outer portion and that of the intruder planetesimal was knocked out into space. The iron core of the interloper sank to the center of Earth, adding to the core.

The material flung out into space settled in an orbit around Earth, forming a ring much like Saturn has today. Eventually this material coalesced into our Moon.

The presence of the Moon changed our terrestrial environment forever. At the time the Moon was forming, Earth's day was only about 16 hours long. Tidal interactions with the Moon have slowed the Earth to its present 24-hour day, and it still slows at the rate of about one second per century.

The Moon also played a critical role in the development of life on Earth. Water is the single most important ingredient for Earth's life forms. Without it, life could never have gained a foothold on our planet. Life began in the oceans. The move to land came courtesy of the Moon and its influences on the Earth, specifically tides.

PRECAMBRIAN AND CAMBRIAN ACTIVITY

The Precambrian Period is the earliest geologic classification, lasting from 4.5 *bya* to 570 *mya* The oldest rocks known in Oklahoma are Precambrian granites and rhyolites formed 1.05 to 1.35 *bya*. Pre-existing rocks, into which these granites were injected, have been destroyed by erosion, metamorphism, or complete melting in magma, although remnants deep underground may exist in some unexplored areas. In a later episode of igneous activity, during the early and middle parts of the Cambrian Period, a different group of thick granites, rhyolites, gabbros, and basalts formed in southwestern and south-central Oklahoma.

Precambrian and Cambrian igneous rocks underlie all of the State and are the floor or "basement" upon which younger rocks rest. The top of the "basement rock" is about 1,000 feet below the Earth's surface in the Ozark uplift of the northeast and plunges to greater depths to the south and southwest toward the great basins of southern Oklahoma, where it is locally 30,000 to 40,000 feet underground. Adjacent to the basins, "basement' rocks have been uplifted above sea level in two major fault blocks, and are exposed now in the Wichita and Arbuckle mountain ranges.

In rocks formed during the Precambrian Period, fossils are few. Life consisted of simple one-celled animals and low-order plants.

Paleozoic Era

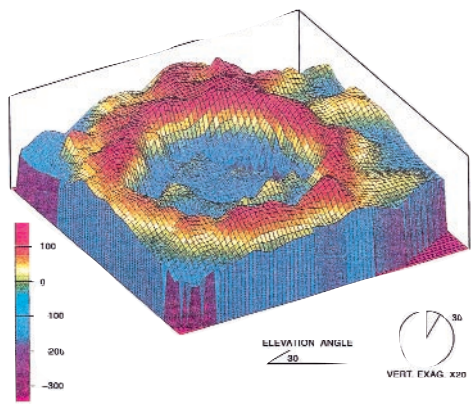
The Paleozoic Era (570,000,000 to 250,000,000 years ago) is characterized by the development of the first fishes, amphibians, reptiles, and land plants.

LATE CAMBRIAN AND ORDOVICIAN PERIODS

The Cambrian Period, the first of the Paleozoic Era, is marked by a profusion of marine animals, especially trilobites and brachiopods. This time period is approximately 500 to 570 *mya*.

The Ordovician Period is the second period of the Paleozoic Era, characterized by an abundance of invertebrate life of many different kinds. The time range is approximately 425 to 500 *mya*.

Following a brief period when the newly formed Cambrian igneous rocks and the ancient Precambrian rocks were partly eroded, Oklahoma lay below sea level, and shallow seas covered all of the State during various parts of the Paleozoic Era. The first sea invasion was in the Late Cambrian and moved across the state from the east or southeast. Sands eroded from the weathered "basement-rock" surface were deposited only in the southeastern half of Oklahoma, whereas the thick overlying formations of Late Cam-



Ames Structure — Evidence of a powerful asteroid impact, now found 9,000 feet below the surface, is illustrated in this 3-D model.

brian and Ordovician age extend over the entire State. The thickness of these sediments increases southward from about 2,000 feet in northern areas to 10,000 feet in the Anadarko basin, Ardmore basin, and Arbuckle Mountains region. Into these seas were brought thick deposits of sand, clay, and lime mud; these deposits were later consolidated into sandstone, shale, and limestone having a total thickness of almost 8 miles.

Impacts by large asteroids or comets are a geologic fact of life in our solar system. Our Moon, as does Mercury and many other moons and planets in the solar system, attest to the scarring caused by such impacts. One site is buried deep below surface strata near Ames, in northwestern Oklahoma. The impact occurred 470 mya, in the Ordovician Period. The Ames astrobleme structure is 6 to 10 miles across, is buried by 9,000 feet of younger sedimentary units, and is a prolific source of oil and gas. It has a nearly circular shape, a distinct outer rim, and it is apparent that approximately 2,000 feet of Cambrian-Ordovician carbonate and some basement rock was excavated by the explosion.

Cambrian life forms in Oklahoma include trilobites and abundant plant life in the ocean. In the Ordovician Period, graptolites and corals were present, and algae grew in the ocean. Animals such as brachiopods and trilobites lived in the sea water, and their shells or imprints are preserved as fossils in the consolidated rocks.

SILURIAN AND DEVONIAN PERIODS

The Silurian Period is characterized in some regions by extensive coral reefs and many invertebrate marine animals. This period is estimated at 405 to 425 *mya*. During the Silurian Period fishes appeared, along with some land plants. During the Devonian Period, an abundance of fishes was present, along with the appearance of the first authentic land plants and amphibians. Scale trees also developed during this period. Fossil wood is found in Devonian and younger formations in Oklahoma. These fossils are often so well preserved that it is possible to determine the species of trees based on the arrangement and form of the cells.

Except for the Ouachita basin, Silurian and Devonian sediments in Oklahoma consist of limestone and dolomite overlain by shale. The limestone is commonly 100 to 500 feet thick and has been eroded from the northern areas. Following widespread uplift and erosion, the Late Devonian to Early Mississippian shale was deposited in essentially the same areas as the limestone.

The oldest fossil tree in Oklahoma is Callixylon, from the Woodford formation of Late Denonian age. It is at least 350 million years old, and representative of the first forest trees of the world. Picture taken at the entrance to East Central State College, Ada.

MISSISSIPPIAN PERIOD

The Mississippian Period is the first coal-forming period of the Paleozoic Era in North America, lasting from approximately 330 to 365 *mya*. During the first half of the Mississippian Period, shallow seas covered all of Oklahoma. Limestone and interbedded chert were the dominant sediments in most areas.

Early Mississippian limestones are the youngest, the last of the thick carbonate sequences that attest to early and middle Paleozoic crustal stability in Oklahoma. In the last half of the Mississippian Period, shale and sandstone were the dominant sediments, with major sites of deposition being rapidly subsiding basins in southern Oklahoma.

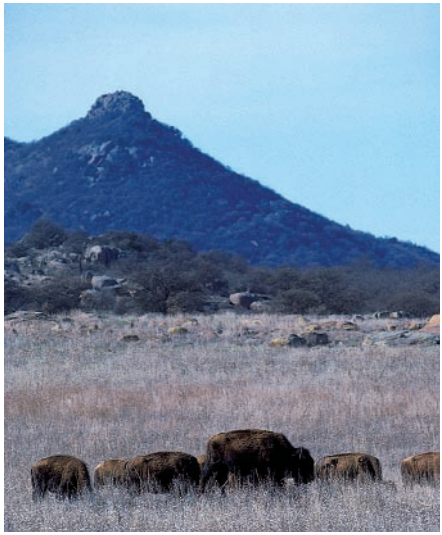
Fishes, amphibians, and crinoids characterize the Mississippian Period, as do scale trees and ferns.

PENNSYLVANIAN PERIOD

The Pennsylvanian Period is the time period from 290 to 330 *mya*, and was a time of important crustal unrest in Oklahoma; a time of both orogeny (the process of uplifting and forming mountain ranges by

folding, faulting, and thrusting) and basinal subsidence (downwarping, or sinking, in the major sedimentary basins) in different parts of the south, and of gentle raising and lowering of broad areas in the north. Rocks deposited earlier in the Wichita, Arbuckle, and Ouachita mountain areas were deformed and thrust up into major mountains, while nearby basins subsided more rapidly and received the greatly increased sediment load eroded from nearby highlands.

Pennsylvanian rocks are dominantly marine shale, but beds of sandstone, limestone, conglomerate, and coal are also present. They are commonly 2,000 to 5,000 feet thick, but are as much as 16,000 feet thick in the Anadarko basin, 15,000 feet in the Ardmore basin, 13,000 feet in the Marietta basin, and 18,000 feet in the Arkoma basin. This is the major period when most of the mountains in Oklahoma were formed, along with the formation of vast coal resources.



Wichita Mountains — Buffalo grazing in the wildlife refuge near Lawton. Photo by Fred W. Marvel.

PERMIAN PERIOD

The Permian Period, the seventh and last period of the Paleozoic Era, is characterized in Oklahoma by increased reptile life, diminished mountain building, deposition of a great thickness of red-colored rocks (red beds), and major deposition of gypsum and rock salt. This period lasted from 250 to 290 *mya*.

Following the Pennsylvanian Period of mountain building, an Early Permian, shallow inland sea covered western Oklahoma, extending northward from western Texas to Nebraska and the Dakotas. The climate was warm and dry, and thick units of gypsum and salt were deposited from evaporating sea water. The Ouachitas, Arbuckles, and Ozarks were still fairly high in the eastern half of the state, and along with the Wichitas they supplied sand and mud to the Anadarko basin and northern areas of western Oklahoma.

The red color so common in Permian-age rocks of Oklahoma results from a stain of red iron oxides deposited with the sand and mud. By Late Permian time the Wichitas were covered with sediment and the mountains of the east were largely worn down. The Permian red sandstones are deeply eroded to form canyonlands in much of western Oklahoma. Thickness of the entire Permian sequence is generally 1,000 to 5,000 feet, but it reaches as much as 7,000 feet in parts of the Anadarko basin.

Mesozoic Era

250,000,000 to 65,000,000 years ago, during which the development and extinction of dinosaurs, the appearance of mammals, flowering plants, grasses, and birds occurred.

TRIASSIC AND JURASSIC PERIODS

The Triassic Period, the first period of the Mesozoic Era, is characterized by the appearance of many reptiles, the dinosaurs, the dominance of cycads and ferns, and the first appearance of mammals. The Triassic Period lasted from 200 to 250 *mya*.

The Jurassic Period is characterized by the dominance of the dinosaurs and the appearance of flying reptiles and birds. This period occurred from 140 to 200 *mya*.

Most of Oklahoma was apparently above sea level during the Triassic and Jurassic periods. Sandstones and shales in the Panhandle and adjacent areas were deposited mainly in rivers and lakes draining the hills of central Colorado, although some of the sand and mud must have come from lowlands of central and western Oklahoma, where the recently deposited Permian sediments cropped out. Triassic and Jurassic strata of the Panhandle are chiefly red and gray in color, and their thickness is typically 200 to 600 feet. The Ouachitas in

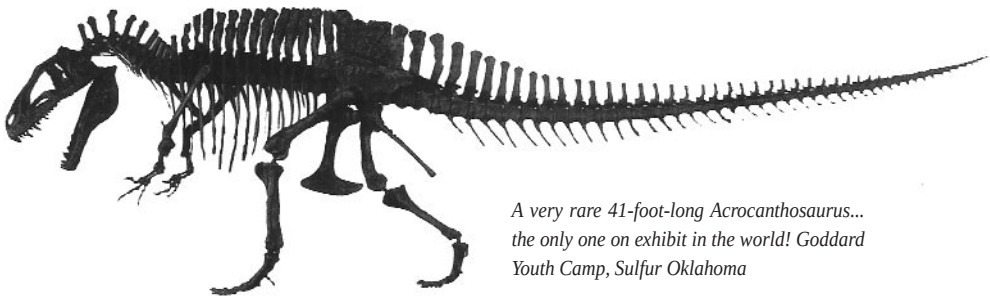
the southeast were probably an area of low mountains and hills. Sands eroded from the Ouachitas were carried to the early Gulf of Mexico, which nearly reached into Oklahoma during the Jurassic Period.

CRETACEOUS PERIOD

The Cretaceous Period, the third and last geologic period of the Mesozoic Era, is marked by the dying out of toothed birds, ammonites, and dinosaurs. It is also the time of expanded development of small mammals, the first appearance of flowering plants, and the deposition of chalk beds in shallow seas in many parts of the world. This period was approximately 65 to 140 *mya*.

Cretaceous seas covered all but northeastern and eastern Oklahoma. The ancestor of the Gulf of Mexico extended up to and across the southern part of the state, and shallow seas spread northward in the last great inundation of Oklahoma and the western interior of the United States. Shale, sandstone, and limestone are generally 450 feet thick in the Panhandle, and as much as 2,000 to 3,000 feet thick in the Gulf Coastal Plain of the southeast. A major unconformity is well exposed throughout the southeast where Cretaceous strata rest on rocks ranging in age from Precambrian through Permian. Formation of the Rocky Mountains by orogeny in Late Cretaceous and Early Tertiary time began an eastward tilt to the entire state and caused withdrawal of the sea.

During the early Cretaceous Period, between 140 and 100 *mya*, an enormous meat-eating dinosaur called *Acrocanthosaurus atokensis* roamed coastal areas in what is now southeastern Oklahoma. Found in 1940 in the Antlers Formation of Atoka County, *Acrocanthosaurus* was one of the largest carnivores that lived during the Cretaceous Period. The largest known *Acrocanthosaurus* fossil is an individual that was 18 feet tall and 43 feet from head to tail. *Acrocanthosaurus* belonged to the Carnosauria, a group of meat-eating dinosaurs with large bodies and extremely large heads, and may have preyed mainly upon a plant-eating dinosaur called *Tenontosaurus*, whose fossil remains have been found in the same area and geological formations in southeastern Oklahoma. *Acrocanthosaurus* specimens have been found in Atoka and McCurtain counties.



A very rare 41-foot-long Acrocanthosaurus... the only one on exhibit in the world! Goddard Youth Camp, Sulfur Oklahoma

Toward the end of the Early Cretaceous Period, the Gulf of Mexico began extending farther northward, and what is now the Arctic Ocean began to extend southward, spreading into the western interior of North America. These two bodies of water eventually joined, forming a shallow interior seaway that covered much of central North America, including most of Oklahoma. The seaway did not begin to recede until the last part of the Cretaceous Period, about 65 *mya*. Numerous pelecypods and oysters are found in Cretaceous limestones of Oklahoma.

Sixty-five *mya*, another asteroid impact may have paved the way for humans to become the dominate life force on Earth. The event occurred during the late Cretaceous period. Triceratops and hadrosaurs foraged in the field. Diplodicus and camerasaurus grazed from the tree tops. All gazed a wary eye at the menacing tyrannosaurus rex. Pteronodons soared gracefully through the air, avoiding the snapping jaws of mososaurs and pliesiosaurs swimming in the shallow oceans near the shore.

It was perhaps a peaceful, sunny afternoon, when suddenly, a deep roar pierced the air. The startled dinosaurs and other creatures would have surely seen a giant asteroid, six miles wide, screaming across the sky. In mere seconds it zoomed down and slammed into the ocean just offshore of what we today call the Yucatan Peninsula in the Gulf of Mexico.

The asteroid hit with the equivalent of millions of megatons of explosive energy. A fraction of a second after impact, the asteroid and hundreds of times as much material from Earth was vaporized, blasting molten rock and super-heated steam high into the stratosphere. A mammoth mushroom cloud ballooned from the explosion.

A shock wave from the blast traveled away from the impact at 1,100 miles per hour, shattering trees and ripping apart the giant dinosaurs and other creatures within a hundred miles of impact. A few minutes later, a tidal wave of unimagined proportions would have slammed onto the shore, carrying a crushing wall of water miles inland.

The molten rock, carried high into the atmosphere from the impact created a fiery inferno all over the planet, instantly frying any living thing it touched, and starting world-wide fires.

The searing heat continued for several days. Meanwhile, the dark mushroom cloud enveloped Earth, cutting off sunlight. It is believed the entire Earth was thrown into artificial night for two years. With no sunlight reaching the ground, temperatures plummeted, and a temporary ice age gripped the world. Seventy-five percent of the life on Earth, plants and animals including dinosaurs, died out at this time, perhaps due to the ruthless aftermath of the asteroid impact.

Cenozoic Era

Following the Mesozoic, the Cenozoic Era began about 65,000,000 years ago and extends up to the present. It is characterized by the development of many varieties of mammals.

TERTIARY PERIOD

The Tertiary Period comprises the Paleocene, Eocene, Oligocene, Miocene, and Pliocene epochs; it lasted from 65 to 1.65 *mya*. The Paleocene Epoch is the earliest of the Tertiary Period. It lasted from 55 to 65 *mya*. The Eocene Epoch is the time during which mammals became the dominant animals. This epoch occurred 40 to 55 *mya*. Next was the Oligocene Epoch, from 25 to 40 *mya*, followed by the Miocene Epoch, lasting from 10 to 25 *mya*. The Miocene Epoch is marked by the evolution of many mammals of relatively modern form. Finally, the Pliocene Epoch, from 1.65 to 10 *mya*, was the time during which many modern plants and animals developed.

The state's pattern of east-flowing drainage developed in the Tertiary Period. The precursor of the Gulf of Mexico extended almost to the southeast corner of Oklahoma in Early Tertiary time, and the shoreline gradually retreated southward through the remainder of the period. Sediments to the southeast include marine and nonmarine sand, gravel, and clay. In Late Tertiary time, a thick blanket of sand, clay, and gravel eroded from the Rocky Mountains was laid down across the High Plains and father east by a system of coalescing major rivers and lakes. These deposits are generally 200 to 600 feet thick in western Oklahoma, and originally may have extended across central Oklahoma.

QUATERNARY PERIOD

The Quaternary Period comprises the Pleistocene and Holocene epochs and lasted from 1.65 *mya* to present time. The Pleistocene Epoch is characterized by the spreading and recession of continental ice sheets and by the appearance of modern humans. This epoch lasted from 10,000 to 1.65 *mya*. The Holocene Epoch is the present epoch, beginning about 10,000 *ya*.

Major drainage systems of today were initiated during the Pleistocene. The Quaternary Period is characterized as a time of erosion. Rocks and loose sediment at the surface were being weathered to soil, and the

The earliest people in North America, Paleoindians, entered what is now Oklahoma toward the end of the Pleistocene Epoch. At that time, Columbian mammoths already had lived in the area for thousands of years.