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OKLAHOMA ROCKS!

WHAT LIES BENEATH

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OKLAHOMA ROCKS! Welcome 2014

I hope you will enjoy reading this publication that will focus on Oklahoma's geologic past and what lies beneath what we see on the surface! This state's rich geologic history spans some 1.6 billion years, and has provided us with the great variety of geography and scenery we see today: The high mesas, caves, and red rocks of the northwest; the Wichita and Arbuckle Mountains and Turner Falls of the south and southwest; the beautiful Ouachita mountains and forests of the southeast; and the rolling plains and Ozark hills of the north and northeast. Few other states, and certainly none our size, can boast of going from cypress swamps to high mesas!

Beneath what is now Oklahoma, continents once came together then broke apart; land masses moved and collided; shallow seas came and went; rocks were folded, faulted, uplifted and eroded and great changes (sometimes rapidly in geologic time, and seemingly forever in human years) came about. These movements formed the Anadarko basin (now filled in), that at one time was deeper than the Marianas Trench, which is today's deepest ocean feature and is more than 7 miles deep. Some of the ancient rock masses that were tilted, faulted, and folded can now be seen at the surface in the Arbuckle Mountains. The I-35 road cuts through these mountains make it possible to see dramatic evidence of these geologic movements as we travel that stretch of road. These now visible features are so unique that geologists from around the world have stopped to get a look.

Our geologic past also is responsible for Oklahoma's rich natural resources of oil, gas, coal, and the aquifers that supply much of the state's water, as well as the gypsum, sand, gravel, shale, and granite deposits that supply building materials for us. Oklahoma is an amazing place for geological study, and we hope this publication will help you learn more about what lies beneath and encourage you to explore further to understand this great state and it's fascinating past!

Dr. G. Randy Keller

Director, Oklahoma Geological Survey

CREDITS: The content for this program was developed by the Oklahoma Geological Survey. Special acknowledgments go to Dr. G. Randy Keller, OGS director; Connie G. Smith, project coordinator; James H. Anderson, graphics.

Oklahoma Geology: When Did That Happen?

Oklahoma has a very rich geologic history that spans about 1.6 billion years, which is a vast amount of time. The upper part of the lithospheric plate (the crust) of Oklahoma formed at that time and is about 25 miles thick (Figure 1).

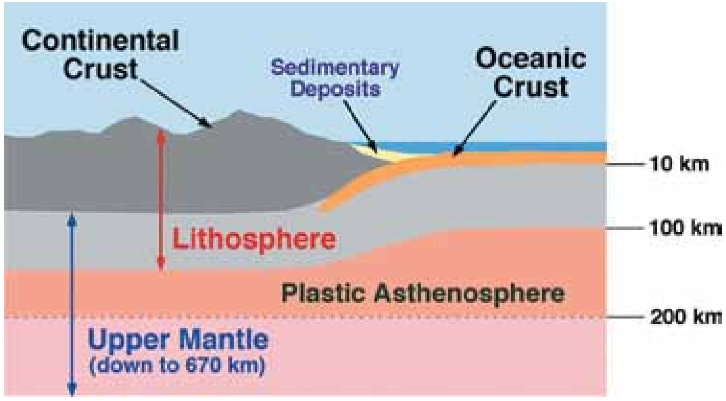


Figure 1. Diagram showing cross section of the earth's crust. Pidwirny, M. (2006).

The lower part of the lithospheric plate (the uppermost mantle) is about 50 miles thick. The lithospheric (tectonic) plates move around the earth at a rate of about 2.5 centimeters (about 1 inch) per year, which is about the rate that your fingernails grow. Geologic activities such as mountain building, faulting, and volcanism occur primarily along plate boundaries, where two or more plates interact with one another.

Oklahoma has had a complex geologic history since the formation of the crust, with several notable events and dramatic changes that produced some of the largest geologic structures in North America.

The first significant event was the thinning and breaking-up of the tectonic plate, which is known as rifting. Rifting resulted in the formation of a rift zone that extended from the Great Lakes area southward across Iowa, Kansas, and into Oklahoma. This rift was not able to completely break this area of North America apart, but some of the faults that extend through central Oklahoma today are thought to have formed at this time.

After rifting ended, small tectonic plates began colliding and attaching themselves to North America, in a process called accretion. This occurred for hundreds of millions of years.

About 600 million years ago, the tectonic plate containing Oklahoma started to break apart again, and the part that is now East Texas, southern Arkansas, and Louisiana broke off of ancient North America. The timing of this event is known from studying fossils in rocks. Many geologists believe that one piece of the rifted area is now a part of the eastern Andes Mountains of Argentina!

At the same time these pieces were breaking off, another rift zone formed that extended across southern Oklahoma, reaching at least as far northwest as southern Colorado. This rift zone probably looked much like the present day Great Rift Valley of East Africa (Figure 2) and involved a lot of deep volcanic activity. This rifting created a large basin (shaded area in Figure 3), as well as the igneous rocks now exposed in the Wichita and Arbuckle Mountains.

Figure 2. The continents 340 million years ago. Map by Ron Blakey, Colorado Plateau Geosystems, Inc.

We cannot be sure how much sedimentary and volcanic rock filled the rift because much of the area was eroded away when it was uplifted at a later time. However, based on studies of the East African Rift, 10,000 feet is a reasonable estimate.

About 300 million years ago, a major plate collision occurred in southwestern Oklahoma. This collision caused the uplift and intense faulting and folding of rocks in southern Oklahoma and produced the Wichita, Arbuckle, and Ouachita Mountains (Figure 3).

Figure 3. The continents 300 million year ago. Map by Ron Blakey, Colorado Plateau Geosystems, Inc.

Back in their day, these mountains were similar to the Rocky Mountains of today, which stretch across Wyoming, Colorado, and New Mexico. Spectacular evidence of faulting caused by this event is perfectly exposed along highway I-35 from the Turner Falls area southward across the Arbuckle Mountains (Figure 4).

Deep basins formed along these uplifted regions, with some parts of the basins obtaining depths of almost 10 miles!

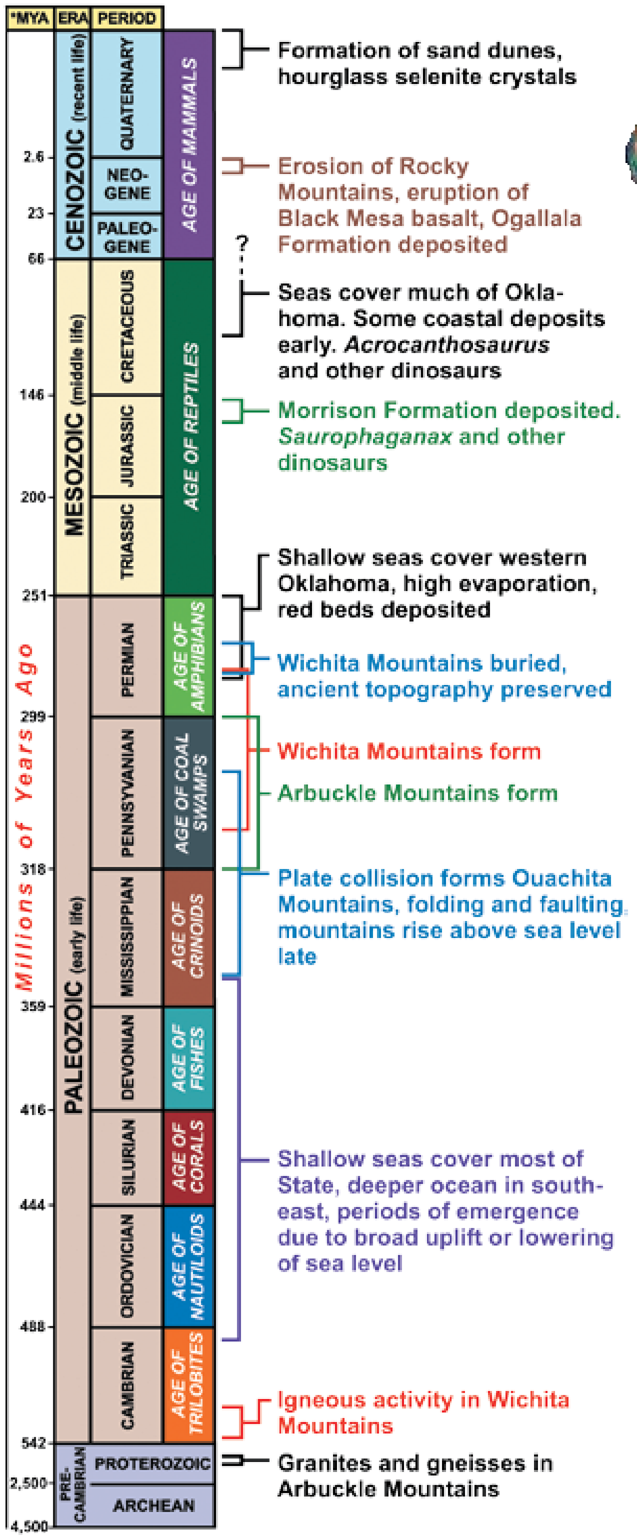
Figure 4. Exposed limestone along I-35 near Turner Falls.

The Anadarko Basin is one of the deepest in the world, and the Arkoma Basin is nearly as deep (Figure 5). Basin depths have been estimated from (1) seismic reflection surveys, which produce data similar to an ultrasound image at the doctor's office; (2) extremely precise measurements of the Earth's gravity field, which indicate if a rock is heavy and dense like a granite or light like a sandstone; and (3) deep drill holes, which let us see different layers of the crust, similar to viewing a cut piece of layered cake.

Over time, the basins were filled with many 1000's of feet of sedimentary rocks (primarily sandstone, shale, and limestone). These rocks were deposited in shallow seas that covered most of Oklahoma. They hold most of Oklahoma's oil and gas, which are the main drivers for Oklahoma's economy.

Figure 5. Map showing geologic provinces of Oklahoma.

OKLAHOMA GEOLOGY: When Did That Happen?



*Millions of years ago.

During parts of the Mesozoic Era (~250-66 million years ago) much of the southeast corner of Oklahoma was covered by a shallow sea, and dinosaurs roamed the area.

Dinosaurs are a diverse group of animals that first appeared during the Triassic Period (~250 million years ago). They were the dominant terrestrial vertebrates from the beginning of the Jurassic Period (~200 million years ago) until the end of the Cretaceous Period (~66 million years ago). At the end of the Cretaceous Period, most dinosaur groups became extinct.

The fossil record indicates that birds evolved from theropod dinosaurs during the Jurassic Period and, consequently, they are considered a subgroup of dinosaurs by many paleontologists. Some birds survived the extinction event that occurred 66 million years ago, and their descendants continue the dinosaur lineage to the present day.

Most recently, Oklahoma existed in a terrestrial environment that was carved out by ancient rivers and formed the landscape we see today.

The Southern Oklahoma Aulacogen: Oklahoma's Classic Geologic Structure

Southern Oklahoma has long been recognized as the home to a series of very large geologic structures (Figure 1) that were part of a rift zone that in essence tried to separate Oklahoma from Texas about 600 million years ago. The result was that large volumes of dense volcanic rock intruded the crust along the rift. The cooling of these rocks formed a broad geologic basin in which the limestones of the famous Arbuckle Group were deposited. These rocks can be seen along I-35 near the Turner Falls area (Figures 1 and 2).

Figure 2. Lower Kindblade Limestone in western Arbuckles.

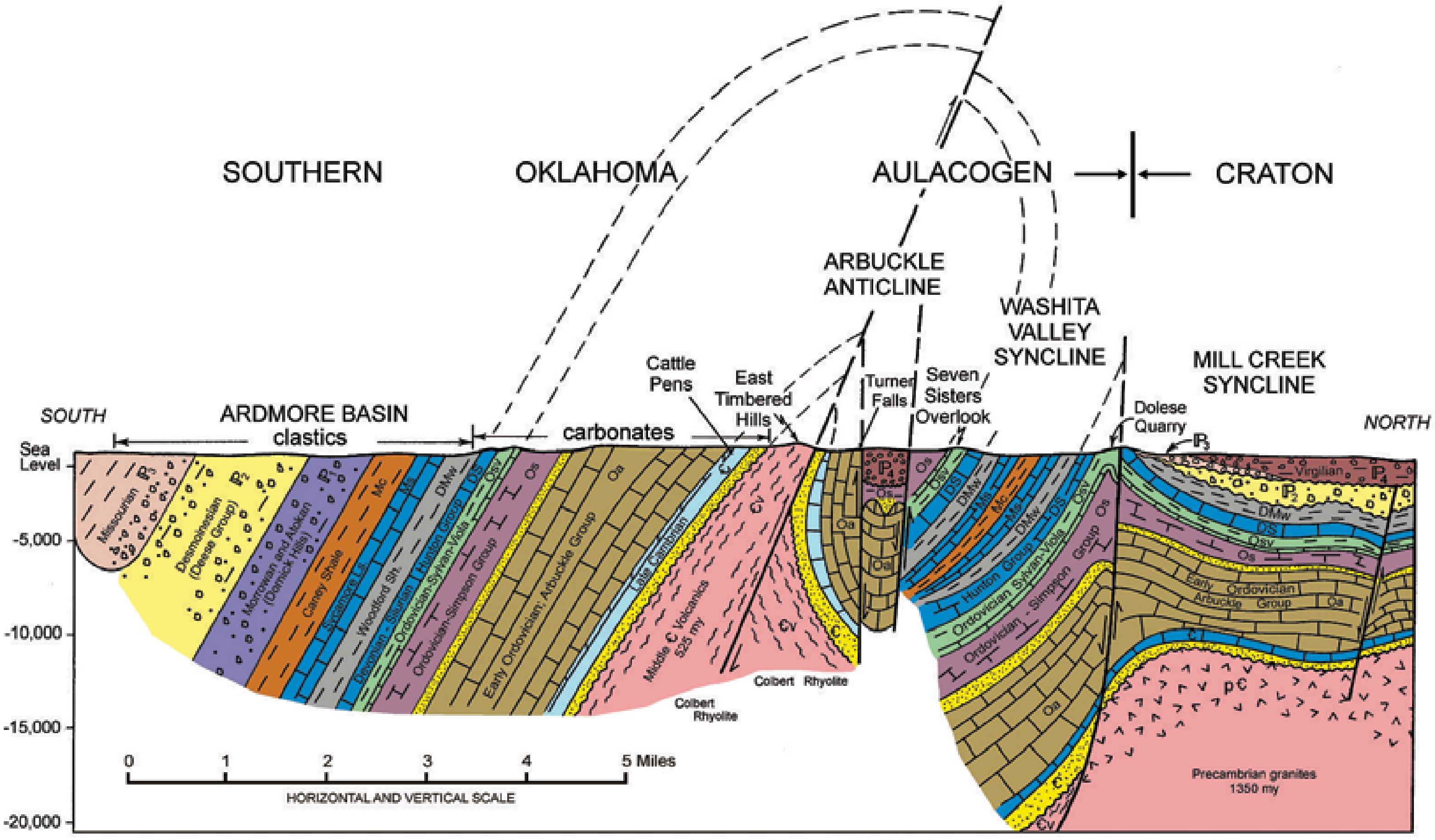


Figure 1. South to north structural cross section of Arbuckle Mountains in the vicinity of Interstate 35

Later, about 300 million years ago, there was a collision of tectonic plates to the south that turned the basin inside out. You can see some of the evidence of this in the Arbuckle Mountains, where the layered Arbuckle Group rocks are standing nearly vertical (Figure 3).

Figure 3. Viola Limestone along the I-35 roadcut. This is the deepest cut in the Arbuckle Mountains, with a vertical span of 156 feet, Murray County.

Horizontal slippage along old rift faults also occurred during this time. Today, the resulting features are together referred to as the Southern Oklahoma Aulacogen (SOA), (Figure 4).

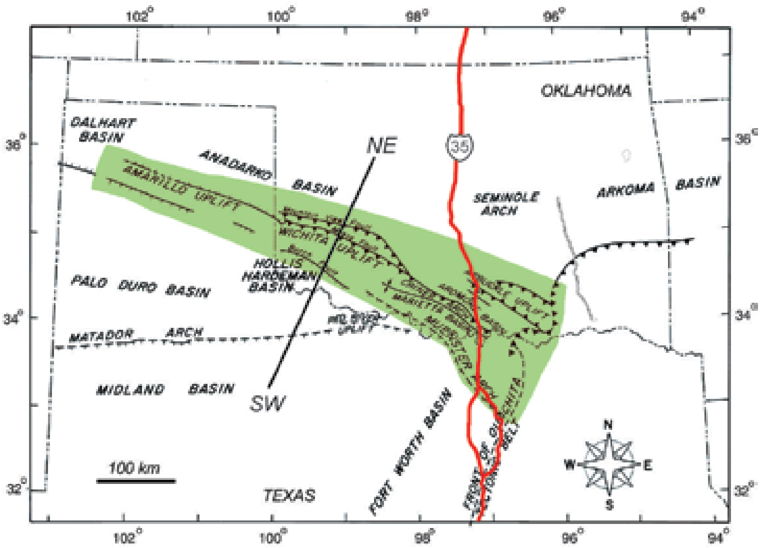


Figure 4. Location of the Southern Oklahoma Aulacogen (shown in green).

In terms of continental tectonics, rifts that do not succeed in breaking a continent apart are often referred to as having "failed." These failed rifts, or aulacogens, often provide geologists with important records of continental evolution and often contain petroleum resources. In the case of the Southern Oklahoma Aulacogen, one would think that the core of 600 million year old rocks under the Arbuckle and Wichita Mountains would be centered under the post-rift basin. However, this does not appear to be the case given the extensive magmatic modification of the upper crust observed by deep sounding seismic experiments integrated with seismic reflection images and drilling. This poses just one of several questions about the structure and evolution of the Southern Oklahoma Aulacogen.

However, the SOA is widely viewed as a classic example of an aulacogen and consists of a linear alignment of structures that have been extensively inverted that begins at the rifted margin of Laurentia (ancient core of North America) in northeast Texas and extends northwestward at least to southern Colorado (Figure 5).

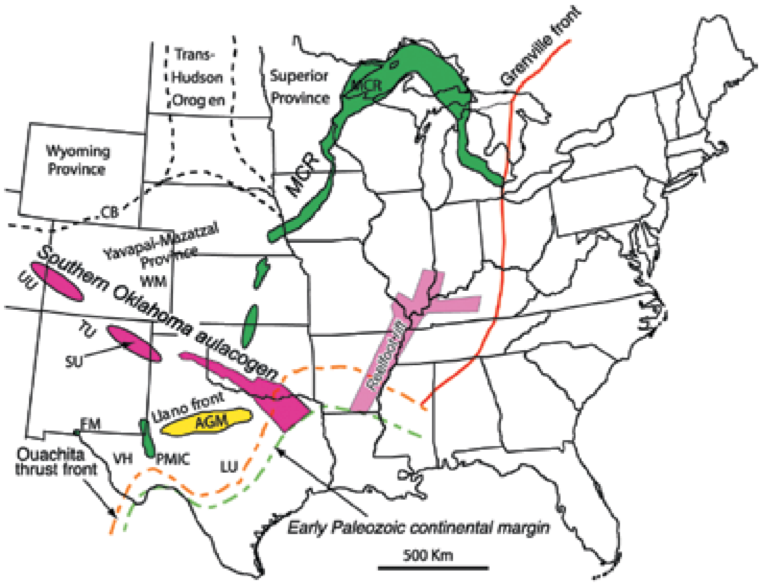


Figure 5. Extent of the Southern Oklahoma Aulacogen and the 600 million year margin (edge) of North America.

The main structures commonly associated with the SOA are the Arbuckle and Amarillo-Wichita uplifts and the Anadarko Basin. Because of extensive petroleum exploration, the geologic processes during the 300 million year period that turned the old basin inside out are well known. However, many other significant geological structures are involved, and the aulacogen has been interpreted to extend as far to the northwest as western Colorado.

The large Late Paleozoic faults and the large upper crustal load represented by the Cambrian mafic intrusions in the Wichita Uplift show that it should be no surprise for the region to have experienced significant young (Holocene) movement along faults in the aulacogen. The Mountain View Fault (MVF on Figure 6) is the northernmost major structure and it's massive (10–15 km of vertical offset) Mountain View fault zone that forms the boundary between the extremely deep Anadarko Basin and the uplifted igneous rocks of the Wichita Mountains (Fig. 6).

To the northwest in New Mexico and Colorado, Mesozoic and Cenozoic tectonism produced younger geologic structures that obscured SOA structures, but strong evidence exists for substantial Cambrian (600 million years) mafic magmatism that resulted in dense intrusions and late Paleozoic (300 million years) structural uplifts across northeastern New Mexico. In Colorado, the Wet Mountains near Royal Gorge appear to be cored by Cambrian mafic rocks. Together, the evidence documents the presence of a major intracratonic geologic structure that is ~1500 km long and has experienced two periods of intense faulting, formation of a deep basin, and then uplift that produced the Arbuckle and Wichita Mountains.

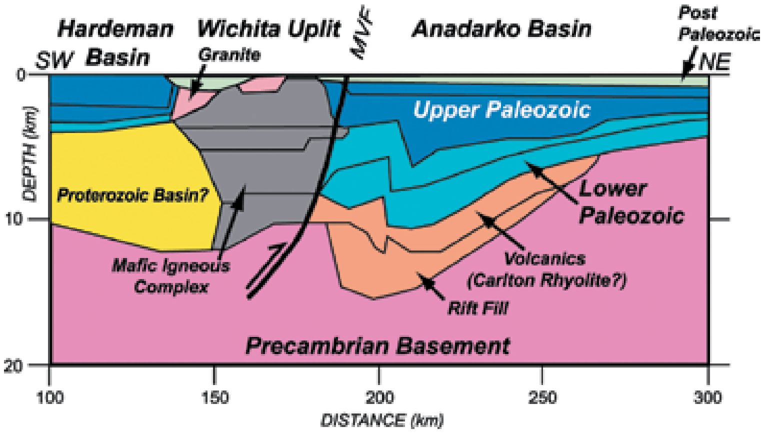


Figure 6. Cross section of Wichita Mountains area.

In summary, we are left with a picture of the southeastern portion of the SOA in which pervasive magmatic modification of the upper crust occurred in the Cambrian (Figure 7); cooling and subsidence followed that was in turn followed by a huge (up to 15 km, 10 miles) amount of faulting and uplift 300 million years ago (Late Paleozoic). The scale of this magmatism and deformation is impressive. The result is the 15 km deep Anadarko basin that is floored by igneous and basement rocks that outcrop in adjacent uplifts.

Figure 7. A quarry in southern Oklahoma showing very old granites (~1.6 billion years) being intruded by Black dikes of 600 million year old volcanic rocks.

Wichita Mountains and Meers Fault

As discussed earlier, an aulacogen (a failed rift zone) formed when the ancient North American continent broke apart. The rifting formed a linear structural trough that extends at a high angle from the continental margin in southeast Oklahoma and northeast Texas. The failed rift is called the Southern Oklahoma Aulacogen (SOA) (Page 7, Figure 4) and is a classic example of a large aulacogen.

The Wichita Mountains in southwest Oklahoma (Figure 1) are part of the aulacogen and feature one of the most extensive exposures of igneous rocks within the midcontinent region of the United States. The geological evolution of the Wichita Mountains area began 600 million years ago with active rifting and volcanic and plutonic activity that produced massive amounts of igneous rocks and lasted about 100 million years.

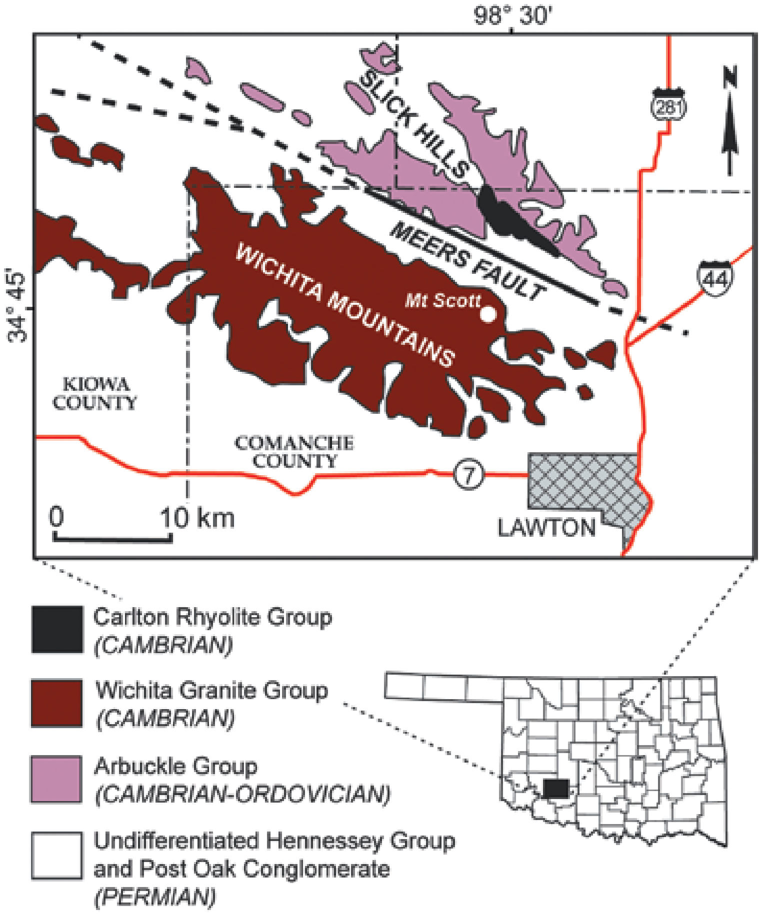


Figure 1. Map showing location of Wichita Mountains Complex and the Meers Fault.

About 500 million years ago the igneous activity ceased and cooling and contraction began and caused subsidence that was the first stage of the formation of the Anadarko Basin and lasted until about 400 million years ago (Middle Cambrian until Late Mississippian).

Then about 300 million years ago, compression due to tectonic plate collision turned the rifted area inside out (a process called structural inversion) to form the uplifted Wichita Mountains and the very deep Anadarko Basin. The resulting geological features are huge, and the faulting involved is extremely complex. The Anadarko Basin continued subsiding after uplift of the Wichita Mountains had ceased, creating over 12 kilometers (8 miles) of structural relief (the difference between the highest and lowest points of a rock bed or stratigraphic horizon in a given region) between the uplift and the basin. Since then, erosion has exposed a wide variety of igneous rocks in the Wichita Mountains, and much of the eroded material has been deposited into the Anadarko Basin. The view from Mount Scott in the Wichita Mountains Wildlife Refuge just west of Lawton (Figure 2) is impressive and is the cumulative result of rifting, uplift, and erosion.

Figure 2. View from the top of Mt. Scott looking west.

The Meers Fault (Figure 3) lies along the southern boundary of the Slick Hills (Figure 4) and is marked by a distinct anomaly in the earth's gravity field. The Meers Fault is the main documented young fault scarp in the U. S. east of Colorado (Figure 3). The most recent movement along the Meers Fault occurred in the late Holocene (1100–1300 years ago – probably producing a magnitude 7 earthquake),

Figure 3. Aerial view of Meers Fault looking northwest.

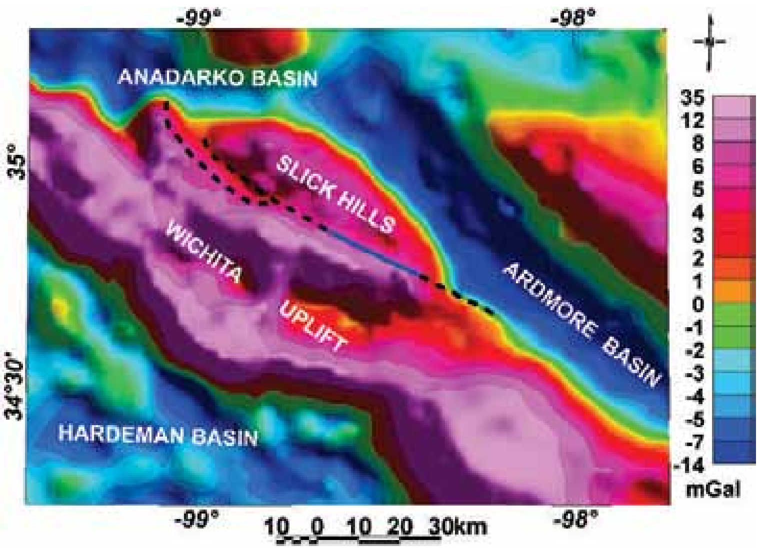


Figure 4. Bouguer gravity map of Wichita Mountains. Blue shows the extent of geologic basins that are filled by low-density sedimentary rocks. Red shows the extent of dense basement rocks that have been uplifted.

and an earlier late Holocene movement occurred 2,000–2,900 years ago. During faulting, the young soils along the fault were folded as well as ruptured, and the resulting scarp (a line of cliffs produced by faulting or erosion, and short for escarpment) has dammed small gullies where fine-grained alluvium has collected (Figure 5). As much as 5 meters (8 feet) of vertical displacement and appreciably more horizontal displacement occurred on the fault. Motion on the Meers Fault represents continued activity on one of the largest structural features in North America and reminds us that Oklahoma is a geologically active area today.

Figure 5. View of part of Meers Fault from the ground.

In summary, southern Oklahoma was the site of significant igneous activity in the upper portion of the earth's crust in Cambrian time. This event was followed by cooling and subsidence that was in turn followed by up to 15 kilometers (10 miles) of structural inversion in the late Paleozoic. The amount of igneous activity and deformation is impressive on a global scale. North of the Wichita Mountains, the 15 kilometer deep Anadarko Basin formed. This basin is floored by Precambrian and Cambrian igneous basement rocks similar to those that outcrop in the Wichita and Arbuckle Mountains. To the northwest in Texas, New Mexico, Colorado, and eastern Utah, substantial Cambrian volcanic activity and late Paleozoic (~300 million years ago) structural uplifts occur as well. Together, this evidence documents the presence of a major intracratonic structure that is ~1500 kilometers (~100 miles) long and has experienced very recent tectonic activity.

Structure and Evolution of the Ouachita Mountains - Arkoma Basin Region

The Ouachita Mountains of southeastern Oklahoma provide some of the most beautiful topography and vacation spots Oklahoma has to offer.

Tranquil and peaceful now, the state's most mountainous area was formed during a tectonic plate collision some 300 million years ago when the stable North American Plate slammed into (the "slamming" process taking roughly 30 million years) the continent of Gondwana with the Sabine Terrane caught in the collision (Figure 1). The collision rippled and lifted the ground to become a series of complex ranges, part of which we know as the Ouachita Mountains.

The Ouachita orogenic belt (orogenic is defined as a region that has been folded or otherwise deformed during a period when a moving plate or region of the earth was impacting another and in the process becoming stable) is a major tectonic feature that winds its way across the southern U. S., Oklahoma, and Texas, and includes the Ouachita, Arbuckle and Wichita Mountains of Oklahoma, before disappearing into Mexico (Page 7, Figure 5). Because much of the Ouachita Mountains area is rugged, remote, and covered with trees and other vegetation, geologists and seismologists are still working to better understand this geologic feature, and several new oil and gas plays are developing in the Arkoma basin (a foreland basin adjacent to the belt) and within the orogenic belt itself. This basin formed as faults pushed the mountains northward and sedimentary rocks were buried to depths that are ideal for the production of hydrocarbons.

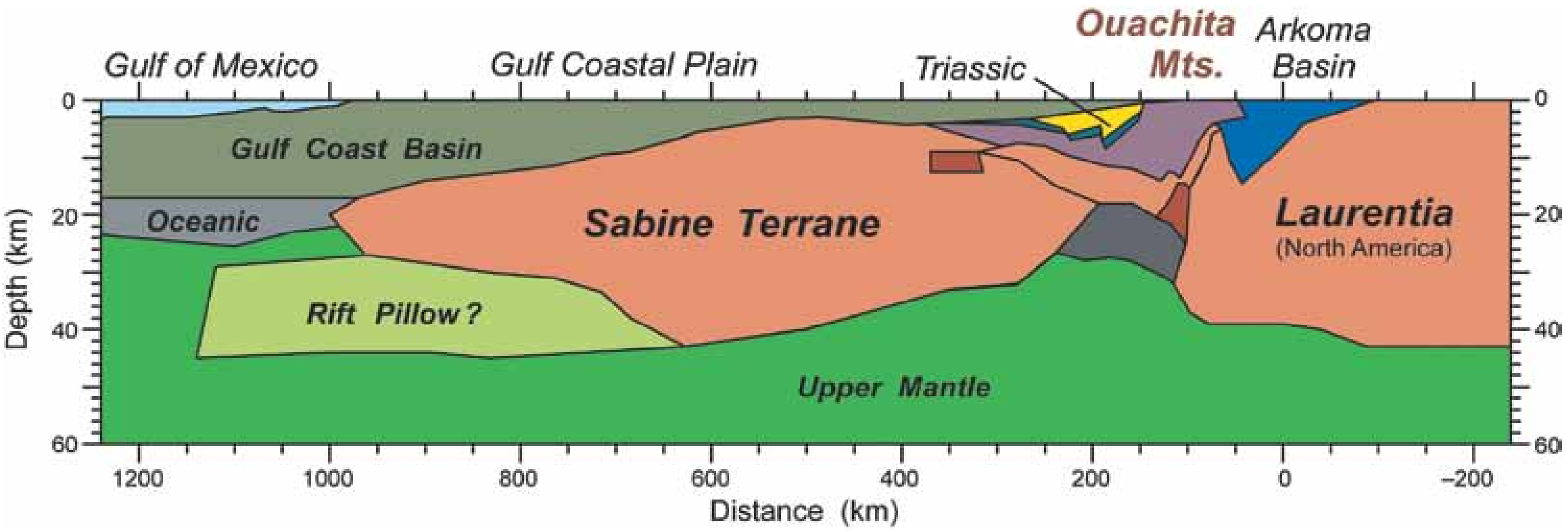


Figure 1. Integrated crustal model extending from southern Missouri to the Gulf of Mexico.

The Precambrian basement that forms the upper crust of the region is relatively young, and some of it formed as recently as about 1.3 million years ago at the end of a period of continental growth in what now is southern North America. This growth formed a supercontinent that is usually called Rodinia, a supercontinent that contained most of Earth's landmasses between 1100 and 750 million years ago in the Neoproterozoic era. By ~600 million years ago, Rodinia began to break apart in the Ouachita region and a rift formed along the southern edge of what is now North America. An interesting and widely accepted interpretation is that a piece of lithosphere, or the earth's crust and part of the mantle, broke off of the Ouachita region at this time and ended up in southern Argentina–all happening over millions of years of course! Until Mississippian time (about 340 Million years ago), a typical passive continental margin developed in the Ouachita region as thick sequences of sedimentary strata were deposited. Then some combination of island arcs, terranes (microcontinents), and South America approached from the south, closing an ocean of unknown width and forming the Ouachita Mountains, (Figure 2).

Figure 2. The continents 300 million years ago. Map by Ron Blakey, Colorado Plateau Geosystems, Inc.

Figure 3. Rock outcrops in the Ouachita Mountains.

The rocks from that time that we encounter in outcrops, and the material brought to the surface from drill holes that go into rocks from that period, are commonly referred to as the Ouachita facies (facies is a term for a body of rocks with distinctive and similar characteristics). Geological studies of the ancient history of the Ouachitas show that this tectonic activity thrust large slices of continental slope rocks onto the continental shelf, and that action lifted these Ouachita rocks onto the passive continental margin of Paleozoic North America.

Since the exciting sequence of events from the rifting in Late-Precambrian/Early Cambrian (about 600 million years ago) to the end of the orogenic activity in the Pennsylvanian (about 300 million years ago), the Ouachitas and the Arkoma foreland basin to the north (Figure 3) have mostly experienced subsidence and burial.

Geophysicists use a variety of tools to study the structure of the earth, including seismic imagining, which uses sound waves that reflect off of geologic structures and refract, traveling back through the structure and providing x-ray-like images that must be interpreted with sophisticated computational tools (Figure 1).

case of Figure 4, the large arc-shaped gravity high that crosses southern Arkansas, southeast Oklahoma, and curves southward through central Texas marks the edge of the North America continent when the rifting formed about 600 million years ago.

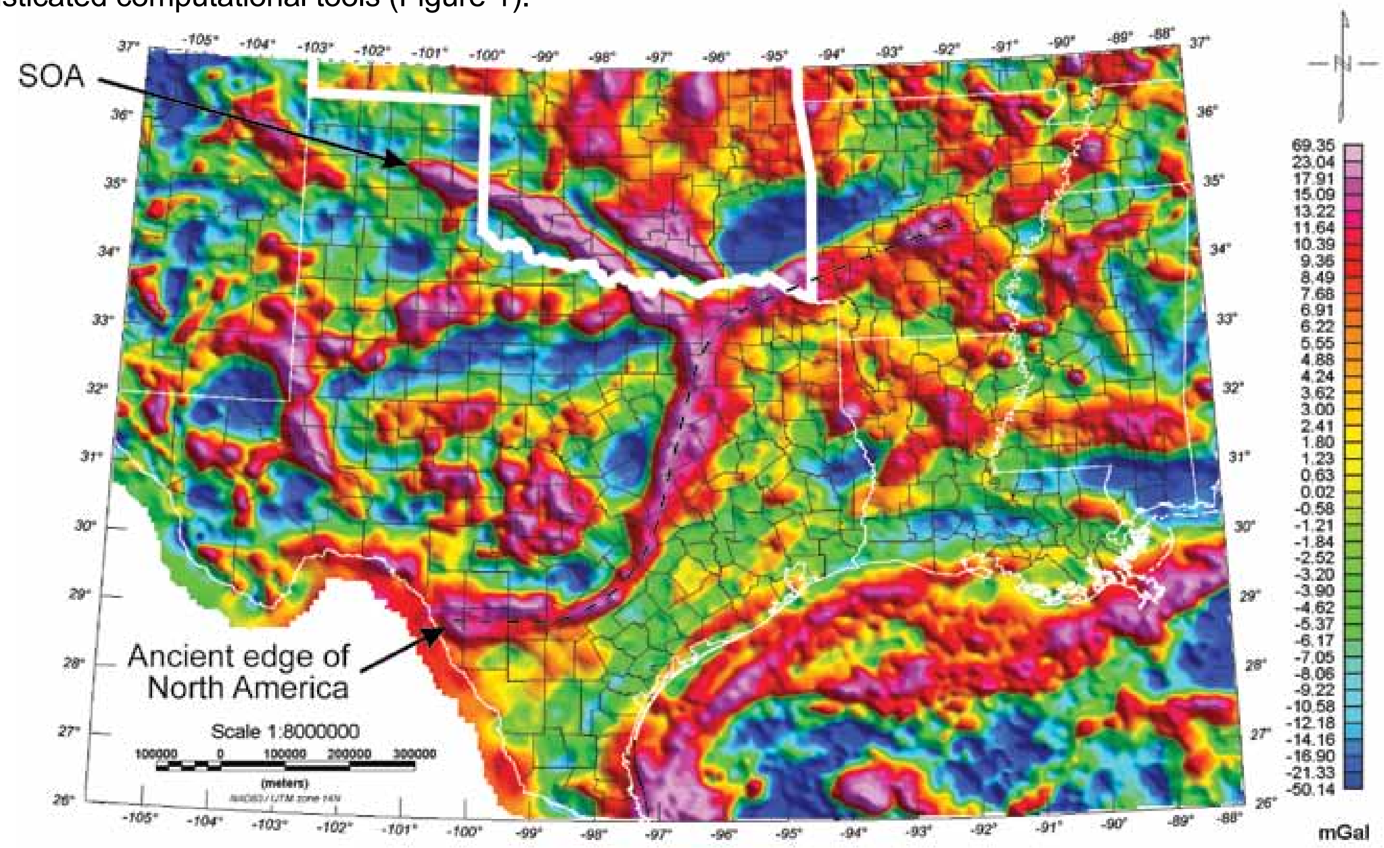


Figure 3. Bouguer gravity map showing Oklahoma, Texas and Arkansas and the ancient edge of the North American continent. Blue shows the extent of geologic basins that are filled by low-density sedimentary rocks. Red shows the extent of dense basement rocks that have been uplifted.

Geophysicists also make very precise measurements of Earth's gravity field in order to study geologic structures. The gravity meters used can routinely measure a change in the gravity field of 1/10,000,000. Geophysicists have derived equations that predict what the average value gravity should be at any location, and the difference between what is observed and the predicted value is called an anomaly. The gravity anomaly values are mapped (Figure 4) and interpreted geologically. In the

Using geologic data from drill holes, geologic maps, seismic data, and gravity data, models of earth structure can be constructed and interpreted. This is how the model of deep earth structure shown in Figure 1 was derived. Other geological and geophysical data such as measurements of the Earth's magnetic field are often integrated into the construction of such models. This model shows that the ancient continental margin of North America was not completely destroyed in the collision.

This implies that the Ouachita orogenic belt formed as the result of a "soft" collision with the Sabine Terrane rather than a strong collision such as India's crashing into to Asia to form the Himalayan Mountains and Tibet plateau. The Sabine block could be a piece of North America that was rifted away in the early Paleozoic, but it could also be a piece of South America or Africa (figure 4).

These processes that shaped the earth's structures today are similar in many respects throughout the world. It is also one of the reasons why geology is such a fascinating field of study, with potential for the use of high-tech equipment and travel to many parts of the world. It is also a fact that in the end, the men and women in geology still have the need to get out, walk along the outcrops of rocks, and see for themselves what has happened—and is still happening!—on this planet.

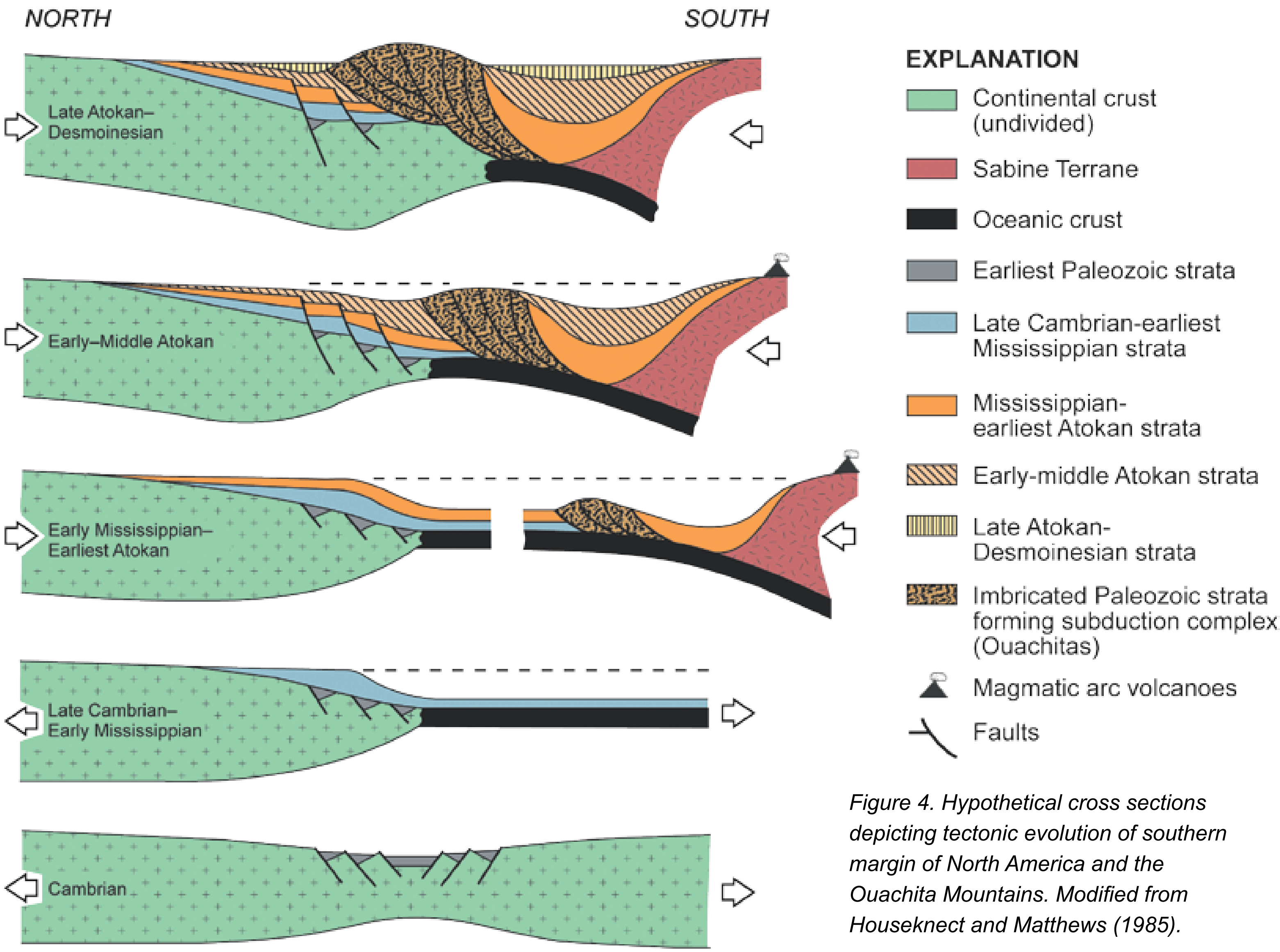


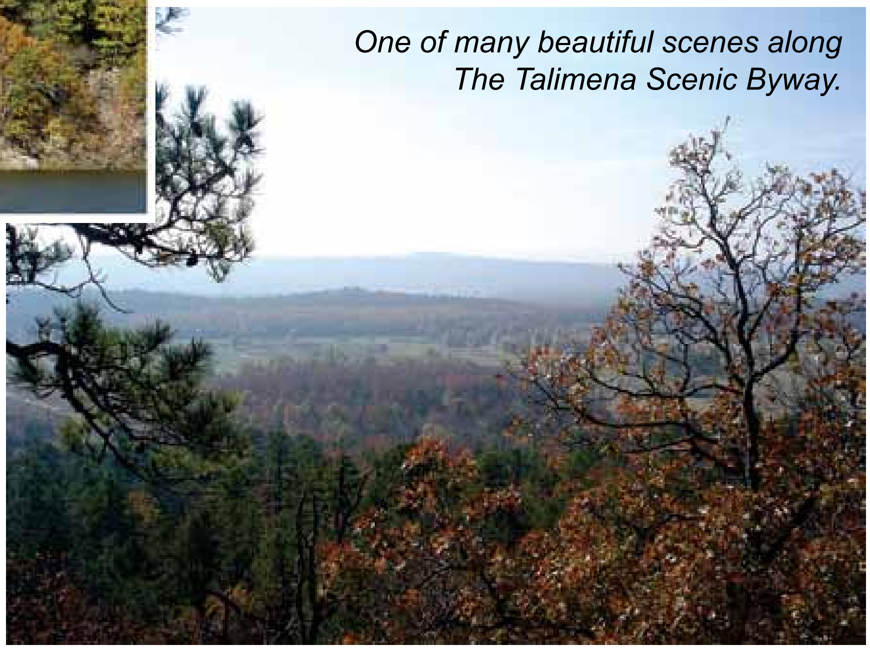
Figure 4. Hypothetical cross sections depicting tectonic evolution of southern margin of North America and the Ouachita Mountains. Modified from Houseknect and Matthews (1985).

The Talimena Scenic Byway is 54 miles along the crest of Rich Mountain and Winding Stair Mountain in the Ouachita National Forest.

Bluff behind Lake Carlton by Robbers Cave near Wilburton, Oklahoma.

(Photo by Rick Andrews).

One of many beautiful scenes along The Talimena Scenic Byway.



ADDITIONAL READING:

Paleogeography of North America: http://www.cpgeosystems.com
Continental Drift: http://education.nationalgeographic.com/education/encyclopedia/continental-drift/?ar_a=1
Origin and Evolution of the Earth: http://www.agiweb.org/education/aapg/curricula/9-12.html#oees
Continental Drift: http://www.ucmp.berkeley.edu/geology/anim1.html
Structure of the Earth System: http://www.agiweb.org/education/aapg/curricula/5-8.html#sem
Earth's History: http://www.agiweb.org/education/aapg/curricula/5-8.html#eh
Gravity anomaly map for the U.S.: http://mrdata.usgs.gov/geophysics/gravity.html

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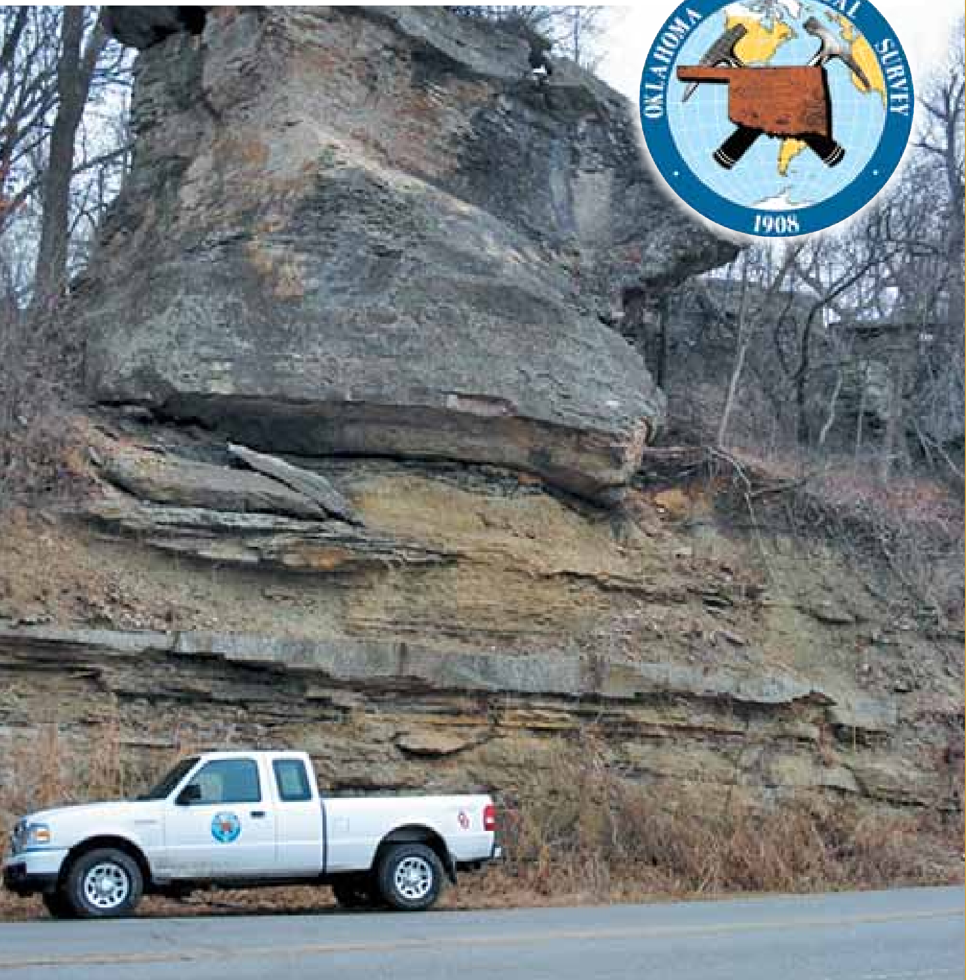
Oklahoma Geological Survey

The Oklahoma Geological Survey is a state agency for research and public service, mandated in the State Constitution to study Oklahoma's land, water, mineral, and energy resources, to make these findings available to the public and to promote wise use and sound environmental practices. Today, this mission seems more important than ever.



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RESOURCES FOR TEACHERS AND STUDENTS

OGS maps and publications, earthquake information for Oklahoma, educational publications, technical publications, basic maps and other materials, articles and information are available for free download from **www.ogs.ou.edu**.

USGS maps are available from OGS Publication Sales

What Local Professional Organization Supports Science Education ?

www.oklahomageologicalfoundation.org

The Oklahoma Geological Foundation is a tax-exempt organization that funds scholarships and awards throughout the State of Oklahoma to pre-college students, undergraduate and graduate students, teachers, and educational institutions on an annual basis.

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