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Bedrock Geology of Rogers Quadrangle, Benton County, Arkansas

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Abstract

A digital geologic map of Rogers quadrangle was produced at 1:24,000 scale using the geographic information system (GIS) software MapInfo. Data regarding stratigraphic relations observed in the field were digitized onto the United States Geological Survey (USGS) digital raster graphic (DRG) of Rogers quadrangle. The geology of Rogers quadrangle consists of sedimentary rocks of the Ordovician, Devonian, and Mississippian systems. The Cotter, Powell, and Everton formations represent the Ordovician System. The Clifty and Chattanooga formations represent the Devonian System. The St. Joe and Boone formations represent the Mississippian System. This mapping effort represents the first time stratigraphy of Rogers quadrangle was mapped utilizing digital technologies. The prominent geologic structures in Rogers quadrangle are east–west and north–south trending normal faults, commonly inferred from stratigraphic relations across small drainages inundated by Beaver Lake; the most extensive faulting was located in the Blackburn Creek arm and the Prairie Creek sub-basin of Beaver Lake. Complex faulting in the Prairie Creek area appears to have a long geologic history; here the Devonian Chattanooga Shale lies directly on top of the Ordovician Cotter formation, suggesting that the Ordovician Powell and Everton formations and much of the Devonian Clifty formation were either never deposited or have eroded from this area. In either case, the Prairie Creek area appears to represent a structural high developed during the Middle to Late Ordovician that was eventually inundated by rising sea level to permit deposition of the Chattanooga Shale. Detailed mapping of Rogers and other northwest Arkansas quadrangles is providing new insights into the geologic evolution of the southern continental craton and Ozark Plateaus during the Paleozoic Era.

Introduction

Rogers quadrangle (Fig. 1) is located in Benton County, Arkansas, and is named for the city of Rogers located on the western boundary of the quadrangle. The quadrangle boundaries are 36°15.0'N 94°07.5'W (southwest), 36°22.5'N 94°07.5'W (northwest), 36°22.5'N 94°00.0'W (northeast), and 36°15.0'N 94°00.0'W (southeast).

Benton County is located on the south flank of the Ozark Dome (Croneis, 1930). The county occupies portions of two erosional plateaus formed along the southern portion of the Ozark Dome. The Springfield Plateau is defined by the top of the Boone formation, a sequence of Lower Mississippian limestone and chert, whereas the higher Boston Mountains Plateau south of Benton County is formed by Upper Mississippian and Lower to Middle Pennsylvanian strata capped by the Middle Pennsylvanian Atoka formation. Brown (2000) and Sullivan and Boss (2002) illustrated the lithostratigraphic succession observed in Rogers quadrangle (Fig. 2).

The landscape of Rogers quadrangle is a maturely dissected, dendritic drainage system dominated by the White River, which flows north through the eastern third of the quadrangle (Figs. 3, 4) and is impounded by Beaver Dam to form Beaver Lake. Whereas upland areas

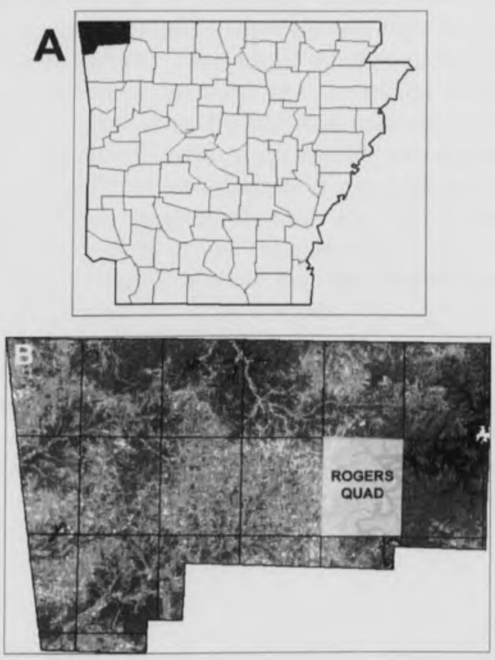

Fig. 1 A) Location map of Arkansas showing Benton County (shaded) and B) Rogers quadrangle in Benton County.

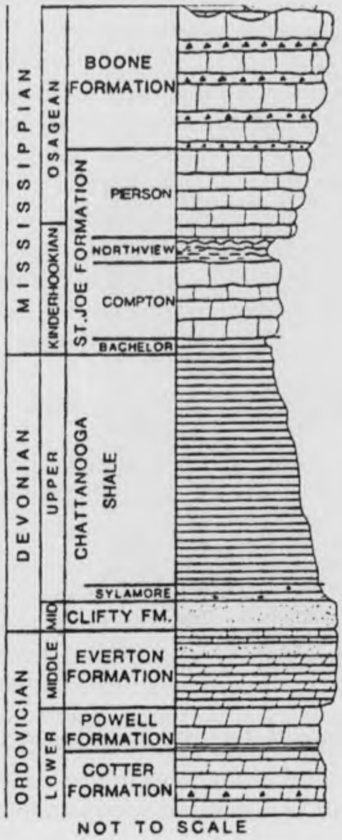

Fig. 2. Generalized stratigraphic column of Rogers quadrangle, Benton County, Arkansas (adapted from Brown, 2000; Sullivan, 1999.)

throughout the quadrangle are heavily forested, excellent exposures of all lithostratigraphic units can be observed along the shores of Beaver Lake, roadcuts along highways US 12 and 94, and along numerous farm-to-market and unimproved roads in the area.

The topography of the quadrangle is controlled principally by the St. Joe and Boone formations (Figs. 3, 4). The Boone formation is found at the tops of most hills in the quadrangle and tends to be a slope forming unit. The underlying limestone of the St. Joe formation tends to form bluffs generally 6 to 9 m height. The Chattanooga Shale is a slope forming formation below the St. Joe formation. Units of Ordovician and Devonian ages are principally exposed along the shores of Beaver Lake in the former bluffs of the White River Valley.

The geologic history and depositional dynamics of Paleozoic rocks in northwest Arkansas continue to attract the attention of the geologic community as a means of investigating the interplay of tectonics and 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; Hudson, 2000). However, relatively little modern research on the geological history of northwest Arkansas exists in the academic literature. Most published reports are from early in the first half of the 20th century and represent early reconnaissance mapping of northwest Arkansas. During the 1950s and early 1960s, a number of quadrangles were mapped at 1:24,000 scale by graduate students at the University of Arkansas –Fayetteville, but most of these works were never published. As such, the present effort to re-map quadrangles in northwest Arkansas in the context of modern geologic theory and advanced digital technologies (Geographic Information Systems, GIS) is providing new insights into the geologic history of this area and the geologic evolution of the southern continental margin and craton during the Paleozoic Era.

Branner (1891) of the Arkansas Geological Survey described the topography, hydrogeology, and stratigraphy of Benton County, Arkansas. The 1891 report also included a geologic map at the scale of 1:126,720 (1 inch to 2 miles). The map showed the carboniferous Boone formation to be widespread at the surface in the vicinity of Rogers, Arkansas, with sandstones, magnesian limestones, and cherts of "Silurian" age (now known to be part of the Ordovician and Devonian Systems) in the White River valley to the east.

Croneis (1930) of the Arkansas Geological Commission described the stratigraphy and structure of the Springfield Plateau. Croneis identified two prominent geologic structures, the Price Mountain (Fayetteville) Fault and the Glade Fault, both of which trend southwest to northeast and are located to the southeast and northeast respectively of Rogers quadrangle. These are normal faults downthrown to the southeast of their respective fault traces Normal faults, the majority of which are downthrown on the southeast side of the fault trace, are typical in the Springfield Plateau region (Croneis, 1930). The report by Croneis (1930) includes a geologic map at a scale of 1:38,160 (1 inch to 6 miles).

Gibbons (1962) studied the fracture patterns in northwest and west central Arkansas looking for a correlation with the timing of the Ouachita Orogenic episode. Gibbons concluded that there are five distinct shear fracture sets of post-Mississippian through Permian age, two sets of folds as a result of compressional forces, and multiple linear zones of tension fractures that are parallel to other structures in the region that compose the regional pattern of northwest Arkansas. Based on the work of Gibbons, Quinn (1963) concluded that the folding and faulting in northwest Arkansas was due to compressional forces from the northwest and southeast directions. In later petrographic

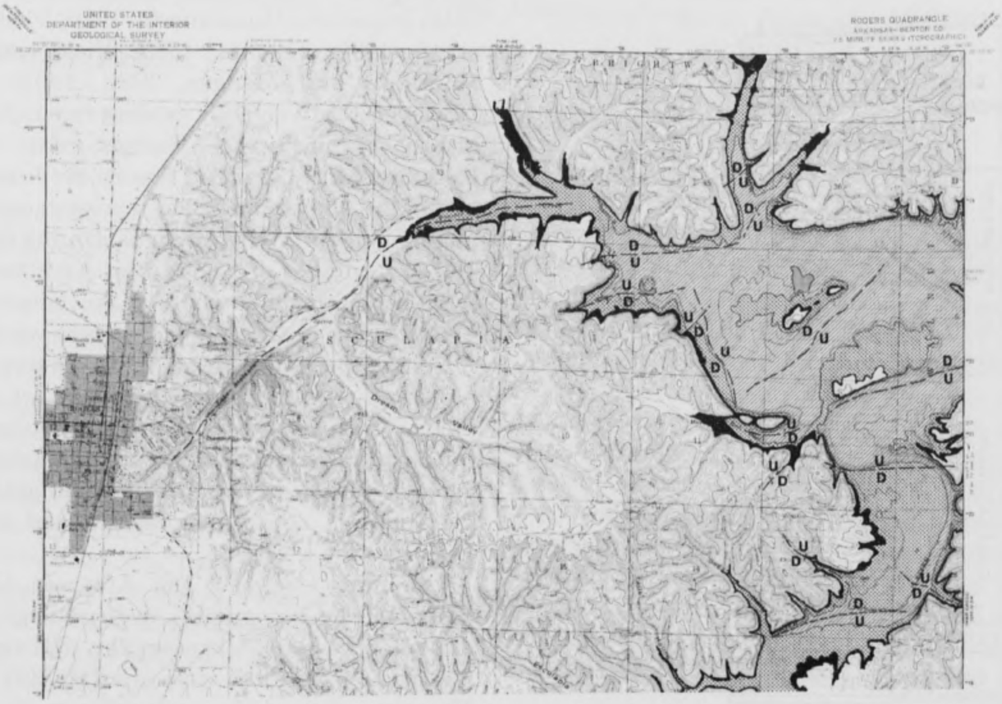

Fig. 3. Map showing bedrock quadrangle geology of northern half of Rogers quadrangle digitized onto Rogers quadrangle 7.5-minute digital raster graphic (DRG).

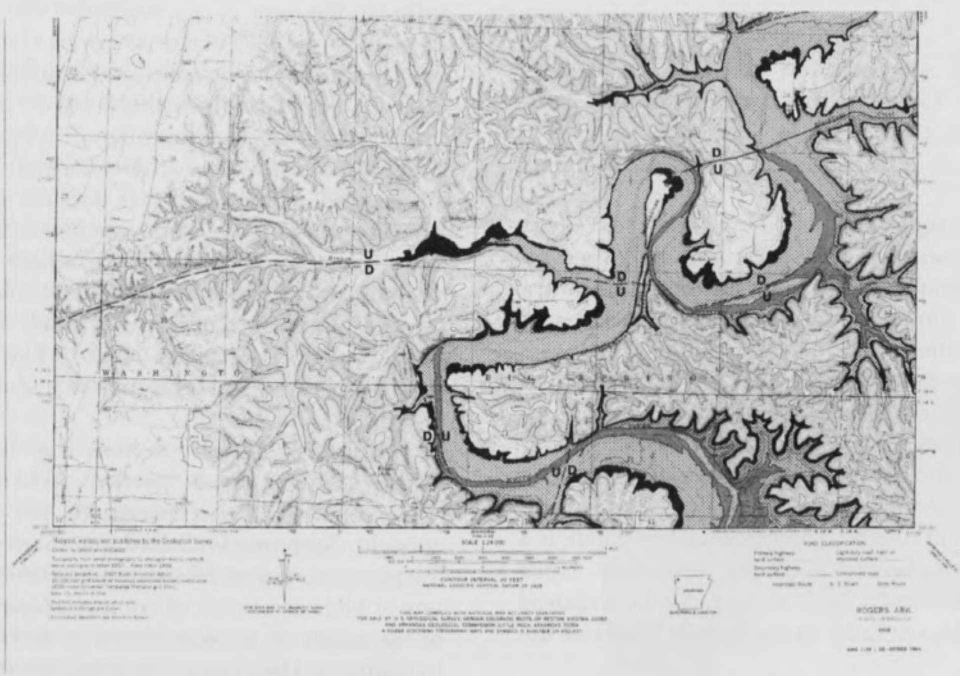

Fig. 4. Map showing bedrock quadrangle geology of southern half of Rogers quadrangle digitized onto Rogers quadrangle 7.5-minute digital raster graphic (DRG).

studies of calcite twin lamellae, Chinn and Konig (1973) showed evidence supporting deformation of northwest Arkansas from north–south compression, but timing of the compression was inconclusive.

Arrington's (1962) thesis and corresponding geologic map were the only 1:24,000-scale geologic map of the area. At the beginning of this study, only a single copy of Arrington's (1962) 1:24,000 map of Rogers quadrangle was preserved in the special collections of the University of Arkansas library. This map was of particular interest because it predated inundation of Beaver Lake. Thus, it provided the only modern description of strata in the main channel of the White River valley (Figs. 3, 4).

Materials and Methods

Field mapping of Rogers quadrangle was conducted in the summer of 2003 through the spring of 2004; various locations were accessed from a network of county and state roadways and by boat on Beaver Lake. 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 (horizontal position accuracies of ca. 3 m). A Garmin Etrex hand-held GPS unit was used to determine elevation, latitude, and longitude for most outcrops. These elevations and coordinates were noted in the field notebook, and the location was indicated on the field map.

Information regarding field geologic relations was transferred from the field map to a digital raster graphic (DRG) of Rogers quadrangle using a "heads-up" digitizing method. Using this method, geologic contacts were drawn directly on the computer screen by moving the cursor over a digital raster graphic (DRG) of Rogers quadrangle and clicking the mouse button at short intervals to trace contacts onto the displayed topography (King et al., 2002; Sullivan and Boss, 2002; King et al, 2001a and b; Sullivan, 1999). Each stratigraphic unit was digitized as a separate layer within the geographic information system such that the display of each layer could be toggled on or off. Faults were digitized as lines onto a separate layer as well. Once all stratigraphic units and geologic structures were digitized, map layers representing those stratigraphic units and geologic structures could be displayed hierarchically to generate the geologic map of the study area (Figs. 3, 4). A legend for the map is presented also (Fig. 5). All data were archived on CD-ROM, and a large-format digital image of the final geologic map is available upon request from the corresponding author.

Results and Discussion

Strata in Rogers quadrangle range from Ordovician through Mississippian periods (Fig. 6A). Detailed lithostratigraphic descriptions of Paleozoic strata can be found in King et al. (2002), Sullivan and Boss (2002), King et al. (2001a and b), and McFarland (1998). The oldest strata exposed in Rogers quadrangle are those of the Ordovician Period (approximately 490-443 Ma BP; Palmer and Geissman, 1999); these strata are comprised of (in ascending order) the Cotter, Powell, and Everton formations (Hopkins, 1893; Adams and Ulrich, 1904; Purdue and Miser, 1916). The oldest Ordovician stratum is the Cotter formation (Fig. 6B). Arrington (1962) mapped the Cotter formation primarily in the main valley of the White River. However, extensive outcrops of Cotter formation were observed throughout the northwest quarter of Rogers quadrangle around the shoreline of the Prairie Creek sub-basin of Beaver Lake. While this and other Ordovician strata were not mapped at these elevations by Arrington (1962), it is interesting to note that Ordovician strata were mapped extensively in this area by Branner (1891). Though the stratigraphic nomenclature used by Branner (1891) was different, it is clear from the rock descriptions that this was the Cotter formation. The Powell formation is not well exposed at the surface throughout Rogers quadrangle (Fig. 6C). Southeast of the U.S. Highway 12 bridge over Beaver Lake, a thin exposure (<2 m) of the Powell formation was observed in unconformable contact with the underlying Cotter formation. The Powell is also exposed on the north shore of the Prairie Creek sub-basin of Beaver Lake on the east side of the mouth of Coose Hollow. Elsewhere around the Prairie Creek sub-basin, it appears that the Powell formation was either eroded or never deposited, suggesting the presence of a localized structural high, perhaps persisting from Late Ordovician through Early to Middle Devonian time. Likewise, the uppermost Ordovician stratum (the Kings River Sandstone Member of the Everton formation) was not observed to crop out throughout the entire northern half of the quadrangle, but was observed around the lake shore south of Blackburn Creek and particularly to the north of Hickory Creek.

Devonian (417–354 Ma BP; Palmer and Geissman, 1999) strata in Rogers quadrangle are the Clifty formation and the Chattanooga Shale. The Clifty formation was named by Purdue and Miser (1916) for friable quartz sandstone exposed on the east fork of Little Clifty Creek, Benton County, Arkansas. Conodonts collected from the Clifty formation exposures at Beaver Dam (Hall and Manger, 1978) are middle Devonian (391–370 Ma BP). In the northwest quarter of Rogers quadrangle, the Clifty formation occurs mainly as massive sandstone in discontinuous mounds or pods. Relatively continuous exposures of Clifty formation (up to 2-3 m thick; Fig. 6D) were observed along the shore of Beaver Lake in the extreme southern portion of the quadrangle. Here, it lies unconformably on the Everton formation (Kings

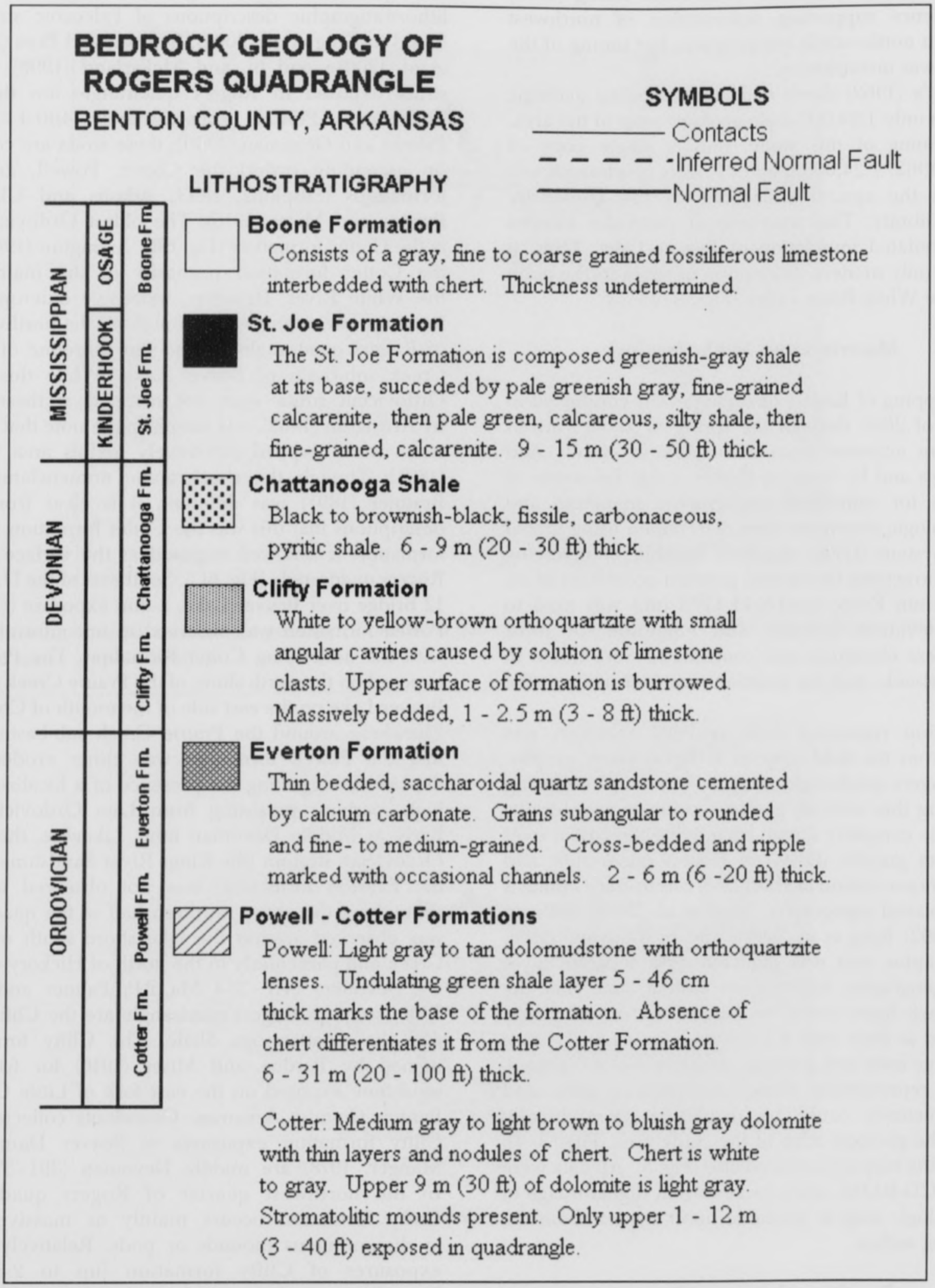

Fig. 5. Legend to accompany geologic map of Rogers quadrangle (Figs. 3, 4).

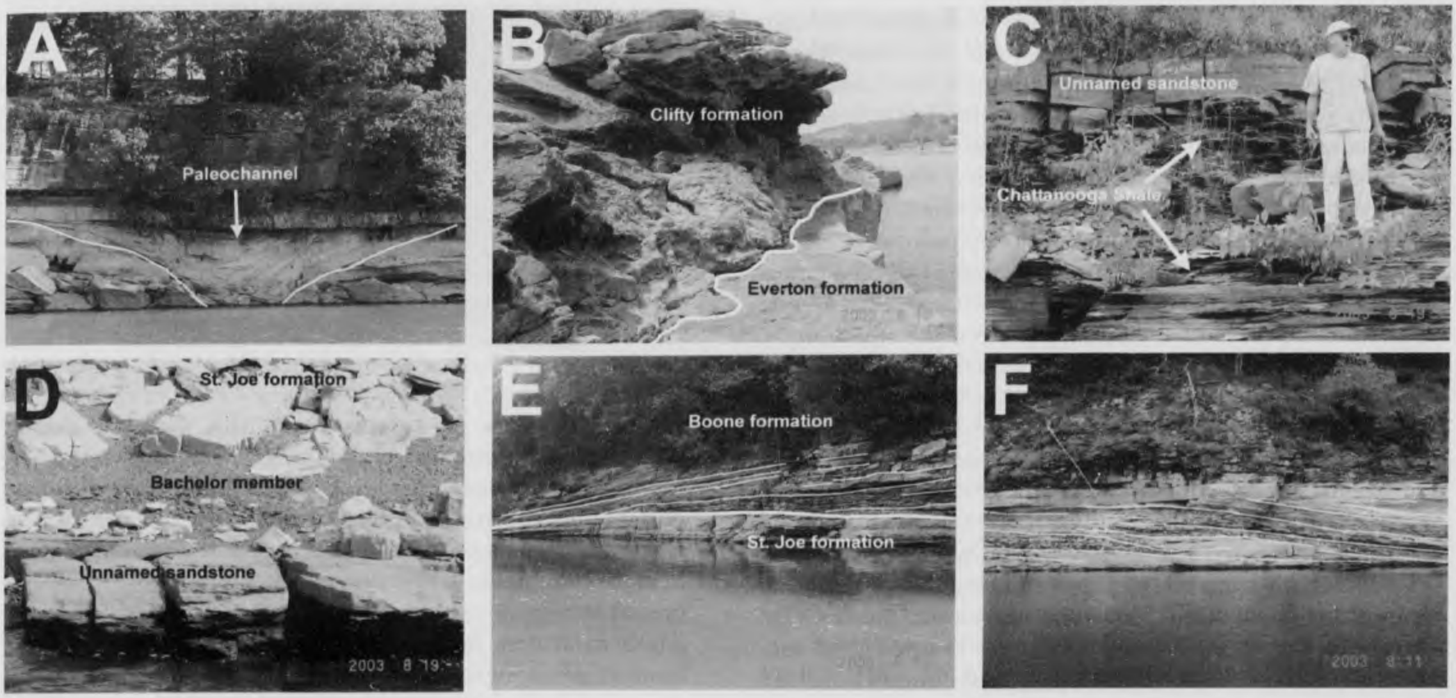

Fig. 6. Images of geologic formations exposed in Rogers quadrangle. A) Succession exposed in hillside along shore of Beaver Lake. Stratigraphic units labeled. B) Domal stromatolite preserved in Cotter formation dolomite. C) Small boulder of Clifty formation (Devonian) sandstone with reworked clasts of Ordovician Powell formation dolomite or limestone. D) Relatively thick (approximately 2–3 meters) outcrop of Clifty formation exposed along shore of Beaver Lake in southern portion of Rogers quadrangle. E) Unconformable contact of Chattanooga Shale (Devonian) on the Cotter formation (Ordovician). Large rock slabs are weathered Sylamore Sandstone, the basal unit of the Chattanooga Shale in Rogers quadrangle. Outcrop located southeast of U.S. Highway 12 bridge, northern portion of Rogers quadrangle. F) Isolated nodular chert embedded in St. Joe formation limestone.

River Sandstone Member). The Clifty formation appears to become thicker as one moves southward into Sonora quadrangle (Hutchinson et al., 2005).

The Chattanooga Shale was identified by Adams and Ulrich (1904). Throughout Rogers quadrangle, the Chattanooga Shale incorporates a thin (0.15–0.45 m), basal sandstone containing phosphatic pebbles called the Sylamore Sandstone (Fig. 6E; Penrose, 1891). Branner (1891) named the Sylamore Sandstone for exposures along Sylamore Creek, Stone County, Arkansas. The Sylamore Sandstone commonly displays a chert breccia at its base (Hall, 1978), indicating that it is unconformable on the underlying Devonian or Ordovician strata. The Sylamore Sandstone is correlative with the Misner Sandstone of Oklahoma and the Hardin Sandstone of Tennessee (Cooper et al., 1942). The Sylamore Sandstone appears to be conformable with the overlying Chattanooga Shale.

The Chattanooga Shale is a black to brownish-black, fissile, carbonaceous, pyritic shale that averages 6 to 9 m (20 to 30 feet) thick and ranges to 15 m (50 feet). The Chattanooga often occurs at or near lake level in Rogers quadrangle where it forms gentle slopes and broad valleys unless it is protected from weathering and erosion by overlying massive limestone of the St. Joe formation. The Chattanooga Shale correlates with the Chattanooga and Woodford Shales of Oklahoma (Frezon, 1962) and the type Chattanooga Shale of Tennessee (Cooper et al., 1942).

Mississippian (354–323 Ma BP; Palmer and Geissman, 1999) strata in Rogers quadrangle are the St. Joe formation and the Boone formation. These are the youngest rocks exposed in Rogers quadrangle. The stratigraphic status of the St. Joe Limestone has been the subject of debate for an extended time (Hopkins, 1893; Cline, 1934; Mehl, 1960; McFarland, 1975; Shanks, 1976; Manger and Shanks, 1977; Shelby, 1986). For this study and for mapping purposes, the St. Joe Limestone was considered a discrete formation. Additional evidence suggesting formation status for the St. Joe Limestone was observed in Sonora quadrangle (Hutchinson et al., this volume) where the St. Joe–Boone formation contact was clearly unconformable. The St. Joe formation is a cliff-forming unit, which helps to distinguish it from the overlying Boone formation where the

St. Joe formation occurs on slopes and wooded hillsides. The St. Joe formation is typically limestone, though locally it contains some nodular chert in southern Rogers quadrangle (Fig. 6F). In Rogers quadrangle, the basal layer of the St. Joe formation is the Bachelor Member, a greenish-gray shale approximately 0.5 m thick that is unconformable on the top of the Chattanooga Shale. The remaining Mississippian stratum is the Boone formation. Branner (1891) named the Boone formation for exposures in Boone County, Arkansas. The Boone formation is the most widespread rock exposed in Rogers quadrangle, occupying approximately 81% of the surface area of the quadrangle. The Boone formation is readily recognized by its abundant chert in a limestone matrix. Weathering and dissolution of the Boone formation results in development of a residuum composed of chert cobbles and red-to orange-colored clay.

Features of the structural geology of Rogers quadrangle were more complex than previously mapped (Branner, 1891; Arrington, 1962). A number of previously undocumented faults were mapped during this project, and faulting is particularly conspicuous along the axis of Blackburn Creek (Fig. 7) and within the Prairie Creek sub-basin of Beaver Lake (Figs 3, 4). Fault orientations are northeast-southwest and east-west and steeply dipping, creating a structurally complicated pattern of tilted fault blocks. Uncertainty exists as to whether these are normal or reverse faults. Normal faulting is generally assumed based on previous work in Rogers quadrangle and elsewhere across northwest Arkansas. Fault offsets are often small (1 to 10 m) and most visible on the cliffs surrounding Beaver Lake (Fig. 7). The timing of faulting cannot be determined precisely since faults offset all strata in the area. Though faulting was presumed to be related to the Ouachita Orogeny (Hudson, 2000), there is some stratigraphic evidence of active faulting and associated uplift predating the Devonian Period (e.g., the apparent structural high observed in the Prairie Creek area where the Chattanooga Shale rests unconformably on Ordovician Cotter formation).

Exposed rocks of Ordovician-Mississippian age in Rogers quadrangle provide insight into the geologic history and evolution of the Ozark Plateaus and southern craton margin during the Paleozoic Era. Revised, detailed, digital mapping of Rogers quadrangle provides several important, practical revisions to the previous geologic map of Rogers quadrangle by Arrington (1962). These include 1) mapping the St. Joe Limestone as a formation distinct from the Boone formation, 2) separation of the Bachelor Member shale from the Chattanooga Shale and assigning it as the basal member of the St. Joe formation, and 3) documentation of previously unknown faults throughout the quadrangle, particularly in the Prairie Creek area. These revisions provide new insights into the geologic evolution of the Ozark Plateaus and southern craton margin during the Paleozoic Era in the context of modern geological thought and plate tectonic theory. In particular, newly identified exposures around the Prairie Creek sub-basin of the Cotter formation (Ordovician) overlain directly by the Chattanooga Shale demonstrate a pronounced unconformity (Ordovician-Devonian) and suggest this area was a localized structural high subjected to erosion or non-deposition prior to deposition of the Chattanooga Shale. Supplemental evidence that the area around Prairie Creek existed as a localized structural high can be found in the northward thinning of the Clifty formation (Middle Devonian) in Rogers quadrangle. In the southern portion of the quadrangle, the Clifty formation is 2–3 m thick, but in the Prairie Creek area, the Clifty formation occurs as isolated pods and lenses of sandstone that appear to be erosional remnants or deposits in localized depressions in the underlying Cotter formation dolomite. Northward thinning of the Clifty formation suggests it was deposited around the margins of a localized structural high with maximum relief in the northwest quarter of the quadrangle.

Fig. 7. Exposure of prominent normal fault in Boone formation limestone and chert along lake shore west of the mouth of Blackburn Creek. Fault trends east-west through axis of Blackburn Creek and appears to extend into War Eagle quadrangle to the east (Sullivan and Boss, 2002). "U" is upthrown block, "D" is downthrown block.

The outcrop belt of the Cotter formation in the Prairie Creek area is bound by several faults. It is possible that these faults were responsible for the observed uplift/erosion or non-deposition across this area before it was finally inundated to permit deposition of the Sylamore Sandstone and Chattanooga Shale. Thus, it appears possible that tectonic activity along the southern craton margin related to plate convergence far to the south may have initiated sometime between the Silurian and Middle Devonian periods and possibly ceased to permit deposition from Late Devonian through Mississippian periods. This is generally much older than what has previously been supposed, and while it may represent a very localized tectonic episode, it does agree with a growing consensus that tectonism along the southern craton margin had a prolonged history throughout much of the Paleozoic Era (Hudson, 2000). In addition, stratigraphic and structural relations observed within Rogers quadrangle may reflect the interplay of global eustasy and tectonics during the Devonian Period.

In addition to the tentative evidence of relatively early tectonism, documentation of faults with different orientations suggests polyphase deformation episodes across the Ozark Plateaus. Previous workers (Quinn, 1963; Chinn and Konig, 1973; Hudson, 2000) have suggested multiple episodes of brittle deformation of the Ozark region related to progress of the Ouachita Orogeny to the south. There is increasing evidence from mapping across northwest Arkansas (Hudson, 2000) that deformation of the Ozark area was a very prolonged and polyphase process.

Continued detailed mapping in northwest Arkansas will ultimately provide the base from which greater understanding of the geologic evolution of the southern craton will emerge. Mapping around the margins of Beaver Lake (Hutchinson et al., 2005; Sullivan and Boss, 2002) shows particular promise in this regard, as the lake level provides a standard datum from which subtle faults can be recognized. Identifying and mapping these faults along with stratigraphic relations throughout a number of quadrangles will thus provide additional details of the intriguing geologic history of the Ozark Plateau.

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