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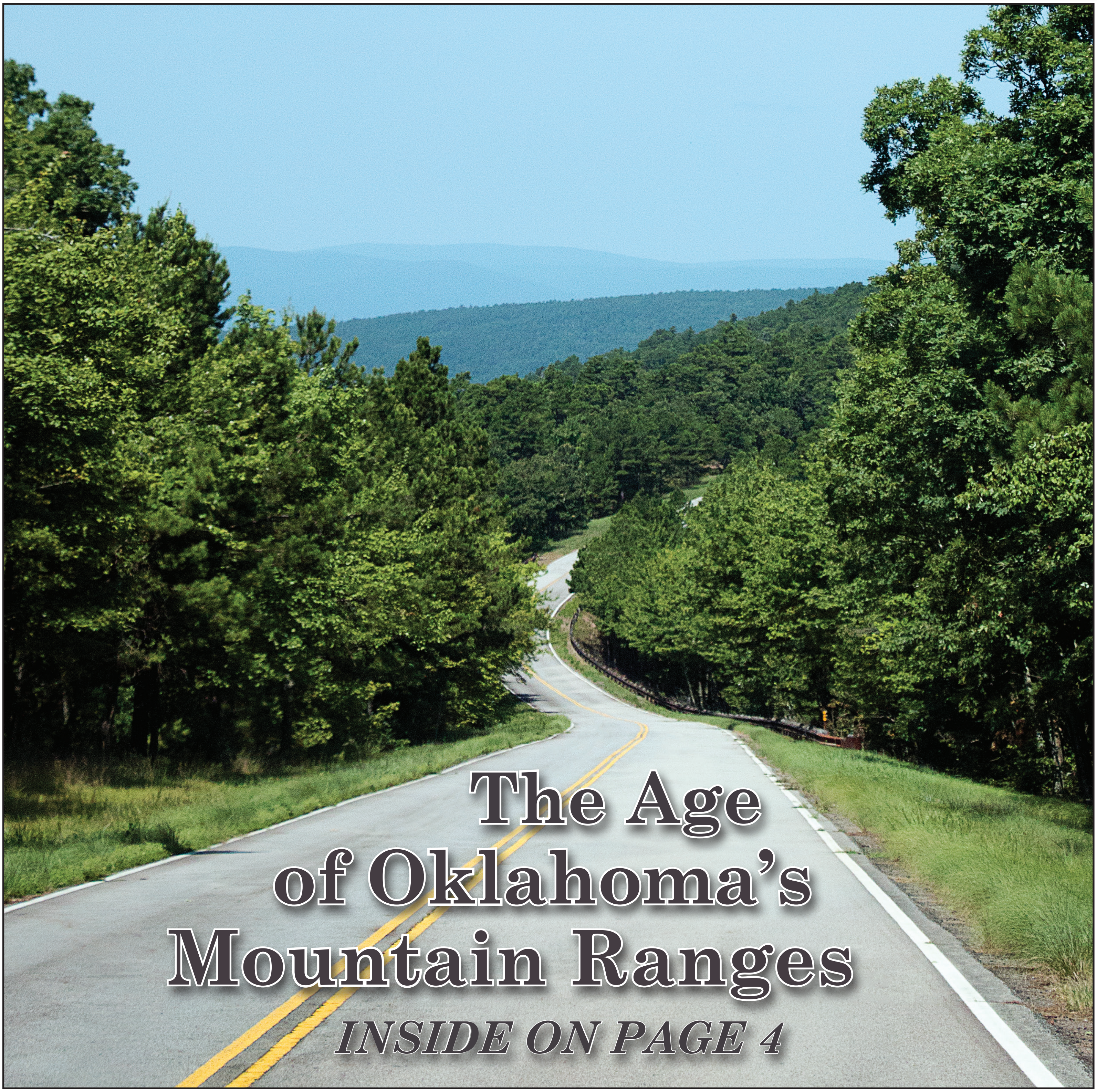

OKLAHOMA GEOLOGICAL SURVEY

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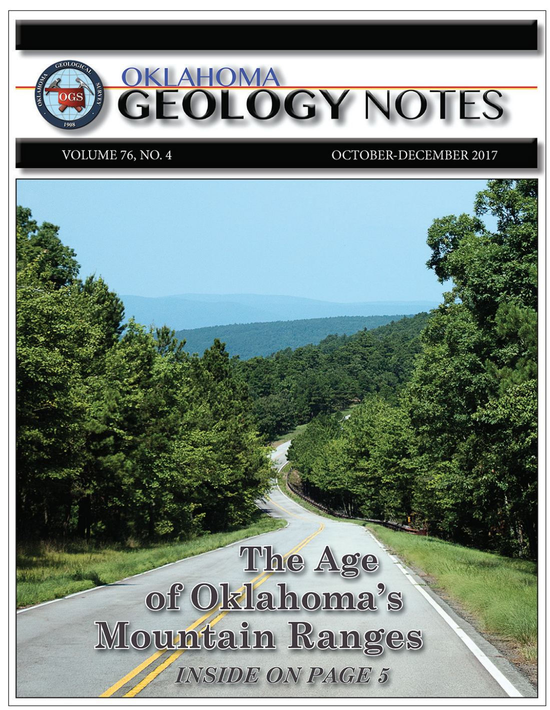


Cover: Photo was shot on the Talimena Drive, which stretches across the Ouachita Mountains in southeastern Oklahoma

Photo and Cover Design by Ted Satterfield

From The Director

Mountain ranges, a new hire, and a new year

This issue focuses on a seemingly very straightforward question, one that all kinds of thoughtful people, experts and lay people, like to ask, and expect a straightforward answer: how old are Oklahoma's mountains? The review by Neil Suneson and Tom Stanley highlights the extent to which, even for this simple question, the answer can be quite complicated, and, in some places, the answer may still be "We don't know." Even for people like Neil and Tom, who have been working on Oklahoma geology for a long time and have a breadth of knowledge that we constantly call on, there are still aspects of a problem like this that can fall in the gap where they have not worked or have not yet come to a solid answer.

Not only that, but while the rocks themselves change very slowly, the science of geology changes over time, overturning some answers and creating new ones, based on new techniques or new insights about our science. The answers of a new generation still have to recognize the sound observations of the previous generation, as the discovery and preservation of the first geologic map of Oklahoma (Notes, vol. 76, No. 2) reminds us. Good data remain good data, and new ideas are commonly part revision and part revolution.

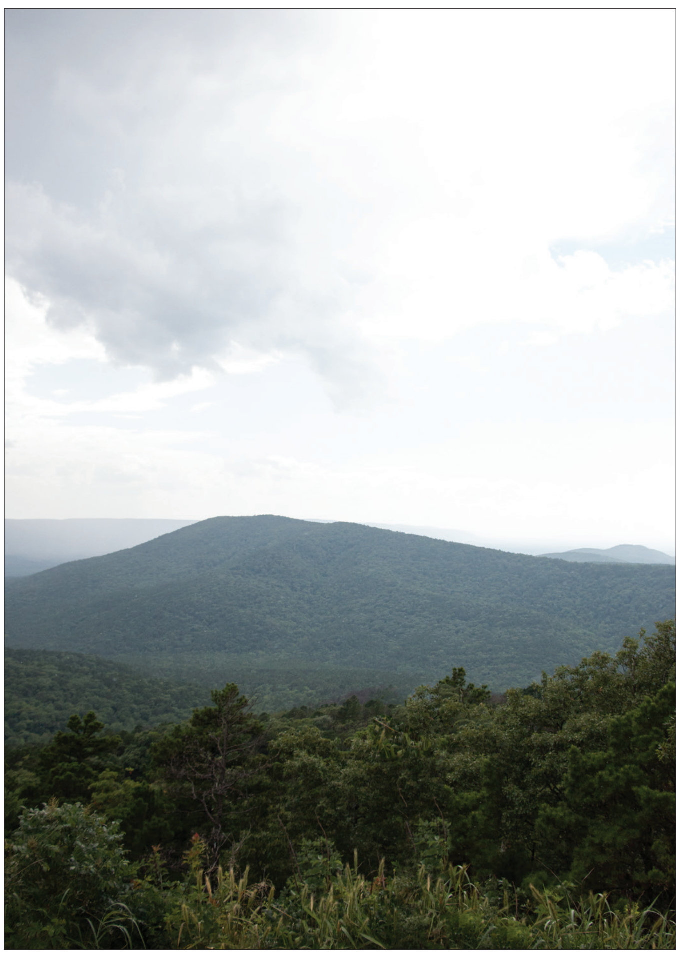
It takes a while to get comfortable with the idea that there is always more to know about an area than you can hold in your brain. However, this is one of the pleasures of doing science, where there is always a frontier of unexplored territory. It is also enjoyable, once you get used to it, to encounter one of the questions that covers so much ground within geology that you are almost certain to have some part of your answer be, "I am not sure of this…" or "Let me get back to you on that…." The devil is, as always, in the details.

While I am mentioning the answers of a new generation, I want to welcome one of that new generation, our Senior Petroleum Geologist, "Ming" Suriamin, who will start in the middle of January at the Survey. He brings both local and global perspectives, being a product of the Conoco Phillips School of Geology and Geophysics at OU but having grown up and received his early training in Indonesia. It has been an extended search, and we are pleased to have him on board.

Jeremy Boak
OGS Director

As we are about to start a new year , I am excited about the products we have ready to come out. We will be issuing a series of geologic structure maps on important stratigraphic horizons as Open File reports. Also on the way is a discussion of the geophysical log characteristics of the Arbuckle Group sedimentary rocks, with relation to induced seismicity caused by deep injection of produced formation water from oil and gas operations.

Seismicity continues to be an important concern for people living in the areas where it is occurring, as well as for the industry, and therefore, for the Oklahoma Geological Survey. Despite a major decrease in the frequency of earthquakes, we are not out of the woods yet. OGS will be hosting a workshop on seismicity for those active in research, operations, and regulation here in February. We have also completed the pilot of a project to install Raspberry Shakes seismometers in schools, museums, and other public places around Oklahoma, so that budding young scientists can help us monitor seismic activity and learn about earthquakes. These products and events will give the year an exciting start, and I will highlight other activities in the next issue.



ABOVE: Photo is of Mount Scott from across Lake Lawtonka in the Wichita Mountains of southwestern Oklahoma.
BELOW: Photo was shot along the Talimena National Scenic Byway in the Ouachita Mountains of southeastern Oklahoma.

The Age of Oklahoma's Mountain Ranges

Neil H. Suneson and Thomas M. Stanley
Oklahoma Geological Survey

INTRODUCTION

One of the more common questions the public ask geologists at the Oklahoma Geological Survey is, "How old are Oklahoma's mountain ranges?" In fact, professional geologists also ask us the same question because they want to know

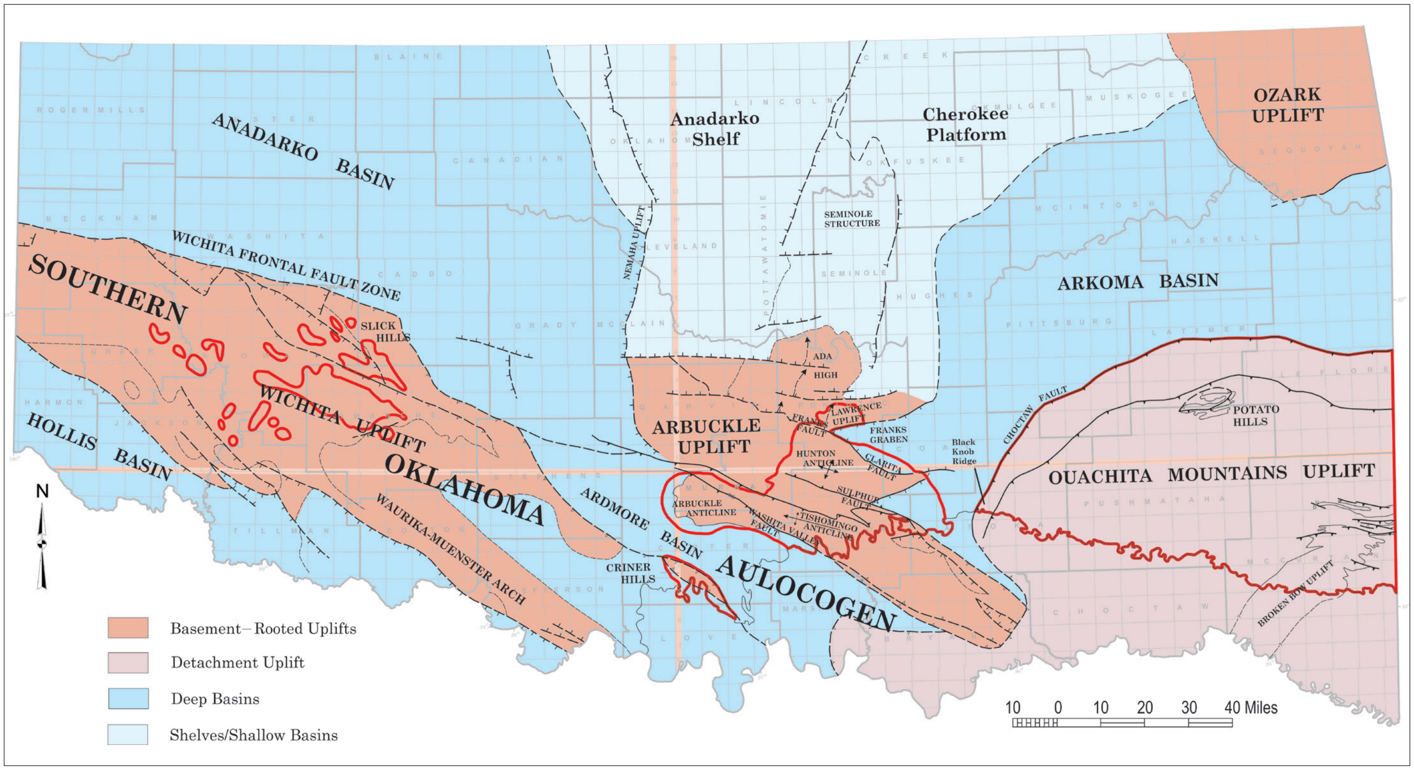


Figure 1. Map showing geologic provinces of southern Oklahoma and features referred to in text. Red outline shows approximate outcrop area of Wichita Mountains, Arbuckle Mountains, and Ouachita Mountains. Modified from Northcutt and Campbell (1995).

whether tectonism proceeded from east to west, west to east, or happened at about the same time throughout Oklahoma. This short note is an attempt to answer that question.

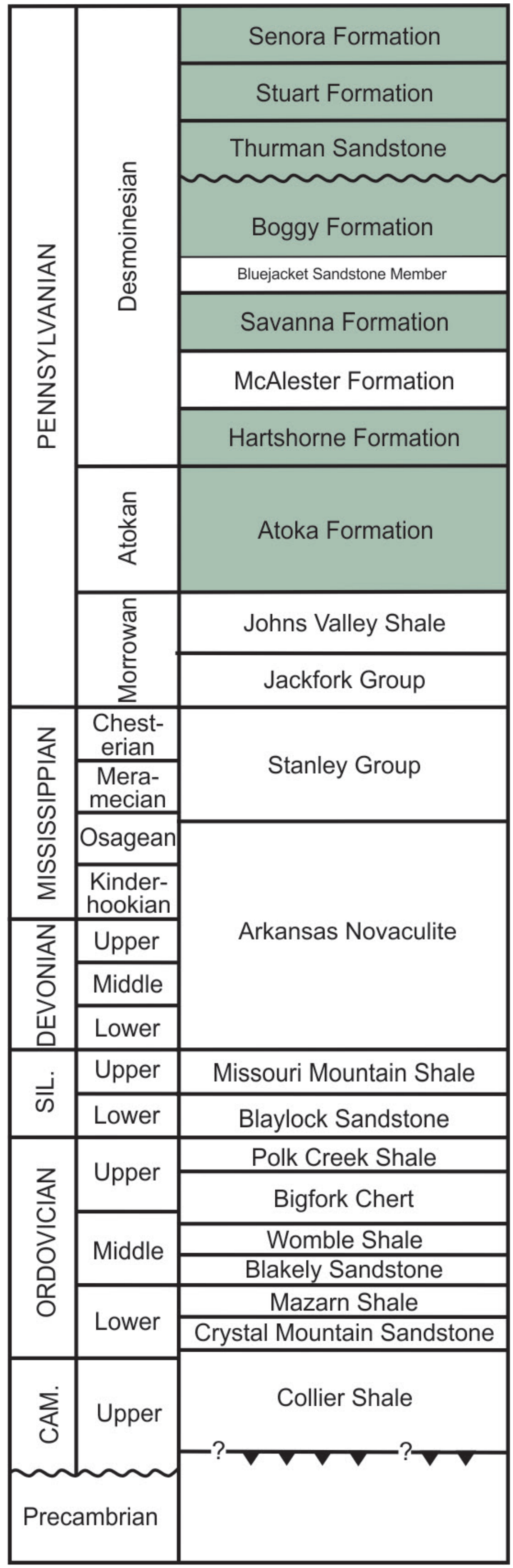
In this paper we discuss the Ouachita Mountains, Arbuckle Mountains, and Wichita Mountains (Figure 1). We include the Arkoma Basin because Ouachita-related tectonism extended north of the trace of the Choctaw Fault. We incorporate the Lawrence Uplift, Franks Graben, Ardmore Basin and Criner Hills structural sub-provinces into the Arbuckle Mountains. The Wichita Mountains include the Slick Hills, and most of the evidence regarding their history is preserved in the adjacent Hollis and Anadarko Basins. We do not address the age of the Ozark Uplift for reasons described below. We also do not address the Nemaha Uplift, a Pennsylvanian feature that is now completely buried by Lower Permian strata. The names of some of these features differ from what is shown by Northcutt and Campbell (1995); ours more closely follow what is shown by Curtis et al. (2008), but there is a great amount of similarity in the maps.

TECTONISM, DEFORMATION, AND UPLIFT

The “age” of Oklahoma’s mountain ranges requires some discussion. Some individuals (usually cited in the popular press) have stated that the Arbuckle Mountains are Oklahoma’s oldest mountain range. This claim probably is made because the oldest rocks in the state – the ~1390 to ~1365 million-year-old Burch Granodiorite, Blue River Gneiss, Tishomingo Granite, and Troy Granite (Denison, 1973; Lidiak et al., 2014) are exposed in the eastern Arbuckle Mountains. However, the age of a mountain range is not the age of the oldest rocks exposed in that range, rather, it is: 1) the age the strata that make up the mountain range were deformed, assuming the strata are, in fact, folded and faulted; and/or 2) the age those strata were uplifted. These events do not necessarily occur at the same time although they commonly overlap. Deformational events can be dated by determining the age of angular unconformities that, in turn, are bracketed by the age of the youngest strata immediately beneath, and the oldest strata immediately above, the unconformity. Periods of uplift can be dated by determining the age of conglomerates (excluding intraformational conglomerates) or other proximal sedimentary deposits eroded off the uplift. (This typically uses biostratigraphy. In this paper we do not review those data but accept the published literature.) However, using near-source sediments to date an uplift requires that the uplifted and eroded landmass was above sea level. Submerged uplifts are more difficult to date. In addition, a source terrane must be at least partly underlain by rocks hard enough to survive erosion, transport, and deposition. A source composed of poorly indurated rocks will leave little recognizable evidence in the sedimentary record. Disconformities may also be evidence of uplift, but the absence of coarse detritus indicates a probable lack of relief in the source terrane.

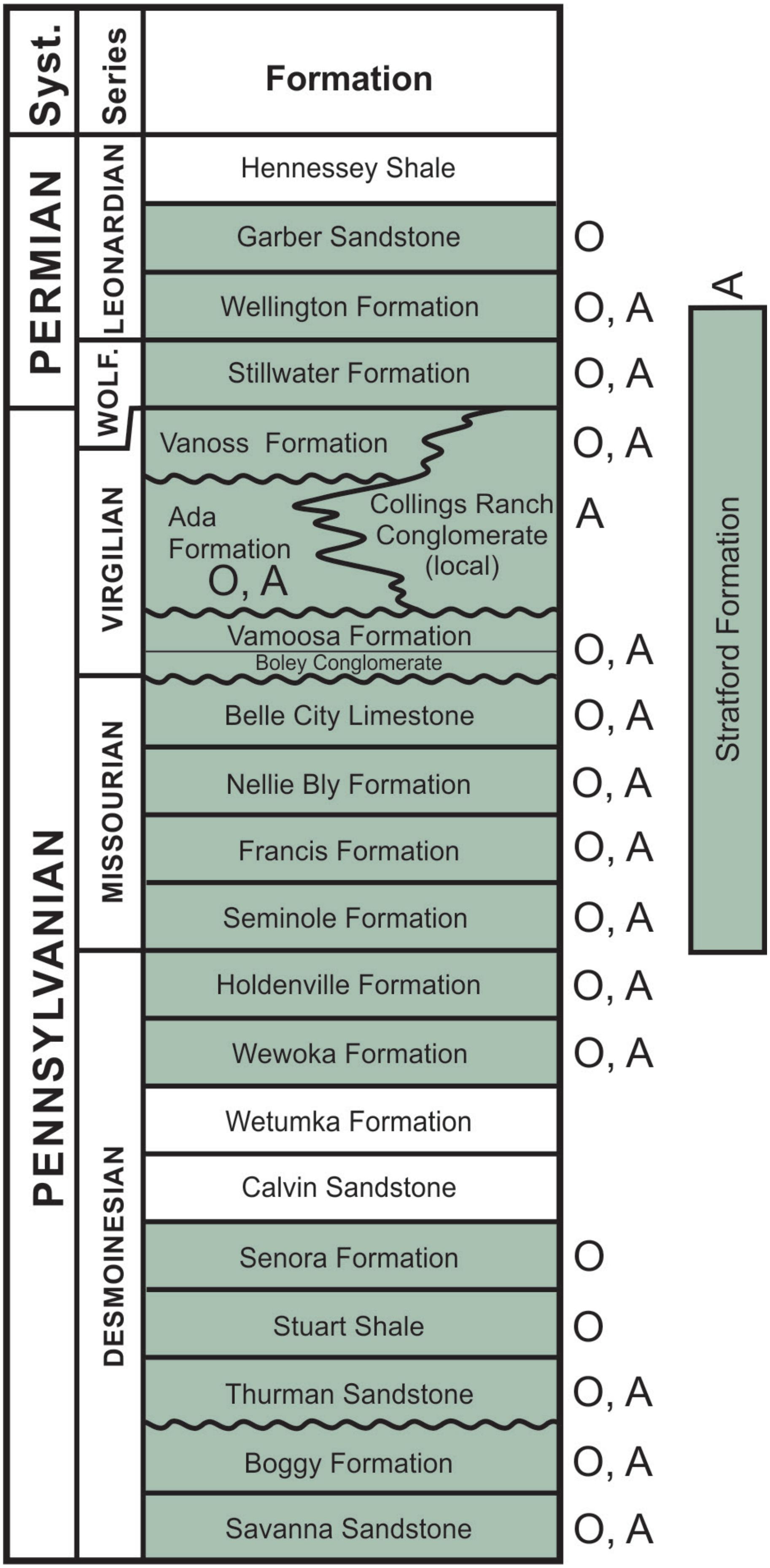
The strata in the Ouachita, Arbuckle, and Wichita Mountains are highly folded and faulted. This paper describes when these strata were deformed. The strata in the Ozark Uplift, in contrast, are faulted but exhibit little folding. The faults, however, do not parallel the margins of the uplift and appear to be younger than it. The Ouachita, Arbuckle, and Wichita Mountains also have "aprons" of sedimentary debris that were eroded off of them – evidence that the mountains were once high. This paper reviews the ages of the sedimentary aprons. The Ozarks, in contrast, do not have an erosional apron. In addition, the Ozarks area has undergone long-lived, repeated epeirogenic uplifts, in contrast to the short-lived uplifts of the mountains in the southern part of the state.

Lastly, any plate-tectonic implications drawn



THIS PAGE: **Figure 2.** Stratigraphic column of Ouachita Mountains and southern Arkoma Basin. Colored units are those formations containing chert fragments derived from the Ouachita Mountains. Contact between Boggy Formation and Thurman Sandstone is an angular unconformity. Modified from Arbenz (2008, plate 2).

NEXT PAGE: **Figure 3.** Stratigraphic column of western Arkoma Basin and southern Cherokee Platform showing units with conglomerate beds containing chert clasts derived from the Ouachita Mountains (O) and clasts (limestone, igneous rocks, feldspar) derived from the Arbuckle Mountains (A). The "lower Franks conglomerate" is equivalent to the Savanna and Boggy Formations; the "upper Franks conglomerate" is equivalent to the Thurman Sandstone through Holdenville Formation.



from what appears to be an east-to-west migration of tectonism (discussed below) must be tempered with the fact that the Arbuckle – Wichita tectonic belt is fundamentally different from the Ouachita tectonic belt. The Ouachita Mountains are a fold-and-thrust mountain range that is arcuate in shape and formed as a result of compression due to plate convergence. The Arbuckle and Wichita Mountains, in contrast, are within the west-northwest-trending Southern Oklahoma Aulacogen (Figure 1) and represent reactivation of an older, Cambrian rifting event. Where they intersect, the aulacogen is at right angles to the Ouachitas and the uplifted blocks of the Arbuckle and Wichita Mountains probably formed largely as a result of left-lateral transpression (e.g., Granath, 1989). The different trends of the mountain ranges have long been recognized, most notably by Van der Gracht (1931). However, the uplift mechanism of the Arbuckles and Wichitas (i.e., compression vs. transpression) continues to be debated.

OUACHITA MOUNTAINS

The pre-Mississippian tectonic history of the Ouachita Mountains is beyond the scope of this paper. Lowe (1989) discusses the coarse deposits (boulders as large as 50 ft in diameter in the Lower Ordovician Crystal Mountain Sandstone) in terms of nearby source terranes, but these have no bearing on the present Ouachita Mountains.

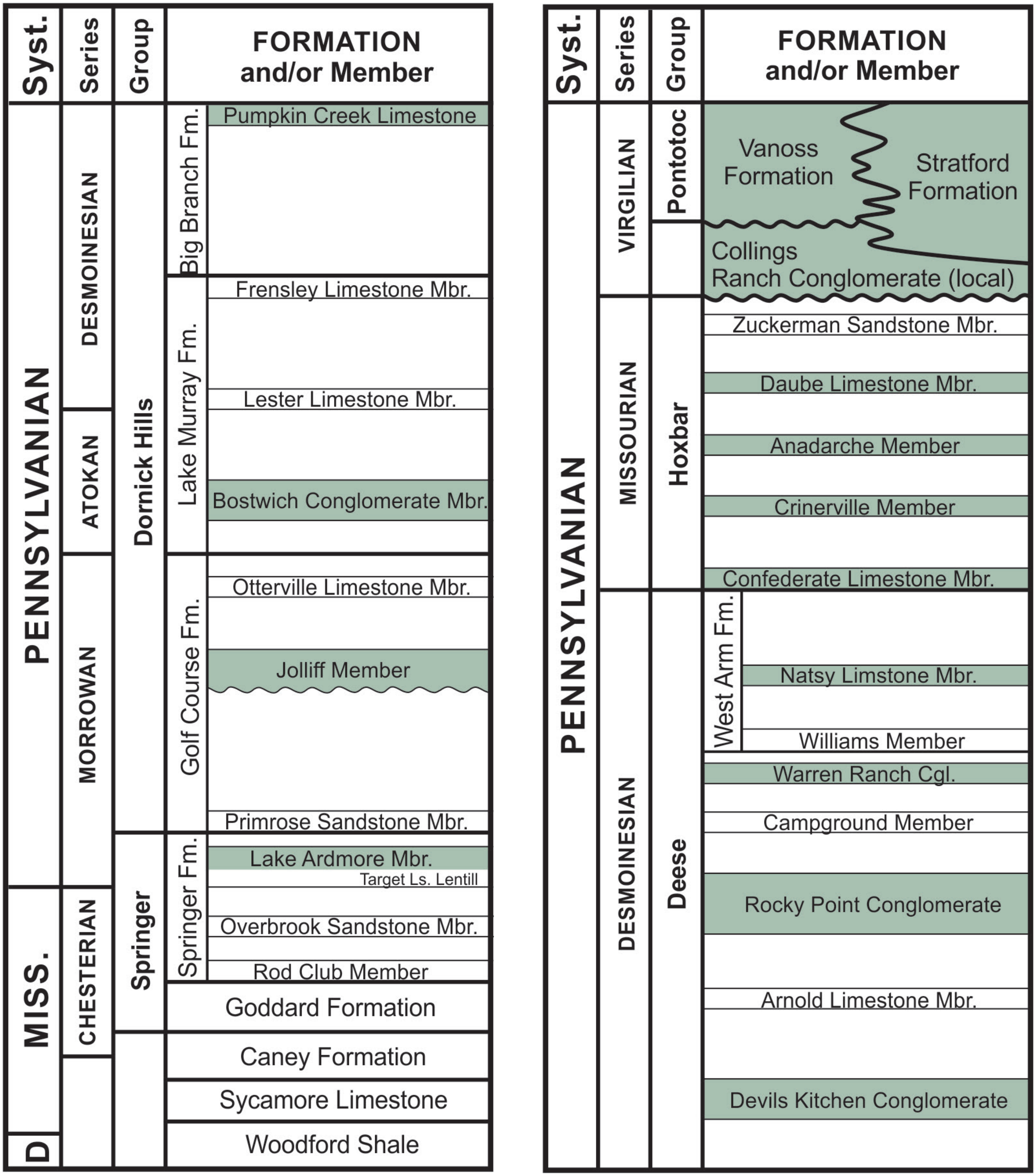


Figure 4. Stratigraphic column of Ardmore Basin. Colored units are those formations containing chert fragments derived from uplifts within the Arbuckle Mountains area.

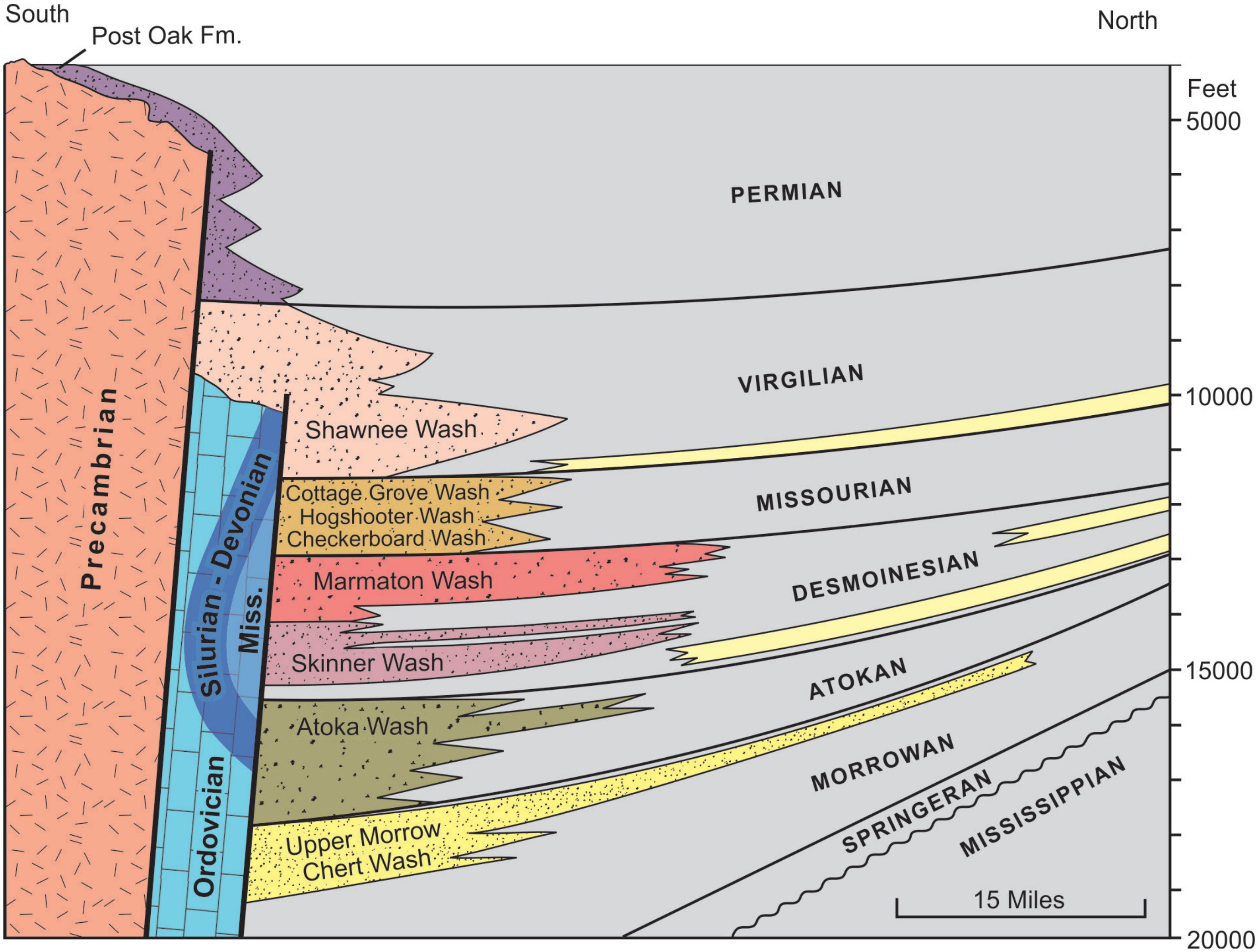


Figure 5. Schematic cross section showing "Granite Wash" units eroded off the Wichita Mountains and deposited along the southern margin of the Anadarko Basin. Modified from Mitchell (2011, figure 5).

Deformation

When deformation in the Ouachita Mountains began can only be indirectly determined and is largely "model-driven," i.e., the timing is based on plate-tectonic reconstructions of the Stanley – Jackfork – Johns Valley – Atoka (or "Ouachita") turbidite basin. This basin contains as much as 43,500 ft of Meramecian to Atokan deep-water deposits (Morris, 1974); however, because the depocenter of the basin migrated north with time, the total thickness at any one place is less than that. The base of the Stanley Group (Figure 2) is about 340 m.y. old (latest Osagean) (Shaulis et al., 2012). This date marks the change from pre-orogenic basinal deposition of chert and shale (the youngest unit being the Lower Devonian to Osagean Arkansas Novaculite) to tens of millions of years of nearly continuous turbidite sedimentation (e.g., Coleman, 2000) into the subsiding Ouachita basin that formed as a result of the collision of the Euramerica and Gondwana plates to form the Pangaea supercontinent. Most of the turbidite sandstones were funneled from east-to-west or northeast-to-southwest down the basin axis (Morris, 1974), but some were derived from the north and south. The northern margin of the basin was the shelf edge of the Euramerica plate, whereas the southern margin remains poorly understood. At least some of the Stanley Group sandstones were "derived from

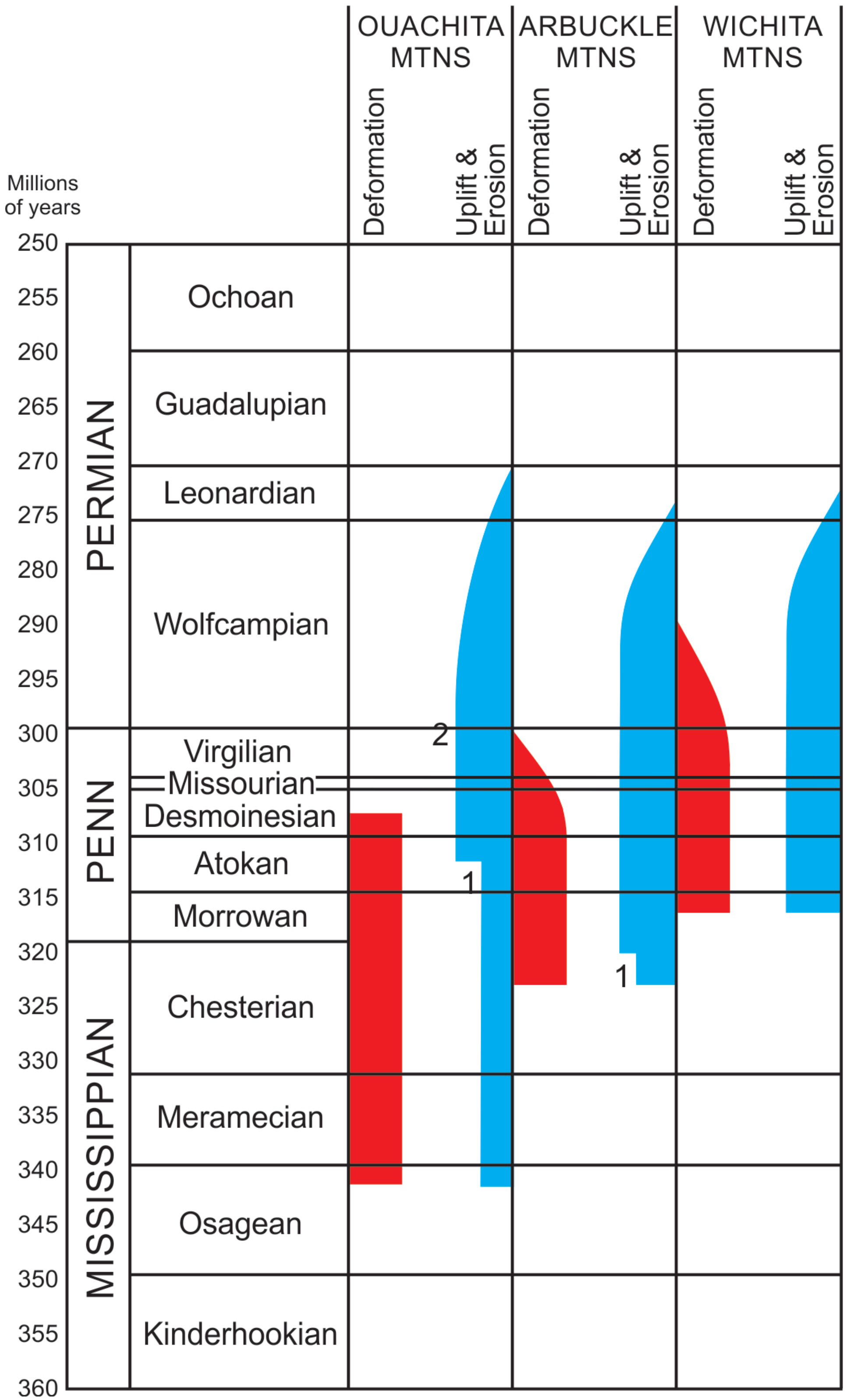


Figure 6. Chart showing ages of deformation and uplift of Ouachita, Arbuckle, and Wichita Mountains. Steps labelled 1 represent ages of subaerial exposure in Ouachita and Arbuckle Mountains. Step labelled 2 represents possible uplift of Broken Bow and Benton Uplifts in Ouachita Mountains.

volcanic, metamorphic, granitic, and sedimentary terranes to the south" (Coleman, 2000, p. 26), but the origin of those terranes is unknown. They may consist of an approaching (northward-migrating) topographic high such as an island-arc, microcontinent, or larger continental landmass; a developing (and northward-migrating) high such as a "subduction complex" (accretionary prism?) (Houseknecht and Kacena, 1983) or an incipient fold-and-thrust belt (Suneson, 2012); or some combination of these. Regardless of the composition and origin of the southern terrane, the base of the Stanley Group marks the beginning of the rapid subsidence of the Ouachita basin and likely start of deformation in the Ouachita Mountains that continued through the Desmoinesian.

The cessation of deformation in the Ouachita Mountains is easier to document assuming that the large open folds and uncommon high-angle reverse faults in the Arkoma Basin represent the northern extent of Ouachita tectonism (Arbenz, 2008). Sutherland (1988) and Elmore et al. (1990) documented the angular unconformity between the Boggy Formation (uppermost formation in the Desmoinesian Krebs Group) and overlying Thurman Sandstone (lowermost formation in the Desmoinesian Cabaniss Group) (Figure 2). Because no folding is evident in the Thurman Sandstone, Ouachita deformation ceased shortly after deposition of the Boggy Formation, i.e., in the Desmoinesian.

Uplift

The beginning of uplift of the Ouachita Mountains is difficult to determine for the following reason. If the Stanley was "funneled" by a topographic high on the south side of the Ouachita basin and shelf-slope to the north, some models suggest that that high was probably originally beneath sea level and would undergo little erosion and leave little stratigraphic evidence of its existence. If the "subduction complex" or incipient fold-and-thrust belt model is correct, initial uplift of the Ouachita Mountains coincided with the initiation of plate collision, basin subsidence, and stratal deformation. Coleman (2000, p. 26) suggested a variety of southern-terrane rock types contributed to the Stanley, and his model suggests that an advancing highland and a developing submarine uplift were present beginning in latest Osagean.

The oldest conglomerates in the Ouachita Mountains and Arkoma Basin that provide clear evidence for subaerial exposure of an eroding highlands are in the Atoka Formation in Atoka County (Taff, 1902; Hendricks et al., 1936; Hendricks et al., 1947). They consist of angular chert pebbles likely derived from a source area to the east or southeast, possibly from the Black Knob Ridge area. These chert fragments do not appear to be widespread, suggesting that the source area was relatively small and nearby. However, it is probable that exposure and erosion occurred before the Atokan because the chert, likely derived from the Arkansas Novaculite (Devonian – Mississippian), was covered by turbidite sandstones and shales of the Stanley and Jackfork Groups that did not form clasts upon erosion and therefore left little evidence of their existence. Chert pebbles are also locally present nearby in the overlying Hartshorne, Savanna, and Boggy Formations (Figure 2).

Sutherland (1988) and Elmore et al. (1990) have shown that the chert fragments in the Thurman Sandstone were derived from an uplifted Ouachita Mountains. Ouachita-derived chert fragments of varying size and abundance are also present to the northwest in most of the post-Thurman Pennsylvanian formations as well as in the Wolfcampian Stillwater Formation (Taff, 1901; Morgan, 1924; Weaver, 1954; Tanner, 1956) (Figure 3). The Leonardian Garber – Wellington Formation (undivided) contains chert clasts (Wood and Burton, 1968), and paleocurrent analyses and facies changes show the Garber and Wellington were derived from the Ouachitas (e.g., Shelton, 1979). The chert pebbles throughout the Middle and Upper Pennsylvanian and Lower Permian formations led Oakes (1948) to identify what he called the "Chert River," a long-lived (Atokan to Leonardian; ~35 m.y. duration) drainage system originating in the Ouachita Mountains. It is possible that the older, relatively local conglomerates (Atoka to Boggy Formations) were derived from nearby, smaller source areas such as Black Knob Ridge. Younger, more widespread conglomerates such as those in the Thurman Sandstone may have also been derived from the Potato Hills. Still younger, coarser, and even more widespread conglomerates may have come from extensive source terranes such as the Broken Bow or Benton (in Arkansas) Uplifts.

It is difficult to determine to what degree the chert fragments in the Middle and Upper Pennsylvanian formations represent repeated periods of Ouachita Mountains uplift or sea-level lowering. The flood of clasts in the Virgilian Vamoosa Formation (many of which may also have come from the Arbuckle Mountains) and Wolfcampian Stillwater Formation suggest renewed uplift; the thinner, more local chert-conglomerate beds with smaller clasts may represent uplift or sea-level lowering. Evidence for post-Desmoinesian uplift of the Ouachita Mountains, possibly as late as Early Permian, is supported by structural fabrics (Nielsen et al., 1989) and radiometric dates (Denison et al., 1977; Shelton et al., 1986) in the Benton and Broken Bow Uplifts. The absence of chert conglomerates in the upper part of the Garber Sandstone is evidence that by the late Leonardian the Ouachita Mountains were a tectonically inactive low-lying source terrane.

ARBUCKLE MOUNTAINS

Although most people recognize the Arbuckle Mountains as the topographic high of deformed Paleozoic strata along I-35 between Davis and Ardmore, we also include the more subtle Lawrence Uplift, Franks Graben, Ardmore Basin, and Criner Hills (Figure 1) as part of the same physiographic area. The Arbuckle Mountains themselves consist of three principal structural "blocks" separated by major fault zones; from south to north, these include the Arbuckle Anticline, Washita Valley Fault Zone, Tishomingo Anticline, Sulphur Fault Zone, and Hunton Anticline (Figure 1). The Hunton Anticline is bounded on the north by the Franks Fault Zone and Clarita Fault. The Washita Valley Fault Zone (Wichita Frontal Fault Zone to the northwest) is generally considered to mark the boundary between the Southern Oklahoma Aulacogen to the south and North American craton to the north. Paleozoic strata in the aulacogen are thicker and typically more highly deformed than strata of the same age to the north. In addition, the Cambrian section in the aulacogen includes a thick sequence of layered igneous rocks that are absent to the north. We do not include the Muenster Arch south of the Ardmore Basin or the Ada High to the north because they are subsurface features and cannot be considered among Oklahoma's "mountain ranges."

Deformation

The Arbuckle Mountains have undergone repeated periods of deformation at different times in different places and to different degrees. To a certain extent, deformation was almost continuous for most of the Pennsylvanian. The oldest period of significant deformation is marked by an angular unconformity at the base of the Jolliff Conglomerate that locally truncates the underlying Primrose Sandstone (Tomlinson and McBee, 1962, p. 471), both of which are lower Morrowan (Figure 4). However, the Jolliff contains abundant fragments of Sycamore Limestone (Mississippian) and Woodford Shale (Devonian – Mississippian) and less common older rocks. Whereas the Jolliff Conglomerate is direct evidence for lower Morrowan uplift, erosion to pre-Woodford strata is evidence that deformation must have accompanied uplift. Slightly older conglomerates in the Lake Ardmore Member are discussed below. These conglomerates are poorly studied, but they provide evidence that the initiation of deformation in the Arbuckle Mountains probably was latest Mississippian.

Van der Gracht (1931) named this syn-Jolliff deformational event the "second Wichita orogeny" because he considered the Criner Hills to be an extension of the Wichita Mountains and not part of the Arbuckle Mountains. (He believed the "first Wichita orogeny" was in the Ouachita Mountains, based on the occurrence of thick, Stanley Group clastics that needed an uplifted source terrane.) This unfortunate choice of nomenclature was accepted by many subsequent workers despite: 1) the Ouachita Mountains (Van der Gracht's "first Wichita orogeny") are not tectonically connected to the Wichitas; 2) Van der Gracht (1931) could only very generally date the uplift of the Wichitas as Early Pennsylvanian and had no evidence for the age of deformation; and 3) there is no evidence for Late Mississippian deformation in the Wichita Mountains, unlike in the Arbuckles.

Ham and Wilson (1967, p. 372) recognized at least six unconformities (disconformities and angular unconformities) in the Arbuckle Mountains area, only the youngest of which van der Gracht (1931) considered to represent his Arbuckle orogeny. The major angular unconformity at the top of the Missourian (Tomlinson and McBee, 1962) marks the cessation of major folding and faulting in the mountains; however, the evidence for the youngest deformation is within the lower part of the Vanoss Formation (Virgilian) (Figure 3). Ham (1973, p. 14) presented clear evidence for the age of the end of deformation in the Arbuckle Mountains: "At most places the rocks (Vanoss Formation) have gentle dips and are not faulted, yet in a few areas they dip as much as 40^{o} and are cut by small faults, the displacements of which die out upward in the conglomerate sequence. Such post-Vanoss local deformation was produced by the dying pulse of the Arbuckle orogeny."

Uplift

Uplift of the different parts of the Arbuckle Mountains can be dated based on the age of sediments, particularly conglomerates, deposited around them. However, as is the case for the Ouachita Mountains, the oldest uplifts may have been below sea level and were not eroded. In contrast to the Ouachita fold-and-thrust belt, the Arbuckle Mountains are structurally more complex and consist of a number of positive flower structures as well as thrust faults and related folds; as a result, many of the conglomerates that eroded off uplifted blocks are relatively local, whereas others are regional in extent. Therefore, we have divided the uplifts and resultant, primarily limestone-clast conglomerates into three general and partly overlapping groups: conglomerates in the Ardmore Basin; conglomerate beds that are part of the Middle and Upper Pennsylvanian strata north of the Arbuckle Mountains; and the conglomerate apron around the north and west sides of the Arbuckle Mountains.

The oldest major conglomerate unit in the Arbuckle Mountains area is the Jolliff Conglomerate in the Morrowan Golf Course Formation (Dornick Hills Group) in the Ardmore Basin (Figure 4). Tomlinson and McBee (1962) showed that it was derived from an uplifted, deeply eroded, and probably deformed Criner Hills Uplift. Older conglomerates eroded off a rising Criner Hills are thinner and less extensive and may have been deposited below sea level (Tomlinson and McBee, 1962; Johnson et al., 1988). Younger Middle and Upper Pennsylvanian conglomerates are present throughout the Ardmore Basin section (Figure 4). Tomlinson and McBee (1962) suggest that the source for most of these is local whereas some may have been derived from the east (Ouachita Mountains), based largely on the absence of limestone clasts. The Collings Ranch Conglomerate (Virgilian), although not within the Ardmore Basin, has an undisputed near-source origin within a pull-apart basin (negative flower structure).

North of the Hunton Anticline, the oldest conglomerates are in the early Desmoinesian "lower Franks conglomerate" (partly equivalent to the Krebs Group) and are evidence that the northern part of the Arbuckle Mountains was high and eroding in the early Desmoinesian. Limestone-conglomerate beds in much of the later Desmoinesian, Missourian, and Virgilian (Figure 3) are additional evidence that the northern part of the Arbuckles were high and eroding throughout much of the Pennsylvanian. The Vamoosa Formation is somewhat unique and contains a thick sequence of probable Arbuckle-derived silica-replaced limestones (now chert) that extend to Creek County (Boley conglomerate) (Suneson et al., 2013). In addition, the Boley contains clasts of Arkansas Novaculite derived from the Ouachita Mountains. It is likely that most of the Pennsylvanian conglomerates on the Cherokee Platform were derived from the Arbuckle and Ouachita Mountains (e.g., Ham and Wilson, 1967) (Figure 3). The conglomerate beds may represent repeated periods of uplift and erosion, sea-level fall, or both.

Recent mapping by Stanley and Chang (2012; 2015) suggest that Ham's (1973) Vanoss conglomerate member is far more extensive than previously suggested and represents a near continuous apron of material beginning just south of Ada and continuing around the north, west, and southwest margins of the Arbuckle Mountains. They have tentatively renamed this conglomeratic apron the Stratford Formation and have shown that it interfingers with Upper Pennsylvanian (Francis Formation) through Lower Permian (Wellington Formation) strata (Figure 3) to the north. The Stratford is genetically similar to the Post Oak-Granite Wash deposits that flank the Wichita Mountains and Slick Hills (described below) and includes Ham's (1973) and Ham and McKinley's (1990) Vanoss conglomerate facies/member and the upper part of Ham's (1973) "Franks conglomerate."

North of the Arbuckles, deformed lower "Franks" and un-deformed Stratford are separated by a sequence of middle to upper Desmoinesian strata that contain chert-bearing conglomerates probably derived from the Ouachitas; limestone clasts are absent within these conglomerates. This suggests that the Arbuckle Mountains may have been submerged at this time whereas the Ouachitas remained emergent and eroding.

The Vanoss Formation contains an increasing amount of arkosic sandstone upsection, evidence that the Paleozoic carbonate strata had been eroded off the uplifted Arbuckle Mountains exposing Proterozoic basement. Locally, however, and particularly on the west end of the Arbuckles, limestone continued to be eroded off the mountains, forming the dominant clast rock type in the conglomerate beds.

Pennsylvanian uplift and erosion of a now-buried Arbuckle Mountains 40 mi southeast of their present outcrop area is supported by northeast-directed paleocurrent indicators in the northwestern-most thrust sheets in the Ouachita Mountains frontal belt (Ferguson and Suneson, 1988). Flute casts in Atoka Formation turbidites are evidence for a source terrain to the south—an area now unconformably overlain by Cretaceous strata. The nature and origin of the source is unknown and is complicated by the poorly known amount of displacement on the frontal-belt thrust faults; what is known is that the area was high and eroding by the Middle Pennsylvanian (Atokan).

In summary, the uplift history of the Arbuckle Mountains is complex because they are divided into several structural blocks that acted independently. Taken as a whole, uplift began in the latest Mississippian and was subaqueous; evidence for erosion are conglomerates in the Lake Ardmore Formation and the Jolliff Conglomerate near the Criner Hills in the Ardmore Basin. The youngest conglomerates are in the lower part of the Leonardian Wellington Formation and contain limestone clasts eroded off the west end of the Arbuckle Mountains. Assuming uplift was associated with faulting and was not epeirogenic and that deformation ceased at the end of the Pennsylvanian (upper part of Vanoss Formation), it took the Arbuckles about 25 m.y. (latest Mississippian to Virgilian) to erode and cease being a source of significant sediments.

WICHITA MOUNTAINS

Deformation

The Wichita Mountains (including the Slick Hills), like the Arbuckle Mountains and unlike the Ouachita Mountains, formed within the Southern Oklahoma Aulacogen (Figure 1). As such, their history of deformation and uplift is probably generally similar to that of the Arbuckles, but the absence of Pennsylvanian strata makes determining the timing difficult. The early Paleozoic strata in the Wichita Mountains, including the folded stratified Ordovician units in the Slick Hills, are everywhere unconformably overlain by the Leonardian Hennessey or Post Oak Formation (Stanley and Miller, 2004; 2005) (Figure 5). Similarly, none of the faults and folds in the Ordovician strata extend into the overlying Permian strata with the exception of the ~1200 to 1300 years-old Meers Fault (Crone and Luza, 1990). Based on surface geology, the beginning and end of deformation can thus only be bracketed between the Ordovician and Leonardian.

Uplift

The earliest faulting and beginning of separation of the Wichita Mountains from the Anadarko Basin to the north (i.e., age of uplift) can be dated based on interpretation of subsurface data and on the age of sediments eroded off the Wichitas and into the basin. Johnson et al. (1988, figure 7) show (probable) Atokan faults within the "granite wash" along the southern margin of the Anadarko Basin, but state that "… chert conglomerates in the upper part of the Morrowan Series (date) the initiation of the Wichita – Amarillo Uplift" (p. 323). Mitchell (2011, figure 5) labels the oldest conglomerates eroded off the Wichita Mountains to be Upper Morrow Chert Wash (Figure 5).

The Wichita Mountains are bounded on the southwest by the Jackson – Tillman Fault system (including the Burch, North Fork, and Waurika – Muenster Faults), which separates the mountains from the Hardeman (Hollis) Basin to the southwest. The nature and timing of faulting along this fault system is less studied than the Wichita Frontal Fault Zone to the north. Tilford and Stewart (2011, figure 4) show faults ending in the Desmoinesian Strawn Group. They also show Atokan conglomerates in the basin – evidence that the Wichitas were high and eroding and that the fault system was active. Evidence for significant earlier tectonic activity, however, is lacking.

The cessation of uplift of the Wichita Mountains is easier to date. Faults of the Wichita Frontal Fault Zone and the Jackson – Tillman Fault system are overlain by Leonardian strata. Adler (1971, figure 7) and Johnson et al. (1988, figure 7) show the faults in the Wichita Frontal Fault Zone as terminating in the Wolfcampian. Thin, slightly post-fault tongues of "granite wash" deposits extend into the Anadarko Basin and date the cessation of Wichita Mountain erosion as Leonardian (Figure 6).

Summary (Figure 6)

Deformation in the Ouachita Mountains probably began in the latest Osagean to earliest Meramecian, assuming coincidence with plate collision and formation of the Ouachita turbidite basin. Deformation ended in the Desmoinesian following folding of the Boggy (and earlier) formations and deposition of the undeformed Thurman Sandstone. Uplift of the Ouachitas probably began about the same time as deformation but was subaqueous; the primary evidence for its timing is the presence of southerly derived clasts in the Stanley Group and the "funneling" of Stanley Group sediments down the axis of the Ouachita basin. The earliest evidence for subaerial exposure of the Ouachitas are chert pebbles in the Atoka Formation (Atokan); evidence for probable earlier exposure is lacking because the rocks overlying the chert-bearing formations consisted of shale and sandstone that probably disaggregated and were not preserved in the sedimentary record. The youngest conglomerates sourced in the Ouachita Mountains are in the Leonardian Garber Sandstone. Younger strata are fine grained and lack chert clasts, indicating the Ouachitas were no longer a topographic high.

Deformation in the Arbuckle Mountains probably started in the Chesterian in the Criner Hills area if interpretations of the origin of the middle and early Paleozoic clasts in the early Morrowan Jolliff Conglomerate are correct and that the Criner Hills were rapidly folded, uplifted, subaerially exposed, and deeply eroded. Like the Ouachitas, the earliest uplifts were probably subaqueous and left little evidence. Deformation ceased in the late Virgilian; faults and folds associated with Arbuckle Mountains deformation terminate in the lower part of the Vanoss Formation. The oldest conglomerates that provide clear evidence for uplift (and erosion) are in the Jolliff Conglomerate and Lake Ardmore Formation; earlier uplift was likely and probably subaqueous. The youngest conglomerates derived from the Arbuckle Mountains are in the Leonardian Wellington Formation.

In the Wichita Mountains, the age of deformation is based entirely on the age of sediments eroded off the uplift which are well-preserved and well-studied in the adjacent Anadarko Basin. Subaerial exposure and erosion and presumed deformation in the Wichitas began in the Morrowan and deformation ended in the Wolfcampian. The youngest "granite wash" units eroded off the mountains are Leonardian and date the end of the Wichitas as a highlands.

To a large extent, the beginning of deformation and uplift in each of the three mountain ranges was synchronous and migrated in time from east to west (Figure 6). The cessation of deformation also migrated in time from east to west. There is no evidence for a distinct Wichita orogeny, Arbuckle orogeny, or orogenic "pulsations" as suggested by Van der Gracht (1931). Unconformities in the Arbuckles and, to a lesser extent, the Wichitas are mostly local, vary in age and extent, and represent positive and negative flower structures in a transpressional tectonic environment. The youngest conglomerates eroded off the mountains were derived from the Ouachitas; this is possibly the result of very late stage Early Permian(?) uplift of the Broken Bow and Benton Uplifts and/or the fact that the Ouachitas are the largest mountain range in the state.

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Neil Suneson started working with the OGS in 1986, mapping the northern Ouachita Mountains and Arkoma Basin as part of the STATEMAP project.

Following this work, he and his colleagues completed some reconnaissance mapping in northwest Oklahoma and detailed mapping of the Oklahoma City metro area.

Before joining the Survey, Neil received his Ph.D. from the University of California Santa Barbara, after which he worked for Chevron Resources Company and Chevron USA in the Bay Area.

In addition to his work on Oklahoma stratigraphy and petroleum plays, Neil has taught the University of Oklahoma's field camp in Colorado and a course on subsurface methods in petroleum exploration and development.

He has published a number of papers and guidebooks, mostly on the stratigraphy and structure of southern Oklahoma. His current interest is completing "Roadside Geology of Oklahoma" for Mountain Press Publishing Company.


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Tom is currently the Principal Investigator of the Oklahoma Geological Survey's (OGS) STATEMAP program, which is a 50/50 cost sharing program between federal and state governments established to foster geologic mapping in areas deemed to be of vital economic, social, or scientific interest.

Prior to joining the OGS in 1998, he received a B.S. degree in geology (1982) from Southern Illinois University—Carbondale, and an M.S. degree in geology (1984) from Kent State University.

After receiving his Master's, Tom spent twelve years as an exploration geologist working in the precious metals industry doing claim block evaluation in the Black Hills, South Dakota, and in central and southern Nevada. Then in 1998, Tom received a Ph.D. in geology from the University of Kansas.

Besides mapping the state of Oklahoma, Tom's other research interests include Oklahoma stratigraphy, sedimentology, and invertebrate paleontology.

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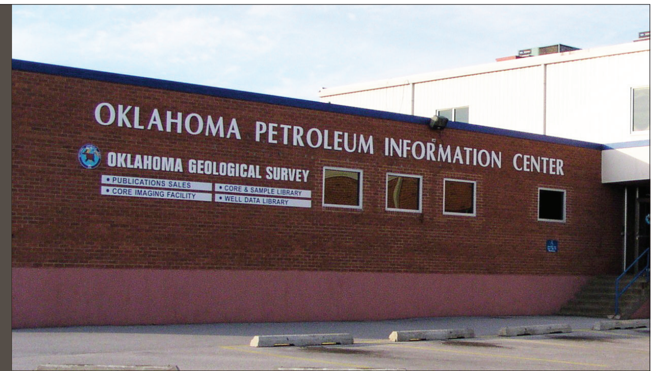

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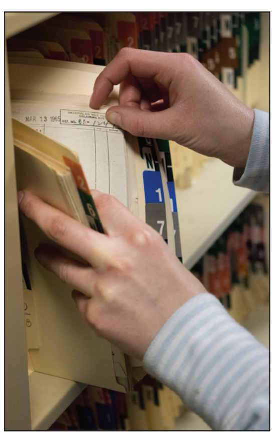

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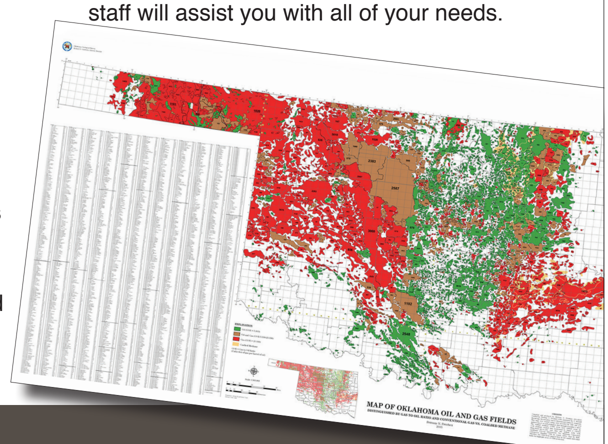

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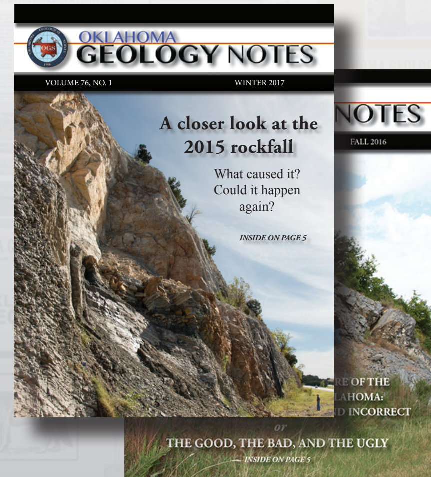

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