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Bedrock Geology of Sonora Quadrangle, Washington and Benton Counties, Arkansas

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Abstract

A digital geologic map of Sonora quadrangle was produced at 1:24,000 scale using the geographic information system (GIS) software MapInfo. The geology of Sonora quadrangle consists of sedimentary rocks from the Ordovician, Devonian, Mississippian, and Pennsylvanian Systems. The Cotter, Powell, and Everton formations represent the Ordovician System. The Clifty and Chattanooga formations represent the Devonian System. The St. Joe Limestone, Boone, Batesville, and Fayetteville formations represent the Mississippian System. The Hale formation represents the Pennsylvanian System. The St. Joe Limestone crops out extensively in Sonora quadrangle and is unconformably overlain by the Boone formation in the southern portion of the quadrangle. This unconformity adds credence to the suggestion that the St. Joe Limestone should be elevated to formation status rather than remain as a member of the Boone formation. The Fayetteville formation consists of the informally named lower Fayetteville Shale, Wedington Sandstone, and informally named upper Fayetteville Shale. The only member of the Hale formation observed in Sonora quadrangle was the Cane Hill member. The two prominent geologic structures in Sonora quadrangle are the White River fault running generally east-west and the Fayetteville fault running generally southwest-northeast. Other subsidiary faults are associated with these primary faults, creating fault zones within the quadrangle. Detailed mapping of stratigraphy and structure in Sonora quadrangle provides new insights into the geologic evolution and sea-level history of the Ozark Plateaus and the southern craton margin during the Paleozoic Era.

Introduction

The Paleozoic geology of the southern Ozark region has attracted worldwide interest because of exposures of the Morrowan Series at the base of the Pennsylvanian System and for the excellent outcrops of fossiliferous strata in proximity to the Mississippian-Pennsylvanian boundary (Frezon and Glick, 1959; Manger and Sutherland, 1984; McFarland, 1998). The geologic history and depositional dynamics of this Paleozoic interval continues to attract the attention of the geologic community as a means of investigating the interplay of global tectonics and global eustasy in the development of continental margin and foreland basin sequences (Houseknecht, 1986; Viele, 1989; Ethington et al., 1989; Thomas, 1989; Viele and Thomas, 1989; Handford and Manger, 1990, 1993; Valek, 1999; Hudson, 2000; Anderson, 2001; Combs, 2001; Cooper, 2001). However, despite continued interest in the Paleozoic stratigraphy of northern Arkansas, no detailed mapping of the geology of Sonora quadrangle has occurred since thesis work undertaken in the early 1960's (Metts, 1961; Cate, 1962; Carr, 1963; Clardy, 1964) at the University of Arkansas and since preparation of the revised Geologic Map of Arkansas by Haley et al. (1976 and 1993).

With the advent of satellite positioning services, advanced digital technologies, and geographic information systems during the last decade, it is now possible to develop highly detailed geologic maps from field data with locations determined using the global positioning system (GPS) and transferred to digital mapping programs. Development of geologic maps in digital formats permits relatively easy manipulation of these data and their export to a variety of software platforms where they can be modified or adapted for many projects. This project represents the first effort to map individual stratigraphic members in Sonora quadrangle using digital technologies.

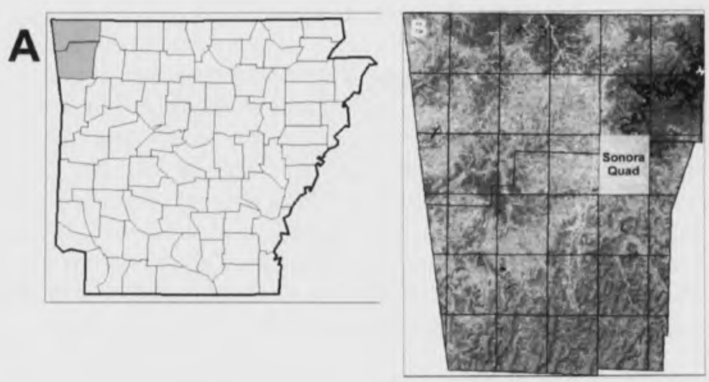

Fig. 1. A) Location map of Arkansas showing Washington and Benton Counties (shaded) and B) Sonora quadrangle in Washington and Benton Counties.

Sonora quadrangle (Fig.1) is located in northeast Washington County and southeast Benton County, Arkansas, and is named for the community of Sonora, which occupies the central portion of the quadrangle (Fig. 1). The quadrangle boundaries are 36°15.0'N 94°07.5'W (northwest), 36°07.5'N 94°07.5.0'W (southwest), 36°15.0'N 94°00.0'W (northeast), and 36°07.5'N 94°00.0'W (southeast). The landscape is a maturely dissected, dendritic drainage system dominated by the White River, which flows north through the quadrangle and into Beaver Lake (Figs. 3, 4). Whereas upland areas throughout the quadrangle are heavily forested, excellent exposures of all lithostratigraphic units through the Hale formation can be observed in ravines associated with Beaver Lake, the White River and its tributaries, roadcuts along highways U.S. 412 and AR 265, and in on-going excavations produced by construction activities in the region.

Washington and Benton counties occupy the boundary of two erosional plateaus formed along the southern portion of the Ozark Dome (Croneis, 1930). The Springfield Plateau is composed of strata deposited during the Ordovician (490-443 Ma BP; Palmer and Geissman, 1999) through Mississippian (354-323 Ma BP; Palmer and Geissman, 1999) periods. The higher Boston Mountains Plateau in the extreme southern portion of Sonora quadrangle is formed of late Mississippian through middle Pennsylvanian strata and is capped by the Pennsylvanian-aged Cane Hill member of the Hale formation (Fig. 2; Stanton, 1993).

The topography of the quadrangle is controlled by a number of stratigraphic units. The Wedington member of the Fayetteville formation is often expressed as an elevated bench on hillsides and caps some hills in the western portion of the quadrangle. Prominent bluffs around the lake and river (ranging to 30 meters high) in Sonora quadrangle are also associated with outcrops of the Everton formation, St. Joe Limestone, and the Boone formation. Finally, sandstone units of the Hale formation form bluffs and cap some hill tops in the southern portion of Sonora quadrangle.

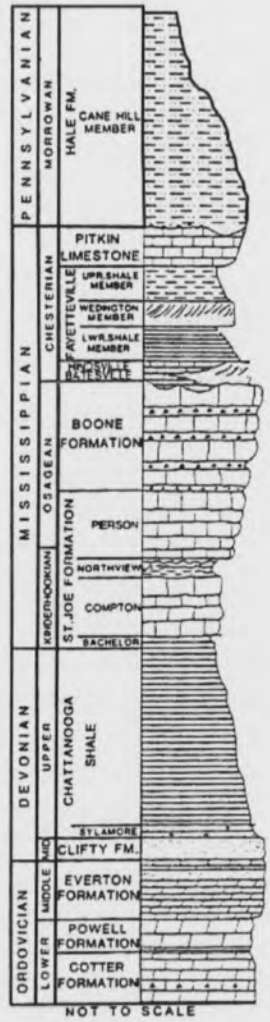

Fig. 2. Generalized stratigraphic column of Sonora quadrangle, Washington and Benton Counties, Arkansas (adapted from Stanton, 1993).

Materials and Methods

Field mapping of Sonora quadrangle was conducted throughout the summer of 2003 accessing various locations from a network of county and state roadways or on foot and from boat around the shoreline of Beaver Lake. Commonly, rock fragments and soil type could be used to determine the bedrock stratigraphy in areas of low relief where outcrops were not discernable.

Locations of outcrop sites for individual stratigraphic members and observed geologic structures were determined using global positioning system (GPS) receivers capable of receiving differential corrections. These receivers typically have horizontal accuracy of approximately 3 meters. For each outcrop or sample location, GPS coordinates were noted in the field notebook, and the location was indicated on the field map. A Garmin Etrex was used to determine elevations. The locations gathered were recorded onto a 1:24,000 topographic map in the field and logged into the field book for later transfer to the MapInfo digital mapping program.

A geographic information system (GIS) is a computer system that records, stores, and analyzes geospatial information. Information regarding field geologic relations was transferred from the field map to a digital raster graphic (DRG) of Sonora quadrangle using a "heads-up" digitizing method that was described in detail in J.T. King et al. (2002), Sullivan and Boss (2002), M.E. King et al. (2001a and b). Using this method, stratigraphic units and geologic structures (e.g. faults) were drawn directly on the computer screen by

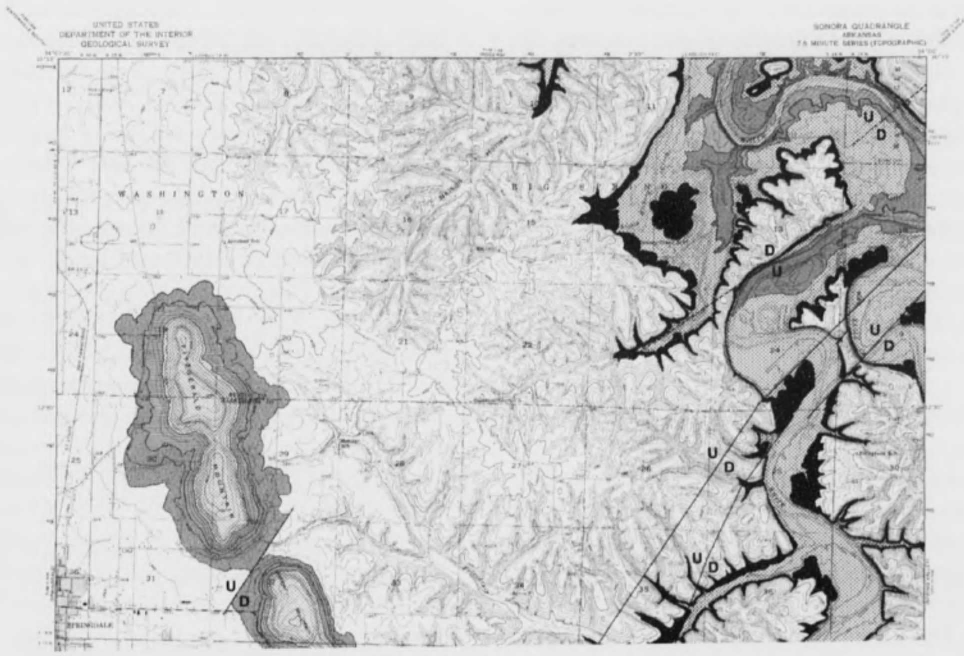

Fig. 3. Map showing bedrock geology of the northern half of Sonora quadrangle digitized onto Sonora quadrangle 7.5-minute digital raster graphic (DRG).

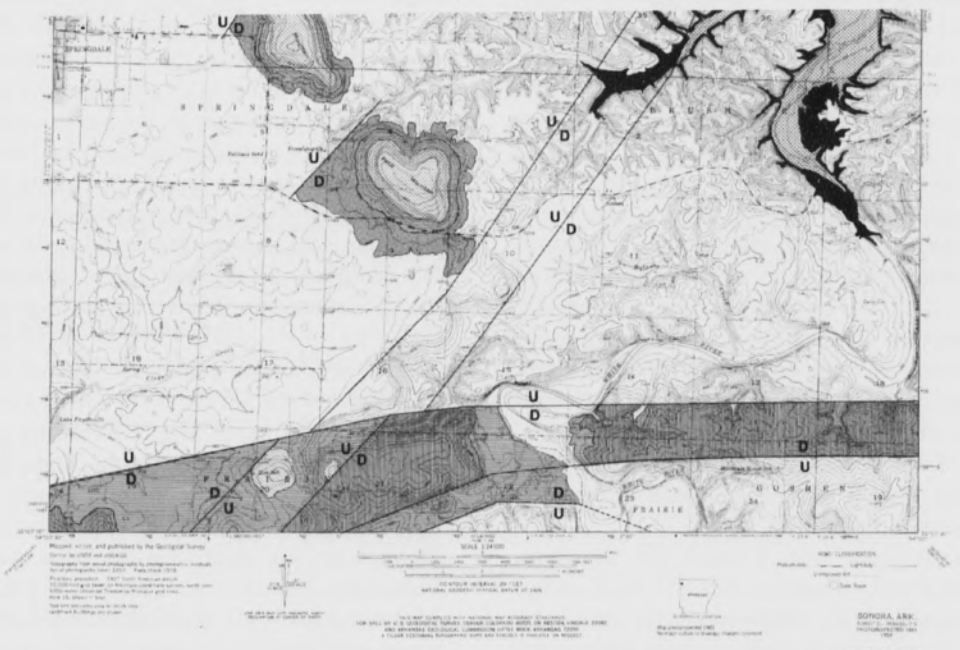

Fig. 4. Map showing bedrock geology of the southern half of Sonora quadrangle digitized onto Sonora quadrangle 7.5-minute digital raster graphic (DRG).

moving the cursor over a DRG of Sonora quadrangle and clicking the mouse button at short intervals to trace contacts onto the displayed topography. Each stratigraphic unit or structural feature was digitized as a separate layer within the GIS such that the display of each layer could be toggled on or off. Once all stratigraphic units and geologic structures were digitized, map layers could be displayed hierarchically to generate the geologic map of the study area (Figs. 3, 4, 5). The final step in preparing the digital geologic map was to convert all data layers to several digital formats to ensure compatibility with popular GIS applications. All data were archived on CD-ROM and are available from the corresponding author upon request.

Results

Sedimentary rocks of the Ordovician Period (490-443 Ma BP; Palmer and Geissman, 1999) through Pennsylvanian Period (323-290 Ma BP; Palmer and Geissman, 1999) are present throughout Sonora quadrangle. Rocks of the Ordovician Period (in ascending order) are the Cotter formation, the Powell formation, and the Kings River member of the Everton formation. Ordovician strata are generally present only along the shoreline of Beaver Lake in the northern portion of the quadrangle (north of the War Eagle Marina and Recreation Area) and on the bottom of the lake along the main axis of the former channel of the White River (Figs. 3, 4).

The Cotter formation in Sonora quadrangle is mostly inundated by Beaver Lake, though exposures of the top of the Cotter formation can be observed when lake level is low east of the Hickory Creek Recreation Area (Fig. 3). When exposed, the Cotter weathers to cobbles of dark gray, blocky chert.

The Powell formation is also poorly exposed in Sonora quadrangle. Outcrops of the Powell formation were observed lying unconformably on the Cotter formation along the northern lakeshore east of the Hickory Creek Recreation Area (Fig. 3). The Powell formation is generally a fine-grained, light-gray to greenish-gray, limy, argillaceous dolostone with thin beds of light green shale (Purdue and Miser, 1916). The Powell formation reaches 65 m (215 feet) thick in its type area. However, within Sonora quadrangle, observed exposures of the Powell formation are less than 3 meters. The top of the Powell formation is unconformable with the overlying Everton formation.

The Everton formation was named for Everton, Arkansas, in Boone County (Purdue, 1907). The Everton formation shows considerable differences in lithologic character across the Ozark region (Suhm, 1970; 1974). It is composed of various mixtures of dolostone, sandstone, and limestone. The formation also has some conglomeratic facies, shale, and chert in limited areas. The limestones are light gray to brownish gray and are generally more or less dolomitic and sandy. The dolostones are light- to dark-gray and generally more or less limy and sandy. The Kings River Sandstone is the only representative of the Everton formation within Sonora quadrangle. This member is composed of massive to thinly parallel layers of friable, quartz sandstone. In Sonora quadrangle, the Everton formation varies in thickness from 2 to nearly 12 m. It is best exposed at the Hickory Creek Recreation Area, along the lakeshore east of Hickory Creek Recreation Area, and around the Pleasant Heights development (Figs. 6A, B). In these areas, the Everton formation forms resistant bluffs and was observed to be filling sinkholes in the underlying Powell and Cotter formations. Exposed cross-sections of Everton formation bluffs also reveals paleochannels (Fig. 6A). Devonian strata present in Sonora quadrangle are (in ascending order) the Clifty formation and Chattanooga Shale (Figs. 3, 4, 5). The Clifty formation rests unconformably on the Everton formation, and excellent exposures of this contact were documented in the vicinity of the Hickory Creek Recreation Area (Fig. 6B). The Clifty formation is often confused with the Sylamore Sandstone member of the Chattanooga Shale (Metts, 1961). However, it is distinguishable from the Sylamore Sandstone in that fresh surfaces are white, saccharoidal quartz sand, whereas fresh surfaces of the Sylamore Sandstone are typically yellow to yellowish brown containing phosphatic pebbles and limonitic concretions (Hall, 1978). McFarland (1998) suggested that the maximum thickness of the Clifty formation was approximately 1 m. However, in Sonora quadrangle, the Clifty formation appears to reach maximum thickness in the Hickory Creek area of 3–4 m.

The Chattanooga formation is a black, fissile, clay shale that weathers into thin flakes. The beds are usually cut by prominent joints creating polygonal blocks upon weathering. In Sonora quadrangle, the basal sandstone member (Sylamore Sandstone; Branner, 1891) of the Chattanooga Shale was not observed. The thickness of the Chattanooga Shale ranged from 3 to approximately 9 m.

An important discovery of this mapping project was documentation of a very fine-to fine-grained, silty sandstone capping the Chattanooga Shale north and northwest of Friendship Creek (Figs. 6C, D). This unnamed sandstone occurred as several layers, each of which was approximately 0.3–0.6 m, and separated the Chattanooga Shale from the overlying Bachelor member of the St. Joe formation (Fig. 6D). In addition, a channel incised into the Chattanooga Shale and backfilled with this sandstone was observed at one location. Elsewhere throughout the quadrangle, this sandstone was not observed, and the Bachelor member lies directly on the Chattanooga Shale. It is not known if this sandstone represents a basal sand unit of

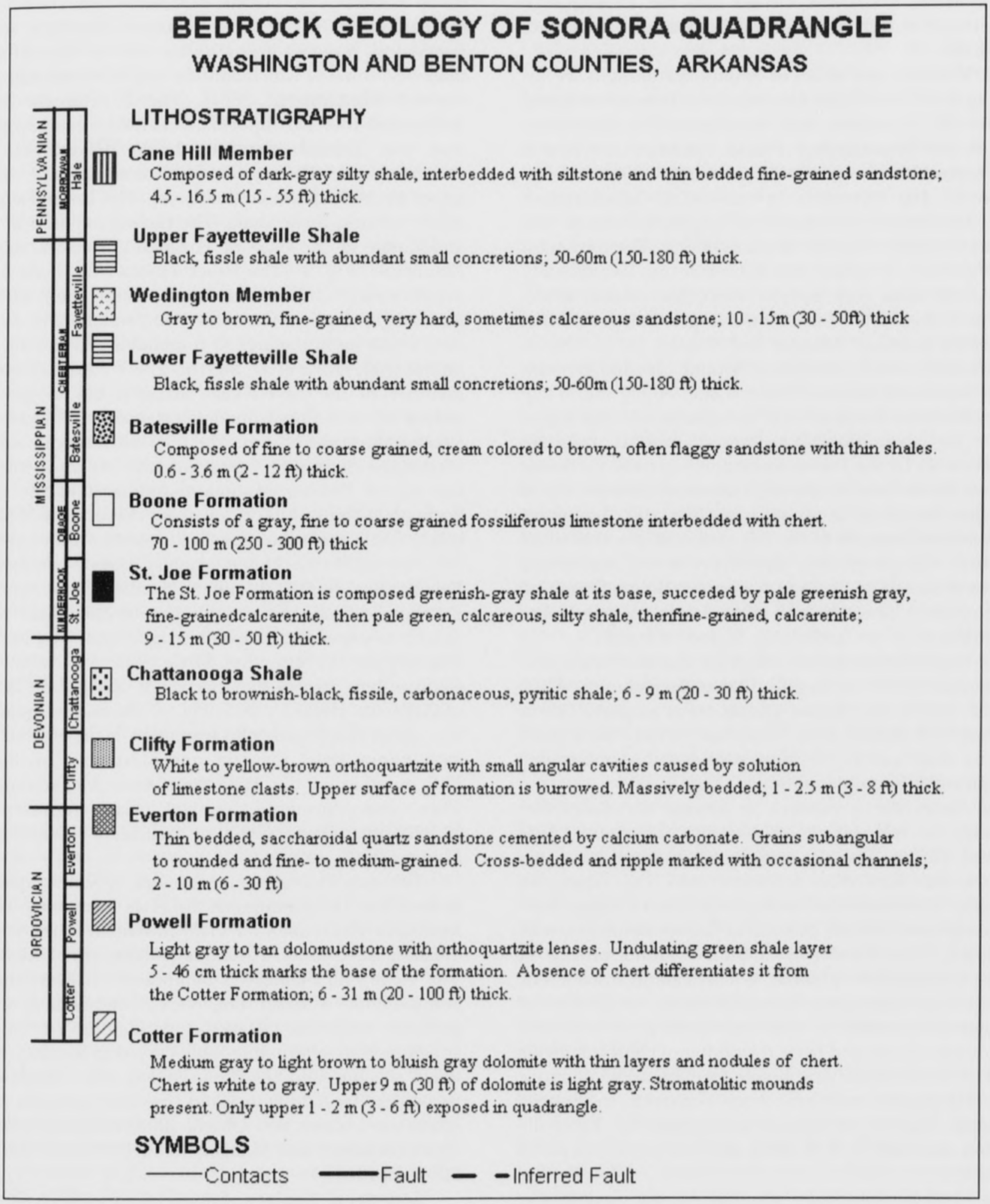

Fig. 5. Legend to accompany geologic map of Sonora quadrangle (Figs. 3, 4).

the Bachelor member. However, its association as the sediment filling a channel incised into the Chattanooga Shale demonstrates the unconformable nature of its contact on the shale.

The Mississippian strata in Sonora quadrangle are (in ascending order) the St. Joe formation, the Boone formation, the Batesville formation, and the Fayetteville formation. Rocks of the Mississippian Period comprise the largest surface exposures throughout the quadrangle (Figs. 3, 4, 5).

The St. Joe formation is the oldest Mississippian stratum. The formation is named for exposures near St. Joe, Arkansas in Searcy County (Hopkins, 1893). The formation is a fine-grained, crinoidal limestone that may occasionally contain some dark gray nodular chert (McFarland, 1998). The base of the St. Joe formation is a greenish-gray shale, the Bachelor member (Manger and Shanks, 1977). The St. Joe formation occurs throughout Sonora Quadrangle with the best exposures around Beaver Lake. Along the White River in the southern portion of the quadrangle, the top of the St. Joe formation is exposed and is overlain unconformably by the Boone formation (Figs. 6E, F). Boone formation layers were observed to downlap onto the top of the St. Joe formation in some areas (Fig. 6E). In others, broad shallow channels in the top of the St. Joe formation were filled with prograding clinoforms at the base of the Boone formation (Fig. 6F), and lowermost Boone formation layers contained limestone and chert clasts that appeared to be reworked from the underlying St. Joe formation.

The Boone formation is named for the unit's extensive development in Boone County, Arkansas (Branner, 1891; Simonds, 1891). The Boone formation is as gray, fine-to coarse-grained fossiliferous limestone interbedded with abundant chert and is the most widespread stratrigraphic unit exposed in Sonora quadrangle (Figs. 3, 4).

The Batesville formation is named for Batesville, Arkansas, in Independence County (Branner, 1891; Simonds, 1891). The formation is divided into two members, the Batesville Sandstone and the Hindsville Limestone. The Batesville Sandstone is often a flaggy, fine-to coarse-grained, cream-colored to brown sandstone with thin shales. The Hindsville member, found mostly in outcrops in northwest Arkansas, is a crystalline, fossiliferous limestone that, when present, usually occurs at the base of the Batesville formation and can have a chert-pebble conglomerate developed from reworking of chert fragments eroded from the underlying Boone formation. No outcrops of the Hindsville member were observed in Sonora quadrangle. Indeed, in Sonora quadrangle the Batesville formation was only 1–2 m thick and was poorly exposed (Figs. 3, 4).

The Fayetteville Shale was named for Fayetteville, Arkansas. Its type locality is in the valley of the West Fork of the White River in Washington County south of the city of Fayetteville (Simonds, 1891). The Fayetteville Shale is black to dark gray, organic-rich, and calcareous in places (McFarland, 1998). It locally contains abundant septarian concretions ranging from a few cm to almost a m in diameter, some of which contain hydrocarbons and siderite cement (Hutchinson, 2001). The Fayetteville Shale is subdivided into two informally named stratigraphic units and one formal member: lower Fayetteville Shale (informal), the Wedington Sandstone (formal), and the upper Fayetteville Shale (informal). The lower Fayetteville Shale is black, fissile shale. The base is exposed in Sonora quadrangle at the base of Fitzgerald, Webber, and Price Mountains (Fig. 3). The lower Fayetteville Shale outcrops occur widely throughout the southern half of Sonora quadrangle (Fig. 4). The shale often weathers to expansive clay, resulting in damage to foundations of structures built on this shale (King et al., 2001b). The Wedington Sandstone member of the Fayetteville Shale is tan to gray, well-indurated, very fine-to medium-grained sandstone with an average thickness of 2 m. The thickest observed outcrop of Wedington Sandstone (approximately 10 m) is located on the top of Webber Mountain, southeast of the town of Springdale (Figs. 3, 4). The upper Fayetteville Shale is a black, fissile shale that contains abundant iron concretions (<0.2 m diameter). This informally named member of the Fayetteville Shale is much thinner than the lower Fayetteville Shale. The upper Fayetteville Shale weathers quickly to expansive clay and is rarely observed in outcrop. The upper Fayetteville Shale can be seen in the southwestern area of the quadrangle along Zion Road east of Arkansas Highway 265 (Fig. 4). In Sonora quadrangle, the top of the Fayetteville formation is an erosion surface with minor relief overlain unconformably by the Cane Hill member of the Hale formation (McFarland, 1998). This unconformable contact also represents the Mississippian–Pennsylvanian boundary (Handford and Manger, 1990, 1993).

The only Pennsylvanian stratum in Sonora quadrangle is the Cane Hill member of the Hale formation. The Hale formation was named for Hale Mountain in the vicinity of Washington County, Arkansas (Adams and Ulrich, 1905). The Cane Hill member is comprised of several lithologic components: a basal tan, very thin-bedded, medium-grained, siliceous/calcareous sandstone or calcareous conglomerate, alternating with very thin-bedded (<0.15 m thick) siltstone and sandstone layers, often ripple-marked, and thick, tan, ripple-marked, medium grained, siliceous sandstone (Adams and Ulrich, 1905; Henbest, 1953; Cate, 1962; Handford and Manger, 1990, 1993; M.E. King et al., 2001a and b).

Structural Geology.–Sonora quadrangle is situated on the southern flank of the Ozark Dome that is centered in southeast Missouri (Croneis, 1930). The regional dip of exposed strata is generally less than 5° to the south. Fractures were observed in outcrops of Ordovician through Pennsylvanian strata, and these fractures were believed to result from brittle deformation related to flexure of the Ozark Plateaus during the Ouachita orogeny (Viele, 1989; Viele and Thomas, 1989; Hudson, 2000). Fractures observed on outcrops of the Chattanooga Shale (Devonian) have strikes of N90°E and N20°W with vertical dips (Fig. 6C).

Several faults were observed in Sonora quadrangle. The dominant structures in the quadrangle are the Fayetteville fault, which crosses the central portion of the quadrangle from southwest to northeast, and the White River fault, which crosses the southern half of the quadrangle from west to east (Figs. 3, 4). The Fayetteville fault is a normal fault downthrown to the southeast. In Sonora quadrangle, the fault is exposed along the shores of Beaver Lake where it is observed to offset the St. Joe and Boone formations. It is poorly expressed in the remainder of the quadrangle because it occurs in the Boone formation. However, it was inferred from a dominant lineament observed on both aerial photographs and digital elevation models of Sonora quadrangle.

The White River fault in Sonora quadrangle is a prominent fault in the southern portion of the quadrangle. It is oriented east-west (Fig. 4) and is downthrown to the south. Several other smaller faults run parallel to the White River fault creating a series of small horsts and grabens. Along the primary trace of the White River fault (Fig. 4), the Boone formation (on the north side) is juxtaposed against the Cane Hill member of the Hale formation (on the south side). Thus, offset along the White River fault is substantial. The White River fault also offsets the Fayetteville fault.

Discussion

The stratigraphy of Sonora quadrangle is composed of alternating layers of shale, limestone, and sandstone in genetically related packages bound by prominent regional unconformities. These sedimentary rocks of Sonora quadrangle represent the response of Earth surface systems to global processes affecting global tectonics and globally fluctuating relative sea level throughout the Paleozoic Era. Understanding the geology of northwest Arkansas is the first step in understanding the interplay of processes controlling the long-term geologic evolution of continental margins in general and the southern cratonic margin of North America in particular. As such, geologic mapping in northwest Arkansas during the last few years has helped develop new insights and ideas into the rate and magnitude of Earth processes, and is leading to renewed interest in the stratigraphy of the Ozark Plateaus.

The present study contributed to this geologic renaissance with several important discoveries. First, Metts (1961) did not recognize outcrops of the Cotter and Powell formations east of Hickory Creek and misidentified the Kings River member of the Everton formation as the Sylamore Sandstone member of the Chattanooga Shale. Ordovician deposits are quite extensive in the Hickory Creek area, and the Sylamore Sandstone member of the Chattanooga Shale was not observed anywhere in Sonora quadrangle. This is interesting because the Sylamore Sandstone is present in the northern portion of Rogers quadrangle immediately north of Sonora quadrangle. A second contribution of revised geologic mapping in Sonora quadrangle is the description of sandstone capping the Chattanooga Shale along with documentation of the occurrence of an incised channel at the top of the formation. The presence of the sandstone and the erosional channel between the Chattanooga Shale and the Bachelor member of the St. Joe formation demonstrates the unconformable relationship of the Chattanooga Shale and Bachelor member elsewhere in northwest Arkansas. In addition, it provides some insight into the timing of tectonism, global sea-level variability, and associated relative sea-level changes related to incipient orogenic activity far to the south in the Ouachita area. Similarly, documentation of the apparent unconformable contact of the St. Joe and Boone formations throughout the southern portion of Sonora quadrangle provides additional insight into the timing and magnitude of relative sea-level changes along the southern craton margin during the Mississippian Period. Finally, offset of the Fayetteville fault by the White River fault (Fig. 4) may help bracket the timing of faulting episodes in northwest Arkansas, and this may ultimately improve understanding of the geologic evolution of the Ouachita Orogen and associated uplift and brittle deformation of the Ozark Dome (Croneis, 1930; Viele, 1989; Viele and Thomas, 1989; Hudson, 2000). For example, since the White River fault offsets the Cane Hill member of the Hale formation, it is reasonable to conclude that movement on the White River fault post-dates deposition of the Cane Hill interval (earliest Pennsylvanian). However, displacement on the Fayetteville fault must pre-date movement on the White River fault because the Fayetteville fault is offset by the White River fault. This relation also indicates that the brittle deformation history of the Ozark region must have multiple episodicity and is, perhaps, more complex and long-lasting than had been previously assumed (Chinn and Konig, 1973; Hudson, 2000).

It is clear from the foregoing discussion that revised mapping of Sonora quadrangle and other quadrangles in northwest Arkansas over the past few years (J.T. King et al., 2002; Sullivan and Boss, 2002; M.E. King et al., 2001a) is providing new insights into the geologic evolution of the southern cratonic margin in the context of modern plate tectonic and sequence stratigraphic paradigms.

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