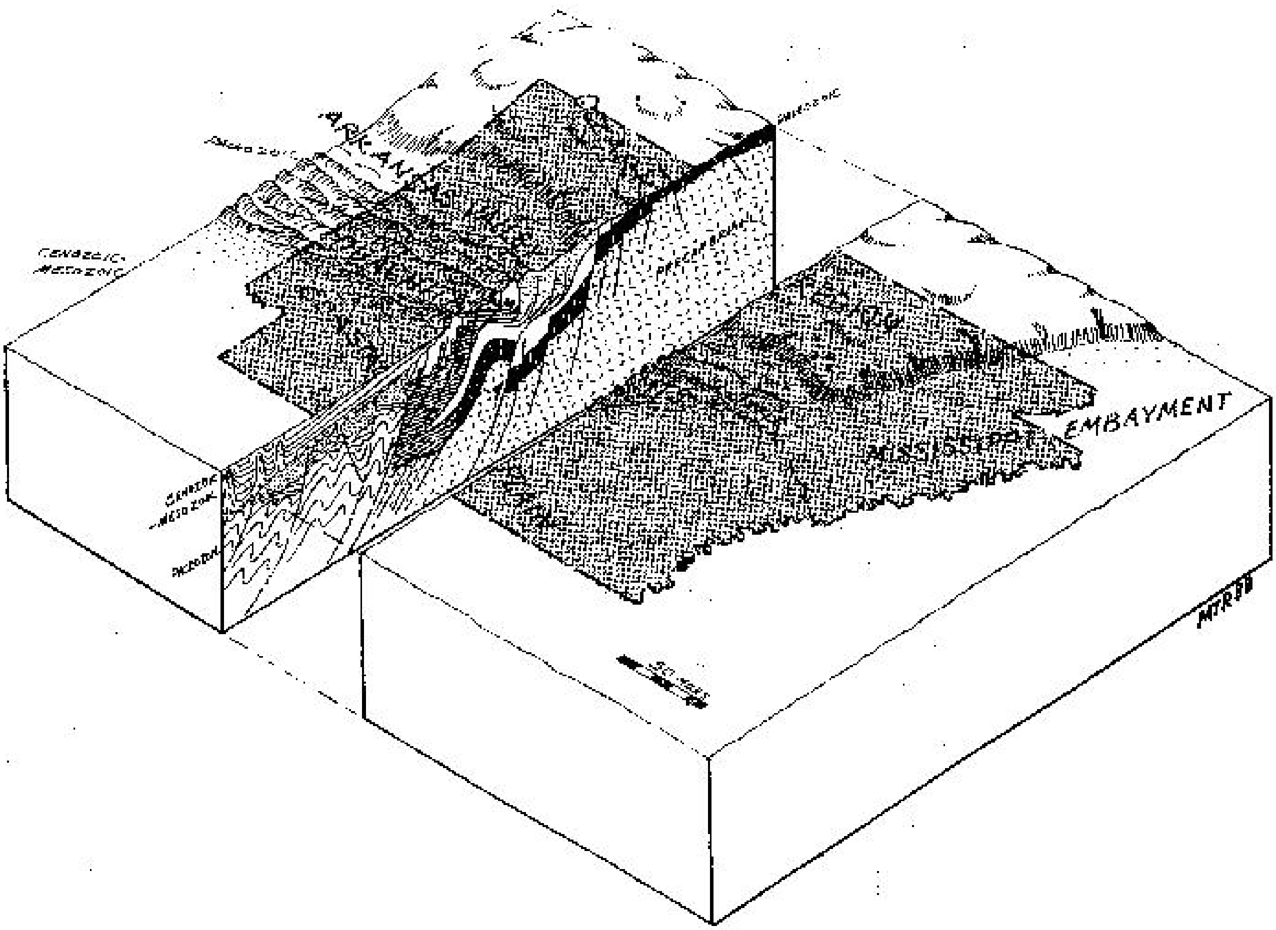

Geologic History of Arkansas Through Time and Space

Written by
M. J. Guccione

Illustrated by
M. T. Roberts
Pauline R. Denham

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Fayetteville, AR 72701
(501) 575-4301

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GEOLOGIC HISTORY OF ARKANSAS

INTRODUCTION

The purpose of this book is to present the geologic history of Arkansas beginning with the oldest record present in the state and ending with today. Knowing several concepts will help you study this history. The first is geologic time. Just as in human history, geologic history is subdivided into intervals of time. These intervals of time are bounded by dates, but they are millions of years long rather than the decades or hundreds of years long as in human history. For convenience these geologic intervals have been given names, just as human history utilizes convenient names such as the World War I Era, the Depression, the World War II Era, etc. The names of these geologic intervals are included in the Geologic Time Scale, which is utilized in this book (Table 1). Geologic history is continuous, but sometimes there is no record of the history in an area. This is called an **unconformity** and may be the result of no rocks being deposited during that time or later **erosion** of those rocks (Fig. 1). Human history is

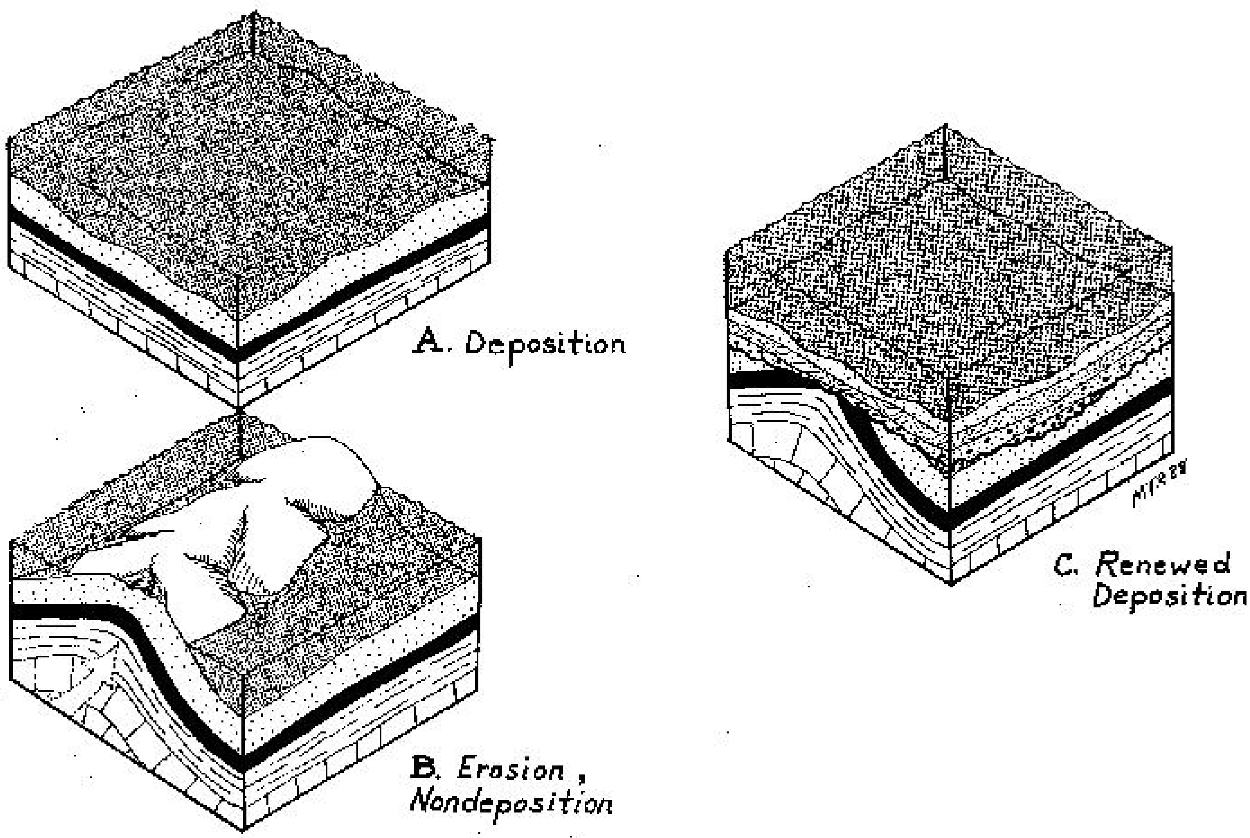


Figure 1.
Formation of an unconformity

ERA	PERIOD	EPOCH	MYBP
Cenozoic	Quaternary	Holocene	0.01
		Pleistocene	1.65
	Tertiary		66
Mesozoic	Cretaceous		144
	Jurassic		208
	Triassic		245
Paleozoic	Permian		286
	Pennsylvanian		320
	Mississippian		360
	Devonian		408
	Silurian		438
	Ordovician		505
	Cambrian		570
Precambrian			

Table1.
Geologic time scale, in millions of years before present (MYBP)

similar. There may be no written record of an interval of time in a area or country because the people did not know how to write or because all the written records were destroyed by a war, flood, or fire (for example, the destruction of the library in Alexandria, Egypt in 47 B.C.).

The second concept to remember when studying the history of Arkansas is geography. The geography that you learned in school is the geography today, including where the various oceans and continents are. The history of Arkansas is 1.4 billion years long. During that great length of time the geography of the world has changed many times because of **plate tectonics**. The continents and oceans were not in the same positions that they are today (Fig. 2). As you study the history of Arkansas, you must be aware of the geography during the time period that you are studying. This is called the **paleogeography**. To help you visualize this, paleogeographic maps for different time intervals are provided. They will show you where the seas, land, shorelines, and mountains were for that geologic period. Make sure that you examine these maps as you study the history for that period so that you understand what is happening in Arkansas and the surrounding area.

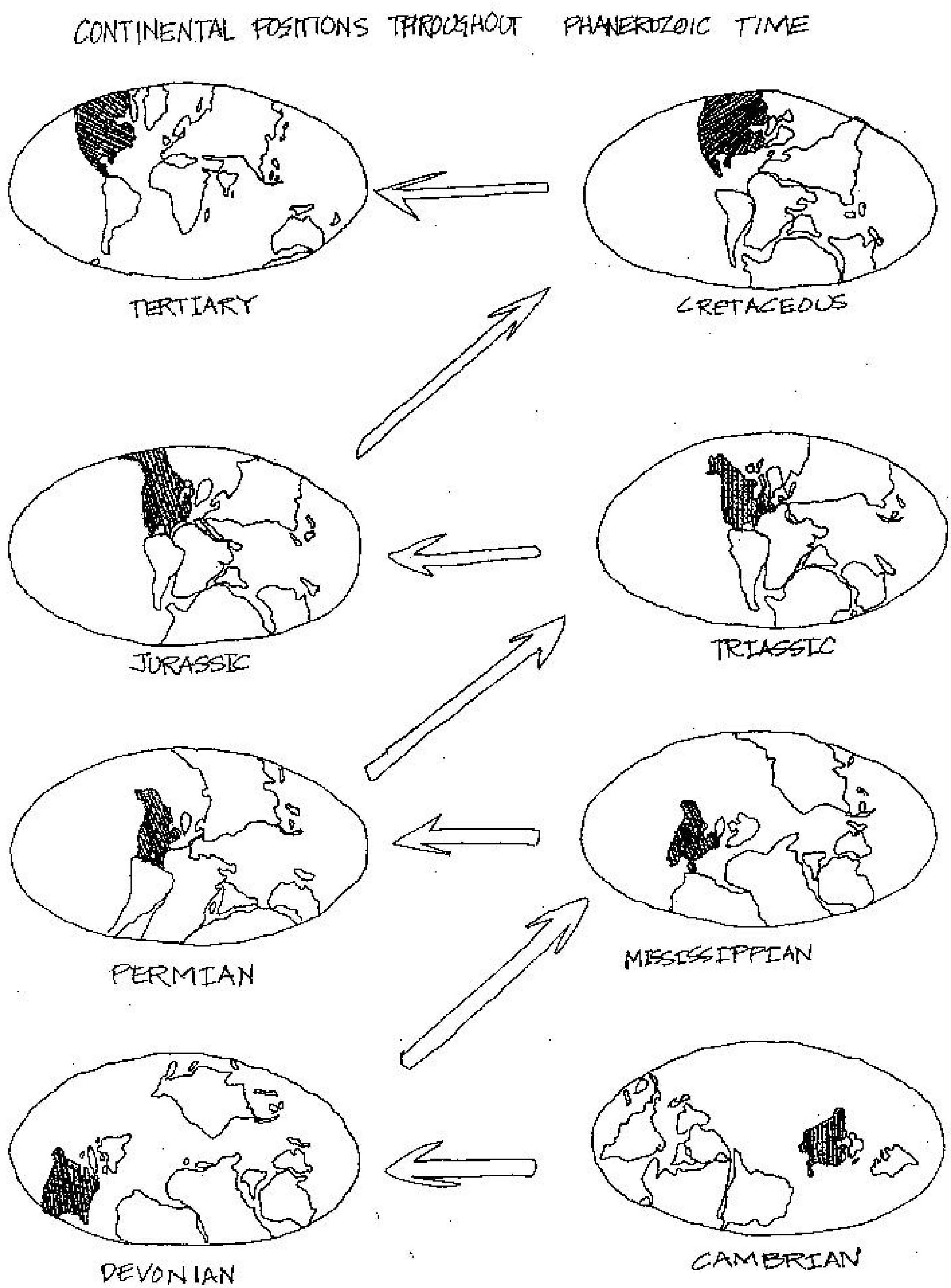


Figure 2.
Paleogeography of the world from the Paleozoic to the present

PRECAMBRIAN ERA
(4700 to 570 MYBP)

The **Precambrian Era** is the oldest, longest, and most poorly known subdivision of the earth's history (Fig. 3). It began with the formation of the earth, approximately 4700 million years before present (MYBP). It ended with the appearance of animals which are easily preserved as **fossils** because they have hard shells or skeletons, approximately 0.57 billion years ago or 570 **MYBP**. Because fossils are almost completely absent in Precambrian rocks, these rocks are difficult and expensive to date. This is the reason that the Precambrian Era is difficult to subdivide and is 4.1 billion years long.

Though we do not understand many of the details, the Precambrian Era was a period of time when vast changes were occurring on earth. The **lithosphere**, or solid portion of the earth, was becoming segregated. The denser materials sank into the center of the earth and the less dense materials became concentrated at the surface of the earth. Rocks of this age at the surface of the earth today are commonly **igneous** and **metamorphic**. The **hydrosphere**, or liquid portion of the earth, was developing as abundant **volcanos** erupted water vapor into the **atmosphere** that condensed to form precipitation and collected to become the earth's oceans, streams, and groundwater. The atmosphere, or gaseous portion of the earth, was altered from a mixture of very light and toxic gasses to **nitrogen**, **oxygen**, **carbon dioxide**, and water vapor that are present in our atmosphere today. The **biosphere**, or organic portion of the earth, developed and subsequently evolved from simple, single-celled organisms to much more complex forms. Prior to 570 million years (the end of the Precambrian Era) these forms were softbodied and therefore are rarely preserved as fossils in Precambrian rocks.

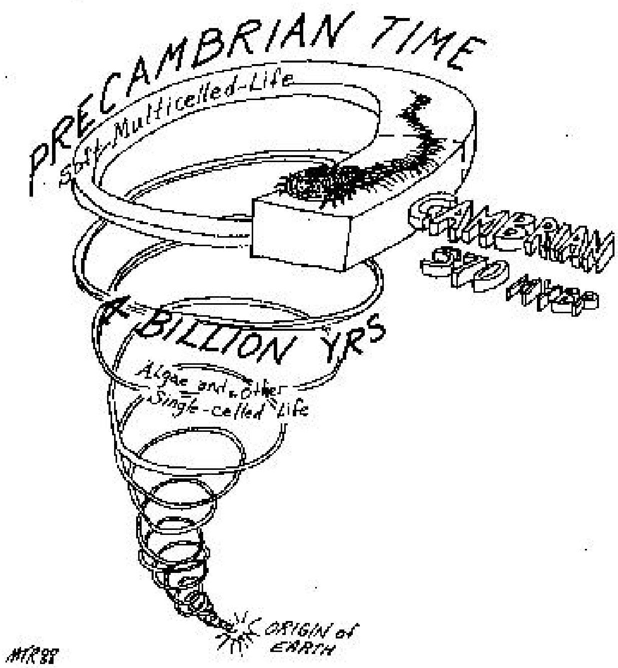


Figure 3.
Precambrian time

During the later part of the Precambrian Era, approximately 1.3 to 1.4 billion years ago, large **volcanos** were present in the northern part of Arkansas and southern Missouri (Fig. 4). These volcanos were quite explosive and erupted large quantities of igneous **volcanic ash** that included **volcanic glass** and pieces of **rhyolite**. Some of these volcanos were so explosive that very large cones, or **calderas**, formed as the crest of the volcanos collapsed into an underground cavity formed by the volcanic eruption. Not all of the **magma** was erupted from the volcano. Some cooled beneath the volcano to form the igneous rock, **granite**. None of this rhyolite ash or granite is exposed at the earth's surface in Arkansas because it is buried by younger **sedimentary rocks (Law of Superposition)**, but it is found in rock cores from deep wells drilled in northern Arkansas. However, Precambrian igneous rocks are present at the earth's surface in local areas of Missouri and Oklahoma.

After the **intrusion** of magma and eruption of the volcanos in Missouri, Oklahoma, and northern Arkansas, the entire area was above sea level for the next 0.6 billion (600 million) years until the end of the Precambrian. While land is above sea level it is generally **weathered** and **eroded** with no rocks being deposited. After it is buried by younger rocks, this erosion surface is termed an unconformity (Fig. 1). In Arkansas and most of the central part of North America there are no rocks which were deposited between 570 million years and 1.3 billion years ago. During this time the continent was above sea level like it is today, but it was not to stay that way!

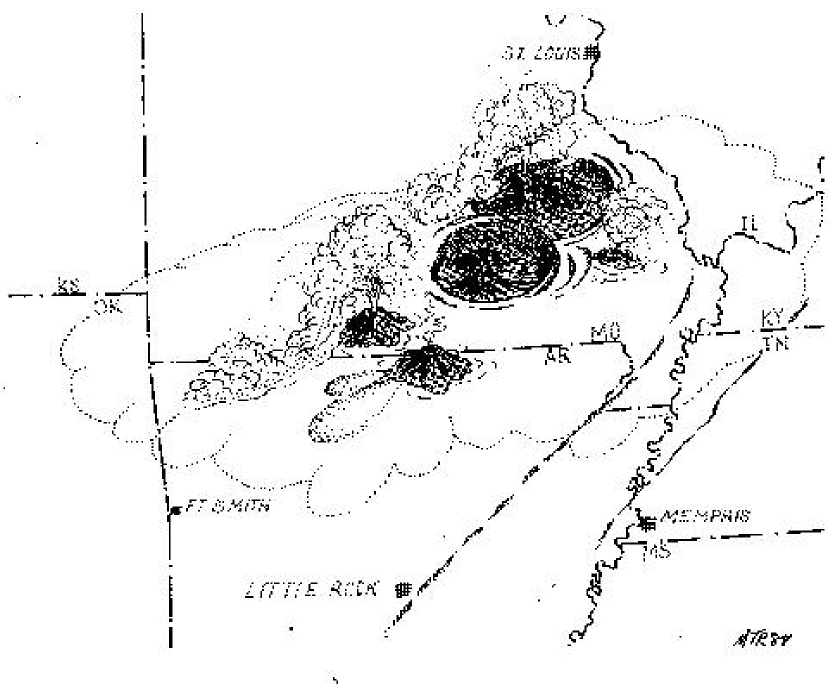


Figure 4.
Precambrian volcanoes in the vicinity of Arkansas

PALEOZOIC ERA
(570 to 245 MYBP)

In the continuation of the earth's history, the next major subdivision of time is the **Paleozoic Era**, when ancient life existed. It begins with the rapid **evolution** of animals that are easily fossilized because they have hard parts or skeletons, approximately 570 million years ago. It ends with the **extinction** of more than half of all types of animals living on the earth, approximately 245 million years ago. Throughout the Paleozoic Era plants and **invertebrate** animals that lived in the sea were common (Fig. 5). **Vertebrate** animals, including fish, **amphibians**, and **reptiles**, evolved during the Paleozoic Era. Plants also began to grow on the land during this era (Fig. 6).

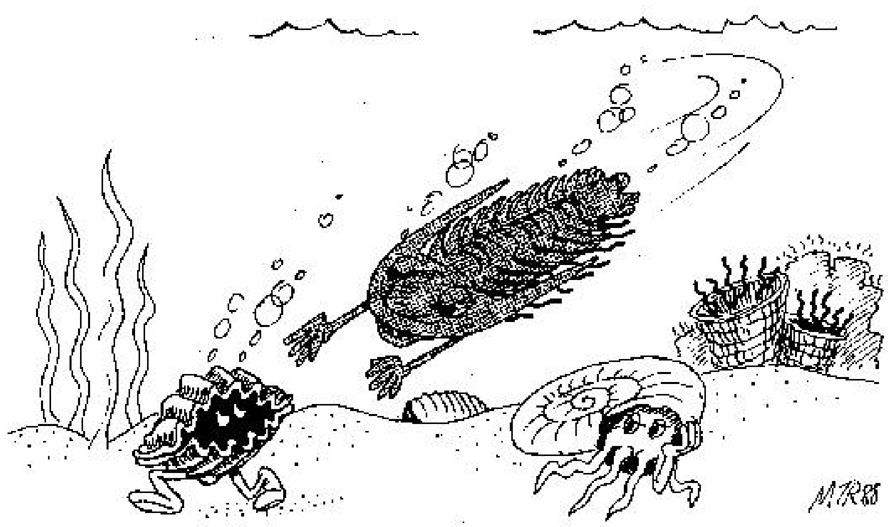


Figure 5.
Paleozoic marine life

Figure 6.
A Pennsylvanian swamp

The appearance of the great variety of plants and animals in the beginning of the Paleozoic Era may be related to plate tectonics and the paleogeography of the world during this era. In the beginning of the Paleozoic Era the continents were drifting apart. **Laurentia**, the land mass that is now North America and Greenland, began to split apart from **Baltica**, the land mass that is now Europe (Fig. 7). **Gondwana**, the land mass that is now South America, Africa, Australia, and Antarctica also began to split apart from Laurentia. **Iapetus**, the ocean that emerged between these continents as they split apart, began to form by **sea-floor spreading** and there were large areas of warm shallow seas in which many marine invertebrate and vertebrate animals could live.

The crises that caused the extinction of so many of these animals at the end of the Paleozoic Era may also be the result of plate tectonics and the paleogeography of the world at that time. By the end of the Paleozoic Era, the continents were colliding into one another to become one large land mass, Gondwana, near the equator. This position may have caused many deserts to form and the extinction of many land animals in the dry climate. The abundance of shallow seas was also reduced at the end of the Paleozoic Era and this may have caused the extinction of many marine organisms.

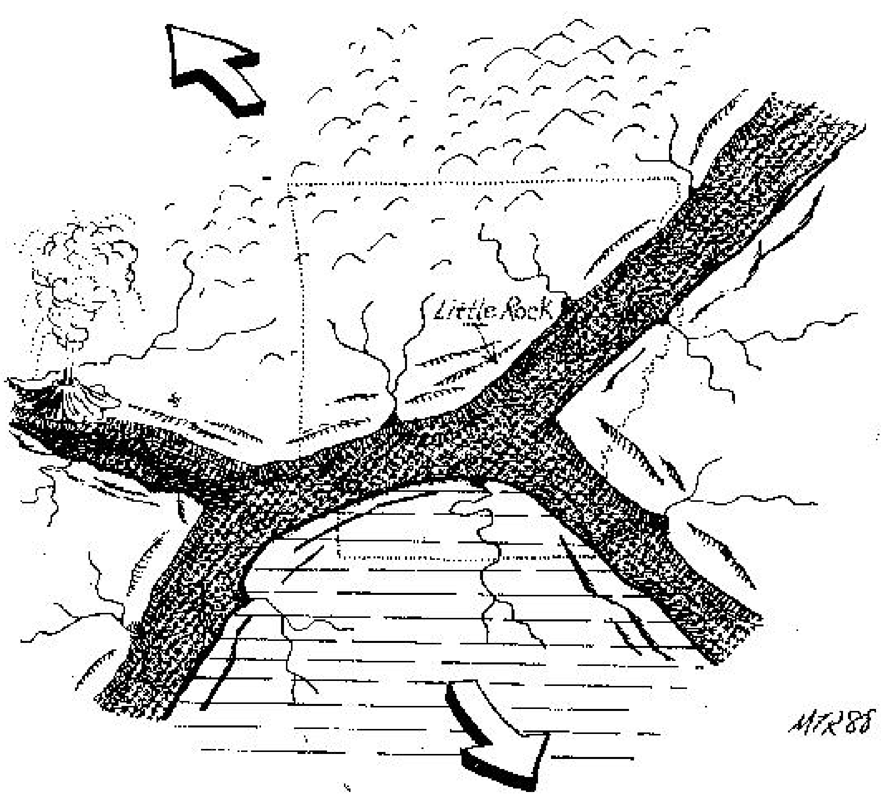


Figure 7.
Late Precambrian to early Cambrian rifting of Arkansas

During a large part of the 285 million years of the Paleozoic Era much of the continent known as Laurentia was covered by the very warm, shallow seas, less than 200 meters deep. This included the northern part of Arkansas (Fig. 8). Sometimes northern Arkansas would emerge above sea level to be weathered and eroded. Later sea level would rise again to cover the land. Marine **sediments** would be deposited over these erosion surfaces to form numerous unconformities in the Paleozoic rocks of the **Ozark Plateaus Region** in northern Arkansas (Fig. 1). To the north in Missouri, the area of Precambrian volcanos was higher in elevation than in northern Arkansas and was above sea level as an island or islands during much of this time.

In contrast, the central and southern portion of Arkansas in the **Ouachita Mountain Region** was part of the deep ocean basin that separated Laurentia and Gondwana (Fig. 8). At the **continental slope** of Laurentia, approximately where the **Arkansas River Valley Region**, Fort Smith, Russellville, and Little Rock are today, there was a rapid dropoff from the shallow **continental shelf** of the Ozark region to abyssal depths of the Ouachita Mountain region. This area was covered by water hundreds to thousands of meters deep and was continuously below sea level. Sedimentary rocks were deposited very slowly, but continuously, throughout the early and middle Paleozoic Era. No unconformities are present between the Paleozoic rocks of central Arkansas.

It is presumed that the deep ocean basin extended to the south for some distance in the area of the **Gulf Coastal Plain Region** but we do not know how far south. Paleozoic rocks that may have been deposited at the bottom of the ocean are so deeply buried by younger rocks that no wells have been drilled deep enough to intersect them. Therefore, we do not know for sure that they even exist.

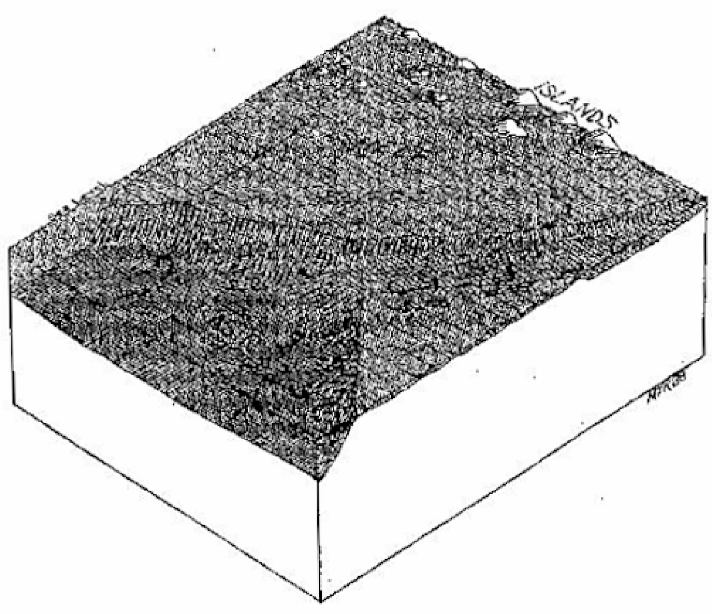


Figure 8.
Early Paleozoic paleogeography of Arkansas

Cambrian Period

(570 to 505 MYBP)

Paleozoic-age rocks contain many fossils, and the Paleozoic Era can easily be subdivided into divisions called periods. The oldest Paleozoic period is the **Cambrian.**

Sedimentary rocks deposited during the Cambrian Period are present in Arkansas. In the area that is near the **Mississippi River Alluvial Valley Region**, including northeast Arkansas, a trench began to form as Laurentia split apart from Gandwana (Fig. 7). Though the trench was deep, it was still above sea level. **Sand**, eroded from higher elevations in northern Arkansas and southern Missouri filled in the trench with **sandstone** deposited by rivers as **alluvial fans**. There are no fossils in these rocks because no plants or animals lived on land yet. These Cambrian rocks have been buried by younger rocks in the Mississippi Alluvial Valley of northeast Arkansas and are not exposed at the earth's surface. We know that they exist because cores of rock have been obtained from wells drilled in the area. By the late Cambrian time the Ozark area in northern Arkansas had been eroded to a very low plain, the trench was filled, and the whole area was slightly below sea level (Figs. 8 and 9). **Carbonate** sedimentary rocks were deposited in the warm, shallow sea. Invertebrate fossils are common in these rocks.

To the south the ocean became deeper and the **shale** and **limestone** that were deposited in this deep, marine water are now exposed in the Ouachita Mountains of central Arkansas.

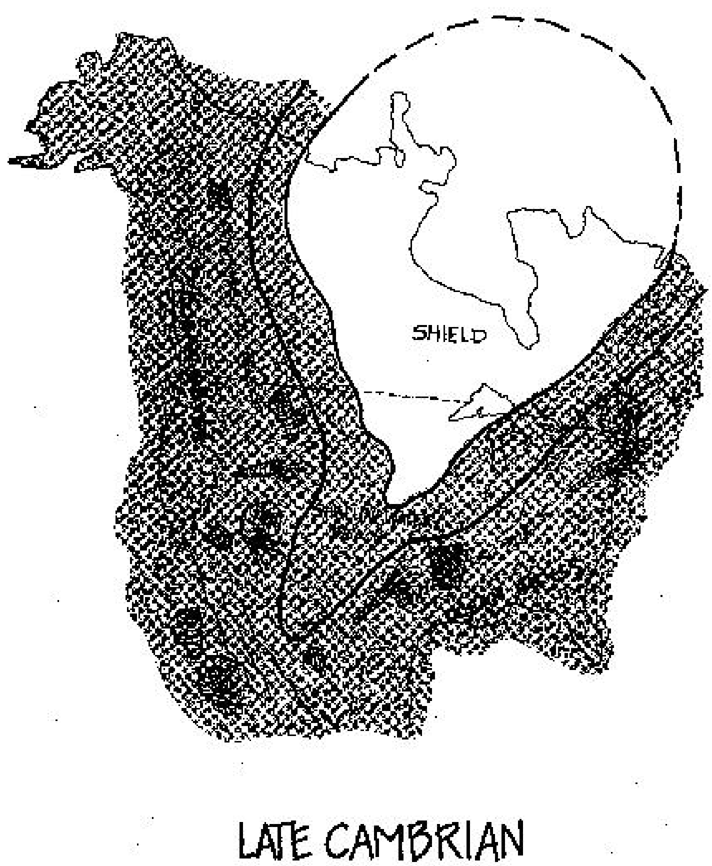
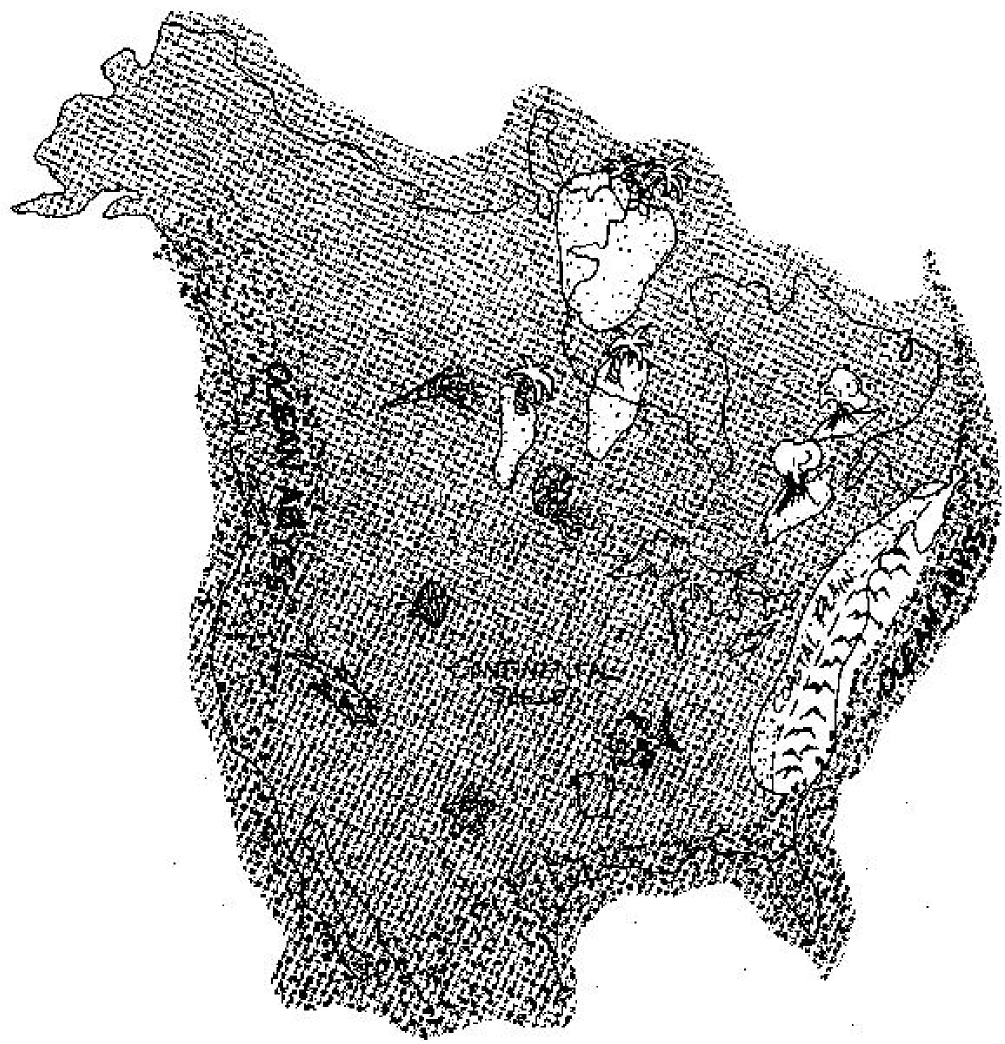


Figure 9.
Late Cambrian paleogeography of North America

Ordovician Period (505 to 438 MYBP)

During the Ordovician Period, the paleogeography of Laurentia was similar to that of the Cambrian Period. Sea level was a little higher and even more of the continent was covered by shallow seas than earlier (Fig. 10). Some volcanic islands developed along a subduction zone next to what is now eastern Canada and the United States as the Iapetus Ocean began to narrow.



LATE ORDOVICIAN

Figure 10.
Late Ordocician paleogeography of North America

Neither of these changes in the paleogeography of North America had much effect on Arkansas. In the Ozark region sandstone was deposited when nearby areas above sea level were being eroded and provided sediment to be deposited in the ocean. Some of this sandstone is nearly pure **quartz** and is mined to make glass. When sea level was high and no land was present, **carbonate rocks** were deposited in a warm and very shallow sea, just as they had been during the Cambrian Period. However, there was one major difference between the Cambrian and the Ordovician seas. There were many invertebrate animals in the Cambrian sea but there were no vertebrates. In the Ordovician seas both invertebrate and vertebrate animals were present because fish evolved during this period.

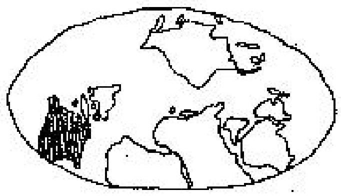
Ordovician-age rocks are very similar to those deposited during the late Cambrian Period and are very common in the Ozarks of northern Arkansas. **Galena** and **sphalerite minerals** have replaced some of the rock and have precipitated in cavities as solutions containing **lead**, **zinc**, and **sulfur** moved through fractures in Ordovician carbonates and sandstones. These minerals are sources of lead (galena) and zinc (sphalerite) and have been mined in the northern part of the state. **Manganese** has locally replaced some of the carbonate rock around Batesville and was mined for use in the steel industry.

To the south, shale and sandstone were deposited in the deep water of the ocean basin. These rocks are very common in the Ouachita region of central Arkansas.

Silurian Period (438 to 408 MYBP)

The **Silurian Period** continued like the late Cambrian and the Ordovician. The Iapetus Ocean continued to shrink as the continents of Laurentia and Baltica moved toward each other. A warm, very shallow sea covered the Ozark region of northern Arkansas and deposited carbonate sedimentary rocks.

To the south, in central Arkansas, shale and sandstone continued to be deposited in deep ocean water. Though all of Arkansas was below sea level, areas that were above sea level in other parts of the world were covered with land plants for the first time.



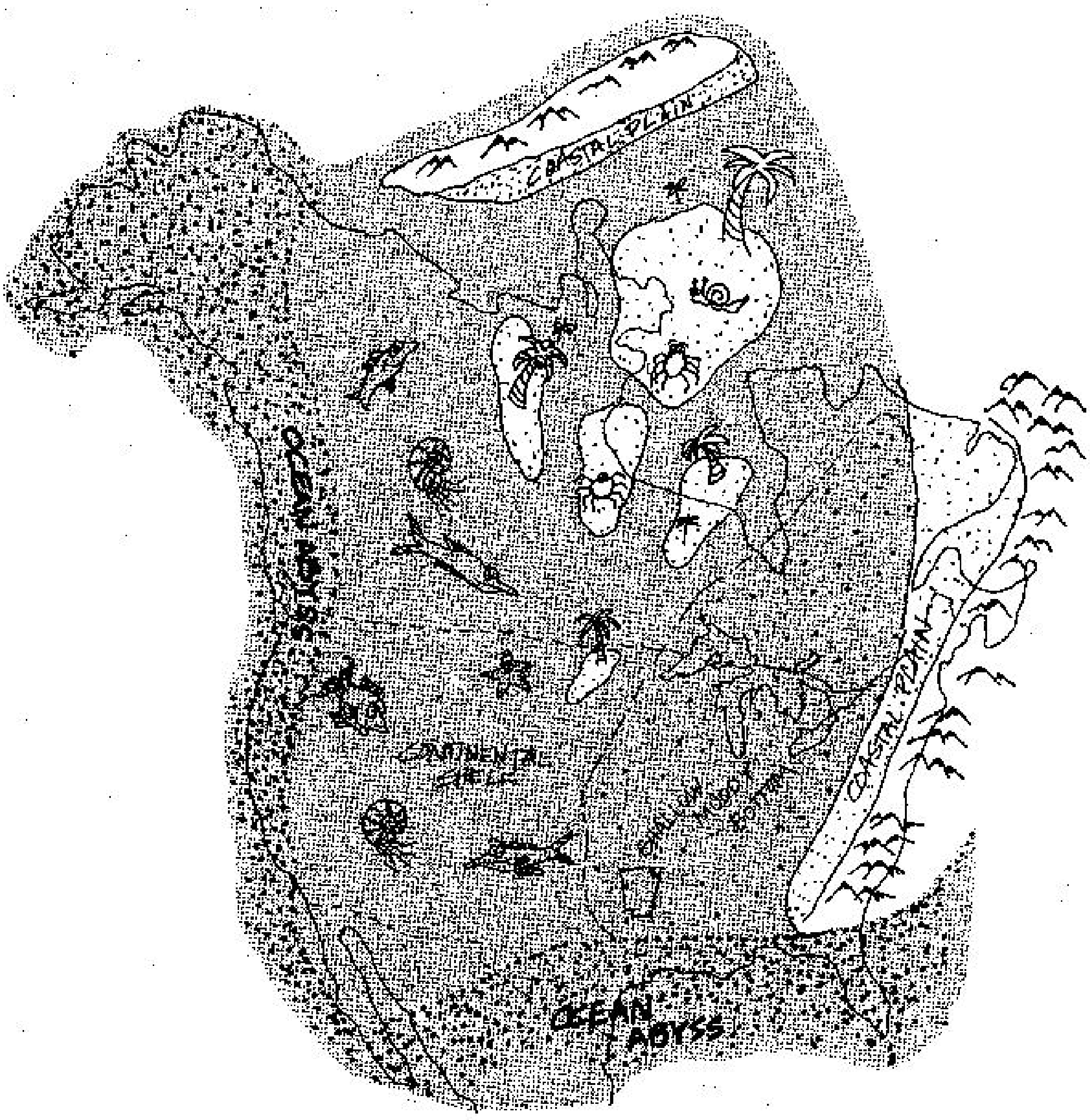
Devonian Period

(408 to 360 MYBP)

During the **Devonian Period** collisions of plates were occurring along both the eastern and western margins of North America. In the west volcanic islands were colliding with Laurentia. In the east the continents of Laurentia and Baltica collided to form a new larger continent, **Laurasia**. Europe was now connected to North America. The collision formed a mountain range where New York, New England, and Scotland are now (Fig. 11). To the west of this mountain chain, a vast shallow sea still covered the central part of North America, including northern Arkansas.

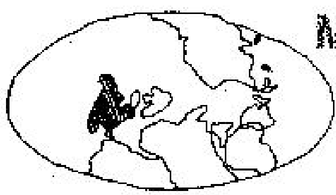
The development of the mountain chain did have some effect on the geology of Arkansas. Erosion of the mountains provided sand which was deposited along the shoreline in Pennsylvania and western New York. Finer grained sediment was transported a greater distance from the shore, and clay (which became shale) was deposited in the eastern half of North America including the Ozark area of northern Arkansas. Fish became very abundant, and amphibians appeared during the Devonian Period. Animals, including amphibians, insects, spiders, and snails, invaded the land during this period and joined the plants which earlier had begun to live on land.

The Ouachita Mountain area in central Arkansas continued to be part of a deep ocean basin. A little of the clay, eroded from the mountains to the east, was also transported into this deep ocean basin and was deposited as shale. In addition to this shale, **chert** was also deposited. Chert is a siliceous sedimentary rock. It was derived from the sponges and other organisms with siliceous skeletons or from siliceous volcanic ash. The skeletons or the ash slowly settled to the bottom of the ocean basin. Later the chert was slightly metamorphosed and converted to **novaculite**. The Arkansas Novaculite is exposed in the Ouachita Mountains near Hot Springs. Because the rock has unique properties, it is used commercially as whetstone to sharpen knives.



LATE DEVONIAN

Figure 11.
Late Devonian paleogeography of North America

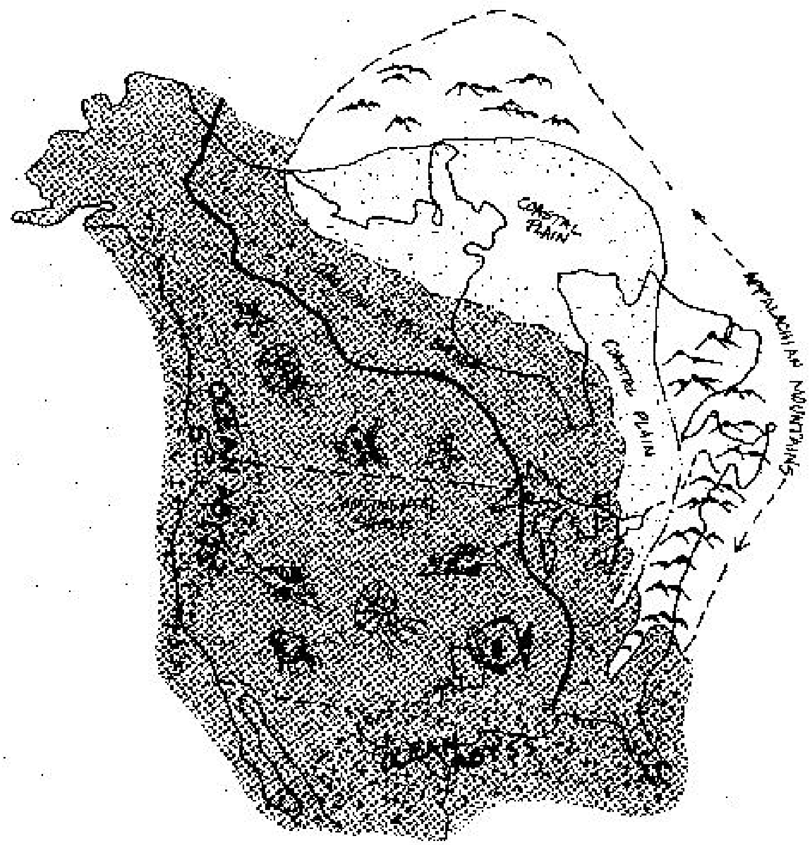


Mississippian Period

(360 to 320 MYBP)

During the Mississippian Period volcanic islands continued to collide with the western edge of the North American plate. The African plate also collided with the southeastern edge of the North American plate to form the Appalachian Mountains and became part of Laurasia (Fig. 12).

Neither of these collisions had much of an effect on the geology of northern Arkansas. The vast shallow sea continued to cover most of North America and carbonate rocks made up of calcareous shells of invertebrate animals were deposited. Some chert was also deposited as siliceous shells and skeletons.



MID-MISSISSIPIAN

Figure 12.
Mid-Mississippian paleogeography of North America

The collision of North America and Africa and formation of the Appalachian Mountains did have a large effect on the geology of central Arkansas in the Arkansas River Valley and the Ouachita Mountains. This part of Arkansas was still a deep ocean basin, but it was becoming quite narrow because Llanoria, a continent to the south, was moving toward Laurasia. In the early Mississippian Period chert continued to be slowly deposited in the basin as it had been during the Devonian. By the late Mississippian the Appalachian Mountains were formed. Erosion of these mountains provided abundant sand and silt that was transported into the deep but narrow basin from the southeast. The ocean basin trapped all of the sand and silt so that none of this sediment was deposited in the shallow water that covered northern Arkansas (Fig. 13).

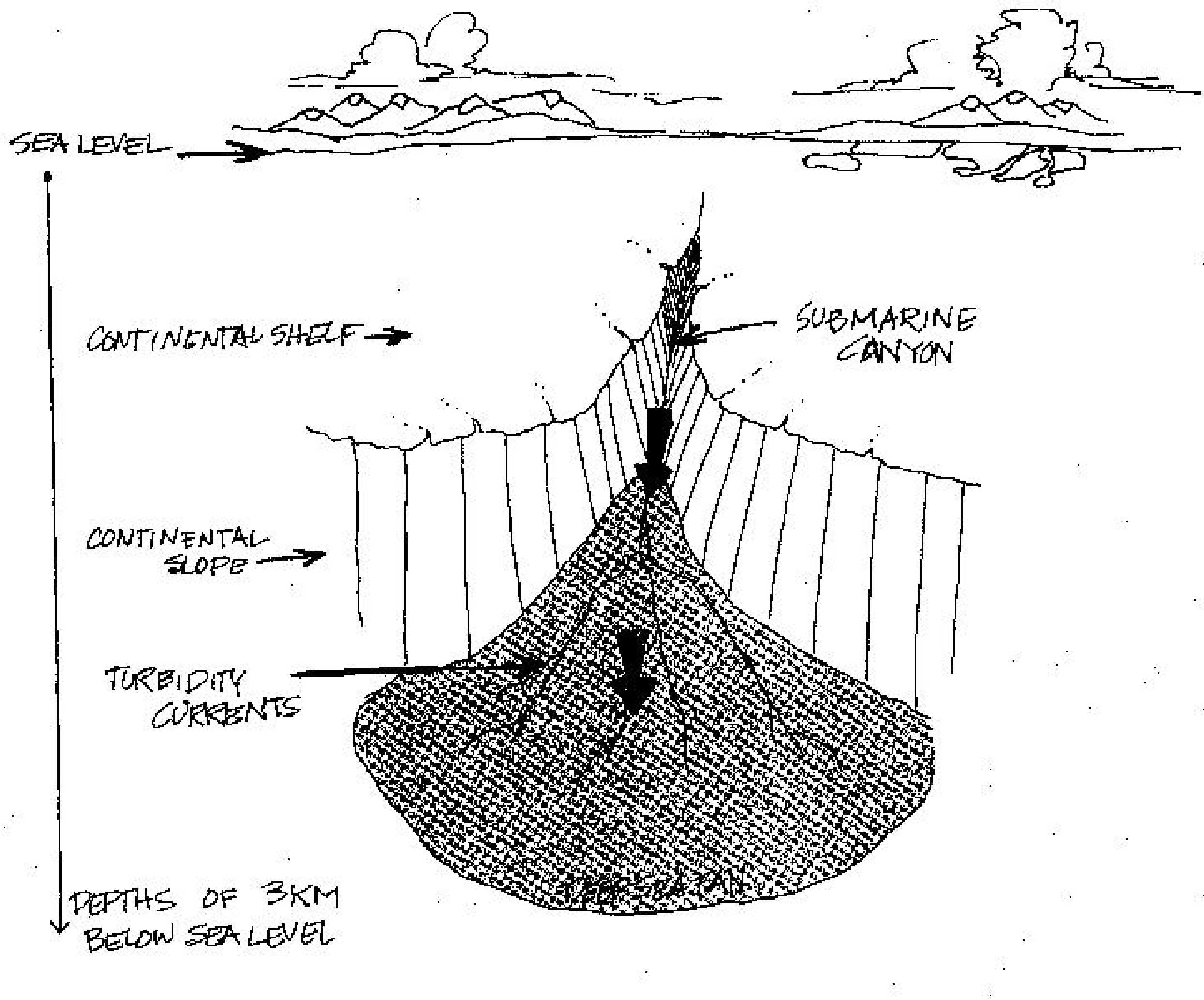
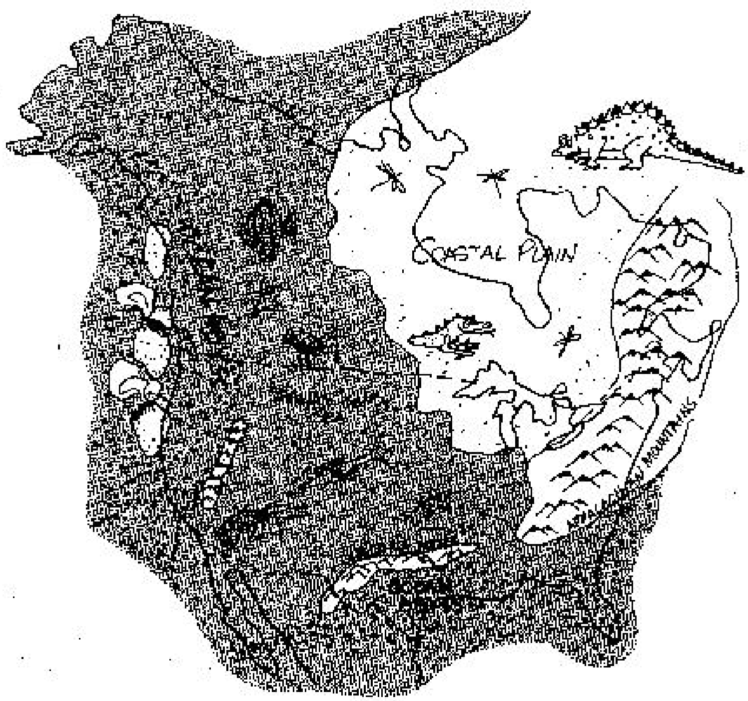


Figure 13.
Sediment from the continental shelf can be deposited as a **submarine fan** at the mouth of a **submarine canyon**. The muddy sediment and water mixture is transported as a **turbidity current**

Pennsylvanian Period (320 to 286 MYBP)

During the **Pennsylvanian Period** great changes were occurring on the Laurasian continent. It was becoming part of a single large continent, **Pangaea**. Along the eastern edge of the continent, Laurasia had already collided with Europe and Africa and formed the Appalachian Mountains (Fig. 14). During the Pennsylvanian Period the southern edge of Laurasia was beginning to collide with a continent, Llanoria, to form the Ouachita Mountains. This collision occurred in what is now Arkansas. In fact, the state of Arkansas comprises two ancient continents. The present day Ozarks and the Arkansas River Valley in the northern part of the state were part of the continent Laurasia and the Ouachita Mountains, and Gulf Coastal Plain in the central and southern part of the state were part of the continent Llanoria. In Arkansas the boundary between these two ancient plates extends from Y City to Little Rock. Along the western edge of the North American continent the ancient Rocky Mountains were being **folded** and uplifted.



MID- PENNSYLVANIAN

Figure 14.
Mid-Pennsylvanian paleogeography of North America

The uplift and collision of the continent on three sides also affected the geology of the interior part of the continent. The whole continent was higher in elevation than it had been during the entire Paleozoic Era. The Appalachian Mountains were being eroded and provided abundant sediment. A lot of sediment was deposited in the deep ocean basin along the southern margin of the continent but not all of the sediment was trapped here as it had been previously. Rivers also transported a lot of sand, silt, and clay across the continent and much of this was deposited as **deltas** along the coast of the inland sea in the eastern and southern part of the continent.

The change in the paleogeography of the Laurasian continent had a great effect on the geology of Arkansas. The Ozark region of northern Arkansas, which had been covered by warm, shallow seas during the Paleozoic Era, did not previously have a source of sand, silt, and clay. This allowed the deposition of carbonate rock throughout most of the Paleozoic. Northern Arkansas was still covered by shallow marine water during the early Pennsylvanian Period. However, carbonate rocks were no longer being deposited because rivers to the north brought large quantities of sand, silt, and clay from the Appalachian Mountains and deposited this sediment in deltas along the shoreline (Fig. 15). The sediment eventually filled much of the ocean in northern Arkansas and raised the elevation above sea level so that deltaic deposits are overlain by river and

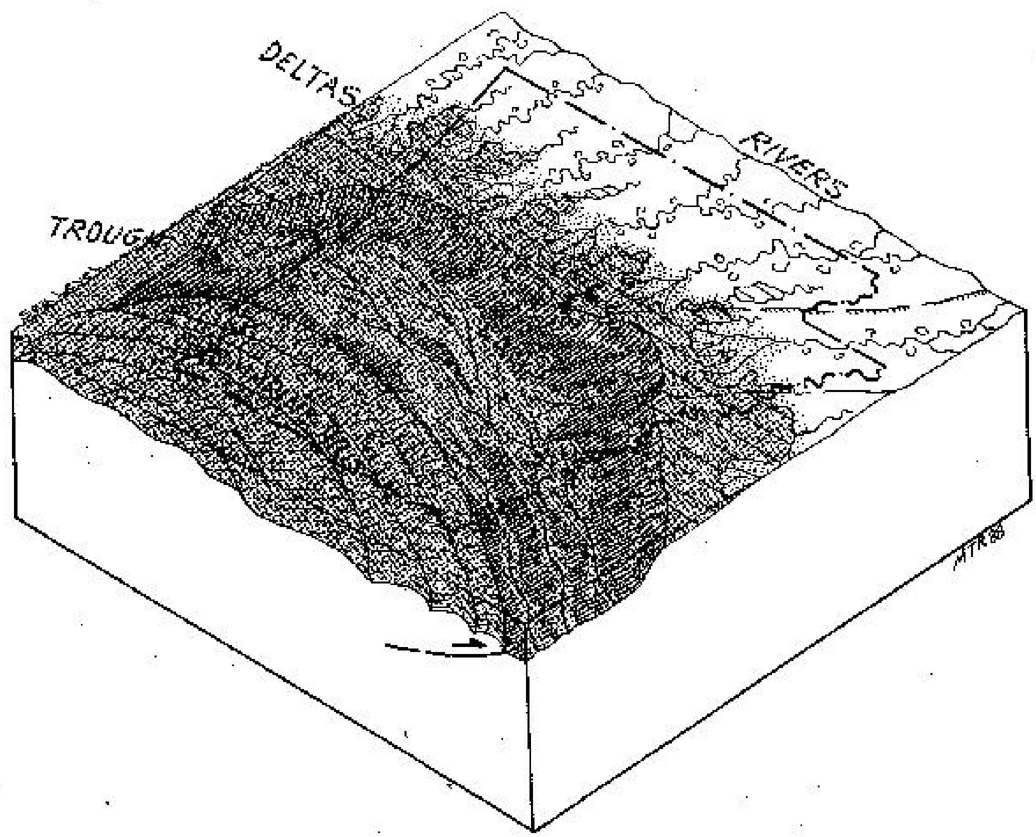


Figure 15.
Early Pennsylvanian paleogeography of Arkansas

swamp deposits near Fort Smith and Russellville. Reptiles developed during this period and inhabited the swamps with the amphibians and plants such as trees and ferns (Fig. 6). This plant material became **coal**, which is mined commercially along the Arkansas River Valley. Small amounts of organic material that were deposited with the sedimentary rocks have changed to natural gas which is now produced from wells drilled into the Paleozoic-age rocks in both the Ozark and Arkansas River Valley regions.

To the south in the Ouachita Mountain area, the deep ocean basin was becoming very narrow as Llanoria was moving toward Laurasia (Fig. 15). During the early Pennsylvanian Period abundant sand was still being trapped and deposited in this trough as submarine fans (Fig. 13), which are similar to deep underwater deltas. By the middle Pennsylvanian Period the trough had been closed as the collision of Laurasia and Llanoria occurred (Fig. 16). During

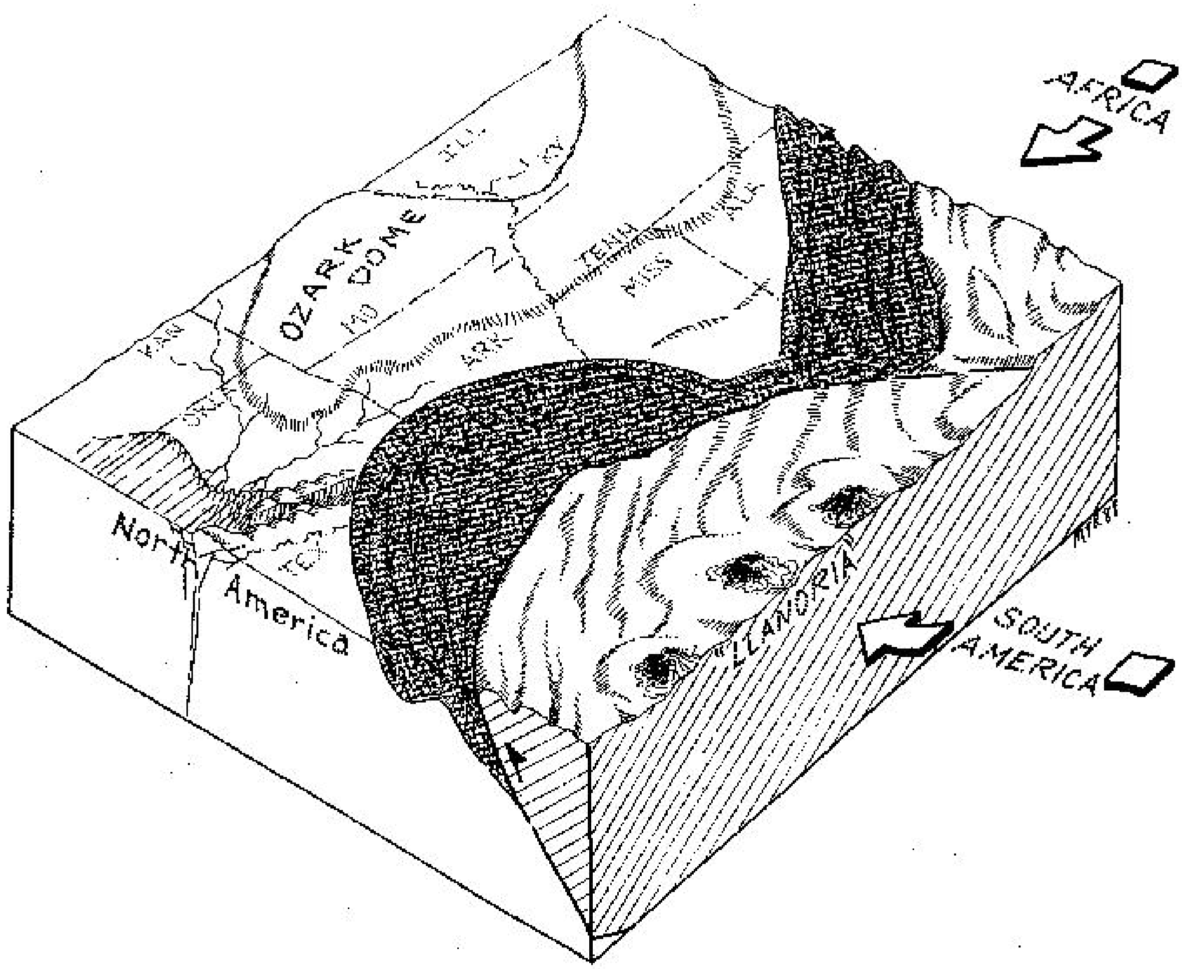
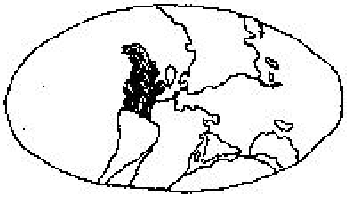


Figure 16.
Middle Pennsylvanian paleogeography of Arkansas

this collision the rocks were folded into **anticlines** and **synclines**, **faulted**, and uplifted to form the Ouachita Mountains and the new continent of Pangaea. The collision not only squeezed together the deep ocean basin shale, sandstone, and chert that had been accumulating during the Paleozoic but it also squeezed in some of the igneous rock from the ocean floor that formed along the **spreading center** of the ocean basin. Very small exposures of this **gabbro**, **soapstone**, and **serpentine** occur south of Little Rock. The soapstone deposits are commercially mined for filler in rubber and roofing products. During the collision, hot fluids rich in **silica**, moved through the fractures in the rocks. Quartz crystals that precipitated from these solutions are now mined in the Ouachita Mountains (Fig. 17). Most of these crystals are sold to tourists, schools, and museums. Some are used for jewelry and optical equipment.

Figure 17.
Quartz crystals



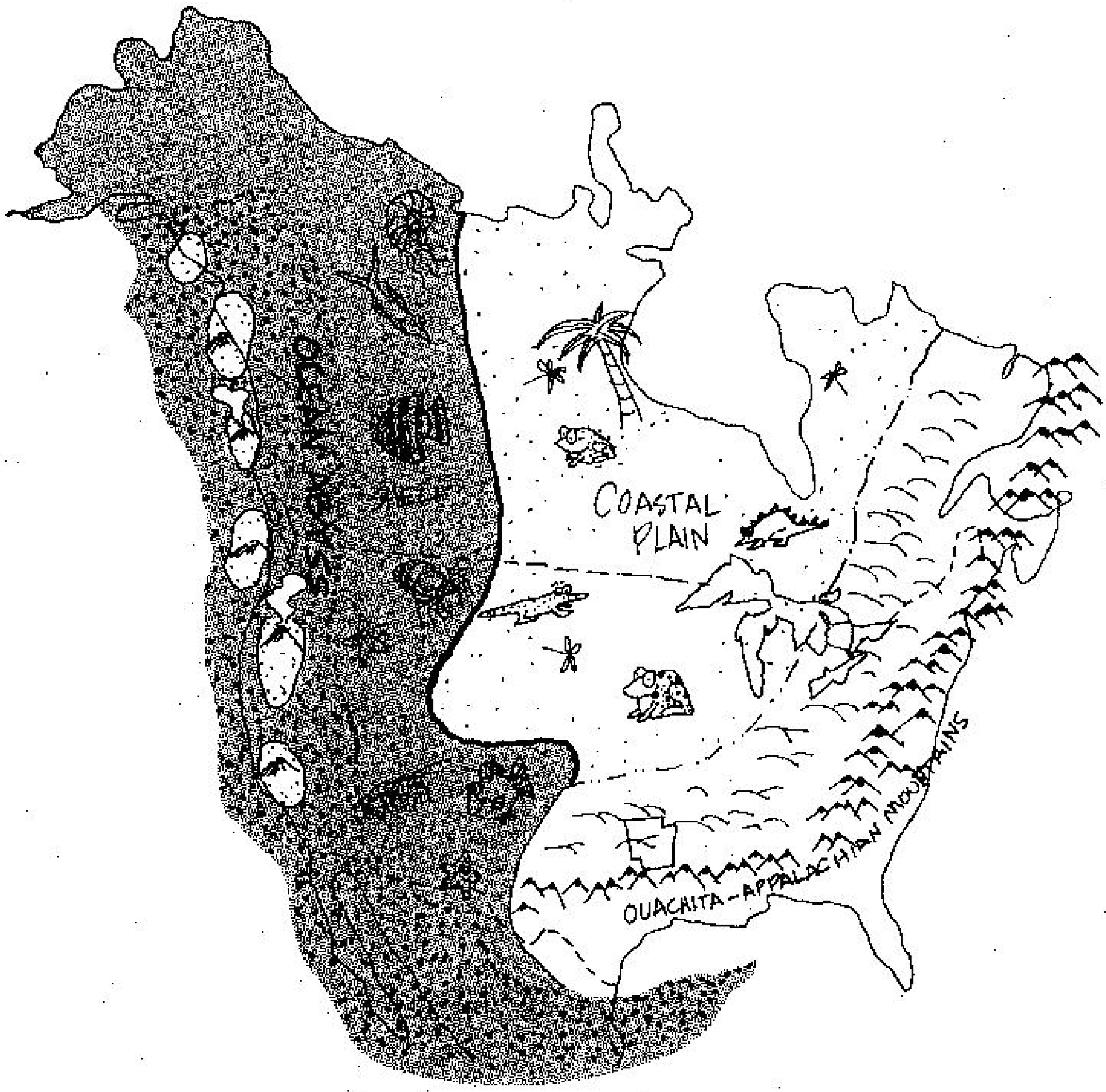
Permian Period

(286 to 245 MYBP)

By the **Permian Period** the formation of Pangaea was complete. All of Arkansas and most of eastern and central North America were above sea level (Fig. 18). In the western portion of the continent, the ancient Rocky Mountains were eroded. The collision of Laurasia and Llanoria and the uplift of the Ouachita Mountains that began in the Pennsylvanian Period continued into the Permian Period. Because the whole area was well above sea level, no Permian rocks exist in Arkansas. The erosion surface began to form in the late Pennsylvanian Period and continued throughout the Permian Period.

At the end of the Permian Period, more than half of the animal families became extinct, perhaps a result of the different world paleogeography and climate compared to that which existed earlier in the Paleozoic Era. This mass extinction marks the end of the Paleozoic Era, 245 million years ago.

The end of the Paleozoic Era marks the end of major sedimentation in the present day Ozarks, the Arkansas River Valley, and the Ouachita Mountains. These areas have been above sea level and undergoing weathering and erosion since the Pennsylvanian Period. During the remaining two eras of the earth's history, major sedimentation occured in the Gulf Coastal Plain Region and the Mississippi Alluvial Valley.



LATE PERMIAN

Figure 18.
Late Permian paleogeography of North America

MESOZOIC ERA
(245 to 66 MYBP)

The third major subdivision of geologic time is the **Mesozoic Era**, or middle life. The mass extinction at the end of the Paleozoic Era provided many environments for new species to populate. At the beginning of the Mesozoic Era, approximately 245 million years ago, a rapid evolution of many new families occurred, especially those of **molluscs** and reptiles. Though reptiles evolved in the Paleozoic Era, they did not become dominant until the Mesozoic Era. The best known of this group are the **dinosaurs**, which persisted throughout this era for 180 million years (Fig. 19) and then became extinct. The first birds and **mammals** evolved during the Mesozoic Era, but they did not become abundant until the **Cenozoic Era**, the last major subdivision of geologic time.

The super continent of Pangaea that had formed at the end of the Paleozoic Era began to break up in the Mesozoic Era, and the geography that we are familiar with today was beginning to form. The present ocean basins began to develop by sea-floor spreading during the Mesozoic Era, and the oldest rocks in those ocean basins are 200 million years old. This is much younger than the continents where the oldest rocks are 3.7 billion years old.

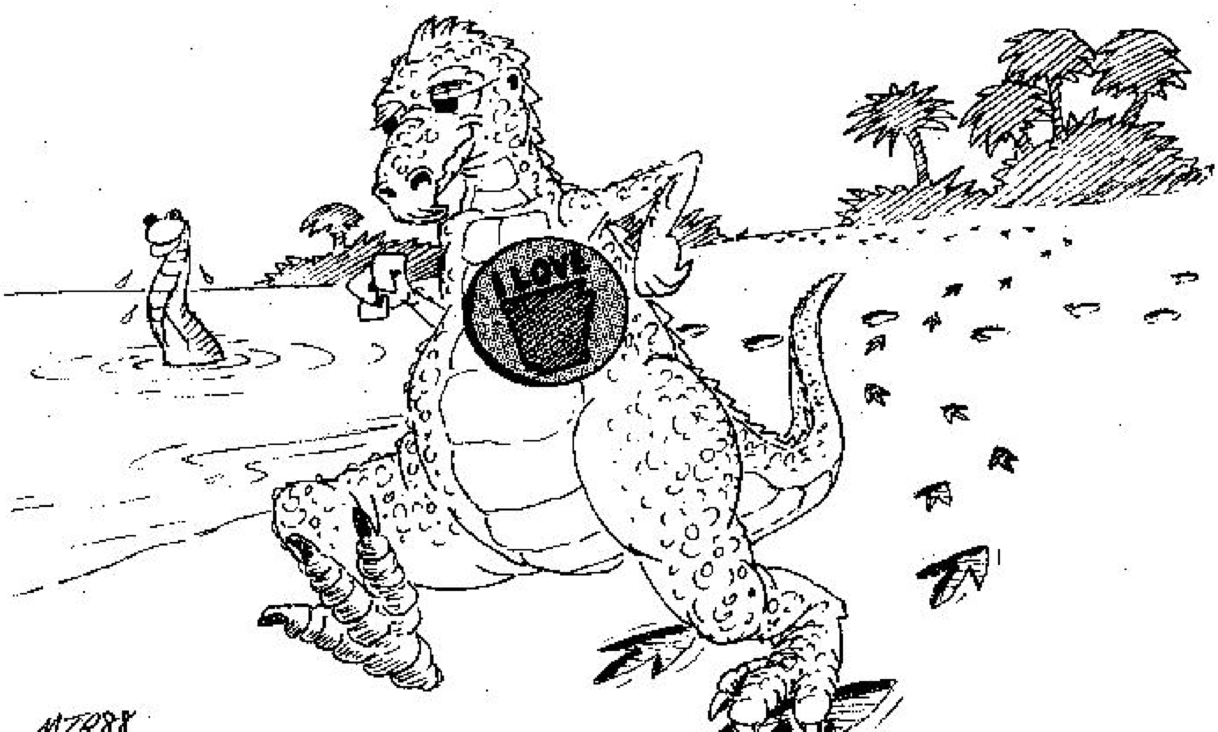


Figure 19.
Dinosaurs in southern Arkansas during the Mesozoic Era

In Arkansas, the Mesozoic history is a history of the Gulf of Mexico. Deposition of sediment during this era was restricted to the Gulf Coastal Plain and the Mississippi Alluvial Valley in the southern and eastern portions of the state. The Ozarks, the Arkansas River Valley, and the Ouachita Mountains in the northern and central part of the state were above sea level during this era and were being weathered and eroded.

The end of the Mesozoic Era, 66 million years ago, is marked by a mass extinction of many different groups, both marine and terrestrial. There are two major competing theories for this extinction. Some argue for a catastrophic extraterrestrial event such as a **meteorite** impact which modified the worldwide environment (Fig. 20). The opposing theory proposes that there was a gradual change in the terrestrial environment and food supply, perhaps as a result of more land being above sea level and a reduction of the area covered by shallow seas. Another possible reason is the appearance of cooler seasons as the continents moved toward higher latitudes and altitudes.

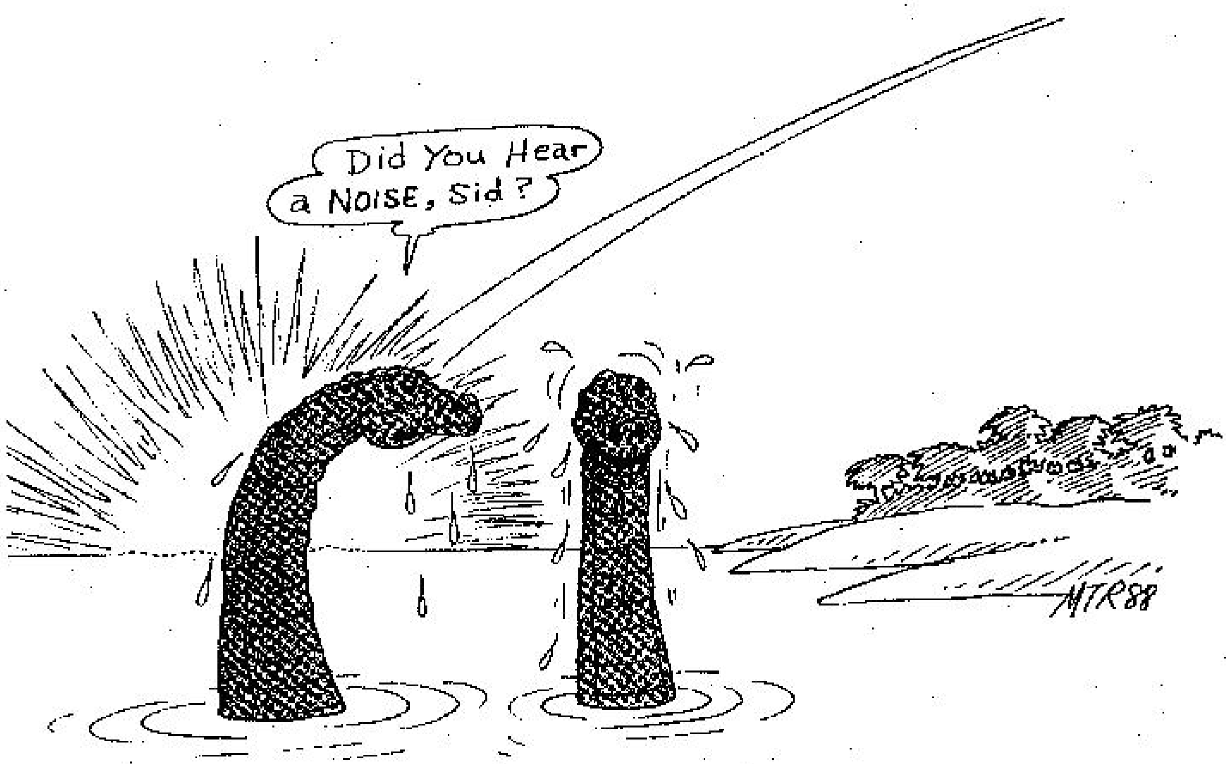
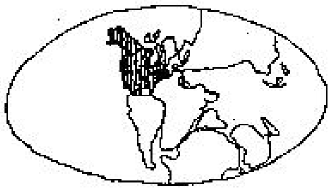


Figure 20.
Meteorite impact theory of late Mesozoic extinctions



Triassic Period

(245 to 208 MYBP)

Much of North America, including the eastern and central portion of the continent, was above sea level during the **Triassic Period**. Pangaea began to **rift** or split apart, with Europe breaking away from the eastern part of North America and South America breaking away from the southern part of North America (Fig. 21). Though the rifting, or splitting apart, began in the Triassic, the faulting had not proceeded long enough for the down dropped fault blocks to be below sea level. Neither the Atlantic Ocean or the Gulf of Mexico existed yet. Basaltic igneous magma was intruded along the developing cracks as the continents began to spread apart. As North America moved westward, the western margin overrode oceanic crust and volcanic islands formed along the subduction zone.

All of Arkansas was above sea level during the Triassic Period. No rocks of Triassic age are present in the Ozarks, Arkansas River Valley, or Ouachita Mountain areas because the northern and central parts of the state were high in elevation and were being eroded. The only rocks of Triassic age in the entire state are in the southern part of Arkansas which was relatively low in elevation. Deep troughs formed where blocks were down faulted as South America began to split apart from North America. Sand and gravel eroded from the high Ouachita Mountains to the north were deposited by rivers in **alluvial fans** which filled these troughs. The Gulf Coastal Plain continued to subside during the rest of the Mesozoic Era and part of the Cenozoic Era. These Triassic-age rocks are now deeply buried by younger rocks and are only seen in cores of rock that have been recovered from wells drilled in the southern part of the state.

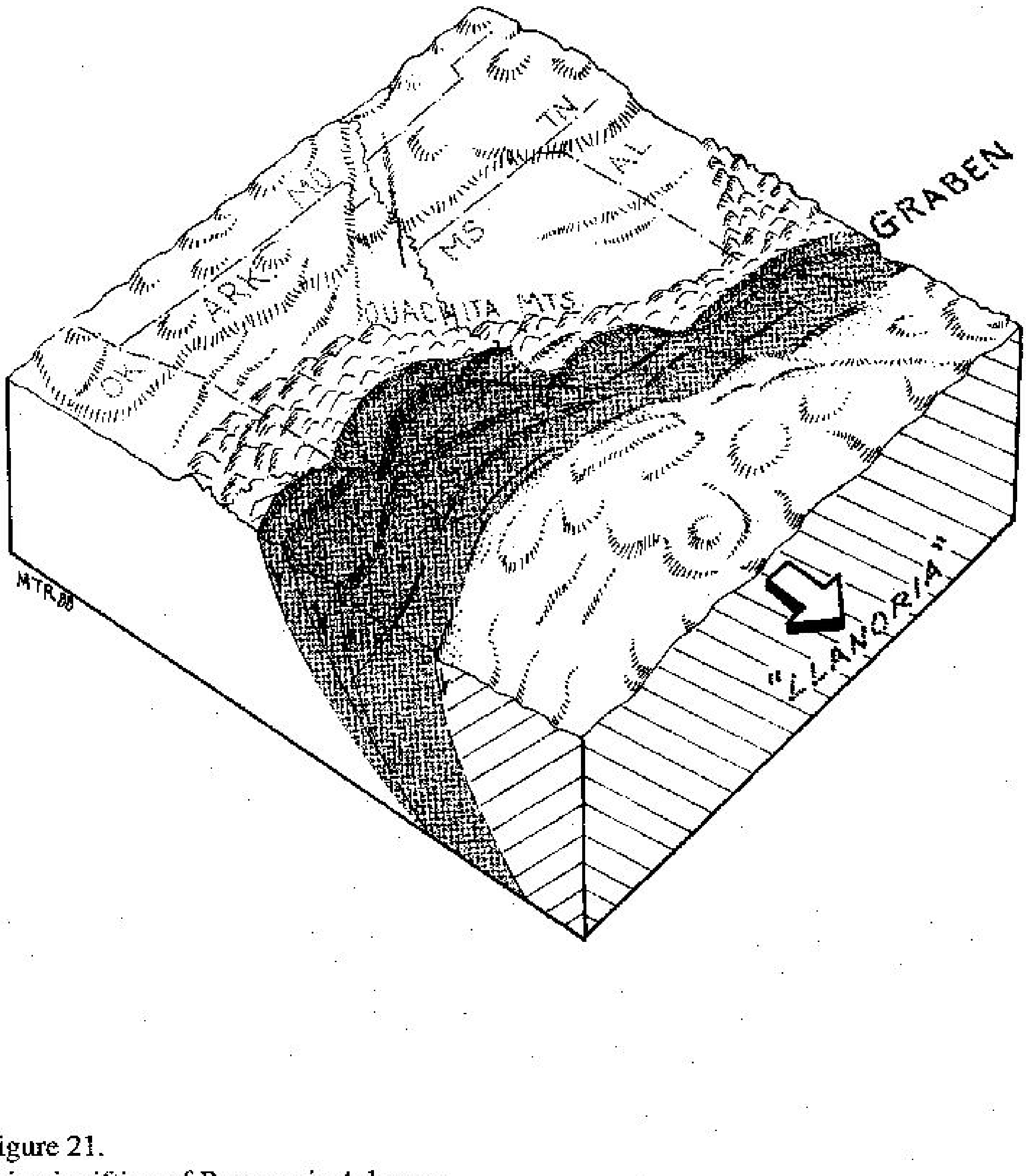
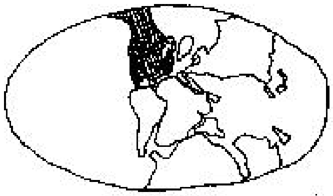


Figure 21.
Triassic rifting of Pangaea in Arkansas



Jurassic Period

(208 to 144 MYBP)

The splitting of Pangaea continued during the **Jurassic Period**, and by this time the continents had rifted apart enough that the Atlantic Ocean and the Gulf of Mexico began to form. Along the western margin of North America, the continental plate continued to override the oceanic plate as it moved westward. Most of the continent was above sea level except for an area that is now Colorado, Wyoming, and Montana where a shallow sea existed.

Northern and central Arkansas were above sea level during the Jurassic Period, but the southern part of the state was covered by the Gulf of Mexico. The Gulf of Mexico was much narrower and shallower than it is today and probably was not permanently connected to the Atlantic Ocean. This geography caused poor water circulation. Water periodically evaporated from the Gulf and deposited beds of salt. The element **bromine** is found in these salt brines and has been produced commercially in Arkansas. It is used as an antiknock additive of gasoline and in medicines. As rifting continued, the Gulf became wider and connected to the Atlantic Ocean. The improved circulation caused **evaporite** beds of salt to become less common and marine carbonates to be deposited. All of these Jurassic rocks have been buried by younger sediments of the Gulf of Mexico but they have been studied extensively because oil is produced from wells drilled into the carbonate rocks.

Cretaceous Period (144 to 66 MYBP)

During the Cretaceous Period the last large sea to cover a major portion of the North American continent came into being (Fig. 22). The rise in sea level may have been the result of higher elevations along the spreading center in the Atlantic Ocean. The uplifted ridge displaced some of the water from the ocean basin and the water overflowed onto the continents. A shallow sea covered the southeastern margin and the western portion of the continent. Areas of higher elevations, including the mountainous areas along the west coast, the Appalachian and Ouachita Mountains, and the eastern part of the continent were above sea level. Mountain building and volcanic eruptions continued along the western margin of North America as the continent continued its western movement and subducted the Pacific oceanic plate.

Figure 22.
Cretaceous paleogeography of North America

The Gulf of Mexico rose to its highest level during the Cretaceous Period and covered Arkansas south and east of the Ouachita Mountains (Fig. 23). The eastern part of the state was covered by a large extension of the Gulf of Mexico, termed the Mississippi **Embayment** because the present Mississippi River flows along center of the area. During the early part of the Cretaceous Period the Ouachita Mountains were high above sea level, and abundant sand and gravel was eroded from the mountains. This sediment was deposited in southern Arkansas as stream and beach deposits and today is quarried for sand and gravel.

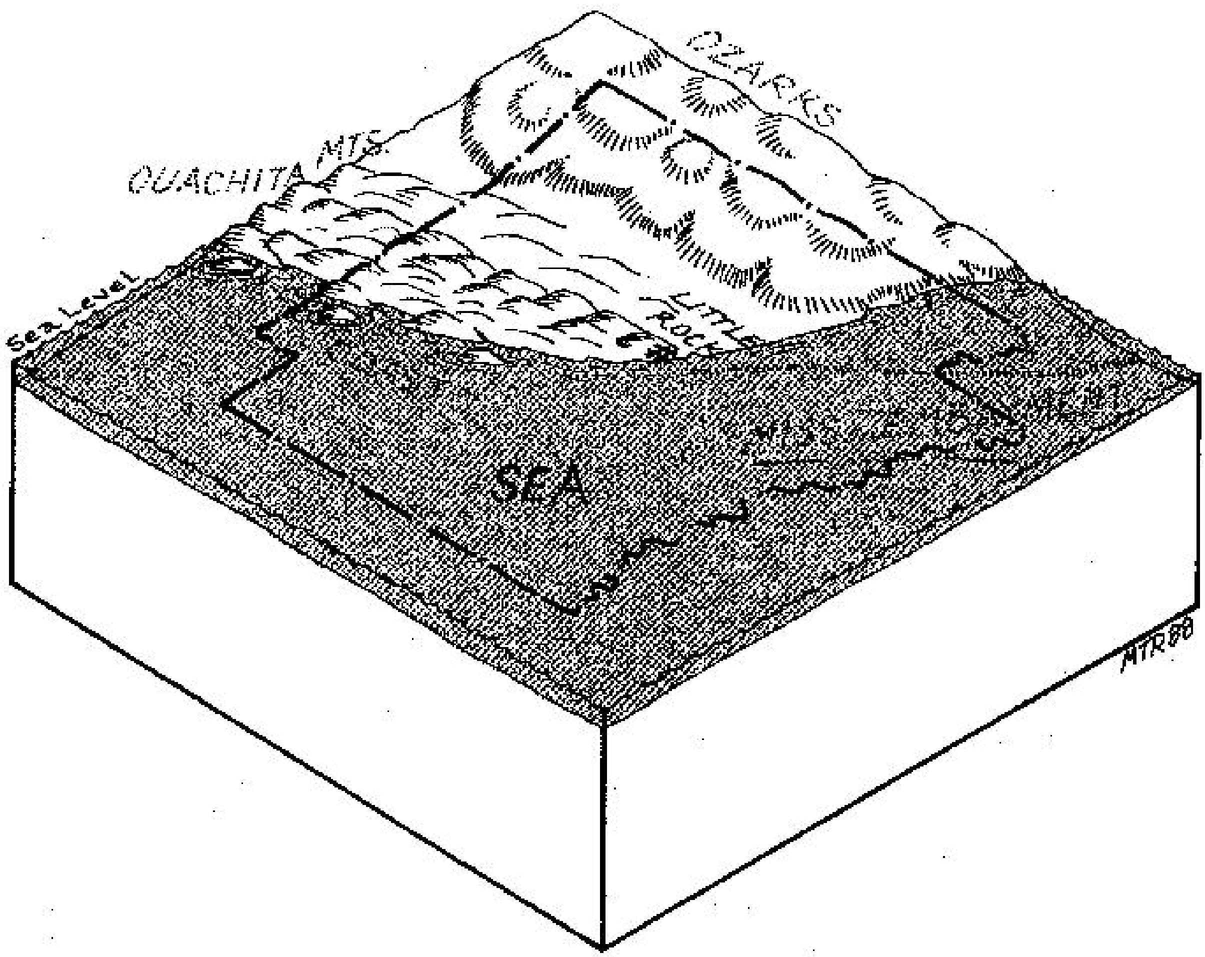


Figure 23.
Late Mesozoic to early Tertiary paleogeography of Arkansas

The mountains were reduced in elevation by erosion during the Cretaceous Period, and by the late Cretaceous Period they were so low in elevation that they did not contribute much sediment to the Gulf. Clay, **chalk** (carbonate rock composed almost entirely of very tiny fossils), and **gypsum** were deposited in the shallow water. Some of the organic matter preserved in these rocks has been converted to oil and this is an important mineral resource in the southern part of the state. In southwestern Arkansas the chalk is mined for agricultural lime and cement and the gypsum is mined to make sheet rock. As these sediments accumulated in the shallow seas, dinosaurs roamed along the shoreline and some of their bones and tracks have been preserved in the Cretaceous-age rocks.

Subsidence of the Mississippi Embayment in eastern Arkansas, southeastern Missouri, and western Kentucky and Tennessee began during the Cretaceous Period and is continuing today. This subsidence is in about the same position as the trough that developed during the late Precambrian Era and early Cambrian Period and may be a reactivation of the same structure.

Igneous rocks were intruded during the early Cretaceous Period along the northeast edge of the subsidence zone from Murfreesboro to Little Rock. All of these rocks are unusual. They have very small amounts of silica. The intrusion at Murfreesboro contains diamonds and is the only area in the U.S. where diamonds have been mined commercially (Fig. 24). Another of these intrusions occurs at Magnet

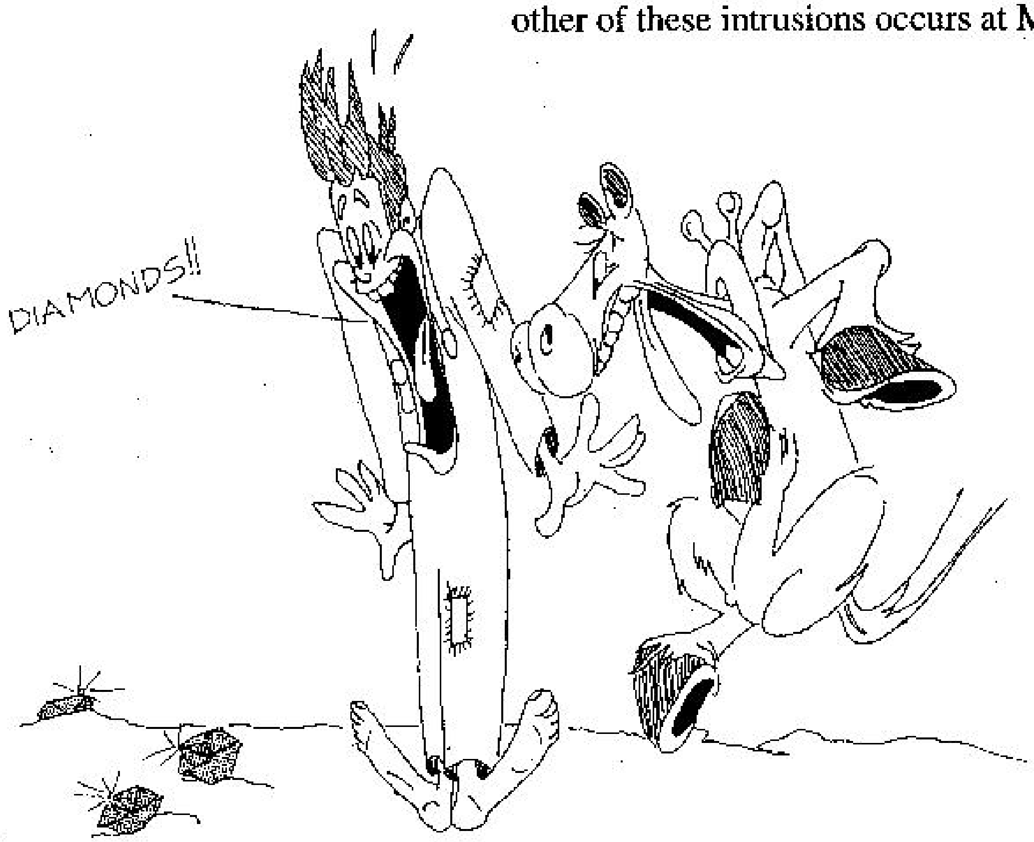


Figure 24.
Diamond mining in southwestern Arkansas

Cove and contains many very unusual minerals which attract mineral collectors from around the world. A third intrusion is Granite Mountain near Little Rock. The name is not very accurate because the rock is really **syenite**, which is similar to granite but does not contain quartz.

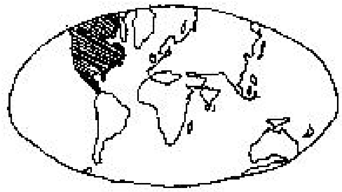
There are a number of economic resources related to these igneous intrusions, in addition to diamonds. **Bauxite** is formed by tropical weathering of syenite. This weathering **leaches** the relatively small amount of silica that was present in these rocks and concentrates the aluminum. It has been economically mined as a source of aluminum near Bauxite, in central Arkansas. Where the syenite weathers to a high alumina clay, the clay is mined to make **refractory** bricks. Unweathered syenite is quarried for **rip rap** and crushed rock for roads and railroads.

Two other economic resources are **barite** and **vanadium**. The origin of the mineral barite in Arkansas is not well known. One of the hypotheses of its formation is the movement of **barium**-rich fluids through fractures in the ocean bottom and flow of the fluid into the sea like hot springs. The barium and sulfur precipitated as barite where the hot water mixed with the cooler ocean water. This mineral was mined for use as drilling mud, as filler, and in the chemical industry. The element vanadium is also associated with the intrusions and is mined near Magnet Cove to be used as an **alloy** in steel.

CENOZOIC ERA
(66 MYBP to Present)

The fourth and last major subdivision of geologic time is the Cenozoic Era, the time of new life. After the extinction of many families (especially the reptilian ones) 66 million years ago, many environmental niches were left vacant and new groups of animals evolved as a result. Mammals and birds became dominant on the land. The most abundant mammal on the land is man. The earliest ancestors of man, *Australopithicus afarensis* evolved about 4 million years ago in east Africa. *Homo sapiens sapiens*, the modern species of man, did not evolve until 35,000 to 50,000 years ago, perhaps in Africa also, and has spread across all the continents. Flowering plants (**angiosperms**) and grasses evolved and provided food for these terrestrial groups. Invertebrate and single-celled animals continued to be successful in the sea.

The diversity of nearly all plant and animal groups in the Cenozoic Era is greater than during any era in the past because of the configuration of the continents and continental shelves. The presence of multiple continents that are separated by ocean basins and that extend from the equator to the poles with different climatic zones has isolated animal and plant groups. This separation allowed divergence in the evolution of the groups and therefore a great diversity in the Cenozoic animals and plants. The Cenozoic Era is not over yet and this diversity continues today.



Tertiary Period

(66 to 1.65 MYBP)

The North American continent continued to move westward during the **Tertiary Period** as it did in the Mesozoic Era, and the geology of both times is similar. The Atlantic Ocean became wider as the continent moved to the west at an average rate of 5 cm/year. Erosion of the Appalachian Mountains supplied sediment that was deposited along the Atlantic seacoast. The Gulf of Mexico was also becoming wider as South America moved away from North America. Erosion of the central part of the continent provided sediment that was deposited along the coast of the Gulf of Mexico. In western North America mountain building continued as the continent collided with and subducted plates of the Pacific Ocean. Some of these mountains were formed by folding such as the Rocky Mountains, some mountains formed by intrusion of magma, some mountains were volcanic, and some mountains formed by uplift along faults.

The greatest difference between the Cretaceous and the Tertiary Periods in North America is that the continent was higher in elevation during the Tertiary Period. There were no shallow seas that covered the central part of the continent during this time. In fact, erosion of the Rocky Mountains provided a large amount of sediment that was deposited across the central portion of the continent to form the **Great Plains** of Texas, Colorado, Wyoming, Kansas, Nebraska, the Dakotas, and Alberta in Canada. The only areas of extremely low elevation were along the Atlantic and Gulf Coasts and these were covered by marine water when sea level rose during the early Tertiary Period.

In Arkansas this rise in sea level during the early Tertiary Period drowned the southern and eastern portions of the state. It was a substantial rise in sea level, but it was not quite as high in most areas as during the Cretaceous Period. Tertiary-age rocks deposited in streams, swamps, and in shallow marine water are exposed throughout southern Arkansas. They are also present in the Mississippi Embayment of eastern Arkansas, but here they are buried by younger deposits of the Mississippi River everywhere but on **Crowley's Ridge** and the western margin of the Mississippi Embayment. Though these deposits are called rocks, they are so soft that they can easily be dug with a shovel. In addition to the sand and clay that was deposited, **lignite** accumulated in the swamps. This is a low-rank coal that could be produced as an energy source, if the price of coal becomes high enough. Marine water did not cover the area of the present day Ozarks, the Arkansas River Valley, or the Ouachita Mountains, which were mountains no longer. Erosion during the late Cretaceous Period had lowered these mountains to mere highlands. This erosion continued during the Tertiary Period.

In the middle and late Tertiary Period, sea level was much lower than during the early Tertiary Period, and the shoreline of the Gulf was to the south of Arkansas. All of Arkansas was above sea level, and most of the area was being weathered and eroded, except eastern Arkansas. The Mississippi Embayment continued to be a relatively low area, and the Mississippi River developed in this trough. Ancient Mississippi River deposits are preserved on Crowley's Ridge and are an important economic source of sand and gravel.

Quaternary Period (1.65 to 0 MYBP)

The **Quaternary Period**, the last 1.65 million years of the earth's history, is characterized by significant changes in the world climate. **Glaciers** have repeatably formed, perhaps 11 times. These glaciers covered a significant portion of the continents and then melted, except in Antarctica and Greenland. They covered and directly affected large areas of the North American continent and had an indirect influence over large areas beyond the margin of the glaciers and over the sea, as well. The direct influence of the glaciers included erosion by the ice and later deposition of that eroded material by the glaciers. The indirect influence included:

1. A lowering of sea level because much of the world's water was incorporated in the glaciers.
2. Thick deposits of river **alluvium** and **loess** in the glacial-**outwash** valleys when the glaciers melted.
3. Sinking of the earth's crust beneath the weight of a glacier.
4. Bulging of the earth's crust beyond the glacier.
5. Deposition of large amounts of coarse sediment in the ocean basins because of increased erosion on the continents by the glaciers and floating ice bergs.

Between **glacial stages** there were warmer **interglacial stages** when most of the ice melted and sea level rose. We are living in one of these interglacial stages.

The cause(s) of alternating periods of glaciation and interglaciation are not well understood. One of the most popular theories is called the **Milankovitch Theory** It proposes that the amount of seasonal **solar radiation** (heat) which reaches a given latitude at the earth's surface varies because the movement of the earth around the sun changes in three ways and these changes are cyclical. Each of the three cycles takes a different length of time to complete. Thus, there are periods of time when winters are cooler and summers are warmer. These periods tend to be interglacial stages because all the snow melts in the summer and it cannot accumulate to form a glacier. During periods of time when there is less seasonal contrast in solar radiation, the winters are not as cold and the summers are not as warm. These are glacial stages because not all the snow melts during the cool summers and it can accumulate to form a glacier. Variation in the seasonal distribution of solar radiation to reach the earth has occurred before the Quaternary Period, but the presence of continents near or over the poles of the earth during this period has allowed glaciers to form.

Glaciers never covered Arkansas during the Quaternary Period and there is no direct evidence of glaciation in the state (Fig. 25). However, there is abundant indirect evidence of glaciation in the Mississippi Alluvial Valley of eastern Arkansas. The Mississippi River was an outwash river for glaciers that covered much of North America. During the early and middle Quaternary Period, the river eroded a deep valley west of Crowley's Ridge. At the same time the Ohio River, also an outwash stream, eroded a deep valley east of Crowley's Ridge. These two rivers joined south of Arkansas. During the late Quaternary Period the Mississippi River cut through Crowley's Ridge, joined with the Ohio River near Cairo, Illinois, and now flows on the east side of Crowley's Ridge.

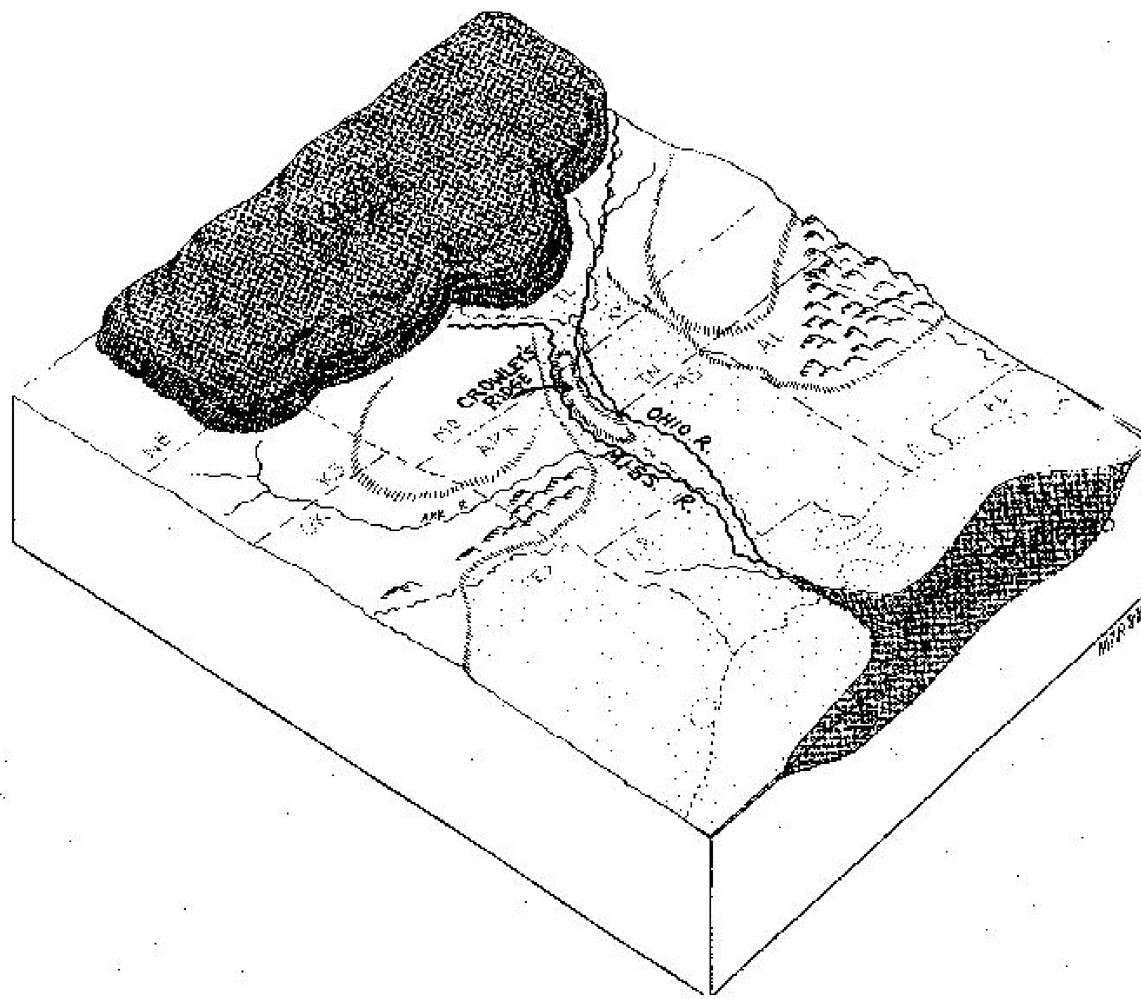


Figure 25.
Early and middle Quaternary paleogeography of the south-central United States

Both the Mississippi and the Ohio rivers deposited abundant sand and gravel in their valleys. When the wind blew across these broad flat areas, it caused dust storms (Fig. 26). This dust was deposited as loess in and along the edges of the valleys. Some sand was also transported and was deposited as sand dunes.

There are other Quaternary deposits in Arkansas that were not affected by glaciation. River deposits occur along the major streams in the state such as the Arkansas, Red, White, and Ouachita rivers. They are an important source of sand and gravel in many parts of the state. **Landslide** deposits occur in the mountains. There are good examples of these at Village Creek State Park on Crowley's Ridge, Queen Willemena State Park in the Ouachita Mountains, and Devil's Den State Park in the Ozarks.

A surface process that is occurring in the Ozark region and that does not involve sedimentation, is solution by groundwater. Caves, such as Blanchard Caverns, were and are forming by solution of soluble carbonate bedrock in the Ozarks. As the Ozark streams have eroded deeper and caused the water table to be lowered, caves that were formed below the water table and were formerly filled with water, are now above the water table and are filled with air. After

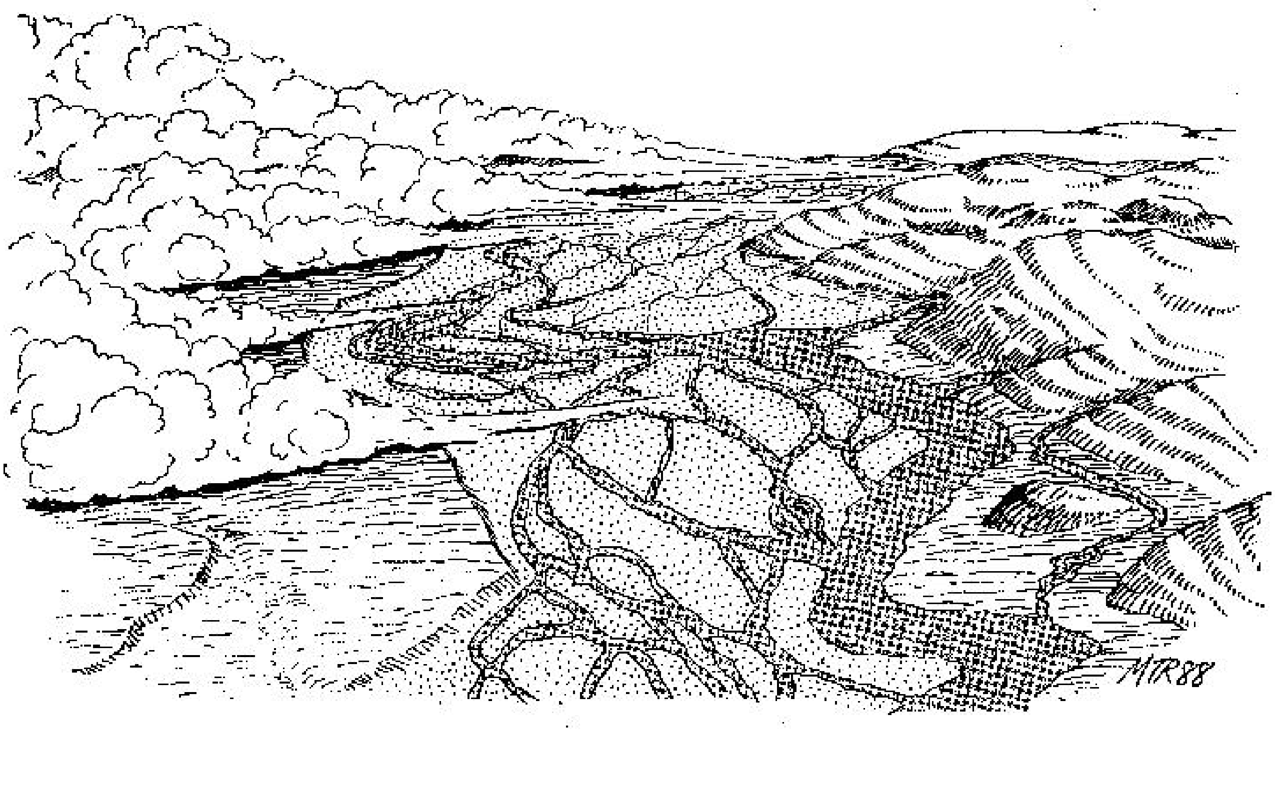


Figure 26.
Late Quaternary dust storms depositing loess along the braided Mississippi river valley

a cave has formed, it can be partly filled with insoluble and/or soluble material. Insoluble materials, such as **clay minerals** and chert gravel, are deposited by water flowing through the cavern. Soluble material, such as calcite, precipitates from water dripping into an air-filled cave. This calcite forms the **stalactites, stalagmites,** and other beautiful cave formations found in many of the Ozark caves.

Earthquakes also have occurred in Arkansas during the Quaternary Period. In fact the most hazardous **seismic area** in eastern North America is the **New Madrid Seismic Zone** that includes northeastern Arkansas and the bootheel of Missouri. During 1811 ad 1812 over 1800 earthquakes were recorded in this area, and four of them were estimated to be great earthquakes, with a **magnitude** of more than 8 on the **Richter Scale** (Fig. 27). Eleven earthquakes of moderate magnitude have been recorded in the area since that time. In addition to damage to man-made structures, these earthquakes have caused landslides or slumping, uplift and depression of the ground, and **fissuring** or splitting of the ground with extrusion of underlying sand and water through the cracks.

Figure 27.
Mississippi river valley during the 1811-1812 New Madrid earthquakes

Northeastern Arkansas is prone to earthquakes because of movement along faults. The faults in the New Madrid area are as old as the Precambrian and Cambrian periods when North America and Llanoria began to split apart. The New Madrid area dropped along faults to form a trough. These faults and the trough were reactivated again during the Cretaceous Period when the trough subsided to form the Mississippi Embayment of the Gulf of Mexico. The earthquakes are evidence that the land is continuing to move along faults in the New Madrid area.

The last 10,000 years of the Quaternary Period are referred to as the **Holocene Epoch**. During this interglacial stage the climate became warmer and the vegetation changed to plants that are suited to this climate. Large numbers of people emigrated to North America from Asia just prior to the beginning of the Holocene Epoch, about 11,000 to 12,000 years ago, by walking across the land which connected these two continents. This landbridge formed during a glacial stage when sea level was lower. During the Holocene Epoch people spread throughout North and South America. The oldest known human skeletal remains in Arkansas are from an Indian cemetery in the northeastern part of the state. These bones are 9,500 to 10,500 years old. Even older tools made by people have been found in many areas of the state, but because these peoples are so old we know little about them.

Shortly after the first humans arrived on this continent, many large mammals that roamed North America, such as **mammoth, mastodon**, and **saber tooth tiger**, became extinct (Fig. 28). This extinction may have

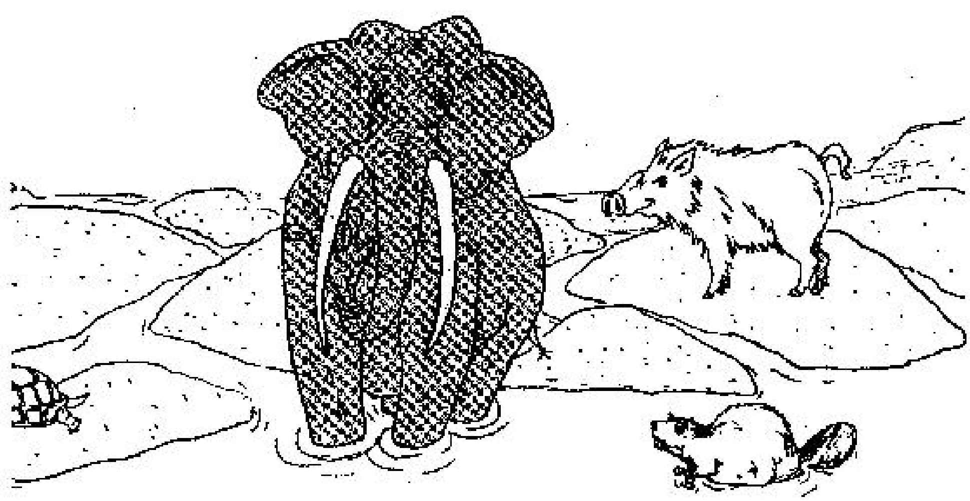


Figure 28.
Large Pleistocene animals which are now extinct

been hastened by man's hunting as people began to populate the Americas (Fig. 29) but the main cause was probably a change in climate and vegetation at the beginning of the Holocene Epoch. In summary, the appearance of man and the changing climate both had a great effect on North America during the last 11,000 years.

Figure 29.
Hunting theory of large mammel extinction in early Holocene

To survive, the early Indians in North America adapted to their environment, just as we have adapted to our environment. In Arkansas early Indians utilized the rich forests that occurred throughout the state (Fig. 30) and used the local chert to make their stone tools. They traveled in small groups and utilized rock overhangs for shelter (Fig. 31). Their diet included many different foods. This good nutrition and the general lack of communicable diseases resulted in a relatively healthy population.

Indians began to use their environment differently about 3,000 years ago when they developed agriculture. They cleared plots of land along the rivers to plant their crops. This change in culture also resulted in poorer health than during the previous 8,000 years. The increase in diseases occurred because the population became con-

Figure 30.
Native Americans gathering forest resources during the early and middle Holocene

centrated in small areas where diseases could spread and because diets became restricted to only a few food types that were consequently less nutritious.

However, agriculture did provide free time and allowed the development of art and religion. In more populated areas the people built mounds as both burial and ceremonial sites. The Toltec mounds in central Arkansas and the Spiro mounds in eastern Oklahoma were two larger centers for the Indians in Arkansas. The major ceremonial center of the entire southeastern region, including Arkansas, was at Cahokia in the present city of East St. Louis, Illinois. Today all of these sites are state parks. This was the culture that existed when Europeans discovered and began to explore North America in the 16th century.

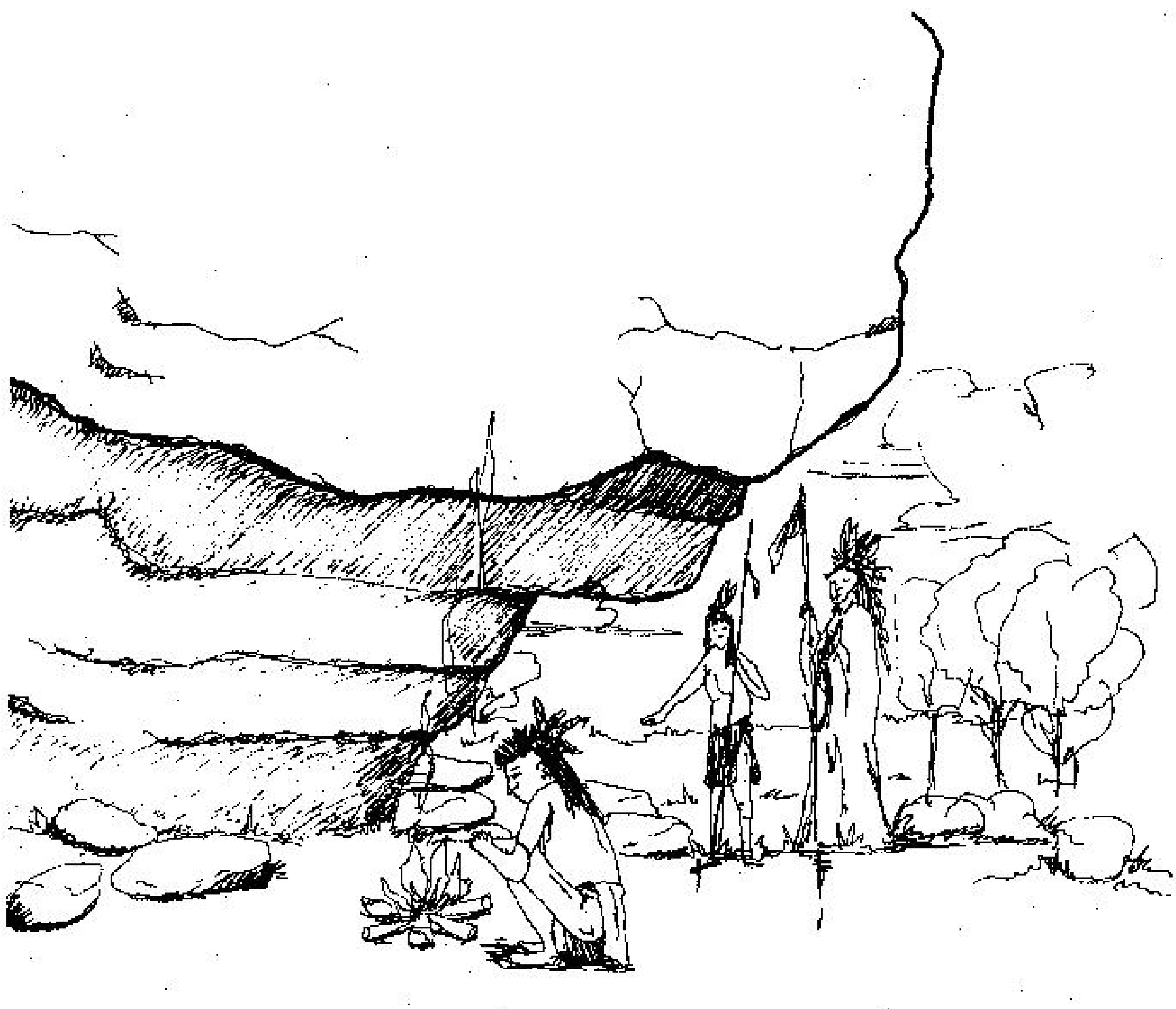


Figure 31.
Rock shelters were and are a favorite place for humans to seek shelter. They commonly preserve artifacts that would normally decay in the moist soil of Arkansas

GEOLOGIC DIVISIONS OF ARKANSAS

When you look at maps of Arkansas that show the stream patterns, or the roads, or the way the land is used, you will probably notice that there are obvious differences in the state. When you travel in Arkansas, these differences are easily seen. The mountains and pastures of northern and central Arkansas are quite different from the vast, flat farmland of eastern Arkansas, and both are different from the low rolling hills of pine forests in southern Arkansas. These various landscapes have natural differences, such as different rock, soil, topography, vegetation, and wildlife, and because of these variations, man has used these landscapes differently. Several areas are quite beautiful and are used for tourism, one area is primarily used for farmland, another for forestry, and some of the areas contain natural mineral resources with oil and gas wells, refineries, mines, and quarries.

Arkansas can be divided into five different divisions or physiographic provinces on the basis of its geology: the Ozarks, the Arkansas River Valley, the Ouachita Mountains, the Gulf Coastal Plain, and the Mississippi Alluvial Valley (Fig. 32). These divisions each have a different landscape determined by the type of rock that is present, the structure of the rock, and the weathering and erosion of the rock. The reason for these differences is the geologic history of the state, and in a larger sense of the continent, discussed in the previous section.

In this section we will summarize the geologic history and examine the type of geology that is present in each division. For more detail on this history and the natural resources associated with rocks of different ages, be sure to refer back to the previous section.

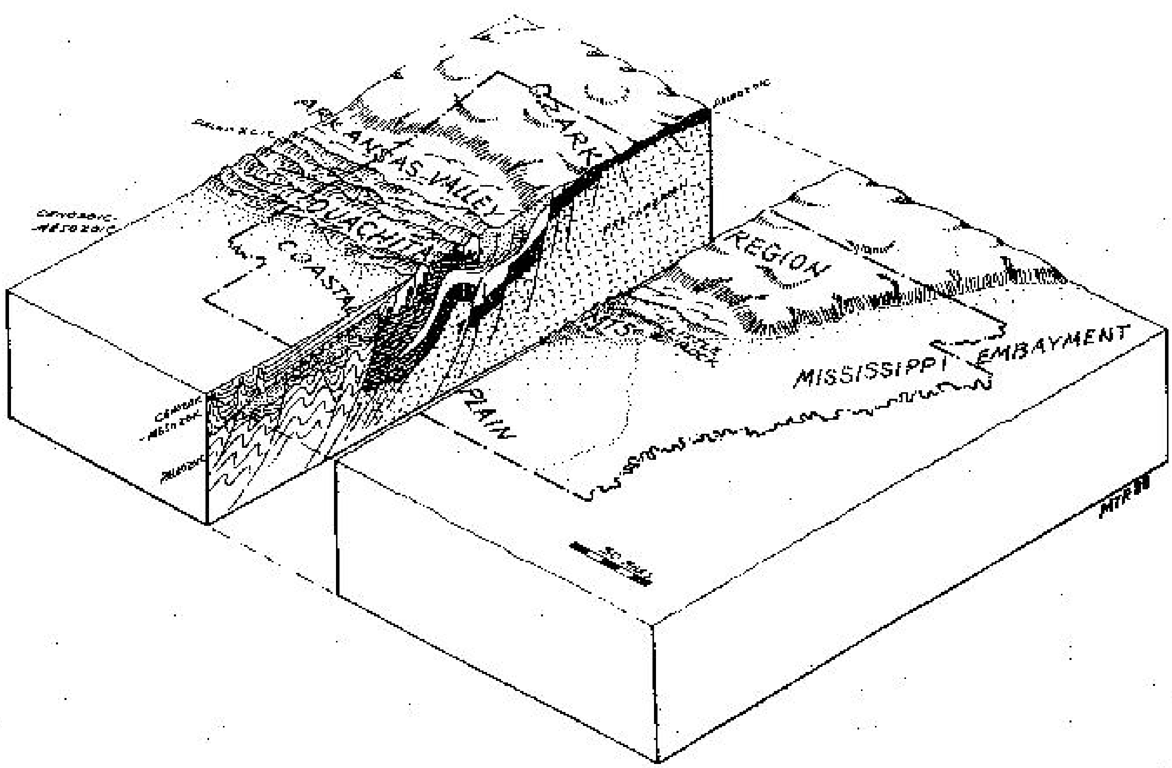
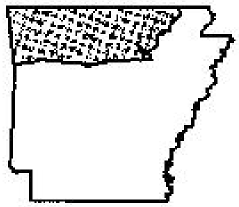


Figure 32.
Block diagram showing the geology of several divisions of Arkansas



THE OZARKS

The Ozark division extends across the north-central and northwestern part of the state and into the southern half of Missouri. This broad area is a **dome** where Precambrian igneous rock has been pushed upward (Fig. 32). It is surrounded by younger Paleozoic sedimentary rocks that dip very gently away from it. The central part of the dome is located in southeastern Missouri, and the surrounding Paleozoic rocks occur in Missouri and Arkansas.

In Arkansas most of the rocks in the Ozark region were deposited during the Ordovician, Mississippian, and Pennsylvanian periods. The rocks of Ordovician and Mississippian ages are mostly carbonates, deposited in the shallow sea that covered northern Arkansas through most of the Paleozoic Era. The Pennsylvanian rocks are mostly sandstone and shale that were deposited in deltas along the coastline of that shallow sea after northern Arkansas was lifted above sea level. These rocks were not strongly affected by the collision of Llanoria and Laurasia (North America), and they are nearly horizontal (Fig. 32).

The Ozark region has been above sea level and subject to weathering and erosion since the collision of the two continents at the end of the Paleozoic Era. The topography and **dendritic drainage** that have resulted from this weathering and erosion are due to the horizontal rocks in the area.

There are broad flat areas called **plateaus**. The Salem Plateau is the flat area that is underlain by the nearly horizontal, Ordovician-age carbonate rocks and is mostly in north-central Arkansas (Fig. 33). The Springfield Plateau is the flat area that is underlain by the nearly horizontal Mississippian-age carbonates and is in northwestern and north-central Arkansas. The Boston Mountain Plateau is the flat-topped mountains that are underlain by the nearly horizontal Pennsylvanian-age sandstones in central Arkansas. Streams have cut deep valleys into this plateau to form the erosional Boston Mountains.

Each of these plateaus is separated from the adjacent plateau by a steep slope. The towns of Eureka Springs, between the Salem and Springfield Plateaus, and Fayetteville, between the Springfield and Boston Mountain Plateaus, are located on two of these steep slopes.

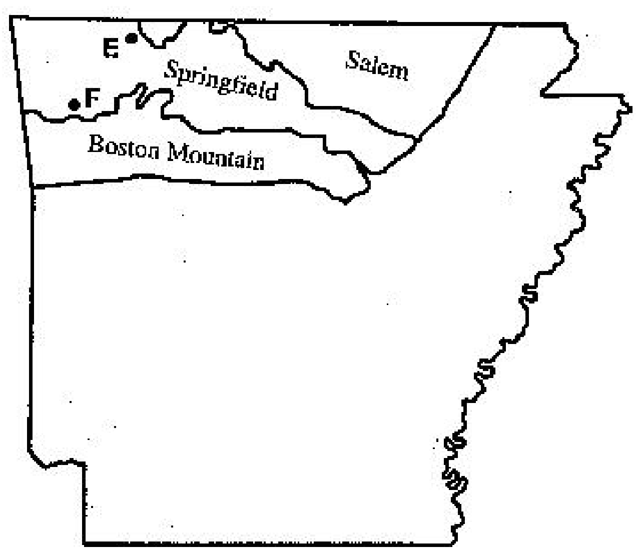
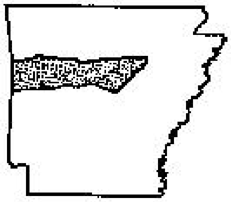


Figure 33.
Plateaus of the Ozark Region
E is Eureka Springs, F is Fayetteville

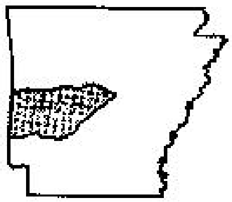


THE ARKANSAS RIVER VALLEY

The Arkansas River Valley is south of the Ozarks and extends across the west-central and central portions of the state along the Arkansas River. It includes both the river valley and a large area on both sides of the valley. This is a region of well developed, but not complex, **folds** that are oriented east-west (Fig. 32). These folds formed because the collision between Laurasia and Llanoria during the late Pennsylvanian and Permian periods compressed the rocks like ribbon candy.

These folded Paleozoic-age rocks in the Arkansas River Valley were originally horizontal layers deposited in the ocean basin. Prior to the Pennsylvanian Period the ocean basin in this area was relatively shallow, but probably near the outer part of the continental shelf. These rocks are predominantly carbonates and shale and are buried by the younger Pennsylvanian-age rocks. By the middle of the Pennsylvanian Period the ocean basin was becoming deeper, the land to east and north was becoming higher, and the continent to the south was getting closer so that very thick deposits of the sandstone and shale accumulated in this narrow ocean basin. Finally, the deep basin filled up with sediment and shallow-water and deltaic deposits spread over the area. All of these rocks, the shallow-water (pre-middle Pennsylvanian age), the deep-water and later the shallow water and deltaic (middle Pennsylvanian age) sediments were folded and uplifted when Laurasia and Llanoria finally began to collide in the late Pennsylvanian Period.

The Arkansas River Valley division has been above sea level and subject to weathering and erosion since the collision of the two continents at the end of the Paleozoic Era. The topography and **trellis drainage** that have resulted from this weathering and erosion are mostly caused by the folded structures in the area. These folds form long, narrow, east-west trending ridges of more resistant sandstone, such as Mt. Magazine, Pettit Jean, and Mt. Nebo. Between these ridges of more resistant rock is less resistant shale that erodes easily and forms broad valleys. The valley of the Arkansas River is also controlled by these folded rocks. Where the river flows through the resistant sandstone, the valley is very narrow, and where it flows through the less resistant shale the valley is very wide.

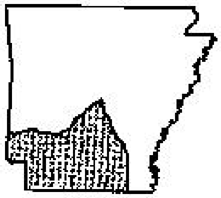


THE OUACHITA MOUNTAINS

The Ouachita Mountains are south of the Arkansas River Valley division and extend across the west-central and central portions of the state. This division contains complex folds and **thrust faults (reverse faults** that are nearly horizontal) which are generally oriented east-west (Fig. 32). These folds and faults formed because the collision of Llanoria with Laurasia during the late Pennsylvanian and Permian periods compressed the rocks. The structures that formed in the Ouachita Mountains are more complex than those in the Arkansas River Valley because the mountain area was closer to the impact of the two continents.

The rocks that were deformed are mostly Paleozoic-age sedimentary sandstone, shale, and chert deposited in a deep ocean basin. Small segments of the underlying basaltic igneous rock were also folded up into the Ouachita Mountains.

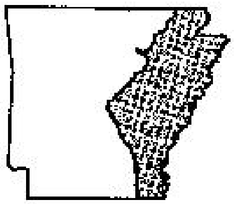
The Ouachita Mountain division has been above sea level and subject to weathering and erosion since the collision of the two continents at the end of the Paleozoic Era. The topography and trellis drainage that have resulted from this weathering and erosion are mostly determined by the folded structures in the area. These folds form long, narrow, east-west trending ridges of more resistant sandstone and chert and narrow, parallel valleys of less resistant shale. The folds and valleys are narrower than those in the Arkansas River Valley division because the rocks have been more tightly compressed.



THE GULF COASTAL PLAIN

The Gulf Coastal Plain is south of the Ouachita Mountain division and extends across southwestern and south-central Arkansas. In this region the rocks dip very slightly to the south (Fig. 32). Folds are absent, but a few **normal faults** are oriented east-west with the down-dropped block on the south side of the fault. These rocks were deposited in the shallow Gulf of Mexico and later in stream valleys. The Gulf covered the southern part of Arkansas beginning in the Cretaceous Period through the early Cenozoic Era. As the Gulf of Mexico shoreline receded to the south, rivers migrated across the entire coastal plain and deposited river sediment throughout southern Arkansas and Louisiana during the middle Cenozoic Era. All the rocks are poorly lithified and include evaporites, sandstone, and shale.

The Gulf Coastal Plain has been high enough above sea level that the streams eroded and have been restricted to distinct valleys since the middle Cenozoic Era. Between the valleys the bedrock has been subject to weathering and erosion. These dendritic streams have not been deeply eroded into this plain. The topography that results is one with low, rolling hills and wide stream valleys cut into easily eroded, horizontal sediments. Quaternary-age river sediments are present in the valleys.



THE MISSISSIPPI ALLUVIAL VALLEY

The Mississippi Alluvial Valley division, which extends along the eastern edge of the state, is commonly called the Delta. It is not a delta in a geologic sense. Instead of being a fan-shaped deposit of a river where it flows into the sea, it is a series of river deposits in a very wide valley (Fig. 32). These sediments are late Tertiary and Quaternary-age deposits of the Mississippi River, which dip very slightly to the south, the direction that the Mississippi river flows.

The topography in the Mississippi River Alluvial Valley has been developing during the Quaternary Period by deposition of river sediments, **eolian** sand dunes, and loess in various parts of the valley. These depositional landforms are different than the erosional landforms that dominate in the other divisions of Arkansas.

When the Mississippi River first formed it flowed in a wide, shallow valley and deposited sand and gravel in a series of channels that migrated across the valley. Later the river eroded more deeply into the Tertiary sediments along the west margin of the valley, and the Ohio River eroded more deeply into the Tertiary sediments along the east margin of the valley (Fig. 25). Crowley's Ridge, which is made up of Tertiary sediments overlain by Mississippi river gravels, was left as a **divide** between these two rivers. Both the Mississippi and the Ohio rivers deposited thick sand in their valleys when the glaciers to the north melted. Later the rivers eroded some of this sandy alluvium and formed a newer and lower **flood plain** in a portion of their valleys. The older and higher flood-plain surfaces that have been left are **terraces**. Because this downcutting has occurred several times there are several terraces, the highest terrace always being the oldest terrace. Finally the Mississippi River cut through Crowley's Ridge, joined the Ohio River at Cairo, Illinois, and began to flow down the eastern side of the Ridge as it does today.

Periodically the wind blew sand and dust from these valleys. The sand was moved a short distance from the channels and was deposited as sand dunes. The dust was lighter and could be blown greater distances. The dust was deposited as loess on Crowley's Ridge and on the older terraces (Fig. 26).

About ten thousand years ago, the Mississippi River switched from a **braided** river to the **meandering** river that forms the eastern boundary of Arkansas today. The river migrates rapidly by eroding on the outside of a river bend and depositing point bars on the inside of the river bend. Abundant oxbow lakes mark old positions of the channel that have been abandoned when the river cut through a narrow piece of land separating two meander bends. Some of these changes have occurred during historic time with the result that the state boundary is not exactly the same as the river. There are small areas of Arkansas that are east of the river and small areas of Tennessee, and Mississippi that are on the west side of the river because the river has suddenly changed position since the boundary was drawn.

CONCLUSION

As you can see, Arkansas has had a complex and long geologic history. It took 1.4 billion years for Arkansas to develop as we see it today. During this time, the area which we call Arkansas has been changed from land to sea and back again to land several times. It has changed its position on the globe and in the process has been pulled apart and smashed together, and pulled apart again due to plate tectonics. Through time organisms that lived on the land and in the seas of Arkansas and the world have changed by becoming more complex and diverse. Two times they experienced mass extinctions, and the subsequent development of even more complex and more diverse organsisms.

Arkansas has five very different areas that provide different topography, different rocks, different fossils, and different economic resources. It is our state to use wisely and to enjoy its abundant natural riches. Treasure them, for they took as long as 1.4 billion years to form!

APPENDIX 1: GEOLOGIC HISTORY OF ARKANSAS

ERA	AGE	PERIOD	OZARK PLATEAUS	ARKANSAS RIVER VALLEY	OUACHITA MOUNTAINS	GULF COASTAL PLAIN	MISSISSIPPI ALLUVIAL VALLEY
PRECAMBRIAN	1400 my		Silicic volcanic eruptions centered around the St. Francis Mountains, Missouri	?	?	?	?
			Weathering and erosion ↓	Weathering and erosion ↓	Development of rift grabens and beginning of a spreading center between Laurasia and Llanoria		Development of rift grabens and deposition of continental sand (sandstone)
	570 my	Cambrian	↓	↓	Shallow marine sedimentation of mud (shale) and carbonate		Cessation of rifting
	505 my	Ordovician	Slow, shallow marine carbonate and mud (shale) deposition on continental shelf with mature quartz sand (sandstone) deposition when land existed to north to provide sediment Many regional unconformities	Slow, shallow marine carbonate and mud (shale) deposition on continental shelf with mature quartz sand (sandstone) deposition when land existed to north to provide sediment Many regional unconformities	Slow abyssal ocean sedimentation of mud (shale) ↓		?
	438 my	Silurian	↓	↓	↓		
PALEOZOIC	408 my	Devonian	↓	↓	Slow, abyssal ocean sedimentation of silica (chert) and mud (shale) ↓		
	360 my	Mississippian	Slightly deeper, slow marine carbonate and mud (shale) deposition on outer continental shelf	Slightly deeper, slow marine carbonate and mud (shale) deposition on outer continental shelf	Rapid, deep, marine sedimentation of mud (shale)		
	320 my	Pennsylvanian	Uplift of land to north and east causing coastal and deltaic sedimentation of sand (sandstone) and mud (shale)	Uplift of land to north and east causing coastal and deltaic sedimentation of sand (sandstone) and mud (shale)	Rapid, deep, marine sedimentation of sand (sandstone) and mud (shale) in submarine fans ↓		
			Weathering and erosion ↓	Downward flexing of Laurasian continental shelf by Llanoria to form a foreland basin as these two continents begin to collide Deep marine sedimentation of sand (sandstone) and mud (shale) in submarine fans	↓		
			↓	Filling of foreland basin as collision of Laurasia and Llanoria is completed to form Pangea Minor folding and faulting Deltaic and coastal sedimentation of sand (sandstone), mud (shale), and some coal	Formation of the Ouachita Mountains and the supercontinent of Pangaea Intense folding and thrust faulting Quartz veining developed ↓		
			↓	Weathering and erosion	Weathering and erosion	Weathering and erosion	Weathering and erosion
	286 my	Permian	↓	↓	↓	↓	↓

APPENDIX 1: GEOLOGIC HISTORY OF ARKANSAS

ERA	AGE		PERIOD	OZARK PLATEAUS	ARKANSAS RIVER VALLEY	OUACHITA MOUNTAINS	GULF COASTAL PLAIN	MISSISSIPPI ALLUVIAL VALLEY
	245 my		Triassic	Weathering and erosion	Weathering and erosion	Weathering and erosion	Development of rift grabens as Pangaea splits up and South America separates from North America Deposition of continental sand (sandstone) in grabens	?
MESOZOIC	208 my		Jurassic				Continued rifting of North and South America Deposition of shallow marine carbonate and evaporites in the restricted basin of Gulf of Mexico	
	144 my		Cretaceous			Intrusion of alkalic igneous rocks along the border between the Mississippi Embayment and the Ozark-Arkansas River Valley-Ouachita Mountains Weathering and erosion	Intrusion of alkalic igneous rocks along the west border of Mississippi Embayment Gravel eroded from Ouachita Mountains and deposited in streams and beaches of the Gulf of Mexico Marine marl, chalk, clay, and sand deposited in the Gulf of Mexico	Renewed subsidence along Precambrian rift to form the Mississippi Embayment of the Gulf of Mexico Intrusion of alkalic igneous rocks along west border of Embayment Deposition of shallow marine clay and sand in the Embayment
	66 my		Paleocene				Sand and clay deposited in the shallow marine water of the Gulf of Mexico	Sand and clay deposited in the shallow marine water of Mississippi Embayment
	58 my		Eocene				Recession of Gulf of Mexico south of Arkansas Weathering and erosion	Recession of Gulf of Mexico south of Arkansas Weathering and erosion
	37 my	Tertiary	Oligocene					
	24 my		Miocene					
	5 my		Pliocene	Deposition of gravel as the modern drainage systems of region develop Weathering and erosion of uplands Development of caverns	Deposition of gravel as the modern drainage systems, including the Arkansas River, develop Weathering and erosion	Deposition of gravel as the modern drainage systems of region develop Weathering and erosion of uplands	Deposition of gravel as the modern drainage systems, including the Red River, develop Weathering and erosion of uplands	Deposition of gravel as the modern drainage systems, including the Mississippi River, develop
CENOZOIC	1.65 my		Pleistocene	Deposition of sand, silt, and clay and formation of terraces along rivers of region Air fills upper caverns as dissection occurs and water table drops Weathering and erosion of uplands Man appears and large mammals become extinct	Deposition of sand, silt, and clay and formation of terraces along rivers of region Weathering and erosion of uplands Man appears and large mammals become extinct	Deposition of sand, silt, and clay and formation of terraces along rivers of region Weathering and erosion of uplands Man appears and large mammals become extinct	Deposition of sand, silt, and clay and formation of terraces along rivers of region Weathering and erosion of uplands Man appears and large mammals become extinct	Deposition of gravel and sand in braided outwash channel of the Mississippi and Ohio rivers Formation of terraces and Crowley's Ridge Deposition of loess on terraces and Crowley's Ridge Man appears and large mammals become extinct
	0.01 my		Holocene	Formation of modern flood plains along rivers of region Air fills upper caverns as dissection occurs and water table drops Weathering and erosion of uplands Man begins farming	Formation of modern flood plains along rivers of region Weathering and erosion of uplands Man begins farming	Formation of modern flood plains along rivers of region Weathering and erosion of uplands Man begins farming	Formation of modern flood plains along rivers of region Weathering and erosion of uplands Man begins farming	Deposition of sand, silt, and clay in meandering channel of Mississippi River Reactivation of the Precambrian rift as New Madrid Seismic Zone Weathering and erosion of uplands Man begins farming

APPENDIX 2: GEOLOGIC DIVISIONS OF ARKANSAS

Geologic Province	Location	Rock Type	Fossils	Age	Environments of Deposition	Structural Setting	Plate Tectonics	Physiography
Ozark Plateaus	northern Arkansas	carbonates (limestone, dolomite), shale, sandstone, chert	abundant shallow marine invertebrates	Paleozoic (Ordovician to Pennsylvanian)	shallow-water marine and delta	nearly horizontal, few simple faults and folds	continental shelf (craton) and slope of passive plate margin	deeply dissected plateaus (Salem, Springfield, Boston Mountain) forming erosional mountains, dendritic and some rectangular drainage
Arkansas River Valley	central Arkansas along Arkansas River	shale, sandstone	scarce shallow to deep marine invertebrates	Late Paleozoic (Pennsylvanian)	delta and submarine fan	open folds (anticlines and synclines) normal and thrust faults	foreland basin	River valley, hills are "canoe-shaped" due to erosion of anticlines and synclines, trellis drainage
Ouachita Mountains	central Arkansas south of Arkansas River	shale, sandstone, chert	scarce deep marine invertebrates	Paleozoic (Cambrian to Pennsylvanian)	abyssal marine and submarine fan	complex folds, thrust faults	collision boundary between Laurasia and Llanoria	low, complexly folded linear and zigzag mountains, trellis drainage
Gulf Coastal Plain	southern Arkansas	sand, silt, clay, gravel, lignite, syenite, alkalic igneous	abundant shallow marine and terrestrial vertebrates and invertebrates, plant fossils, insects	Late Mesozoic to Early Tertiary (Cretaceous to Eocene)	shallow-water marine, coastal plain streams and deltas	gently dipping south, normal faults	continental shelf of passive plate margin	low dissection of plains by dendritic drainage
Mississippi Alluvial Valley	eastern Arkansas	sand, silt, clay, gravel	scarce terrestrial vertebrates	Late Tertiary (Pliocene to Holocene)	alluvial and loessial	horizontal	intraplate	meandering streams with wide flood plains and terraces

GLOSSARY

Alloy A substance with metallic properties which is comprised of two or more elements. A least one of the combined elements must be metallic.

Alluvial fan A fan-shaped deposit of sediment deposited by a river where the river slope is abruptly reduced, the width of the river valley is abruptly widened, or near the confluence of a tributary stream with a main stream.

Alluvium Unconsolidated sediment deposited by a stream.

Amphibians A class of four-legged, cold-blooded vertebrates. Many amphibians have an aquatic larval phase and a partial or completely terrestrial adult phase.

Angiosperms Flowering vascular plants which produce seeds enclosed in ovaries.

Anticline Linear upfolded rocks with the oldest rocks in the center of the fold. It is the opposite of a syncline.

Arkansas River Valley Region A geologic region of Arkansas in the west-central part of the state and to the west in Oklahoma. It is a transitional between the intensely deformed rocks in the Ouachita Mountains to the south and the nearly undeformed rock in the Ozark Plateaus Province to the north. The late Paleozoic rocks in the region are somewhat deformed. Long ridges of resistant rock approximately parallel the Arkansas River. Some of the flat area between the ridges has been cleared for farm and pasture land.

Atmosphere The gaseous portion of the planet, which is mostly oxygen and nitrogen, with some argon and carbon dioxide.

Baltica An ancient Paleozoic continent that included most of the present continent of Europe and Asia.

Barite A sulfate mineral comprised of barium, sulfur, and oxygen.

Barium An element with an atomic number of 56. Its abbreviation is Ba.

Bauxite Aluminum ore formed by intense weathering of aluminum-rich rocks.

Biosphere The living organisms of the planet. They may reside in the lithosphere, the hydrosphere, or the atmosphere.

Braided river A river with many channels that intertwine by merging and separating. The channels are separated by elongate islands or bars. These channels resemble a complex braid.

Bromine An element with an atomic number of 35. Its abbreviation is Br.

Caldera A very large volcanic depression formed by collapse of the volcano after an eruption.

Cambrian Period A subdivision of the Paleozoic Era of geologic time. The Cambrian Period lasted from 570 million years ago to 505 million years ago.

Carbon dioxide A compound of one part carbon and 2 parts oxygen that is common in the earth's atmosphere. It is exhaled by most animals and used by most plants.

Carbonate rock A group of sedimentary rocks comprised chiefly of carbonate minerals such as calcite and dolomite. It is formed by organic or inorganic precipitation of carbonates from water. The most common rocks are limestone and dolomite or dolostone.

Cave A naturally-formed underground chamber or series of chambers that are large enough for a human to move through. Caves are most commonly produced by solution of soluble rock such as limestone, dolomite, and evaporites.

Cenozoic Era A division of geologic time from 66 million years ago until today when "new" or modern life forms existed.

Chalk A soft, porous, usually white limestone made up of calcite shells from floating marine organisms.

Chert A sedimentary rock that is comprised of very dense and very finely crystalline quartz. It has conchoidal fracture and can be used to make arrowheads, axes, etc.

Clay A grain that has a maximum diameter of 0.002 mm.

Clay mineral A group of hydrous alumina silicate minerals with a platy structure. Generally these minerals are clay size.

Coal A combustible rock that is mostly carbonaceous material derived from plant remains.

Continental shelf The submerged gently sloping ($<3°$) margin of the continent. It occurs between the shoreline and the continental slope.

Continental slope The submerged steep (3-6°) slope at the edge of the continent. It separates the continental shelf from the deep ocean basin.

Cretaceous Period A subdivision of the Mesozoic Era of geologic time. The Cretaceous Period lasted from 144 million years ago to 66 million years ago.

Crowley's Ridge A linear hill that rises about 50 meters above the level of the surrounding Mississippi Alluvial Valley in eastern Arkansas. The ridge extends from the Arkansas-Missouri state line south to Helena, Arkansas.

Delta Sediment deposited near the confluence of a river and a standing body of water, such as the ocean or a lake. A delta generally is a triangular or fan-shaped deposit that is partly submerged and partly above water.

Dendritic drainage A stream system that resembles the pattern of a branching tree. This pattern occurs here the streams have developed on horizontal rocks.

Devonian Period A subdivision of the Paleozoic Era of geologic time. The Devonian Period lasted from 408 million years ago to 360 million years ago.

Dinosaur Nickname for two extinct groups of terrestrial reptiles that had two openings behind the eye and had hips like a bird or hips like a lizard, but didn't fly or live in the ocean. Dinosaurs lived during the Mesozoic Era. The name means "terrible lizard" but they were misnamed because none of them were lizards and not all of them were terrible.

Divide An imaginary line that usually corresponds to a ridge and separates two adjacent streams. All surface water on one side of the divide will flow to the stream on the same side of the divide.

Dome Circular or elliptical upfolded rocks with the oldest rocks in the center of the fold. The rocks dip away from the center in all directions. It is the opposite of a basin.

Earthquake Vibration of the earth produced by a rapid release of energy due to faulting or volcanic activity.

Embayment A bay or indentation of the shoreline that forms where water covers the low area near the mouth of a river.

Eolian Pertaining to the wind.

Erosion Transportation of rock and/or sediment across the earth's surface.

Evaporite A sedimentary rock formed by precipitation of minerals from solution as water evaporates.

Evolution The theory that the earth's life has developed gradually from one or a few simple organisms to many more complex organisms.

Extinction The death of all the individuals of a single subdivision of life, such as a species or genera.

Fault A fracture in rock along which there has been movement.

Fissuring Fracturing or cracking of the ground along which there is distinct separation.

Flood plain The flat, low-lying land adjacent to a stream channel that is frequently covered with flood water.

Folds Bent rocks due to deformation of the original horizontal rock layers.

Fossils Remains, traces, or imprints of organisms that lived in the past.

Gabbro A dark-colored, coarsely crystalline igneous rock that cooled slowly beneath the earth's surface. It is relatively low in silica and high in calcium, iron, and magnesium.

Galena An economic mineral comprised of lead and sulfur. It is mined for lead.

Glacial Stage A subdivision of a generally cool-climate interval (Ice Age) when glaciers were common.

Glacier A large mass of ice that forms at least in part on land from the compaction of snow that survives from year to year. This ice slowly moves or flows downslope under its own weight.

Gondwana An ancient late Paleozoic and early Mesozoic continent that included all the continents and subcontinents of the southern hemisphere: South America, Africa, Antarctica, Australia, and India.

Granite A coarsely crystalline igneous rock with abundant quartz that formed deep beneath the earth's surface.

Great Plains A generally flat plain that extends from the Rio Grande River in Texas north to the Arctic Circle and from the Rocky Mountains east to central North and South Dakota, Nebraska, Kansas, Oklahoma, and Texas.

Gulf Coastal Plain Region A geologic region in the south-central and southwestern part of the state, to the south in Louisiana, the southwest in Texas, and to the west in Oklahoma. The late Mesozoic and early Cenozoic rocks are nearly horizontal and generally not consolidated to form rock yet. The area has low rolling hills covered with pine forests. Some of the area has been cleared for farm and pasture land.

Gypsum An economic mineral comprised of calcium, sulfur, and oxygen. It is mined to make sheet rock and for agricultural lime.

Holocene Epoch A subdivision of the Quaternary Period. The Holocene Epoch lasted from 10,000 years ago until today.

Hydrosphere The water of the planet, including the oceans, rivers, lakes, glaciers, ice, and groundwater. It does not include water in the atmosphere.

Iapetus An ancient ocean basin that existed during the Paleozoic and separated the ancient continents of Laurentia and Baltica. It was in the approximate position of the modern north Atlantic Ocean.

Igneous Rock A rock that has formed from cooling and crystallization of molten material.

Interglacial stage A subdivision of a generally cool-climate interval (Ice Age) when the climate is relatively warm, similar to or warmer than that of today. Glaciers are not as dominant as in a glacial stage. We are living in an interglacial stage.

Intrusion The emplacement of magma in previously existing rock.

Jurassic Period A subdivision of the Mesozoic Era of geologic time. The Jurassic Period lasted from 208 million years ago to 144 million years ago.

Invertebrates Animals without a segmented spinal column or a notochord.

Landslide Moderately rapid to rapid movement of rock, sediment, and/or soil downslope en masse. It is due to the force of gravity on the material.

Laurasia An ancient Paleozoic continent that included most of the present continents of North America, Greenland, Europe, and Asia. This continent formed due to the collision of Laurentia and Baltica.

Laurentia An ancient Paleozoic continent that included the most of the present continents of North America and Greenland.

Law of Superposition A law which states that where rocks are undeformed by folding and faulting, each bed of sedimentary or extrusive igneous rock is older than the layer above it and younger than the layer below it.

Leach The removal of more soluble materials from the upper part of the soil by dissolving them in water as it moves downward through the soil.

Lead An element with an atomic number of 82. Its abbreviation is Pb.

Lignite A brownish-black relatively low-rank coal that is between peat and bituminous coal.

Limestone A sedimentary rock mostly comprised of the mineral calcite.

Lithosphere The outer rigid layer of the earth, including all of the crust and the upper part of the mantle.

Loess Wind-blown silt derived from deserts, outwash plains, or alluvial valleys and deposited as a blanket across adjacent vegetated areas.

Magma Molten rock present beneath the earth's surface that may include some dissolved gasses and suspended mineral crystals.

Magnitude A measure of the total amount of energy released during an earthquake. It is determined using a seismograph.

Mammals A class of warm-blooded vertebrates with body hair that produce milk for their offspring.

Mammoths All extinct elephants. They were grazers with teeth designed for grinding.

Manganese An element with an atomic number of 25. Its abbreviation is Mn.

Mastodons Large extinct mammals, similar to mammoths, but were slightly smaller than mammoths and were browsers instead of a grazers.

Meandering river A river channel with sinuous curves or loop-like bends.

Mesozoic Era A division of geologic time from 245 million years ago until 66 million years ago when "middle" life forms existed.

Metamorphic Rock A rock derived from a previously existing rock. It is formed by alteration in the solid state due to changes in temperature, pressure, and/or chemically active fluids.

Meteorite An interplanetary object that strikes the earth's surface.

Milankovitch Theory An astronomical theory of glaciation. This theory explains climatic change as a result of different amounts of incoming solar radiation to different areas of the earth. The changing amount of incoming radiation in an area is due to variations in the earth's inclination and its orbit around the sun.

Mississippi Alluvial Valley Region A geologic region of Arkansas located in the eastern part of the state, to the north in Missouri, to the east in Tennessee and Mississippi, and to the south in Louisiana. The area is underlain by late Cenozoic sediment of the Mississippi River and its tributaries. Its broad, flat surfaces and fertile soils make it excellent farmland.

Mississippian Period A subdivision of the Paleozoic Era of geologic time. The Mississippian Period lasted from 360 million years ago to 320 million years ago.

Molluscs A class of invertebrates with a nonsegmented symmetrical body and a symmetrical mantle or shell. Snails, clams, squids, octopus, and the pearly nautilus are molluscs.

New Madrid Seismic Zone An earthquake region centered around New Madrid, Missouri, which includes northeastern Arkansas. Surface deformation and faults are rare in the area.

Nitrogen An element with an atomic number of 7. Its abbreviation is N. It is a common gas in the atmosphere.

Normal fault A fault where the rock or sediment above the fault plane moves down in relation to the sediment or rock below the fault plane.

Novaculite slightly metamorphosed chert which is very dense, hard, and finely crystalline. The term is most commonly used in Arkansas and Oklahoma.

Ordovician Period A subdivision of the Paleozoic Era of geologic time. The Ordovician Period lasted from 505 million years ago to 438 million years ago.

Ouachita Mountains Region A geologic region of Arkansas located in the west-central part of the state and to the west in Oklahoma. In this region Paleozoic rocks are intensely folded and faulted due to the collision of two continents during the late Paleozoic. This mountainous area is forested.

Outwash Sediment derived from a glacier and deposited beyond the glacier by streams of meltwater.

Oxygen An element with an atomic number of 8. It is a common gas in the atmosphere and comprises about half of the earth's crust.

Ozark Plateaus Region A geologic region of Arkansas located in the north-central and northwestern part of the state, to the north in Missouri, and to the west in Oklahoma. In this region Paleozoic rocks have not been deformed and are horizontal. They underlie several different levels or plateaus in the region, which are naturally forested. Much of this province has been converted to farm and pasture land.

Paleogeography The geography of the past, including the location of the continents, ocean basins, mountains, and shorelines.

Paleozoic Era A division of geologic time from 570 million years ago until 245 million years ago when "old" life forms with hard parts existed.

Pangaea An ancient late Paleozoic Era continent that included most, if not all, of the continental land masses. Pangaea began to break apart during the early Mesozoic Era into the present continents.

Pennsylvanian Period A subdivision of the Paleozoic Era of geologic time. The Pennsylvanian Period lasted from 320 million years ago to 286 million years ago.

Permian Period A subdivision of the Paleozoic Era of geologic time. The Permian Period lasted from 286 million years ago to 245 million years ago.

Plate Tectonic Theory The theory that the earth's outer shell, the lithosphere, is broken into smaller plates. These lithospheric plates move in various ways, causing earthquakes, volcanoes, the movement of the continents, the formation and destruction of the oceans basins, and the formation of mountains.

Plateau A broad flat area of high elevation.

Precambrian Era A division of geologic time from the beginning of the earth about 4.6 billion years ago until 570 million years ago. Though life was present during part of this era, most organisms did not have hard parts and were not easily fossilized.

Quartz A very common mineral in the earth's crust. Quartz is comprised of one part silicon and two parts oxygen.

Quaternary Period A subdivision of the Cenozoic Era of geologic time. The Quaternary Period lasted from 1.65 million years ago to the present.

Refractory Heat-resistant, nonmetallic, ceramic materials, such as bricks. These materials can be used in furnaces where heat would destroy common ceramic materials.

Reptiles A class of cold-blooded, commonly terrestrial vertebrates, that have scaly skin and lungs for breathing.

Reverse fault A fault where the rock or sediment above the fault plane moves up in relation to the sediment or rock below the fault plane.

Rhyolite A volcanic igneous rock with abundant quartz.

Richter Scale A numerical scale of earthquake magnitude based on the motion of a seismograph.

Rift zone A linear area along which spreading of the earth's crust occurs.

Rip rap A wall of stones without order placed in deep water or on an embankment slope to prevent erosion.

Saber tooth tiger An extinct carnivore (meat eater) of the cat family that was the size of a lion and had two huge saber-shaped teeth.

Sand A grain or rock fragment that has a diameter between 0.5-2 mm.

Sandstone A siliceous sedimentary rock comprised of sand-sized (0.5-2 mm) mineral grains (most commonly quartz) or rock fragments that have been cemented together.

Sea-floor spreading A hypothesis that oceanic crust is formed by upwelling of magma along ridges or rifts. The new oceanic crust splits and moves apart at a slow rate (cm per year), enlarging the ocean basin. This hypothesis has been incorporated into and is part of the theory of plate tectonics.

Sediment Unconsolidated particles, inorganic or organic, created by weathering of previously existing rock, precipitation from solution, or secretion by organisms. These particles are transported and deposited by air, water, or glacial ice.

Sedimentary rock A rock formed from weathering products of previously existing rock. The previously existing rock fragments may be: 1) transported, deposited, and lithified (i.e. sandstone), 2) precipitated from solution (i.e. limestone), or 3) consist of the remains of plants and animals (i.e. coal).

Seismic area An earthquake zone.

Serpentine A group of siliceous minerals with a greasy luster and slightly soapy feel. They are formed by altering magnesium-rich siliceous minerals and rocks such gabbro.

Shale A sedimentary rock mostly comprised of small (<0.002 mm) mineral grains that are most commonly clay minerals. These grains have been compressed or cemented together.

Silica An element with an atomic number of 14. Its abbreviation is Si. Silica comprises about a quarter of the earth's crust.

Siliceous A material that contains abundant silica.

Silurian Period A subdivision of the Paleozoic Era of geologic time. The Silurian Period lasted from 438 million years ago to 408 million years ago.

Soapstone A common name for the mineral talc.

Solar radiation (energy) from the sun by electromagnetic waves. This requires no carrier and the heat can be transferred through a vacuum.

Sphalerite An economic mineral comprised of equal amounts of sulfur and zinc. It is mined for zinc.

Spreading center A region in the earth's crust along which divergence of two or more lithospheric plates is occurring.

Stalactite A conical or cylindrical-shaped mineral deposit, usually of calcium carbonate, that forms on the ceiling of a cave by dripping water.

Stalagmite A conical-shaped mineral deposit, usually of calcium carbonate, that develops upward where dripping water falls on the floor of a cave.

Subduction Zone A long, narrow region where one lithospheric plate descends beneath another lithospheric plate.

Submarine canyon gully eroded into the edge of a continental shelf and the adjacent continental slope by turbidity currents.

Submarine fan A cone or fan-shaped deposit of sediment deposited below sea level by turbidity currents at the mouth of a submarine canyon.

Sulfur An element with an atomic number of 16. Its abbreviation is S.

Syenite A coarsely crystalline igneous rock that is similar to granite. It has abundant silica and formed deep beneath the earth's crust. Unlike granite, syenite does not have abundant quartz.

Syncline Linear downfolded rocks with the youngest rocks in the center of the fold. It is opposite of an anticline.

Terrace A long, narrow, nearly flat surface within a stream valley. A terrace is a former flood plain but is rarely covered by floodwater any longer because the stream has cut downward and developed a new, lower flood plain.

Tertiary Period A subdivision of the Cenozoic Era of geologic time. The Tertiary Period lasted from 66 million years ago to 1.65 million years ago.

Thrust fault A low angle (<45°) reverse fault.

Trellis drainage A stream system that has nearly parallel streams with tributaries that join them at right angles. This system resembles the pattern of a vine on a trellis. It forms in areas where the rocks are folded into anticlines and synclines.

Triassic Period A subdivision of the Mesozoic Era of geologic time. The Triassic Period lasted from 245 million years ago to 208 million years ago.

Turbidity current A movement down a submarine canyon of dense sediment-laden water that flows underneath less-dense clear water.

Unconformity An interruption in the geologic rock record caused by erosion or nondeposition.

Vanadium A metallic element with an atomic number of 23. Its abbreviation is V.

Vertebrates A subdivision of animals with a segmented spinal column or a notochord.

Volcanic ash Small (< 4 mm), solid material erupted from a volcano.

Volcanic glass Solid material erupted from a volcano that formed from very rapid cooling of lava or magma.

Volcanos A vent at the earth's surface where gases, liquids (lava), and solids (bombs, cinders, and ash) erupt. The liquids and solids collect around the vent, commonly building a hill or mountain.

Weathering The decomposition and disintegration of rock or sediment near or at the earth's surface by physical and chemical changes.

Zinc An element with an atomic number of 30. Its abbreviation is Zn.

References

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