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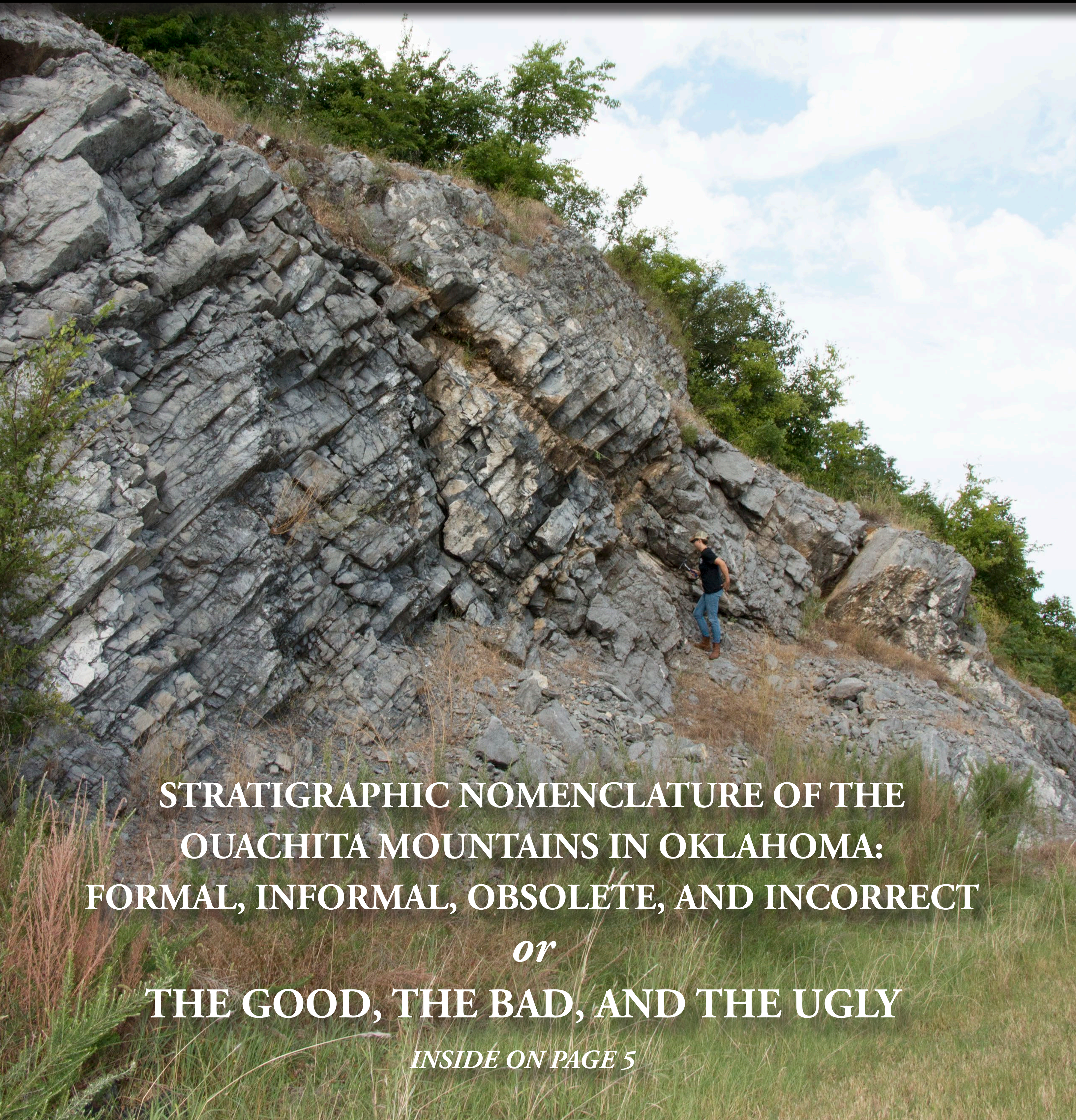

STRATIGRAPHIC NOMENCLATURE OF THE OUACHITA MOUNTAINS IN OKLAHOMA: FORMAL, INFORMAL, OBSOLETE, AND INCORRECT

or

THE GOOD, THE BAD, AND THE UGLY

INSIDE ON PAGE 5

OKLAHOMA GEOLOGICAL SURVEY

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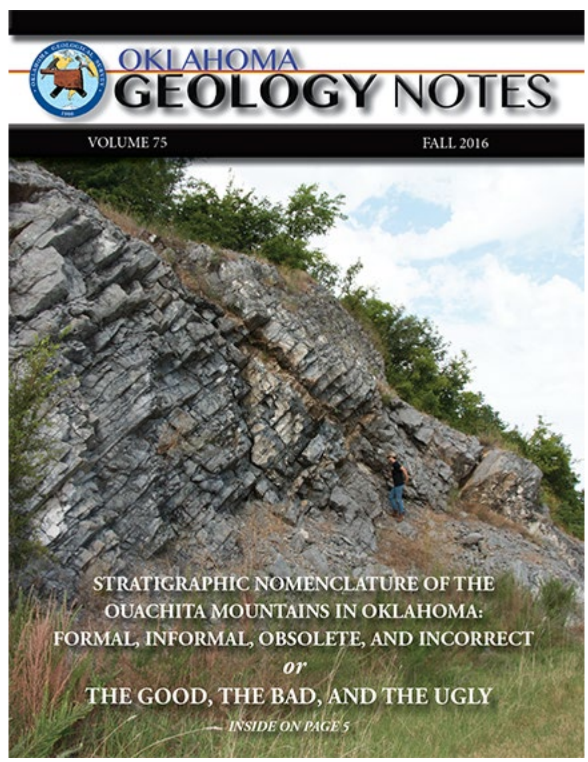
IN THIS ISSUE

OGS Geologist Neil Suneson delves into the Good, the Bad, and the Ugly of the topic of stratigraphic nomenclature in the Ouachita Mountains.



Cover: Outcrop of the Wapanucka Limestone east of Hartshorne, Oklahoma. (Photo by TED SATTERFIELD).

From The Director

Grateful to be back

As the Director of the Oklahoma Geological Survey (OGS), I am very glad to see the revival of the Oklahoma Geology Notes, which had been a feature of the Oklahoma geology scene since the early 40s, but was last published in 2014. This issue, marking the return, introduces a new format, becoming less of a newsletter and more of a scientific publication. From there we proceed, as many geological investigations do, from the surface downward.

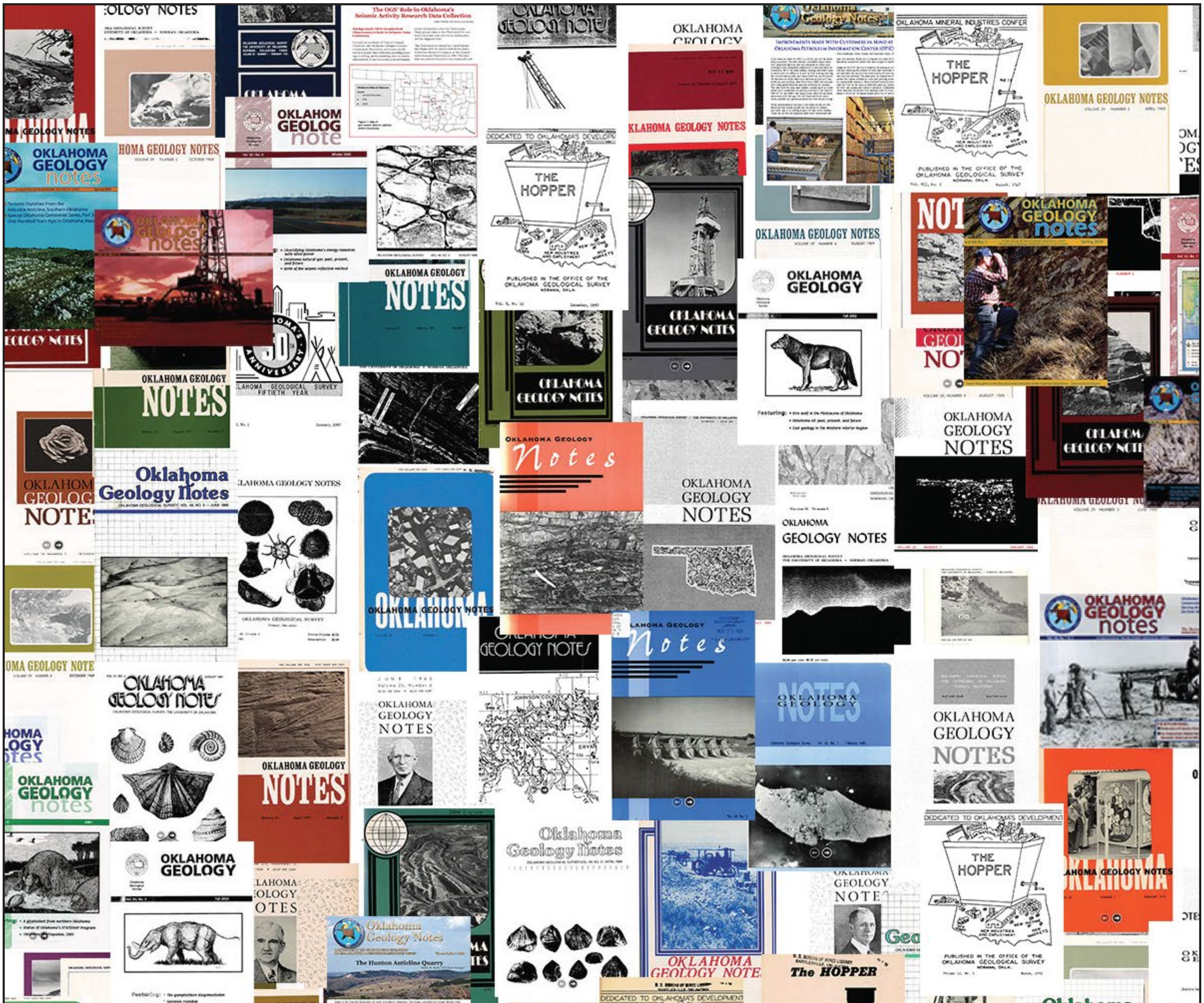
We start up the Notes again with Neil Suneson's take on stratigraphic nomenclature in the Ouachita Mountains. Just the word "nomenclature" tends to produce yawns among many scientists, but making sure that we are talking about the same rock units can be a challenge when different regional names don't necessarily meet in the middle due to the lateral variations of rock units.

As geologists, we are tasked with characterizing the crust of the earth in three spatial dimensions, through time. But, as OGS geophysicist Kevin Crain pointed out to me recently, the problem is really n-dimensional, as we must identify and measure critical properties, each of which covers its own natural range, varying through time as well. In the realm of sedimentary rocks, we can count in general on greater variation in the vertical than the horizontal dimension (or we would not be able to identify strata to begin with). But the recognition that lithostratigraphic units are not the same as chronostratigraphic units can lead to confusion.

Jeremy Boak
OGS Director

Providing clear rationale, and straightforward description of any revision of rock names — what names are being changed, and how do the new names relate to existing stratigraphic terms — is needed to ensure that the value of older literature will not be lost.

Our hope is that the new Oklahoma Geology Notes will channel the best of the previous long series and bring some new scenes, new takes on old locations, current developments, interesting ideas, and show that, no matter how old, there is always something new to be learned about Oklahoma geology.



Oklahoma Geology Notes is back

The Oklahoma Geology Notes, originally called "The Hopper", has been a fixture at the Oklahoma Geological Survey since 1941. It was last printed in Winter 2014, but is now back with a new look. For information about how to contribute to the Oklahoma Geology Notes, contact Ted Satterfield at tgsatterfield@ou.edu

STRATIGRAPHIC NOMENCLATURE OF THE OUACHITA MOUNTAINS IN OKLAHOMA: FORMAL, INFORMAL, OBSOLETE, AND INCORRECT

or

The Good, the Bad, and the Ugly

By Neil H. Suneson

INTRODUCTION

The nomenclature of the stratigraphic units (groups, formations, members) in the Ouachita Mountains in Oklahoma has changed since the first geologic map of part of the mountain range was published in 1902 (Taff, 1902). Proposed revisions to the formation names were typically based on a number of factors: 1) more detailed mapping than was previously available; 2) more and better paleontological data; 3) better stratigraphic correlations with units exposed in the Oklahoma *and Arkansas* Ouachita Mountains and the Arkoma Basin; and 4) more and better subsurface data. In addition, changes in the "rules" for naming geologic units as prescribed in the 1933, 1961, 1970, 1983, and 2005 "Codes of Stratigraphic Nomenclature" forced Ouachita stratigraphers and geologists to reexamine formerly accepted names. In many cases, however, geologists ignored the existing code and introduced new terms without emphasizing their informal nature. Petroleum geologists exacerbated the confusion, particularly in the northern frontal belt (Figure 1) of the Ouachitas, by using new names that applied to strata encountered only in the subsurface.

This report briefly describes the history of the stratigraphic nomenclature of the Ouachita Mountains in Oklahoma. It describes the currently accepted group, formation (Figure 2), and member names and distinguishes between those that are generally considered "formal" by geologists and those that, while widely used, are informal. This report also comments on some problems with the accepted formal and informal nomenclature and proposes some solutions to those problems. The subsurface nomenclature used in the northern frontal belt is discussed and clarified. More importantly, perhaps, this paper recommends that some commonly used but informal names be viewed as formal and that formal, but little-used or poorly justified, names or those of local units be changed.

The names reviewed in this report are of those units that are exposed or are in the subsurface in the Oklahoma Ouachita Mountains and that are present in the subsurface near the Choctaw Fault. The units in the subsurface in the southern part of the Arkoma Basin are typically folded and faulted and are part of the Ouachita tectonic belt. The names are limited to those of units that are older than the Desmoinesian Hartshorne Formation. Whereas the Hartshorne and younger formations are folded and faulted, they are not present at the surface south of the trace of the Choctaw Fault and are therefore beyond the scope of this paper.

BACKGROUND

The basis for this paper is the Code of Stratigraphic Nomenclature. As discussed below, many names were assigned before any code existed. Ashley et al. (1933) published the first "code" (although the term "code" was not included in the title), and two of its co-authors – Charles Gould and Hugh Miser – were very familiar with the stratigraphy of the Ouachita Mountains. The authors used the word "rules" in their paper, but admitted that the "rules" were really "guidelines." The American Commission on Stratigraphic Nomenclature (ACSN) published a revised code in 1961 (ACSN, 1961) and an only slightly revised code again in 1970 (ACSN, 1970). The code was largely rewritten in 1983 by the North American Commission on Stratigraphic Nomenclature (NACSN) (NACSN, 1983) who also published a revised version in 2005 (NACSN, 2005). Like the 1933 "code," the 2005 version is more a set of guidelines than rules as evidenced by the common use of the word "should" instead of "must." For example, when naming a subsurface unit, "the hole or mine *should be* (instead of "must be") located precisely" (NACSN, 2005, p. 1564) (author's italics and parentheses).

Many of the units in the Oklahoma Ouachita Mountains were named before the 1933 "code" was published and have been widely used for almost 100

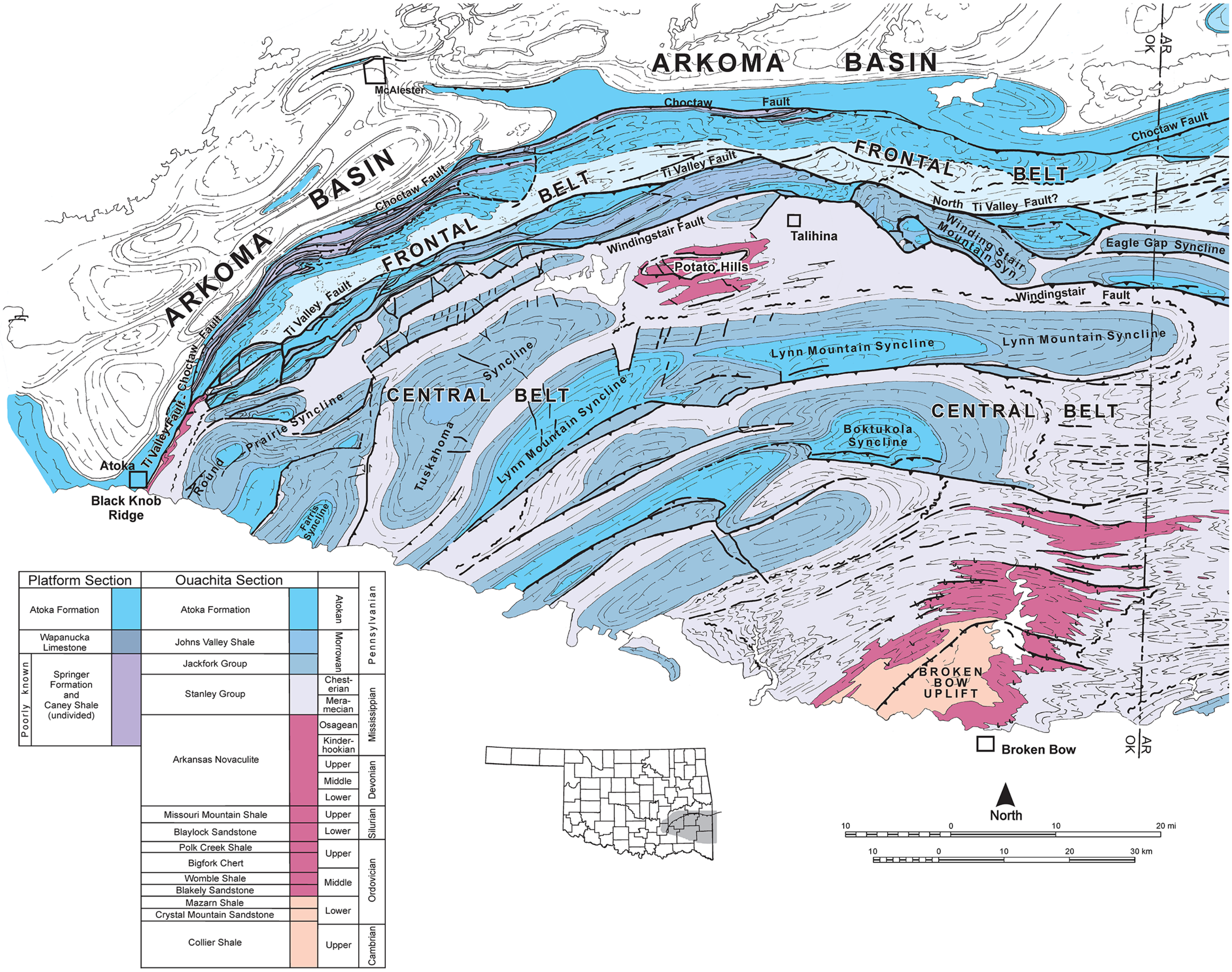


Figure 1. Generalized geologic map of the Ouachita Mountains, Oklahoma. Modified from Arbenz (2008, plate 2).

years. Although their names do not fulfil many of the criteria now necessary for a name to be recognized, they are considered formal because they have been used for many years and are well-established in the geologic literature. Article 7 (c) of the modern stratigraphic code (NACSN, 2005) recognizes the need to preserve commonly used, but perhaps imprecisely defined, names of stratigraphic units. One unit – the Spiro Sandstone at the base of the Atoka Formation – is widely used in the petroleum industry and is easily recognized and mapped on the surface and subsurface. Although it has not met the rigorous requirements for being considered formal, this paper recognizes it as such.

An important source for stratigraphic nomenclature is the U.S. Geological Survey's (USGS) U.S. Geologic Names Lexicon ("Geolex") (http://ngmdb.usgs.gov/Geolex/search). Geolex is a searchable database based on lexicons published as hard-copy bulletins by the USGS. This database lists names used by the USGS and the different state surveys and claims to identify with a slash (see website) those that do not conform with the stratigraphic code(s) cited above; in fact, Geolex does not do this (e.g., see discussion on Lynn Mountain Formation, below). Geolex also does not always restrict the name of a unit to a specific rank; for example, the USGS and OGS recognize the Springer as a group and a formation. In addition, the OGS recognizes Springer Shale as a formal unit. Table 1 shows the names of the units in the Oklahoma Ouachita Mountains as recognized by the USGS and Oklahoma Geological Survey (OGS) (source: Geolex database at

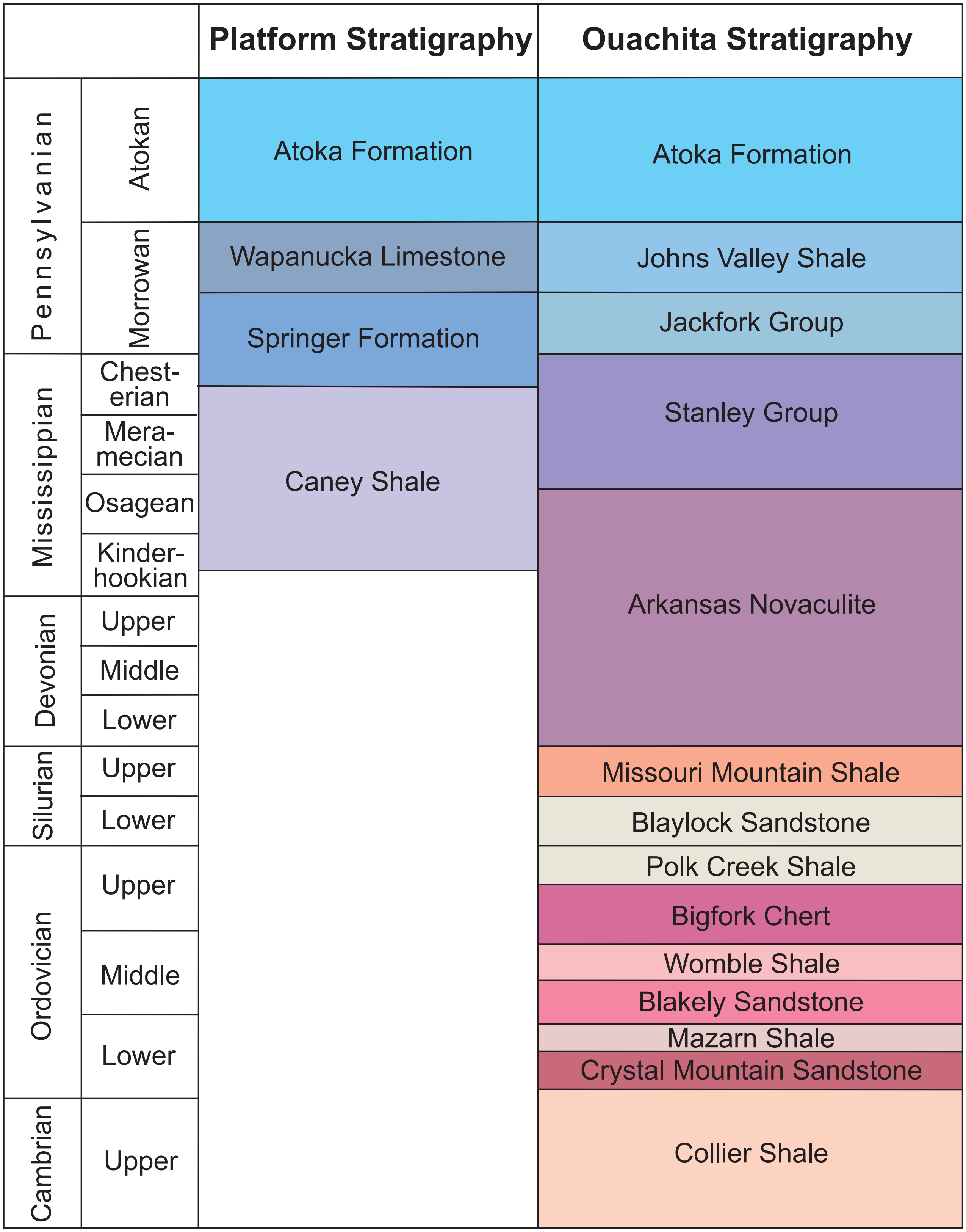


Figure 2. Generalized stratigraphic column of the Ouachita Mountains, Oklahoma. Subdivisions of groups and formations discussed in text. Modified from Arbenz (2008, plate 2).

ngmdb.usgs.gov/Geolex/search; accessed June 28, 2016). In addition, proposed changes to and problems with generally accepted nomenclature are shown; the reasons for the changes are summarized in the table and/or discussed in the text.

Throughout this report, unit names with all capital first letters are considered or are recommended to be formal in this report.

Figure 3. Atoka Formation. Location: on south side of US Highway 259 just south of intersection with US Highway 59. SE NW SE sec. 17, T. 3 N., R. 26 E. Photograph taken in 1988 and is now more vegetated.

FORMAL STRATIGRAPHY OF THE OUACHITA MOUNTAINS, OKLAHOMA

INTRODUCTION

The generally accepted stratigraphy of the Ouachita Mountains in Oklahoma is shown in Figure 2. The names and ranks of all of the units shown are recognized by the USGS and are used by the OGS. The following section briefly describes the origin of the names used by geologists mapping in southeastern Oklahoma; most of them were established before any code of stratigraphic nomenclature existed and are accepted because they have been referred to in the geological literature for nearly 100 years. Some of the formally named formations, however, should be reexamined; in particular, the Devonian formations in the frontal belt (Figure 1) that may be olistoliths in the Johns Valley Shale and the formations that make up the Jackfork Group.

FRONTAL BELT

Atoka Formation (Atokan)

The youngest formation exposed in the Ouachita Mountains and the oldest exposed in the Arkoma Basin is the Atoka Formation (Figure 3). The name first appeared in a report (Taff and Adams, 1900) on the eastern Choctaw coal fields in what was then Indian Territory. The coal fields, however, did not extend into either Atoka County or the town of Atoka. Taff (1902) later mapped the formation in the Atoka County area, but never designated a type section. The name “Atoka Formation” has been used in all (but two) publications on the geology of the Ouachita Mountains and Arkoma Basin, most notably Hendricks (1939), Hendricks et al. (1947), Cline (1960), Shelburne (1960), Seely (1963), Hart (1963), and Fellows (1964). Geologic maps produced by the OGS as part of the COGEOMAP and STATEMAP programs beginning in 1989 also show the Atoka Formation. Two publications (Pitt et al., 1982; Marcher and Bergman, 1983) refer to the Atoka Formation as the Lynn Mountain Formation; this name is discussed below. In addition, the petroleum industry recognizes several named producing units in the Atoka Formation; these are also discussed below.

Spiro Sandstone Member, Atoka Formation

The Spiro sandstone member (of the Desmoinesian Savanna Formation, Krebs Group) was used by Wilson (1935) and Wilson and Newell (1937) for exposures in Muskogee and McIntosh Counties but was named for sandstone outcrops near the town of Spiro in Le Flore County. Wilson (1935) believed the Spiro sandstone in Muskogee County was the same as a sandstone that was mapped (unpublished) near Spiro by W.T. Thom, Jr. Wilson (1935) did not formally designate a type section but did describe, in a very general way, the Spiro sandstone. Knechtel (1949) did not recognize Wilson’s Spiro sandstone in northern Le Flore County and Jordan (1957) noted that the OGS abandoned the name as a member of the Savanna Formation. Geolex, however, erroneously shows this Spiro sandstone as being used by the OGS.

An identically named Spiro Sandstone (or “sand”) (of the Atoka Formation) (Figure 4) is a prolific gas reservoir in the southern part of the Arkoma Basin and frontal belt of the Ouachita Mountains (Lumsden et al., 1971; Grayson and Hinde, 1993; Gross et al., 1995) and is widely recognized by petroleum geologists working in the area. (It is also referred to in well completion

Figure 4. Spiro Sandstone Member, Atoka Formation. Location: along Pittsburg – Latimer County line about 2.5 mi east-southeast of Hartshorne and just south of Oklahoma Highway 1/63. SW SW SW sec. 10, T. 4 N., R. 17 E. Photograph taken by Ted Satterfield, OGS.

reports as "basal Atoka" or "lowermost Atoka" sandstone.) It was first named in the Le Flore Gas and Electric Company No. 1 Frank Parnell well (NE SE sec. 18, T. 9 N., R. 27 E.), located about eight miles east of the town of Spiro, and was the discovery well for the Cedars Southwest (now Cedars) gas field (Maravich, 1955). This Spiro Sandstone also crops out throughout the central part of the frontal belt of the Ouachita Mountains where it underlies turbidite sandstones and shales that form most of the Atoka Formation and overlies the Wapanucka Limestone or the Johns Valley Shale (OGS COGEOMAP and STATEMAP geologic maps).

The code of stratigraphic nomenclature allows subsurface units to be formalized (Article 16), but the Spiro Sandstone (Atoka Formation) has not met several of the criteria for formal recognition. However, the name "Spiro Sandstone" is now so established in the geologic literature, so widely recognized and mappable in outcrop, so easily recognized on well logs, and so important as a gas reservoir in this part of Oklahoma, that it is considered a formal member of the Atoka Formation in this report and is therefore capitalized, despite not being listed in the USGS Geolex database.

Wapanucka Limestone (formation) (Morrowan)

The Wapanucka Limestone (Figure 5) underlies the Atoka Formation and overlies the Springer Formation in the Ouachita Mountains frontal belt. It was named by Taff (1901) probably for exposures near the town of Wapanucka in Johnston County, but he did not specify a type locality or type section. The Wapanucka Limestone appears on detailed geologic maps of the Ouachita Mountains frontal belt, including Hendricks et al. (1947) and the northwestern COGEMAP and STATEMAP maps published by the OGS. Harlton (1938) proposed subdividing Taff's Wapanucka into three formations, from oldest to youngest, the Primrose Formation, the Limestone Gap Shale, and the Wapanucka Limestone; however, despite Harlton's detailed stratigraphic work, this proposal was not followed by subsequent workers.

Chickachoc Chert Member, Wapanucka Limestone (formation)

Taff (1901) named the Chickachoc Chert in his study of the western part of the Arkoma Basin, presumably for the Chickiechockie Post Office (current name Chockie) located just east of his map area. Like all of the units named by Taff, neither a type area, a type locality, nor a type section was identified. Taff (1901) believed the chert was a lentil within the Atoka Formation and Hendricks et al. (1947) mapped it as a formation separate from, but correlative with, the Wapanucka Limestone. Grayson (1979) identified the Chickachoc Chert as the lower informal member of the Wapanucka Formation present only in the more southeastern thrust sheets of the Ouachita Mountains. The USGS recognizes Chickachoc Chert and Chickachoc Chert Member despite its uncommon usage and lack of formal publication.

Springer Formation (Morrowan and Chesterian)

The Springer Formation is exposed not only in the Ouachita Mountains where it underlies the Wapanucka Limestone and overlies the Caney Shale, but in the Arbuckle Mountains and Ardmore Basin where it has been far more thoroughly studied. The Springer is also referred to as the Springer Shale and locally is recognized as a group where it is thick, paleontologically well dated, and contains numerous sandstone beds. Goldston (1922) named the unit for the town of Springer in the Ardmore Basin and recognized it as a member of the Glenn Formation, but he did not identify a type section. Tomlinson (1929) raised its rank from member to formation based partly on the presence of persistent mappable sandstone beds that he considered as members, but did not identify a type section or locality.

Despite its lack of detailed study, the Springer in the Ouachita Mountains is considered a formation

Figure 5. Wapanucka Limestone. Location: along Oklahoma Highway 1/63 three miles east-southeast of Hartshorne. NE SE SW sec. 10, T. 4 N., R. 17E. Photograph taken by Rick Andrews, OGS.

by the USGS and OGS. It is present in several thrust sheets in the western part of the Ouachita Mountains frontal belt (Figure 1) where it is underlain by the Caney Shale (Hendricks et al., 1947) and is present as far east as the town of Red Oak (Hemish et al., 1990).

Caney Shale (formation) (Chesterian to Kinderhookian)

The Caney Shale (Figure 6) has one of the more interesting nomenclatural histories in southern Oklahoma. Much of the discussion focusses on the age of the Caney (both "Mississippian Caney" and "Pennsylvanian Caney" appear in numerous papers) and its relation to the overlying shale units; most of these discussions are based on exposures in the Ardmore Basin and adjacent Arbuckle Mountains and have little bearing on how the Caney is used in the Ouachita Mountains which is where the Caney was named. Ulrich (1927) was the first to describe the differences between what he called the "Ouachita Caney" and the "Arbuckle Caney." The result of many of these studies was that the name "Caney" and origin of the formation were the source of years of misinterpreted geology.

Taff (1901) first named the unit in his work on the Coalgate quadrangle which is mostly in the Arkoma Basin, but he probably named it after Cane Creek (Caney Creek on some maps) in the Tuskahoma Syncline about 20 mi to the east (Cline, 1960, p. 60). Cane Creek is one of several streams that drain Johns Valley, the type locality of the Johns Valley Shale (discussed below). (Additional confusion regarding the name "Caney" is described by Elias and Branson (1959, p. 4), who also proposed a type section for the Caney in the Arbuckle Mountains (Elias, 1956; Elias and Branson, 1959).) Modern geologic maps (especially Hendricks et al., 1947) show no Caney Shale in Johns Valley; the Caney outcrops there are allochthonous submarine slide masses (olistostromes) within the Johns Valley Shale. Thus, the Caney Shale in its presumed type area is stratigraphically out-of-place. The failure to recognize the allochthonous nature of the Caney Shale in the Johns Valley Shale led many geologists to suggest that the underlying Jackfork Group was Mississippian.

Hendricks et al. (1947) mapped what they believed to be stratigraphically autochthonous Caney Shale in the western part of the Ouachita Mountains frontal belt (Figure 1). Most of these outcrops(?) are shown as long narrow bands at the base of thrust sheets overlain by even narrower bands of the Springer Formation. Very few strike and dip measurements are shown along these bands; therefore, their true continuity is unknown. Because these Caney Shale outcrops are autochthonous, the Caney Shale is included on Figure 2. However, other, typically smaller areas of the Caney Shale are underlain by the Woodford Shale and, in one case, the Woodford Shale is underlain by the Pinetop Chert. Suneson and Ferguson (1990) mapped a Woodford – Caney outcrop in the eastern part of the frontal belt as a large olistolith in the Johns Valley Shale. The (Pinetop) – Woodford – Caney outcrops mapped by Hendricks et al. (1947) are probably also slide masses within the Johns Valley (Suneson and Hemish, 1994a, p. 74-75); therefore, these units are not included in a stratigraphic column of the Ouachita Mountains (Figure 2).

Figure 6. Caney Shale. Location: along Brushy Creek. NW SW NW sec. 5, T. 2 N., R. 15 E.

Woodford Shale (formation) (Chesterian to Upper Devonian)

The Woodford Shale (also Chert) was named by Taff (1902) in his work on the Atoka quadrangle, presumably for outcrops near the town of Woodford in Carter County about 50 mi to the west. Because many, if not all, of the Woodford outcrops in the Ouachita Mountains are probably stratigraphically allochthonous and are contained within the Johns Valley Shale, the unit is not described in this report.

Pinetop Chert (formation) (Lower Devonian)

Miser (1934, p. 974) named the Pinetop Chert for exposures near Pinetop School in the Ouachita Mountains and Hendricks et al. (1947) showed the single, small outcrop of the unit on their map. Amsden (1983) correlated the Pinetop with the Haragan and Bois d'Arc Limestones of the Hunton Group and Ham (1959) correlated it with the lower part of the Arkansas Novaculite. However, as noted above in the description of the Woodford Shale and by Suneson and Campbell (1990), this unit probably is stratigraphically allochthonous and therefore is not described in this report.

CENTRAL BELT

Atoka Formation (Atokan)

The Atoka Formation (Figure 3) in the Ouachita Mountains central belt (Figure 1) differs little from that in the frontal belt and is described above.

Johns Valley Shale (formation) (Morrowan)

The nomenclatural history of the Johns Valley Shale is closely related to that of the Caney Shale described above. Ulrich (1927) proposed the name Johns Valley Shale for the same unit Taff (1901) called Caney Shale, and Cane Creek (also called Caney Creek), Taff's (1901) presumed type locality of the Caney Shale, is one of several creeks that drain the bowl-shaped depression known as Johns Valley. Although Ulrich (1927) identified Johns Valley as the type locality of the Johns Valley Shale, he did not identify a type section, probably because the exposures in the area are very poor.

The Johns Valley Shale is widely recognized throughout the Ouachita Mountains (Hendricks et al., 1947; Cline, 1960; Shelburne, 1960; Seely, 1963; Hart, 1963; Fellows, 1964; Pitt et al., 1982; and OGS COGEOMAP and STATEMAP geologic maps) although its distribution is not agreed upon. Early workers (e.g., Miser, 1929, p. 25; Cline, 1960, p. 17; Hendricks et al., 1947) restricted exposures of the Johns Valley to south of the Ti Valley Fault and suggested that the pre-Atoka Pennsylvanian and Mississippian formations north of the fault resembled those in the Arkoma Basin whereas those units south of the fault consisted of deep-water turbidites. More recent mapping by the OGS in the frontal belt has shown that the Johns Valley is present north of the Ti Valley Fault (Suneson, 1988). This difference is partly related to the interpret-

Table I. — Formal Nomenclature of the Ouachita Mountains, Oklahoma

Frontal Belt

- Atoka Formation
  - Spiro Sandstone Member (1)
- Wapanucka Limestone (formation)
  - Chickachoc Chert Member
- Springer Formation
- Caney Shale (formation) (3)

Central Belt

- Atoka Formation
- Johns Valley Shale (formation)

Jackfork Group
- Game Refuge Sandstone (formation)
- Wesley Shale (formation) (3)
- Markham Mill Formation (3)
- Prairie Mountain Formation (3)
  - Prairie Hollow Shale Member (2)
- Wildhorse Mountain Formation

Stanley Group
- Chickasaw Creek Shale (formation)
- Moyers Formation
- Tenmile Creek Formation

Broken Bow Uplift

Stanley Group (Chesterian to Osagean)
- Tenmile Creek Formation
  - Hatton Tuff Lentil

- Arkansas Novaculite (formation)
- Missouri Mountain Shale (formation)
- Blaylock Sandstone (formation)
- Polk Creek Shale (formation)
- Bigfork Chert (formation)
- Womble Shale (formation)
- Blakely Sandstone (formation)
- Mazarn Shale (formation)
- Crystal Mountain Sandstone (formation)
- Collier Shale (formation)

Footnotes: no number – unit recognized by USGS and OGS; (1) recommended addition of unit (see text). (2) recommended change of unit (see text). (3) Caney Shale (of Springer Group) used by USGS; Wesley, Markham Mill, and Prairie Hollow require re-evaluation (see text) ed origins of the (Pinetop) – Woodford – Caney outcrops discussed above. Are the large, stratigraphically coherent blocks slide masses (large olistoliths) within the Johns Valley Shale, in which case the Johns Valley is present north of the Ti Valley Fault in the western Ouachitas, or do they form the base of thrust sheets? The origin of these exposures, as well as the origin of the Johns Valley Shale itself, is beyond the scope of this report, but both are critical for determining how to map and interpret the formation.

Jackfork Group (Morrowan)

Taff (1902) first named the Jackfork sandstone in his work on the Atoka quadrangle for Jackfork Mountain, which is about 15 mi east of his map area. Taff (1902, p. 4) did not designate a type section; he merely stated, "it receives its name from Jackfork Mountain, in which a large part of the formation is exposed." Much later Pitt et al. (1982, p. 80) attempted to identify a type section on Jackfork Mountain but ignored many of the recommendations set forth in the then-accepted Code of Stratigraphic Nomenclature (ACSN, 1970). Their lithologic descriptions are brief and much of the unit, including the top and base, is covered. In addition, part of their "type section" crosses a fault and includes part of the Stanley Group (Suneson, 1991). As a result the Jackfork, like most of the Mississippian and Pennsylvanian units in the Ouachita Mountains, has a type area or type locality but does not have a type section.

The Jackfork Group (formerly sandstone or formation) (Figure 7) is widely recognized as a formal unit in the Ouachita Mountains and is shown on most of the detailed maps of the region (Honess, 1923; Hendricks et al., 1947; Cline, 1960; Shelburne, 1960; Seely, 1963; Hart, 1963; Fellows, 1964; Briggs, 1973; Pitt et al., 1982; and OGS COGEOMAP and STATEMAP geologic maps). The age of the Jackfork, however, has been controversial mostly because the age (and origin) of the overlying Johns Valley Shale was controversial. Cline (1956) first proposed that the Jackfork was Mississippian based entirely on his belief that the base of the overlying Johns Valley consisted of *in situ* "black shale of typical Caney lithology" (p. 105). Cline (1960) presented additional observations on the Mississippian age of the lower part of the Johns Valley and Jackfork in his study of the Lynn Mountain Syncline and greatly influenced several students whose work on the Ouachitas was later published (Shelburne, 1960; Hart, 1963; Seely, 1963; Fellows, 1964; Briggs, 1973). The age of the Jackfork was clearly resolved by Gordon and Stone (1977) who showed that the immediately underlying Chickasaw Creek Shale was uppermost Chesterian and that most of the Jackfork was Morrowan, thereby agreeing with Hendricks et al. (1947) and most previous workers. Whiteside and Grayson (1990) confirmed the Pennsylvanian age using conodonts.

Harlton (1938) elevated the rank of the Jackfork to group status and divided it into four formations – from bottom to top, the Wildhorse Mountain, Prairie Mountain (including the Prairie Hollow Member), Markham Mill, and Wesley. Harlton (1938) based his divisions on what he believed to be widespread siliceous shales, although it is unclear what his evidence for this is because his published geologic maps are of relatively small areas. (As described below, many later workers failed to find Harlton's siliceous shales.) In 1959 Harlton added a fifth, uppermost formation — the Game Refuge — and moved the Prairie Hollow Shale Member into the Wildhorse Mountain (Figure 8). The nomenclatural history of these are described below. The Jackfork Group names used in Oklahoma are not recognized in Arkansas, rather, the Jackfork is divided into an upper Brushy Knob Formation and lower Irons Fork Mountain Formation (Morris, 1971).

Harlton's (1938) formation names were used by many subsequent workers (e.g., Cline, 1960; Shelburne, 1960; Hart,1963; Seely, 1963; Fellows, 1964, Briggs, 1973) in the central and eastern Oklahoma Ouachita Mountains, but many of the formations were combined (shown as "undivided" on the geologic maps) because the siliceous shales used by Harlton (1938) were "obscure," unmappable, or absent (Figure 8). The only units within the Jackfork Group that were mapped and/or recognized by most workers are the Game Refuge Sandstone (formation) and the Prairie Hollow Shale Member, and most workers followed Harlton (1959) and Cline (1960) who included the Prairie Hollow in the Wildhorse Mountain Formation and not the Prairie Mountain Formation (Harlton, 1938). Hendricks et al. (1947) recognized the widespread distribution of the siliceous shales in the Jackfork Sandstone (his term) in the western Ouachita Mountains but did not use the formation names suggested by Harlton (1938). Morris (1971) was not able to map Harlton's (1938) siliceous shales and therefore did not recognize Harlton's formation names. As a result the Jackfork in Arkansas is divided into the Irons Fork Mountain Formation and the overlying Brushy Knob Formation, and the contact between the two is the same as that between the Prairie Mountain and Wildhorse Mountains Formations of Oklahoma.

Game Refuge Sandstone (formation)

The uppermost formation of the Jackfork Group is the Game Refuge Sandstone, originally named by Harlton (1959) for exposures near a state game refuge on the southeast flank of the Lynn Mountain Syncline. Harlton (1959) did not specify an exact location nor did he publish a measured section of the unit, rather, the location was chosen because a name was available despite better exposures elsewhere. The only detailed map of the area (Pitt et al., 1982) does not show the Game Refuge, rather, shows only the upper (undivided) part of the Jackfork Group there to be bounded by faults. Despite its poor definition, the Game Refuge Sandstone has been used by most subsequent workers in the Ouachita Mountains.

Wesley Shale (formation)

The type locality for the Wesley Shale was precisely located by Harlton (1938) on the northeast flank of an unnamed syncline "near" (five miles southwest of) the village of Wesley. No measured section of the unit in the type locality was published and Harlton's (1938) description is brief, except for those of several petrographic thin sections. Harlton (1938, p. 886) claimed the Wesley was "one of the best developed and most widespread of diagnostic shales … and is easily recognized and has been found at many localities in the Ouachita Mountain (sic) area," but several later workers were not able to distinguish it from the underlying Markham Mill Formation and/or overlying Game Refuge Sand-

Table II. — Informal Nomenclature of the Ouachita Mountains

- Atoka Formation
  - Fanshawe sandstone
  - Red Oak sandstone
  - Panola sandstone
  - Diamond sandstone
  - Brazil sandstone
  - Bullard sandstone
  - Cecil sandstone
  - Shay sandstone
  - Foster sandstone
- Johns Valley Shale (formation)
  - Stapp conglomerate (1)
- Jackfork Group
  - Hope sandstone
  - Secor pay zone
- Stanley Group
  - Moyers Formation
    - Chickasaw Creek tuff
    - Miller sand
    - Moyers siliceous shale; Siliceous shale member; Schoolhouse chert member (2)
  - Tenmile Creek Formation
    - Middle Tenmile Creek siliceous shale; Middle siliceous shale bed; Battiest chert member (2); Smithville chert lentil
    - Faith chert member (2)
    - Albion siliceous shale member; Tuskahoma siliceous shale (2); Middle Stanley siliceous shale; Albion Creek chert member (2); Campbell Creek siliceous shale(?)
    - Friendship chert member (2)
    - Siliceous shale at base; Lower siliceous shale bed; Basal Ten Mile Creek Siliceous Shale; Black Knob Ridge chert member (2)
    - Mud Creek tuffs (upper and lower)
    - Beavers Bend tuff (3)
  - Blaylock Sandstone (formation)
    - Beavers Bend illite (3)

Footnotes: (1) Stapp conglomerate member of Union Valley Formation (Springer Group) recognized by OGS, not by USGS. (2) unit not recognized by USGS, recognized by OGS. (3) see text for discussion.

Figure 7. Wildhorse Mountain Formation, Jackfork Group. Location: along U.S. Highway 259 just west of Three Sticks Monument. NE SW SE sec. 34, T. 2 N., R. 25 E.

stone. Harlton (1938) also suggested the Wesley Shale was present in the Choctaw Fault Zone and at the Pinetop schoolhouse and that its siliceous "character" extended to the Arbuckle Mountains. No modern geologic maps support this. Furthermore, he correlated the Wesley with the "Pennsylvanian Caney" of the Ardmore Basin and recommended replacing the latter with the Wesley Shale. No work in the last 78 years has followed this suggestion.

Markham Mill Formation

Harlton (1938) named the Markham Mill Formation for a saw mill located along the northwest flank of the Farris Syncline. He identified a second type locality along the western flank of the Round Prairie Syncline that he appears to have preferred, but "no name was available" (p. 884). Harlton (1938) did not publish a measured section of the Markham Mill, and his description of the unit is brief. He separated the formation from the underlying Prairie Mountain based on the presence of a widespread shale that he named the Markham Mill siliceous shale. Harlton (1938, p. 884) suggested that the Markham Mill Formation "is very widespread in distribution in the entire Ouachita Mountains and is easily recognized," however, most subsequent workers were unable to distinguish it from the underlying Prairie Mountain Formation and some from the overlying Wesley Shale.

Prairie Mountain Formation

The Prairie Mountain Formation was named by Harlton (1938) presumably for a nearby Prairie Mountain, but modern maps do not show a mountain with that name nearby. The type locality is closely located (northwest flank of the Round Prairie Syncline) but the description of the unit is brief and is not accompanied by a measured section. Harlton (1938) included the Prairie Hollow Shale Member, described below, within the Prairie Mountain Formation. Harlton (1938) also noted that a widespread marker bed that he called the Prairie Mountain siliceous shale was present at the base of the formation. Many subsequent workers in the Ouachita Mountains were unable to identify this siliceous shale and some combined the Prairie Mountain with the upper part of the Wildhorse Mountain on their maps.

Prairie Hollow Shale Member

Harlton (1938) originally suggested that the Prairie Hollow Shale, named for Prairie Hollow on the west side of the Round Prairie Syncline, was the basal member of the Prairie Mountain Formation and noted that it was well exposed in Prairie Hollow (present on modern maps and presumably the type locality), but he did not specify a type locality nor present a measured section of the unit. In 1959 he revised the position of the Prairie Hollow and placed it in the upper part of the Wildhorse Mountain Formation. Most map-based studies in the Ouachita Mountains (Hendricks et al., 1947, "maroon shale member"; Cline, 1960; Shelburne, 1960; Hart, 1963; Fellows, 1964; Briggs, 1975; Pitt et al., 1982) note the widespread nature of the Prairie Hollow Shale. Seely (1963), however, stated that the unit was untraceable in the eastern frontal belt but suggested that it may be covered by float.

Wildhorse Mountain Formation

Harlton (1938) named the Wildhorse Mountain Formation (Figure 7) presumably for a nearby Wildhorse Mountain, but modern maps show his type section crossing Parker Mountain, Razorback Mountain, and White Rock Mountain. The closest Wildhorse Mountain is about 20 mi to the east. Harlton's (1938) type "locality" is precisely located and described but about 70 percent is covered, including the top and base. Harlton (1959, p. 880) also identified a second, less precisely located type locality, but did not include a detailed description of it. Despite these inadequacies, most modern studies of the Jackfork Group recognize the Wildhorse Mountain Formation as the basal unit in the group, but the upper part (above the Prairie Hollow Shale) is variably mapped as undivided Wildhorse Mountain and Prairie Mountain.

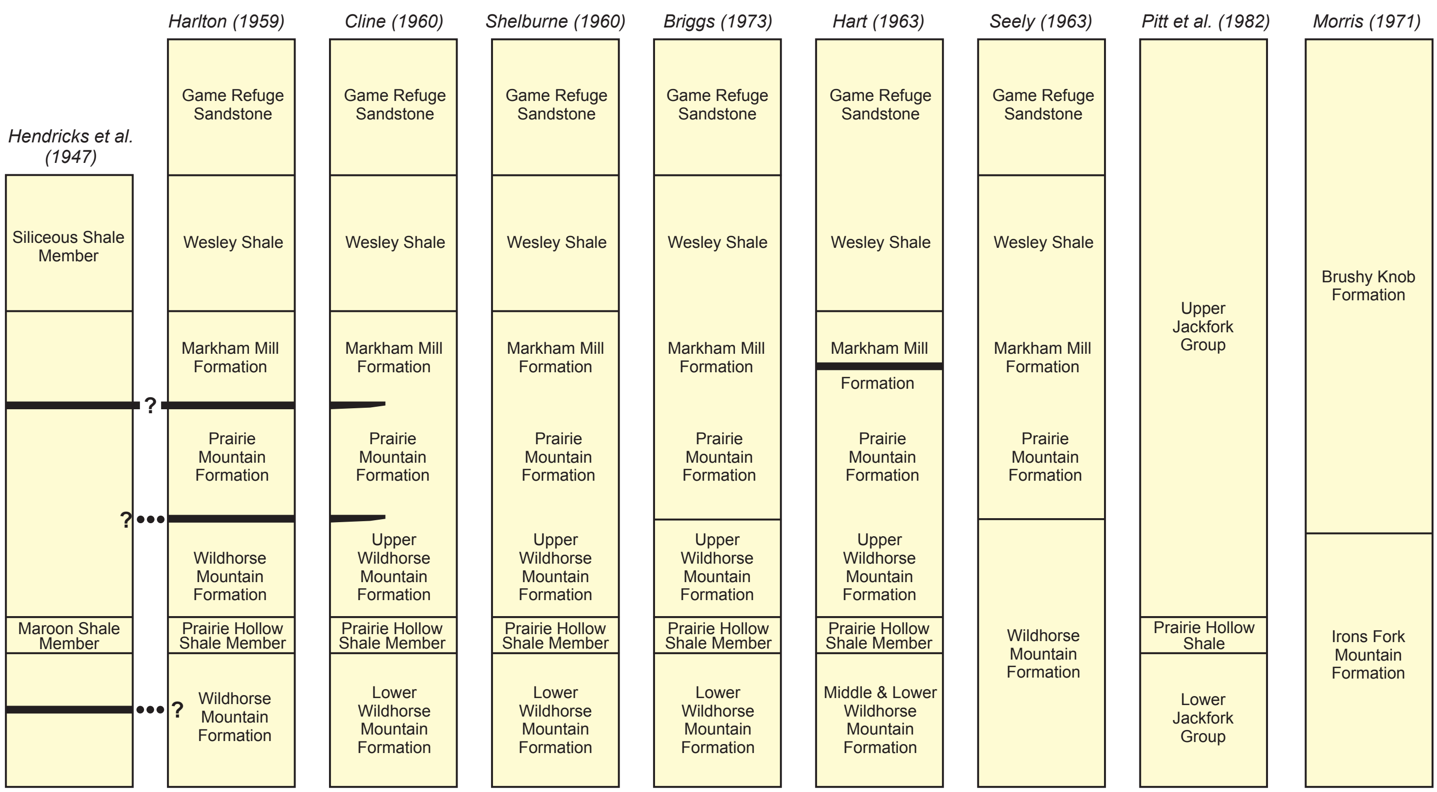


Figure 8. Stratigraphic nomenclature of Jackfork Group as used by different authors. Thick black lines represent siliceous shale beds.

Figure 9. Moyers Formation, Stanley Group. Location: east side of emergency spillway to Lake Carl Albert about two miles northwest of Talihina. NW NE NW sec. 2, T. 3 N., R. 21 E. Photograph taken by Brett Riley, University of Oklahoma.

Stanley Group (Chesterian to Osagean)

Taff (1902) named the Stanley Group "Standley" shale after the small town of Standley on the Kiamichi River in Pushmataha County. Purdue (1909) changed the spelling to Stanley because the name of the village had changed and applied it to similar strata in Arkansas. Only the upper part of the Stanley is exposed near the village and Taff (1902) did not describe a type section or type locality. Pitt et al. (1982), however, suggested a type section for the Stanley Group extending from the south side of the Potato Hills south to the north flank of the Kiamichi Mountains. As noted by Pitt et al. (1982, p. 19), however, "many units are covered by colluvium and alluvium" (44 percent is covered or mostly covered); in addition, two faults cross the line of section but are not noted in the detailed description.

The Stanley Group (Figure 9) is widely distributed throughout the Ouachita Mountains in Oklahoma (Hendricks et al., 1947; Cline, 1960; Pitt et al., 1982; Fellows, 1964; Hart, 1963; Seely, 1963; Briggs, 1973; Shelburne, 1960; Honess, 1923) and the top and base are generally well defined. Some early disagreements centered on the age of the unit, but most workers agreed that the Stanley is Mississippian. Between 1934 and 1959, however, Harlton (1934, 1938, 1959) greatly confused the entire issue of the age of the strata from the base of the Stanley Group to the base of the Atoka Formation by suggesting that a "Bendian System" existed between the Mississippian and Pennsylvanian and that a "Pushmataha Series" and/or a "Springer Series" existed and included what is now the Johns Valley, Jackfork, and Stanley. Harlton seems to have become so confused he misquoted himself (Suneson and Hemish, 1994, p. 87).

Harlton (1938) elevated the rank of the Stanley to group and identified three formations – from bottom to top, the Tenmile Creek (shown as Ten Mile on his mea-

Figure 10. Chickasaw Creek Shale, Stanley Group. Location: along Talimena Drive (Oklahoma Highway 1) east of U.S. Highway 259. NW SW NE sec. 1, T. 2 N., R. 25 E.

sured section), Moyers, and Chickasaw Creek Shale. Harlton (1938) divided the two older formations based on the presence of a widespread siliceous shale that he named and mapped as the Moyers siliceous shale (not member). The Chickasaw Creek consists of abundant siliceous shale beds and is lithologically distinct from the underlying Moyers and overlying Wildhorse Mountain Formation (Jackfork Group).

The Tenmile Creek and Moyers Formations have been accepted by most workers in the Ouachita Mountains, but in many places the basal Moyers siliceous shale is absent (or has not been recognized) and resultant maps show the two formations as undivided. Cline (1960), Shelburne (1960), Fellows (1964), and Seely (1963) traced the shale eastward into Arkansas with varying degrees of success; Shelburne (1960, p. 19) said the shale is "thin and discontinuous" and Fellows (1964, p. 29) said it is "fairly persistent." Briggs (1973, p. 7) accurately summarized the basal Moyers siliceous shale as "laterally persistent over a wide area, (but) not present everywhere ….". Briggs (1973) also noted that the sandstones and shales in the Tenmile Creek and Moyers Formations are similar and that the only difference between the two formations is that the Moyers contains more sandstone (35 to 40 percent) than the Tenmile Creek (15 percent).

Chickasaw Creek Shale (formation)

Harlton (1938) named the Chickasaw Creek siliceous shale (Figure 10) for exposures along Chickasaw Creek on the north flank of an unnamed syncline about four miles east of Stringtown. He precisely identified the type locality but noted that the top and base of the formation there is covered. Harlton (1938) identified a second type locality where the base was exposed but did

Figure 11. Arkansas Novaculite. Location: small quarry at south end of Black Knob Ridge. SW SW SW sec. 13, T. 2 S., R. 11 E.

Figure 12. Blaylock Sandstone. Location: quarry used for construction of emergency dam for Broken Bow Lake. NE SW NW sec. 4, T. 5 S., R. 25 E. Photograph taken in 1988.

not note how much of the upper part was covered. The Chickasaw Creek Shale is one of the most widespread and recognizable formations in the Carboniferous section in the Ouachita Mountains not only in Oklahoma but in Arkansas.

Moyers Formation

The Moyers Formation (Figure 9) is named for the village of Moyers, Pushmataha County, on the southeast nose of the Tuskahoma Syncline where Harlton (1938) precisely located a type section. The top and base of the formation are exposed and about 44 percent of the unit is not covered at the type section. As noted above, the name Moyers is used by most workers in the Ouachita Mountains but is mapped as undivided with the Tenmile Creek Formation where the basal Moyers siliceous shale is not present.

Tenmile Creek Formation

Harlton (1938) named the Tenmile Creek Formation (shown as Ten Mile Creek in his figure 6) for exposures on the south nose of the Tuskahoma Syncline. Tenmile Creek is located in the valley on the west side of the syncline. Harlton (1938) precisely located a type section but the top of the unit there is not exposed and the base is overlain by Cretaceous strata. About 63 percent of the type section is covered. Harlton (1938) noted that siliceous shale beds are present in the Tenmile Creek and subsequent authors assigned them a variety of informal names; these are discussed below. Tuff beds are also present in the Tenmile Creek Formation; the most prominent one and the only one with a formal name is the Hatton Tuff Lentil, also described below.

BROKEN BOW UPLIFT

Stanley Group (Chesterian to Osagean)

A detachment zone (Arbenz, 2008) within the Stanley Group (probably within the Tenmile Creek Formation) separates the unit into an underlying complexly deformed sequence similar in complexity to the Arkansas Novaculite and older rocks of the Broken Bow Uplift and an overlying sequence of less-deformed rocks that conform to the broad synclines and sharp, typically thrust-faulted anticlines of the central belt of the Ouachita Mountains. The stratigraphic nomenclature of the Stanley Group in the lower sequence is the same as that in the upper.

Figure 13. Bigfork Chert. Location: west end of Potato Hills along Cedar Creek. NE NW NE sec. 31, T. 3 N., R. 20 E.

Figure 14. Womble Shale. Location: Potato Hills. Section-Township-Range unknown.

Figure 15. Collier Shale. Location: west shore of Broken Bow Lake. SE NW NE sec. 32, T. 4 S., R. 25 E. Photograph taken by Mike Willeby, Beavers Bend State Park.

Tenmile Creek Formation

Hatton Tuff Lentil (note: lentil synonymous with lens as used by NACSN (2005))

The Hatton Tuff Lentil was originally named by Miser in an abstract in the Geological Society of America Bulletin in 1920 but more fully described by Miser and Purdue (1929). The unit was named for outcrops along the Kansas City Southern railroad just south of the town of Hatton in Polk County, Arkansas. Honess (1923, p. 150) believed only one tuff was present in the Stanley, in contrast to Miser (1921) who counted at least three and possibly as many as five tuff beds. Later workers confirmed Miser's (1921) observations and named several, all of which are informal and are described below.

Arkansas Novaculite (formation) (Osagean to Lower Devonian)

Griswold (1892) first named the Arkansas Novaculite (also Arkansas stone) (Figure 11) as a kind of rock quarried for whetstones, but he also referred to the "novaculite formation." Purdue (1909) mapped the Arkansas Novaculite throughout a large part of the Arkansas Ouachita Mountains and formally ranked it as a formation, and Miser and Purdue (1929) suggested that the Caddo Gap area in Arkansas serve as the type locality.

Taff (1902) called the Arkansas Novaculite through the Bigfork Chert at Black Knob Ridge the Talihina chert (discussed below). Purdue (1909) recognized that some of Taff's Talihina chert there and similar strata in the Potato Hills were the same as those already named in Arkansas (Hendricks et al., 1937), but Miser (1926) retained Taff's nomenclature on the 1926 Geologic Map of Oklahoma. Honess (1923) followed Arkansas nomenclature and mapped the Arkansas Novaculite in the Broken Bow Uplift area, and Miser (1929) did the same in the Potato Hills as did Hendricks et al. (1937) at Black Knob Ridge. In Arkansas the formation consists of three lithologic divisions (not members) (Miser, 1918) but how these apply to the formation in Oklahoma is not agreed upon.

Missouri Mountain Shale (formation) (Upper Silurian)

Purdue (1909) named the Missouri Mountain Slate for exposures on Missouri Mountain (Missouri Mountains on map) in southwestern Arkansas. He also recognized that part of Taff's (1902) Talihina chert at Black Knob Ridge and in the Potato Hills was, in fact, the Missouri Mountain. Like the Arkansas Novaculite, Honess (1923) applied the name Missouri Mountain in the Broken Bow Uplift (slate), Miser (1929) in the Potato Hills (shale), and Hendricks et al. (1937) at Black Knob Ridge (shale).

Blaylock Sandstone (formation) (Lower Silurian)

The Blaylock Sandstone (Figure 12) was named by Purdue (1909) for exposures at Blaylock Mountain in southwestern Arkansas. Honess (1923) mapped the same formation in the Broken Bow Uplift. The formation is absent in the Potato Hills and at Black Knob Ridge.

Polk Creek Shale (formation) (Upper Ordovician)

The Polk Creek Shale is named for Polk Creek in Montgomery County, Arkansas (Purdue, 1909). Like the Arkansas Novaculite and Missouri Mountain Shale, it was included in the Talihina chert by Taff (1902) at Black Knob Ridge and in the Potato Hills on the 1926 Geologic Map of Oklahoma (Miser, 1926). Honess (1923) used Polk Creek Shale on his map of the Broken Bow Uplift, and Miser (1929) and Hendricks et al. (1937) used Polk Creek in the Potato Hills and at Black Knob Ridge, respectively.

Bigfork Chert (formation) (Upper to Middle Ordovician)

Purdue (1909) named the Bigfork Chert (Figure 13) for its widespread exposure near the Big Fork (Bigfork on his map) Post Office in Montgomery County, southwestern Arkansas. Like the younger formations through the Arkansas Novaculite, the Bigfork in Oklahoma was originally called the Talihina chert (Taff, 1902; Miser, 1926), but was replaced by Miser (1929) and Hendricks et al. (1937).

Womble Shale (formation) (Middle Ordovician)

The Womble Shale (Figure 14) was named by Miser (1918) for exposures near the town of Womble (now Norman), Montgomery County, Arkansas and was originally considered the upper part of Purdue's (1909) Ouachita shale. The type section is at Crystal Mountain, Arkansas (USGS Geolex) but is unpublished. Taff (1902) mapped the Womble as the Stringtown shale in the Black Knob Ridge area and Miser (1926, 1929) showed the Stringtown in the Potato Hills. Honess (1923) mapped the Womble throughout the Broken Bow Uplift area and first suggested (Honess, 1930) that the shale beneath the Bigfork at Black Knob Ridge and in the Potato Hills was the same age as the Womble. Hendricks et al. (1937) followed Honess (1930) and replaced Stringtown with Womble at Black Knob Ridge. When the name Womble was first applied to the oldest rocks in the Potato Hills is unknown.

Blakely Sandstone (formation) (Middle to Lower Ordovician)

Miser (1918) formally named the Blakely Sandstone for Blakely Mountain in Garland County, Arkansas, but did not identify or measure a type section. The name was proposed by A.H. Purdue in a letter cited by Ulrich (1911) and Honess (1923) used the name in his report on the Broken Bow Uplift. The Blakely and older units are not exposed in the Black Knob Ridge or Potato Hills areas.

Mazarn Shale (formation) (Lower Ordovician)

Miser (1918) named the Mazarn Shale for Mazarn Creek in Montgomery County, Arkansas; Purdue (1909) included it in his Ouachita shale (lower part). In Oklahoma the unit is only exposed in the Broken Bow Uplift where Honess (1923) used the name and accepted the stratigraphy as identified in Arkansas.

Crystal Mountain Sandstone (formation) (Lower Ordovician)

The Crystal Mountain Sandstone was named for the Crystal Mountains in Montgomery County, Arkansas by Purdue (1909). Honess (1923) accepted and followed the Arkansas nomenclature in his work in the

Broken Bow Uplift area.

Collier Shale (formation) (Lower Ordovician to Upper Cambrian)

The Collier Shale (Figure 15) was named for Collier Creek in Montgomery County, Arkansas by Purdue (1909). Like all the formation names in the Broken Bow Uplift, Honess (1923) followed the Arkansas nomenclature.

SUMMARY OF FORMAL NOMENCLATURE

Most of the formal and most commonly used names in the Ouachita Mountains of Oklahoma might be called "legacy" names that were established in the first decade of the twentieth century by Joseph Taff working in Oklahoma and Albert Purdue working in Arkansas before any "code of stratigraphic nomenclature" existed. As a result, type sections defined by the original workers do not exist and, in some cases, type localities or type areas are unclear. Later workers proposed type sections for previously named units, but in most cases these should have been designated as reference sections (NACSD, 2005).

The nature and origin (and thus the name) of the Johns Valley Shale and its relation to the Caney Shale was controversial for many years but has been resolved, although the extent of the Johns Valley in the northern part of the Ouachita Mountains and the possible existence of large, coherent slide masses that appear to be stratigraphically autochthonous remains a topic worthy of further research.

Bruce Harlton's names for the Jackfork Group formations confused stratigraphers for decades. Harlton did not follow the newly published code but, more importantly, he mistakenly suggested that key siliceous marker beds that he used as formation boundaries were widespread. Tom Hendricks wisely rejected the suggestion in his mapping and, much later, so did William Pitt and his colleagues. In contrast, Louis Cline and his students attempted to use Harlton's names but, lacking the siliceous shales, were forced to combine units. Had they not followed Harlton's suggestion, they may have divided the Jackfork into four mappable units that most of them recognized – from top to bottom, the Game Refuge Sandstone, a "middle Jackfork formation," Prairie Hollow Shale, and Wildhorse Mountain Formation.

INFORMAL STRATIGRAPHY OF THE OUACHITA MOUNTAINS (INCLUDING THE ARKOMA BASIN)

INTRODUCTION

The currently used North American Stratigraphic Code (NACSN, 2005) allows for the formal naming of subsurface units, but the requirements for doing so are strict. For example, a description of the rock types that make up the unit are required; these descriptions can come from examination of drill cuttings or cores. NACSN (2005) only recommended, however, that the material used for the description be made available from a public repository.

Because the Arkoma Basin is a major gas province in Oklahoma and has been extensively drilled, a number of reservoir units that are not exposed at the surface or have not been correlated with units exposed on the surface have been named (Table II). The depositional origins of these units and their reservoir characteristics are related to Ouachita tectonism and they are therefore discussed here. Because none of the subsurface nomenclature is formalized, the following discussion focuses on the origin of the name and is mostly based on information in a database available from IHS. The two units that include informally named subsurface petroleum reservoirs are the Atoka Formation and Jackfork Group; the named reservoirs are described from youngest to oldest.

In addition to the subsurface units in the frontal belt and Arkoma Basin, a number of surface units have been given names (Table II) and in some cases a type section and/or type locality, but the regional extent of the unit is questionable. Some of these informally named units are referred to in only one paper and others are referred to by several authors but are given different names.

FRONTAL BELT

Atoka Formation

Fanshawe sandstone

The Frankfort No. 1 Hulsey (SE sec. 18, T. 6 N., R. 22 E.) was the first well to identify the Fanshawe sandstone in the subsurface. The well spudded on August 8, 1960, drilled to 12,465 ft total depth (TD), and was completed as a Red Oak gas well on August 1, 1961. The well tested the Cromwell, Spiro, Red Oak, and Fanshawe sandstones; all showed gas. Drilling reports show the top of the Fanshawe at 6296 ft drilled depth and a tested interval from 6296 ft to 6320 ft. The unit was probably named after the town of Fanshawe, which is located about seven miles south-southeast of the well.

The Fanshawe currently produces from a number of gas fields throughout the Arkoma Basin, including Bokoshe South, Red Oak – Norris, Wilburton, and Haileyville Southwest (field locations after Pritchett, 2015).

Figure 16. Miller tar sand. Location: Redden oil field. SE NW NE sec. 9, T. 1 S., R. 14 E.

Red Oak sandstone

The first well to produce gas from a unit identified as the Red Oak sandstone is the Midwest No. 1 Kane (NW sec. 8, T. 6 N., R. 23 E.). The well spudded on April 23, 1955, and was completed on July 12, 1966 in the Red Oak. Well records show the top of the Red Oak at 8600 ft and a perforated interval from 8606 ft to 8705 ft. The well probably was named for the town of Red Oak, which is about 11 mi west-southwest of the well.

The Red Oak sandstone is one of the most prolific Atoka Formation sandstones in the Arkoma Basin and produces gas in the Wilburton, Kinta, Red Oak – Norris, and Bokoshe South fields, as well as in wells in other fields in the southern part of the basin.

Panola sandstone

The Sunset No. 1 Fisherman (NE sec. 34, T. 6 N., R. 20 E.) was the first well to identify the Panola sandstone in the subsurface. The well spudded on June 12, 1969, drilled to 13,200 ft TD, and was completed on September 30, 1969. The well tested minor gas in the Red Oak sandstone. The top of the Panola sandstone was reported at 9304 ft drilled depth. The sandstone was named for the town of Panola, located about two miles southwest of the well. Gas was discovered in the unit about 15 years later immediately southwest of the town.

The Panola currently produces from the Red Oak – Norris, Panola, and McAlester Southeast gas fields, as well as scattered locations throughout the southern part of the Arkoma Basin.

Diamond sandstone

The first well to identify the Diamond sandstone in the subsurface is the Williford No. 1-7 Butzer, located in SE sec. 7, T. 5 N., R. 20 E. The well spudded on May 12, 1983, TD'd at 12,890 ft., and was completed as a gas well in the middle Atoka on January 16, 1984. The operator identified the top of the Diamond sandstone at 6680 ft drilled depth. The origin of the name of the sandstone is unknown. There are no geographic features in the area with the name Diamond.

The Diamond sandstone produces gas from about ten wells in the Panola field.

Brazil sandstone

The Pan American No. 1 C.L. Gould was the first well to identify the Brazil sandstone (SE sec. 35, T. 8 N., R. 23 E.). It spudded on September 22, 1966 and drilled to a TD of 12,360 ft. It was completed as a gas well in the Red Oak sandstone on February 16, 1967. In addition to the Red Oak, the well tested some gas in the Brazil sandstone from 8140 ft to 8160 ft. Drilling reports noted the top of the Brazil at 8018 ft drilled depth. The sandstone is probably named for the town of Brazil, which is located about four miles east of the well.

The Brazil sandstone is productive in the Bokoshe South, Red Oak – Norris, and Haileyville Southwest fields and in scattered wells in other fields in the southern part of the Arkoma Basin.

Bullard sandstone

The Tenneco No. 1-13 Heitner (NE sec. 13, T. 5 N., R. 19 E.), was the first well to identify the Bullard sandstone. The well spudded on February 14, 1984, drilled to 13,000 ft TD, and was completed as a gas well in the Diamond, Panola, and Bullard sandstones. Drilling reports show Bullard perforations from 9964 ft to 10,011 ft and that the top of the Bullard was at 9962 ft drilled depth. The origin of the name Bullard is unknown; there are no geographic features in the area with the name Bullard.

The Bullard sandstone produces gas from about 12 wells in the Panola gas field.

Cecil sandstone

The first report of the Cecil sandstone in Oklahoma is from the Diamond Shamrock No. 1-5 Lear-Vliet Trust well (NW sec. 5,T. 9 N., R. 27 E.). The well spudded on October 11, 1975, drilled to 6891 ft TD, and was completed as a Cecil gas producer. The top of the Cecil was reported at 5854 drilled depth, and Cecil perfs were from 5926 ft to 5938 ft.

The Cecil sand is a productive sandstone in the Cecil gas field named for the town of Cecil, Arkansas. In Oklahoma the Cecil produces mostly from the Panola and Poteau Southeast fields.

Shay sandstone

The Unit No. 1 Cox (NE sec. 8., T. 5 N., R. 20 E.) first identified the Shay sandstone. The well spudded on February 11, 1983, drilled to 12,400 ft TD and was completed in the Shay on July 27, 1983 as a gas well. The Shay was reported at 12,120 ft to 12,202 ft drilled depth and all perforations were within that interval. The origin of the name of the unit is unknown; there are no geographic features in the area named Shay.

The Shay sandstone produces gas from about 12 wells in the Panola field as well as a single well in the Red Oak South field.

Spiro Sandstone

The Spiro Sandstone is considered a formal unit in this paper and is discussed above.

Foster sandstone

The Humble 1 Summings Estate (SW sec. 9, T. 8 N., R. 22 E.) is the first well to identify the Foster sandstone. It spudded on December 20, 1964, drilled to 6250 ft TD, and was completed in the Foster on March 4, 1965. The top of the Foster was drilled at 6025 ft, was cored from 6108 ft to 6201 ft, and perforated from 6105 ft to 6191 ft. The origin of the unit is unknown and the Foster is reported to produce gas only from this well.

The Foster sandstone consists of early Atokan fluvial sandstones eroded into late Morrowan strata along the northern margin of the Arkoma Basin (Lumsden et al.,1971); the channels transported sand from north to south where the sand was reworked by marine processes. These reworked sandstones are partly coeval with and partly overlie the Foster and are recognized as the Spiro Sandstone (described above). Thus, the Foster sandstone represents, in part, the landward equivalent of the Spiro. Only six other wells identified the Foster sandstone in their drilling reports and none of them reported the Foster to be reservoir strata.

Johns Valley Shale

Stapp conglomerate

Harlton (1938) first named the Stapp conglomerate for exposures along the Kansas City Southern Railway about one mile south of the village of Stapp and identified it as a member of the Morrowan Union Valley Formation. All later workers consider the Stapp conglomerate to be a facies of the Johns Valley Shale (summarized in Suneson and Hemish, 1994b; Suneson et al., 2005, p. 59).

Jackfork Group

Hope sandstone

Cunningham and Namson (1994) proposed the informal name Hope sandstone for a reservoir unit in the lower part of the Jackfork Group in two wells in the Buffalo Mountain and Talihina Northwest gas fields. Very little has been published on the subsurface stratigraphy of this area and the name has not been used by other geologists.

Secor pay zone

Montgomery (1996) used the name Secor pay zone to describe a reservoir interval in three wells the Jackfork in the Buffalo Mountain and Talihina Northwest fields. Like the Hope sandstone above, this name is not used.

Stanley Group

Moyers Formation

Chickasaw Creek tuff

The Chickasaw Creek tuff is the youngest and least-studied pyroclastic deposit in the Stanley Group. It appears to have been first identified in a Ph.D. dissertation (Laudon, 1959). Hart (1963) and Seely (1963) identified a tuff or tuffaceous sandstone in the Chickasaw Creek Shale on the south flank of the Simmons (Winding Stair) Mountain Syncline and north flank of the Eagle Gap Syncline, respectively, but they did not name it. Mose (1969) first used the name Chickasaw Creek Tuff (capital "T"); later workers (e.g., Niem, 1977; Loomis et al., 1994; Shaulis et al., 2012) all used a lower-case "t," although it is not clear whether or not the use of a capital vs. lower-case "t" was intentional. Morris (1974) stated that the "tuffaceous interval" within the Chickasaw Creek Shale was present for 100 mi in the northern part of the Ouachitas in Oklahoma and Arkansas.

Miller sand

The Miller sand (Figure 16) is a general name given to shallow oil-productive sandstones in the Stanley Group in the Redden oil field (Campbell, 1990). The IHS database lists four wells spudded between 1930 and 1943 that produced oil; all were located on property owned by E.P. Miller, after whom the sandstones were named.

Moyers siliceous shale, Siliceous shale member, Schoolhouse chert member

Harlton (1938) identified and described a siliceous shale that he used to mark the base of the Moyers Formation. He located the shale within his type section of the Moyers Formation, but he did not describe the underlying strata and the strata over the shale were covered. He identified a "second type locality" only generally located (probably along the road in the identified section) but did not describe it. Cline (1960) mapped the same siliceous shale bed at the base of the Moyers and called it a member of the Moyers Formation; he also noted that the siliceous shale member was "widespread" (p. 37). Pitt et al. (1982) renamed the unit the Schoolhouse chert member for outcrops just west of the schoolhouse in Moyers, but did not describe the section. These outcrops are close to those used by Harlton (1938) on the east side of the school in his type section of the Moyers Formation.

Tenmile Creek Formation

Middle Tenmile Creek siliceous shale, Middle siliceous shale bed, Battiest chert member, Smithville chert lentil

Harlton (1938) identified several siliceous shale beds in the Tenmile Creek Formation that he considered to be widespread; later workers had varying degrees of success identifying the same beds elsewhere in the Ouachita Mountains. The youngest siliceous shale is labeled Middle Ten Mile Creek siliceous shale on his map (figure 6), but Harlton (1938) noted that it is "poorly represented in known sections" (p. 868). Cline (1960) named the same unit the Middle siliceous shale bed and noted that it is a widespread marker bed in the Tenmile Creek Formation throughout the Ouachitas, but he did not map it on his map of the Lynn Mountain Syncline. Shelburne (1960) named the same unit the Battiest chert member and noted many localities in the Boltukola Syncline area where it is well exposed. He described it well but did not propose a type section. Pitt et al. (1982) also named the unit the Battiest chert member and noted that it is the most "persistent" of the Tenmile Creek siliceous shales. Miser and Honess (1927) named the unit the Smithville chert lentil, however, that name had been preempted (Branson, 1957) and was never used in subsequent work.

Faith chert member

Pitt et al. (1982) identified and named the Faith chert member in the Tenmile Creek Formation. They published a type locality but did not provide a measured section; in addition, the type locality was outside the area of their report so there is no record of how continuous the unit is.

Albion siliceous shale member, Tuskahoma siliceous shale, Middle Stanley siliceous shale, Albion Creek chert member, Campbell Creek siliceous shale(?)

Harlton (1947) briefly mentioned using the name Albion siliceous shale member for a unit he observed in the lower part of the Tenmile Creek Formation on the east side of Black Knob Ridge. Goldstein and Hendricks (1953) renamed the unit the Tuskahoma siliceous shale for its type section near the town of Tuskahoma; they noted that the section had been measured by T.A. Hendricks and P. Averitt, who called it the Middle Stanley siliceous shale (Tulsa Geological Society, 1947, p. 35). Pitt et al. (1982) renamed the unit the Albion Creek chert member and identified a type area near Albion Creek on the east end of the Potato Hills; however, they did not measure a type section of the unit, nor did they describe it.

Hendricks and Averitt (Tulsa Geological Society, 1947, p. 35) noted that "this siliceous shale may be the same as the Campbell Creek siliceous shale of Harlton," but there is no mention of a Campbell Creek in any of Harlton's published work.

Friendship chert member

Pitt et al. (1982) identified a chert bed they named the Friendship chert member of the Tenmile Creek Formation. The chert is named after a school about four miles west of the type section, which they precisely located. Pitt et al. (1982, p. 75) described the chert at its type section, but the description is cursory and 45 percent of the section is covered.

Siliceous shale at base, Lower siliceous shale bed, Black Knob Ridge chert member

Like all the other siliceous shale and/or chert units in the Stanley Group, the lowest siliceous unit has been given a number of names. Harlton (1938) informally called the unit the siliceous shale at the base. Goldstein and Hendricks (1953) called it the Basal Ten Mile Creek siliceous shale, Cline (1960) called it the Lower siliceous shale bed, and Pitt et al. (1982) named it the Black Knob Ridge chert member. Despite its supposedly formal name, Pitt et al. (1982) did not locate or describe a type section.

Mud Creek tuffs (upper and lower)

Niem (1977) named the upper and lower Mud Creek tuffs for exposures near the town of Bethel. (Mud Creek is about six miles south of Bethel.) He did not publish measured sections of the tuffs and subsequent workers (e.g., Loomis et al., 1994; Shaulis et al., 2012) differ on whether to consider it an informal or formal unit within the Tenmile Creek Formation. The unit is not shown in the USGS Geolex database.

Beavers Bend tuff

Niem (1977) stated that the Beavers Bend tuff was first identified and named in 1967 in a Ph.D. dissertation by Hill and published a very generalized measured section of the tuff at its type section. The tuff is named for the state park in which the type section occurs, and the park is named for an abrupt bend in the Mountain Fork River next to land originally owned by John T. Beavers, an early settler in the area. Although a number of workers have studied the unit, it is considered informal. Geolex notes that the name is "… considered invalid," that it has been abandoned or is no longer used, and that it is "uncertain if used by the Oklahoma Geological Survey. Not used by the USGS".

Blaylock Sandstone

Beavers Bend illite

Mankin and Dodd (1963) named the Beavers Bend illite for an outcrop in the Blaylock Formation in Beavers Bend State Park near Broken Bow. They located the outcrop precisely and published a brief description but did not attempt to map the unit beyond where they identified it. Geolex precedes its listing with a [?] and notes that the unit is "not synopsized to date."

SUMMARY OF INFORMAL NOMENCLATURE

Natural gas reservoir units occur in the Atoka Formation and Jackfork Group; except for the prolific Spiro Sandstone that is easily recognized on the surface and in the subsurface, their names should remain informal as the current code recommends.

Bruce Harlton recognized a number of siliceous shale beds in the Tenmile Creek Formation, as did other later workers, but a failure to correlate them throughout the Ouachita Mountains has made naming them impossible. The reasons for this failure are legitimate: the Stanley is structurally complex, the exposures are poor, and it is possible that the shales are not continuous. These siliceous shales should be reexamined; perhaps the trace-element geochemistry of the shales could be used to correlate them.

The Hatton Tuff Lentil is an important unit because it provides some data on the plate tectonic history of what some researchers call the Ouachita Basin. The Beavers Bend, two Mud Creek, and Chickasaw Creek tuffs deserve more study and, assuming those studies can meet the recommendations of the current code, recognition as formal units.

OBSOLETE NAMES

INTRODUCTION

Two names established by Taff (1902) were later determined to consist of several formations that were identified in Arkansas. Units named early in the geological investigations of an area are typically subdivided into others upon more detailed mapping and stratigraphic study and the Ouachita Mountains are no exception. These early names are now considered obsolete (Table III) and are shown in lower-case letters below.

Table III. — Obsolete Nomenclature

Brushy Creek chert
Talihina chert
Stringtown shale

Brushy Creek chert

Ulrich (1927, figure 2) named the Brushy Creek chert for limestone and chert outcrops underlying the Woodford Shale along Brushy Creek. Miser (1934, footnote, table 1) replaced the name with Pinetop Chert after the nearby Pinetop School because the name Brushy Creek was preempted.

Talihina chert

Taff (1902) originally used Talihina chert to refer to a sequence of cherts and shales in the Black Knob Ridge area of Atoka County. He presumably named the sequence after similar rocks he had observed in the Potato Hills, just west of the town of Talihina in Le Flore County. Purdue (1909) mapped and subdivided the sequence into the Bigfork Chert, Polk Creek Shale, Blaylock Sandstone, Missouri Mountain Slate, and Arkansas Novaculite in Arkansas. Honess (1923) followed Arkansas nomenclature in the Broken Bow Uplift area, Miser (1929) replaced Talihina chert with the Arkansas nomenclature in the Potato Hills, and Hendricks et al. (1937) did the same in the Black Knob Ridge area.

Stringtown shale

Taff (1902) identified the Stringtown shale beneath the Talihina chert in the Black Knob Ridge area and named it for the town of Stringtown. Miser (1918) mapped the same formation in Arkansas and named it the Womble Shale. Honess (1923) accepted Miser's nomenclature and applied it to his work in the Broken Bow Uplift area. Ulrich (1927) equated the Stringtown and Womble Shales, and Hendricks et al. (1937) used the name Womble in their work on Black Knob Ridge. The USGS formally replaced Stringtown shale with Womble Shale in 1938 (Wilmarth, 1938), but when Womble was first applied to the oldest rocks in the Potato Hills is unknown.

INCORRECT NOMENCLATURE

INTRODUCTION

For the purposes of this paper, incorrect names (Table IV) are those that were proposed by geologists who flagrantly ignored the existing code of stratigraphic nomenclature or miscorrelated units from other tectonic provinces. In this paper these names are shown in lower-case letters. (Names shown in Table IV with capital letters are accepted in other geologic provinces but should not be used in the Ouachitas.) In the case of the stratigraphy of the Oklahoma Ouachita Mountains, the nomenclature proposed by two geologists – Bruce Harlton and William Pitt – must be viewed with a great deal of skepticism.

Lynn Mountain formation

The Lynn Mountain formation was used by Pitt et al. (1982) to include the same strata mapped by others in Pushmataha County (e.g., Cline, 1960) as the Atoka Formation but gave no reason why they did so. Marcher and Bergman (1983) mapped all strata younger than the Johns Valley Shale and the Wapanucka Limestone south of the Choctaw Fault as Lynn Mountain and limited using Atoka Formation to those rocks north of the Choctaw Fault older than the Hartshorne Formation. Suneson (1987) reviewed the objections to using the name Lynn Mountain formation and recommended abandoning it; a key argument was that the age of the Lynn Mountain was poorly constrained and based on "tentative" identification of Morrowan palynomorphs outside of Pushmataha County and "Atoka palynomorphs of Desmoinesian age" (Pitt et al., 1982, p. 35) in Pushmataha County. The detailed palynological

Table IV. — Incorrect Nomenclature

Lynn Mountain formation (1)
Barnett Hill formation (2)
Limestone Gap shale (1)
Primrose formation (2)
Round Prairie formation (1)
Union Valley Sandstone
Goddard Shale (2)
Delaware Creek Shale (2)
Lukfatah sandstone (1)

Footnotes: no number – unit recognized by USGS and OGS. (1) unit not recognized by USGS, recognized by OGS. (2) unit recognized by USGS and OGS in Arbuckle Mountains, not in Ouachita Mountains.

work was never published.

The name Atoka is so well recognized in the geological literature on the Ouachita Mountains and Arkoma Basin that it should be retained and Pitt et al.'s (1982) and Marcher and Bergman's (1983) changes should be ignored.

Barnett Hill formation

Harlton (1938) first proposed using the name Barnett Hill for Morrowan limestones and cherts underlying *Desmoinesian* (author's italics) Atoka Formation. He correlated it with the Barnett Hill Formation near Clarita on the eastern end of the Arbuckle Mountains and separated it from the underlying Wapanucka Limestone based on fossils and the character of the chert nodules. Laudon (1958) noted that the Barnett Hill is lithologically similar to the Atoka Formation and, as a result, Harlton's (1938) suggestion was never accepted by later workers.

Limestone Gap shale

Harlton (1938, figure 1) proposed using the name Limestone Gap for a shale below the Wapanucka Limestone and above the Primrose Formation in the frontal belt of the Ouachitas and correlated it with a similar shale in the Ardmore Basin. Marcher and Bergman (1983) also showed the Limestone Gap in the northwestern part of the mountains. Hendricks et al. (1947) mapped the same unit as the Wapanucka Limestone. Few subsequent workers followed Harlton's (1938) use of the term and most include Harlton's Limestone Gap in the Wapanucka Limestone.

Primrose formation

Harlton (1938) correlated the well-studied Primrose Formation in the Ardmore Basin with what Taff (1901) called the Chickachoc chert lentil. Harlton (1938, p. 901) noted a good exposure south of Blanco that Hendricks et al. (1947) mapped as Wapanucka Limestone. Like the Limestone Gap, recent workers include the Primrose with the Wapanucka.

Round Prairie formation

The origin of the name Round Prairie is related to the origin of the Caney olistoliths in the Johns Valley Shale and Harlton's (1938) use of the Bendian period between the Mississippian and Pennsylvanian. Harlton (1938) divided what others recognized as the Johns Valley Shale in Johns Valley into three formations based on the age of the shale containing the olistoliths; from bottom to top, the Caney, Wesley, and Round Prairie. Harlton's (1938) Caney probably is a large olistolith, possibly a slide mass. The Wesley probably consists mostly of Morrowan shale, and the Round Prairie is more typical Johns Valley and consists of numerous boulder beds. Harlton (1938) did not, however, extend his proposed stratigraphy into his type locality of the Round Prairie where it is shown overlying the Union Valley sandstone. Hendricks et al. (1947) mapped Harlton's (1938) Round Prairie type locality as Johns Valley Shale and no recent workers in the Ouachitas use Round Prairie.

Union Valley sandstone

Harlton (1938) correlated the Union Valley sandstone in the Arbuckle Mountains with a unit of the same age in the Ouachita Mountains. Later workers, as well as Harlton (1959), recognized this unit as the uppermost member of the Jackfork Group – the Game Refuge Sandstone.

Goddard shale

Marcher and Bergman (1983) mapped the Goddard shale above the Delaware Creek shale and below the Limestone Gap shale (Wapanucka Limestone of Hendricks et al., 1947) in the frontal belt of the Ouachita Mountains. The type locality of the Goddard is in the Arbuckle Mountains and it has been widely studied in the Ardmore Basin. Hendricks et al. (1947) mapped the Goddard in the frontal belt as Springer Formation, and this has been accepted by most recent workers.

Delaware Creek shale

Marcher and Bergman (1983) mapped the Delaware Creek Shale near or at the base of numerous thrust sheets in the frontal belt of the Ouachita Mountains. The Delaware Creek Shale is widely recognized in the Arbuckle Mountains as a member of the Caney Shale. Hendricks et al. (1947) mapped the same unit in the Ouachitas as the Caney Shale, where it is not divided into individual members. Some of the more extensive Caney (Delaware Creek) outcrops probably are stratigraphically autochthonous units at the base of thrust sheets; others probably are slide masses within the Johns Valley Shale.

Lukfata sandstone

Pitt (1955) identified what he thought was the oldest formation in the Ouachita Mountains and named it the Lukfata sandstone. He precisely located a type section along Lukfata Creek and described it, although the (physically) basal contact was not exposed. Pitt (1955) divided the formation into three members based on differences in lithology, and the concept of a pre-Collier Shale formation in the Ouachitas was widely cited in the literature until Goldstein (1975) questioned it. Shortly afterwards, Visher et al. (1978, p. 130-131) noted that sedimentary structures within the sandstone indicated it overturned, and conodonts studied by Repetski and Ethington (1977) showed that the Lukfata was younger, rather than older, than the Collier Shale.

SUMMARY OF INCORRECT NOMENCLATURE

William Pitt and his colleagues ignored the code and named and renamed many of the units in Pushmataha County. Renaming one of the most widespread units in the area – the Atoka Formation – without explanation was an egregious error that was repeated on the 1:250,000 geologic map of the McAlester-Texarkana quadrangles (Marcher and Bergman, 1983), a map co-produced with the USGS. That same map attempted to correlate and rename shales in the Ouachita Mountains with well-studied shales in the Ardmore Basin without evidence. Tom Hendricks' 1947 USGS map retain the correct nomenclature of the frontal belt.

In addition to his mistaken suggestion regarding the extent of the siliceous shales in the Jackfork Group that he saw at the southern end of the Tuskahoma Syncline, Bruce Harlton not only attempted to add another geologic period between the Mississippian and Pennsylvanian, he forced well-studied units in the Ardmore Basin into his timescale and then applied those Ardmore Basin names to what he thought were correlative units in the Ouachitas. He revised and re-revised his nomenclature more than once. Fortunately, no Ouachita Mountains workers accepted his stratigraphy.

William Pitt's attempt to find the oldest formation in the Ouachita perhaps led him to overlook the sedimentary structures that would have been evidence that even subhorizontal strata can be overturned.

RECOMMENDATIONS

1. Elevate the Spiro Sandstone of the Atoka Formation to formal member status;

2. Reexamine the stratigraphy and nomenclature of the Jackfork Group in light of regional studies;

3. Determine the extent of the tuffs in the Stanley Group, establish principal reference sections, and elevate to formal member status;

4. Determine the extent and continuity of siliceous shales in the Stanley Group using modern analytical techniques and identify with a single informal or formal name.

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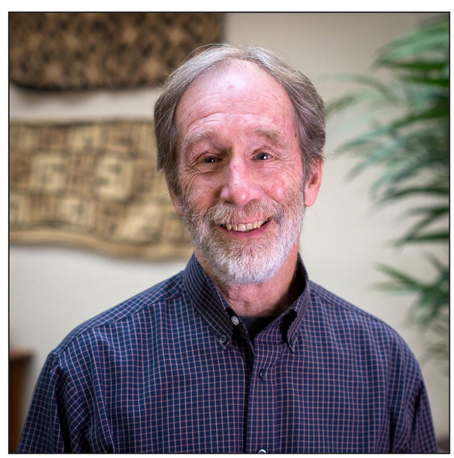
About the Author

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.

Looking Down the Road

Coming up next in *The Oklahoma Geology Notes*

2015 Rockfall **By David Brown**

In the Winter 2016 issue of the Oklahoma Geology Notes, OGS Geologist David Brown looks back at the 2015 rockfall on Interstate 35. Other states like Colorado have far more frequent and substantial landslides that impact people more seriously, so this occurrence was a bit of a surprise, and something the OGS will need to look at more carefully. Human alteration of the landscape can create unstable land surfaces just about anywhere.