An introduction to landscapes, rocks, minerals, and fossils, ed. by *R. C. Buchanan*, 1984, University Press of Kansas, 212 p.

Land of the post rock, its origins, history, and people, by *G. Muilenburg* and *A. Swineford*, 1975, University Press of Kansas, 221 p.

Geologic highway map of Kansas, 1988, Western Geographics, scale 1:1,000,000 (folded only)



Kansas Geological Survey
The University of Kansas
1930 Constant Avenue
Lawrence, Kansas 66047-3726

ISBN 1-58806-317-8

Cartwright et al. A Kansan's Guide to Science Kansas Geological Survey 2000 Educational Series 15