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Abstract

A digital map depicting the detailed bedrock geology of Fayetteville Quadrangle, Washington County, Arkansas was produced at 1:24,000 scale. This map was developed utilizing state-of-the-art Geographic Information Systems technology and represents the most detailed map of the geology of Fayetteville Quadrangle that has been produced. In addition, the stratigraphy was interpreted to develop a regional sea-level history for the quadrangle.

The bedrock geology of Fayetteville Quadrangle consists of sedimentary rocks of the Mississippian and Pennsylvanian systems. The Mississippian System is represented by (in ascending order) the Boone, Batesville, Fayetteville, and Pitkin Formations. The Pennsylvanian System is represented by (in ascending order) the Hale, Bloyd, and Atoka Formations. Each of these formations has members that were mapped at 1:24,000 scale, with the exception of the Hindsville Member of the Batesville Formation. Depositional environments represented by Fayetteville Quadrangle strata range from shallow marine to terrestrial and were interpreted to reflect the interplay of tectonics and eustasy during the Mississippian-Pennsylvanian Periods. Analysis of the apparent tempo and amplitude of sea-level variations suggests tectonic processes dominated over eustatic processes during these times. Within Fayetteville Quadrangle there are also several geologic structures that deserve further investigation. These structures include faults, fractures, domes, and so-called collapse or subsidence structures.

Introduction

Fayetteville Quadrangle (Fig. 1) is located in Washington County, Arkansas, and is named for the city of Fayetteville, which occupies the northeast portion of the quadrangle. The quadrangle boundaries are 36°00.0'N 94°15.0'W (southwest), 36°07.5'N 94°15.0'W (northwest), 36°07.5'N 94°07.5'W (northeast), and 36°00.0'N 94°07.5'W (southeast).

The Carboniferous 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 interval 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; Viele and Thomas, 1989; Handford and Manger, 1990; 1993; Hudson, 2000). The section continues to serve as the training ground for students at the University of

Fig. 1. Location map of Arkansas showing Washington County (shaded) and Fayetteville Quadrangle (white inset) in Washington County.

Arkansas as they prepare for employment in the petroleum industry (most recently in theses by Valek, 1999; M. King, 2001, J. King, 2001; Combs, 2001; Cooper, 2001; Anderson, 2001). Despite continued interest in the Carboniferous stratigraphy of northern Arkansas, there has been no mapping of the Carboniferous geology of this region since thesis work undertaken in the late 1950's and early 1960's (Pohlo, 1958; Neumeier, 1959; Wainwright, 1961; Cate, 1962; Vest, 1962; Carr, 1963) at the University of Arkansas and during preparation of the revised *Geologic Map of Arkansas* by Haley et al. (1976).

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 community planning projects.

Thus, detailed mapping of the geology of Fayetteville Quadrangle is relevant not only for its scientific value but also as an aid to development of the Fayetteville area by providing knowledge of the geology and spatial distribution of various strata.

Materials and Methods

Field mapping of Fayetteville Quadrangle was conducted throughout the summer of 2000. Global Positioning System receivers were used to determine locations of 482-field sites where stratigraphic units, formation or member boundaries, or geologic structures were observed in outcrop. A Garmin Etrex Summit GPS receiver with a built in barometric pressure gauge was used in conjunction with a paper topographic map to determine elevation of outcrops located in steep terrains. In the areas of low elevation where outcrops were difficult to observe, a two-meter Dutch augur was used to penetrate the ground and recover samples of weathered rock for stratigraphic identification.

All field locations and observations were sketched onto a 1:24,000 scale topographic map in the field, logged into the field book, and later digitized using Geographic Information System software (MapInfo version 5.0). Geology was transferred from the field map to a Digital Raster Graphic (DRG) of Fayetteville 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 Fayetteville Quadrangle and clicking the mouse button at short intervals to trace contacts onto the displayed topography (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. 2, 3). A legend for the map is presented as Fig. 4. 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. Digital formats produced for this study were 1) MapInfo native format, 2) ArcView shape files, and 3) AutoCad DXF. All data were archived on CD-ROM.

Results

Lithostratigraphy of the Mississippian System.--In the Fayetteville Quadrangle, the Mississippian System is represented by, in ascending order, the Boone Formation, the Batesville Formation, the Fayetteville Formation, and the Pitkin Formation (Simonds, 1891; Adams and Ulrich, 1904, 1905; Purdue, 1907; Croneis, 1930; Frezon and Glick, 1959; Haley et al., 1976; McFarland, 1998). The Mississippian System composes the majority of the surface area of Fayetteville Quadrangle (Figs. 2, 3). Each formation of the Mississippian System contains marine fossils, thus indicating marine depositional environments throughout this portion of the stratigraphic succession.

The Boone Formation is a fossiliferous limestone containing abundant chert, especially in its upper interval (Simonds, 1891; Shelby, 1986; Sullivan, 1999). The Boone Formation represents marine deposition on a relatively shallow (5–50 m deep) continental shelf or ramp. The Boone Formation forms bedrock over 16.5% of Fayetteville Quadrangle.

The Batesville Formation rests unconformably on the upper, eroded surface of the Boone Formation (Simonds, 1891; Haley et al., 1976; McFarland, 1998). The Batesville Formation in Fayetteville Quadrangle is sandstone or (less commonly) sandy limestone (Hindsville Member) (Handford and Manger, 1990; 1993) and has a distinctive basal breccia containing angular to sub-angular chert pebbles derived from erosion and weathering of the underlying Boone Formation (McFarland, 1998). Throughout Fayetteville Quadrangle, the Batesville Formation weathers quickly and forms flat areas or areas of gentle slope (outcrops are rare). The Batesville Formation and its weathered equivalent forms the surface of 14.7% of Fayetteville Quadrangle, primarily in the northwest quadrant.

The Fayetteville Formation is a black to dark gray, organic-rich, fissile shale (Simonds, 1891). The Fayetteville Formation is subdivided into two informally named strati-

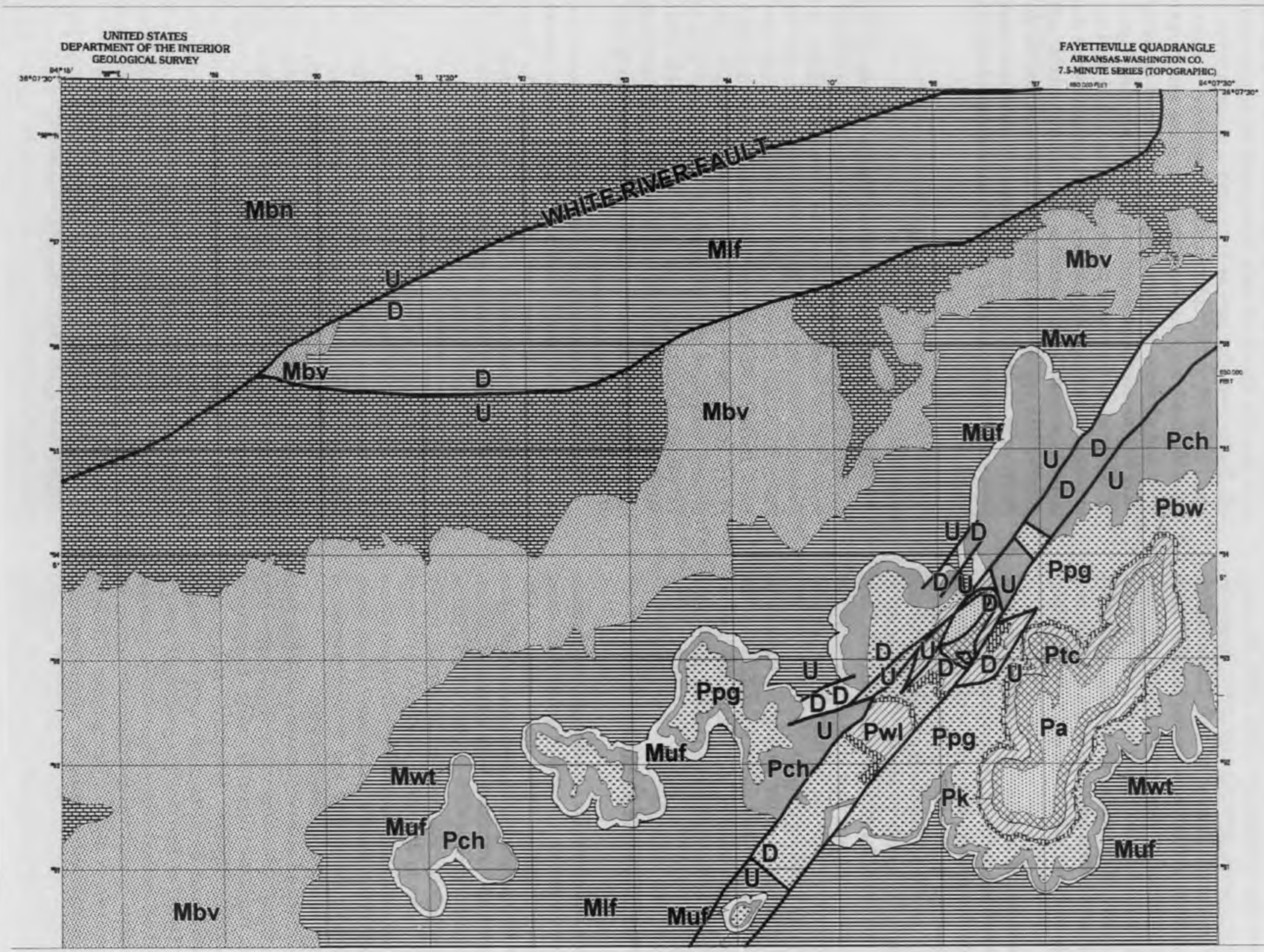

Fig. 2 Map showing bedrock geology of the northern half of Fayetteville Quadrangle digitized onto Fayetteville Quadrangle 7.5-minute digital raster graphic (DRG). Overlying grid is Universal Transverse Mercator (UTM)in 1-km intervals.

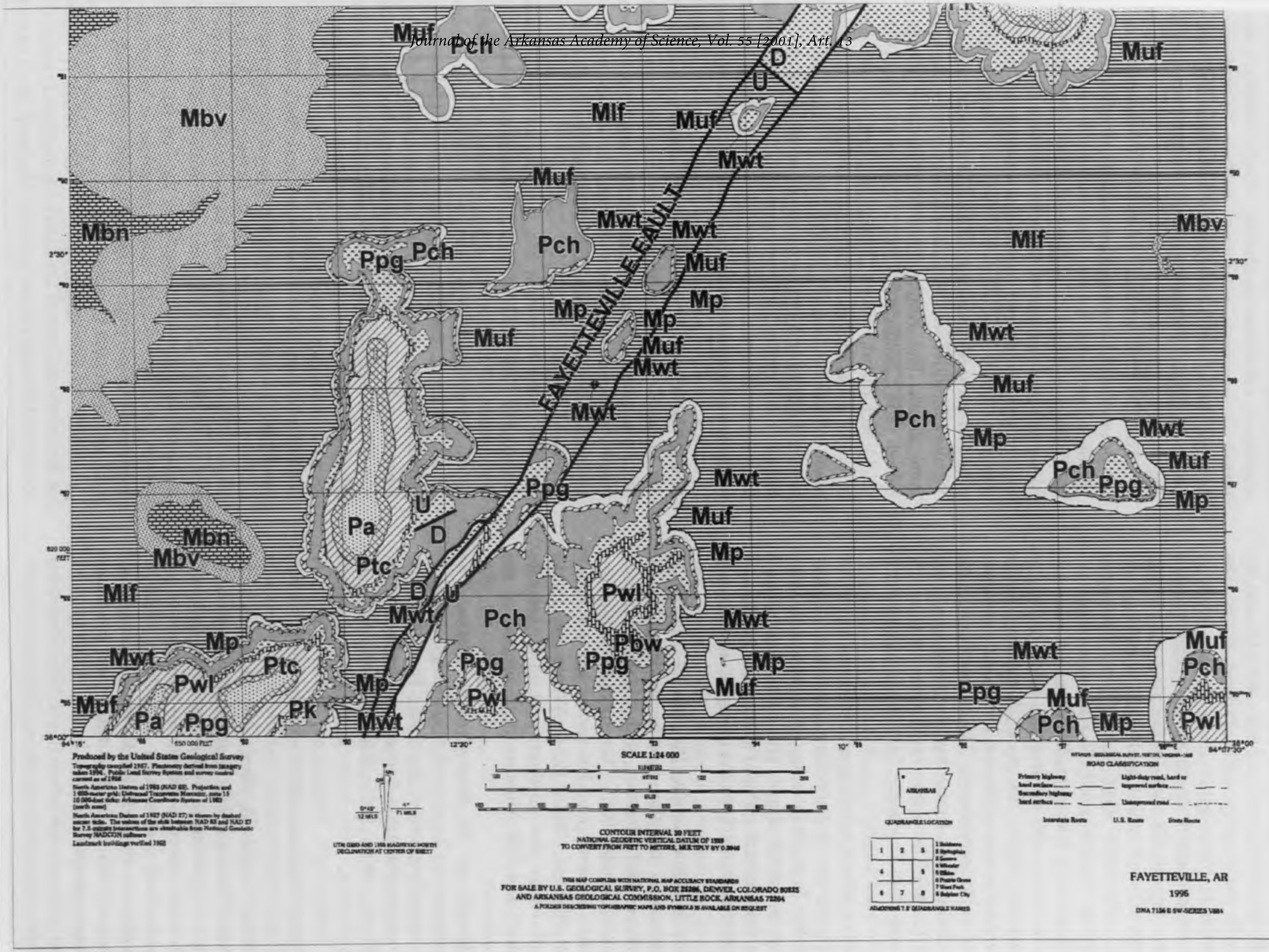

Fig. 3 Map showing bedrock geology of the southern half of Fayetteville Quadrangle digitized onto Fayetteville Quadrangle 7.5-minute digital raster graphic (DRG).

graphic units and one formal member: lower Fayetteville shale (informal), the Wedington Sandstone (formal), and the upper Fayetteville shale (informal)(McFarland, 1998). The lower Fayetteville is black fissile shale characterized by abundant siderite-cemented septarian concretions at its base. The lower Fayetteville shale is the most widely outcropping stratum in Fayetteville Quadrangle, occurring over 45.5% of the quadrangle (Figs. 2, 3). The Wedington Sandstone Member of the Fayetteville Formation is typically tan to gray, hard, very fine to medium grained, siliceous, crossbedded sandstone with an average thickness of 1.5 meters (McFarland, 1998). In some locations of the Wedington Sandstone, a fossiliferous limestone comprises the upper three to six centimeters. The upper Fayetteville shale is black, fissile shale, containing abundant small iron concretions (< 20 cm). The upper Fayetteville shale weathers quickly to soft clay. The upper Fayetteville shale occurs over 4.7% of the quadrangle.

The Pitkin Formation is the uppermost formation of the Mississippian System in Fayetteville Quadrangle (Easton, 1942; Tehan, 1976). Typically, it is an oolitic, bioclastic limestone obviously of marine origin. The Pitkin Formation is present only in the southern half of Fayetteville Quadrangle (Figs. 2, 3), occurring in outcrops over only 1% of the quadrangle.

In Fayetteville Quadrangle, the top of the Pitkin Formation is erosional and therefore unconformable with the overlying Cane Hill Member of the Hale Formation (McFarland, 1998; Tehan, 1976). This unconformable contact is also the Mississippian–Pennsylvanian boundary (Handford and Manger, 1990; 1993). Where the Pitkin Formation is absent in the northern part of Fayetteville Quadrangle, the Cane Hill Member rests directly on the Fayetteville Formation.

Lithostratigraphy of the Pennsylvanian System.--The Pennsylvanian System in Fayetteville Quadrangle is represented by, in ascending order, the Hale Formation, the Bloyd Formation, and the Atoka Formation (Simonds, 1891; Adams and Ulrich, 1904; 1905; Purdue, 1907; Croneis, 1930; Frezon and Glick, 1959; Haley et al., 1976; Handford and Manger, 1990; 1993; McFarland, 1998). The Hale Formation is comprised of two members; the lower portion is named the Cane Hill Member, and the upper portion is termed the Prairie Grove Member (Adams and Ulrich, 1905; Cate, 1962). The Cane Hill Member is comprised of several lithologic components: a basal tan, very thin-bedded, medium grained, siliceous/calcareous sandstone or calcareous conglomerate containing limestone pebbles reworked from the underlying Pitkin Formation; alternating very thin-bedded (< 0.15 m thick) siltstone and sandstone layers, often ripple-marked; and thick, tan, ripple-marked, medium grained, siliceous sandstone (Cate, 1962; Handford and Manger, 1990; 1993; M. King, 2001). The Prairie Grove Member of the Hale Formation is a tan to dark brown, thick-bedded, fine to coarse grained, fossiliferous (crinoid stems abundant), calcareous sandstone, which exhibits a characteristic honeycomb weathered surface (Handford and Manger, 1990; 1993). Large-scale cross bedding was also observed. Hale Formation strata occur over 13.5% of Fayetteville Quadrangle (Figs. 2, 3).

The Bloyd Formation consists of (in ascending order) the Brentwood Limestone Member, the Woolsey-Dye Shale Member, and the Kessler Limestone Member (Purdue, 1907; Haley et al., 1976; McFarland, 1998). The Brentwood Member is well-indurated, cross bedded limestone containing quartz sand and occasional bryozoan bioherms (Hoaster, 1996). The overlying Woolsey Member is composed of greenish gray silty shale (McFarland, 1998). The Woolsey Member weathers rapidly, forming gentle to moderate slopes. The Woolsey Member contains a coal bed called the Baldwin Coal (approximately 0.2 m thick)(McFarland, 1998). This coal bed is widespread throughout Fayetteville Quadrangle and serves as a convenient marker horizon (M. King, 2001; J. King, 2001). The Kessler Limestone Member can be observed in several locations in the Fayetteville Quadrangle (Figs. 2, 3). The Kessler Limestone Member weathers to a dull tan to brown, crumbly surface and freshly broken clasts of this rock usually emit a smell of petroleum distillates. In some areas the Kessler Limestone Member contains abundant sand. The top of the Kessler Limestone, when exposed in a roadcut, has a phosphatic, conglomerate surface marking the unconformity between the Morrowan and Atokan Series (Cate, 1962). Strata of the Bloyd Formation occur over 3% of Fayetteville Quadrangle.

The Atoka Formation is a sequence of marine mostly tan to gray silty sandstones and grayish-black shales (Taff and Adams, 1900; Henbest, 1953; McFarland, 1998; Valek, 1999). In Fayetteville Quadrangle, the lowermost member of the Atoka is the Trace Creek Shale. It rests unconformably on the Kessler Limestone Member of the Bloyd Formation. The Trace Creek Shale is black, fissile shale with some thin beds of sandstone. This is a marine shale (Henbest, 1953). The unit is rarely observed in outcrop but forms a moderate slope below the first sandstone of the Atoka Formation. Above the Trace Creek Shale Member, a sandstone unit of the Atoka Formation forms prominent bluffs and caps a few mountains in Fayetteville Quadrangle (Figs. 2, 3). Atoka sandstone in Fayetteville Quadrangle is a fine to medium grained, hard, sandstone, which is somewhat resistant to weathering. Only the first sandstone layer above the Trace Creek Shale Member is observed in Fayetteville Quadrangle. Atoka Formation rocks occur over 1.9% of Fayetteville Quadrangle.

Structural Geology.--Fayetteville Quadrangle is situated on the southern flank of the Ozark Dome that is centered in southeast Missouri (Croneis, 1930). Regional dip is generally less than 5° to the south. Fractures can be easily observed

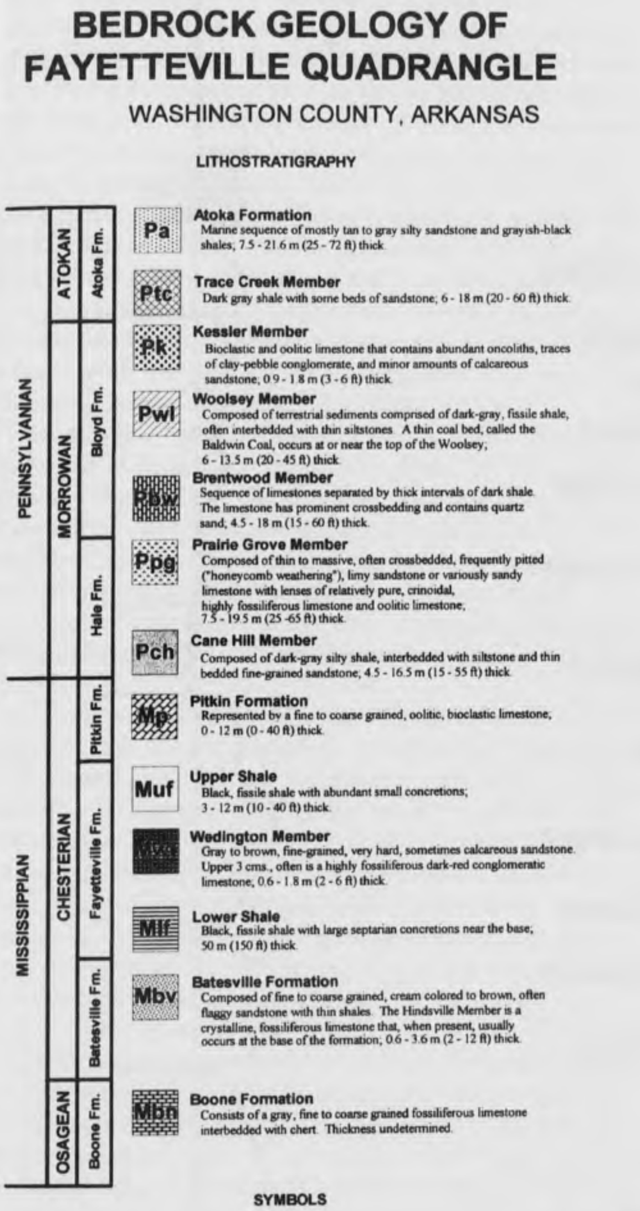

Fig. 4. Legend to accompany geologic map of Fayetteville Quadrangle (Figs. 2, 3).

in outcrops of all ages, and these fractures are believed to result from brittle deformation related to flexure of the Ozark Plateaus and formation of the Ozark Dome during the Ouachita orogeny (Viele, 1989; Viele and Thomas, 1989; Hudson, 2000). Two major faults traverse the Fayetteville Quadrangle. They are the Fayetteville Fault and the White River Fault (Croneis, 1930)(Figs. 2, 3).

The Fayetteville Fault crosses Fayetteville Quadrangle SW-NE (Figs. 2, 3) and through the center of the city of Fayetteville. The strike of the Fayetteville Fault is N30°E. The Fayetteville Fault has at least one prominent branch fault (Figs. 2, 3) and an undetermined number of smaller related branch faults. The Fayetteville Fault is a normal fault, downthrown toward the southeast. Total displacement on the Fayetteville Fault is not known but appears to be approximately 35 m (M. King, 2001).

The White River Fault strikes N65°E through the northern quarter of Fayetteville Quadrangle. The White River Fault has a significant branch on its south side and forms a prominent graben in northern Fayetteville (Fig. 2). The White River Fault is also a normal fault, downthrown to the south. Total displacement on this fault was estimated to be approximately 20 m because a construction site in north Fayetteville revealed the trace of the fault and showed the Boone Formation juxtaposed with upper Fayetteville Formation strata (M. King, 2001).

One small domed structure was discovered and mapped two kilometers south of the town of Farmington, Arkansas (southwest corner of Fig. 3). The Boone Formation crops out at the surface core of the dome and is surrounded by eroded outcrops of both the Batesville Formation and the lower shale of the Fayetteville Formation (Fig. 3). Whether the origin of this dome is structural or depositional is not known. However, localized mounds (either small bioherms or olistoliths) are well documented in the Boone Formation (Manger and Thompson, 1982; Shelby, 1986), and it seems most probable that this dome is the surface expression of a mound in the Boone Formation on top of which sediments of the Batesville Formation and Fayetteville Formation were draped, displaying quaquaversal dips similar to those observed across Silurian reefs of the northern midcontinent (Heckel and O'Brien, 1975).

Where faulting is most complex in Fayetteville Quadrangle, so called collapse or subsidence structures (Quinn, 1963) have formed. These structures are enigmatic, though the prevailing consensus regarding their formation suggests they result from dissolution and collapse of underlying limestone units.

Discussion

Regional Sea-Level History.--The stratigraphy of Fayetteville Quadrangle is composed of alternating lithologies (limestone, shale, sandstone) in genetically related packages bound by prominent regional unconformities. These depositional sequences represent the response of the sedimentary system of northwest Arkansas to fluctuating relative sea-level (i.e., combined effects of tectonics and eustasy) during the late Mississippian and Pennsylvanian Periods. The stratigraphic succession illustrated in Figure 5 indicates the major unconformities marking the Osagean-Chesterian boundary, Chesterian-Morrowan (Mississippian-

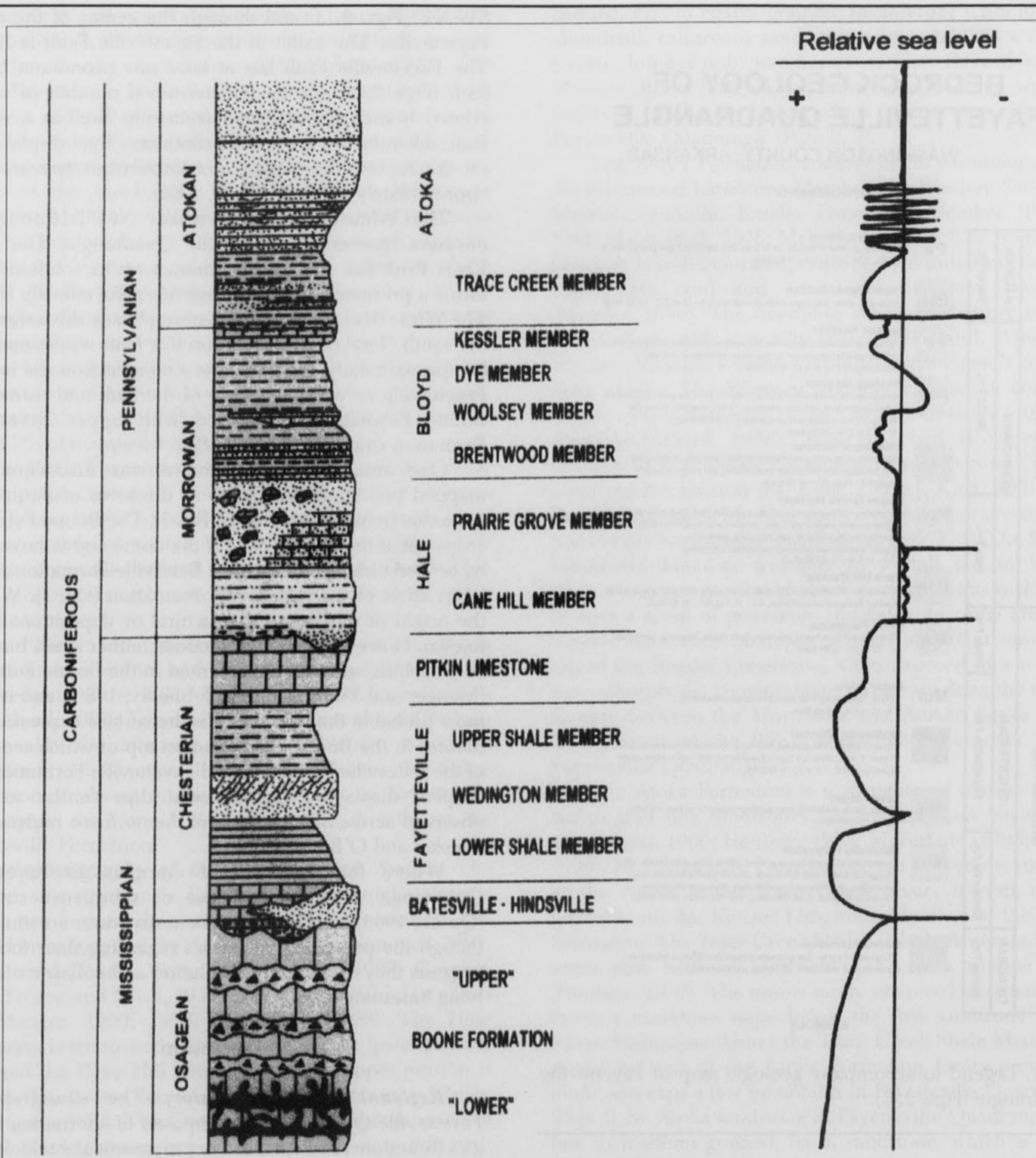

Fig. 5. Lithostratigraphy and interpreted sea-level history of Fayetteville Quadrangle, Washington County, Arkansas (adapted from Brown, 2000; M. King, 2001). King et al., Fig. 1.

Pennsylvanian) boundary, and Morrowan-Atokan boundary. The sedimentary facies of strata exposed throughout Fayetteville Quadrangle have been interpreted in the context of relative sea level in order to generate the relative sea-level curve (Fig. 5).

The Mississippian (Osagean) Boone Formation is limestone that clearly represents relatively shallow marine conditions. The occurrence of oolitic limestone near the top of the Boone Formation in some areas suggests water depths no greater than 5–8 m (Shelby, 1986). Following deposition of the Boone Formation, the shallow seas apparently retreated from the area for some time as the upper surface of the Boone Formation displays evidence of subaerial exposure and karstification. This subaerial exposure surface represents the Osagean-Chesterian boundary. Weathering of the Boone Formation during this interval produced a residuum of chert pebbles that were incorporated into the basal deposits of the (Chesterian) Batesville Formation during the ensuing transgression (McFarland, 1998). Batesville Formation sandstones are interpreted to represent deltaic or nearshore sand, but were definitely deposited under marine conditions (Manger and Sutherland, 1984).

Transgression and relative sea-level rise continued through the Chesterian with deposition of the lower Fayetteville shale of the Fayetteville Formation. Deposition of shale implies deeper, quiet water conditions. Though the lower Fayetteville shale contains appreciable organic matter (septarian concretions often contain hydrocarbons), the water column was apparently well oxygenated because ammonoid fossils (nektonic organisms) are abundant in the shale.

A minor regressive event within the Chesterian is represented by the abrupt transition from lower Fayetteville shale to sandstone of the Wedington Member of the Fayetteville Formation. The depositional environment of the Wedington Member appears to be fluvial/deltaic based on the occurrence of medium to fine grained sand that is often cross bedded (Manger and Sutherland, 1984). Fluvial/deltaic deposition appears to have ended abruptly as relative sea level rose once more, depositing a thin layer (0.05 m-0.10 m thick) of brachiopod-rich limestone across the top of the Wedington sandstone.

As relative sea level continued to rise, the upper shale of the Fayetteville Formation was deposited. This unit has higher silt content than the lower Fayetteville shale, indicating either eolian transport (Cate, 1962), relatively shallower water than the lower Fayetteville shale, or a closer sediment source. Finally, the Chesterian interval is capped by deposition of marine limestone of the Pitkin Formation (Tehan, 1976). The Pitkin Formation appears to be conformable on the Fayetteville Formation (McFarland, 1998) and represents a shallow-marine inner shelf environment (Easton, 1942; Tehan, 1976; Handford and Manger, 1990). The top of the Pitkin Formation was subaerially exposed and forms the Chesterian-Morrowan (Mississippian-Pennsylvanian) boundary. In the northern half of Fayetteville Quadrangle, the Pitkin Formation was completely eroded to the Fayetteville Formation, suggesting an up-ramp situation. This is the major relative sea-level event recorded by Fayetteville Quadrangle strata, and it has been a topic of great interest to the geologic community throughout the world.

The Pennsylvanian (Morrowan) Cane Hill Member of the Hale Formation was deposited on the Mississippian-Pennsylvanian unconformity at the top of the Pitkin Formation. Basal deposits of the Cane Hill Member contain clay pebbles and limestone clasts reworked from the underlying Pitkin Formation. Much of the Cane Hill Member appears to have been deposited very near sea level because thinly layered shale, siltstone, and sandstone indicate a tidal flat depositional setting (Cate, 1962; Handford and Manger, 1990; 1993; M. King, 2001) (Fig. 5). Continued transgression of the Fayetteville area during earliest Pennsylvanian time resulted in deposition of the Prairie Grove Member (Hale Formation), a more massive sandstone with larger-scale cross bedding indicative of tide-dominated channels or shallow shelf settings dominated by longshore currents. Deepening relative sea level ultimately resulted in deposition of shale conformably on top of the Prairie Grove Member, and this shale marks the basal deposit of the Bloyd Formation (McFarland, 1998).

The (Morrowan) Bloyd Formation is subdivided into the Brentwood Member, the Woolsey-Dye Shale Member, and the Kessler Member (Purdue, 1907; Haley et al., 1976; McFarland, 1998). The Brentwood Member represents continued transgression but is interrupted by several minor regressive/transgressive intervals presumably caused by glacio-eustatic processes (McGilvery, 1982). Deposition of the Brentwood Member appears to terminate with development of an unconformity separating clearly marine deposits (bryozoan-bearing limestone and green shale) from clay deposits of the Woolsey Member, which appears to have been deposited in a marine-marginal terrestrial environment (McFarland, 1998). The Woolsey Member contains abundant fossils of plant fragments and also hosts a thin (0.2 m thick) coal bed known as the Baldwin Coal. This coal bed occurs throughout Fayetteville Quadrangle and represents marine-marginal swamp environments. The Kessler Member of the Bloyd Formation in Fayetteville Quadrangle is a bioclastic and oolitic marine limestone representing transgression over the Woolsey Member (McFarland, 1998). The top of the Kessler Member exhibits a phosphatic conglomerate, indicative of regression and subaerial exposure. This conglomerate represents an unconformity developed between the Bloyd Formation (Morrowan) and the Atoka Formation (Atokan).

Only the basal portion of the Atoka Formation is exposed in Fayetteville Quadrangle. The Trace Creek Member of the Atoka Formation is the first member of the formation and represents marine transgression of the Morrowan-Atokan unconformity (Henbest, 1953). An unnamed sandstone layer above the Trace Creek Member represents the highest stratigraphic level of the Atoka Formation in Fayetteville Quadrangle (Fig. 4).

The strata exposed in Fayetteville Quadrangle record relative sea-level changes over an interval of at least 40 million years (Ethington et al., 1989). The most prominent unconformities are found at the contacts of the Boone Formation-Batesville Formation, the Pitkin Formation-Hale Formation, and the Bloyd Formation-Atoka Formation. These unconformities appear to represent time intervals on the order of 10 million years, 7 million years, and 4 million years, respectively (Ethington et al. 1989), or 52.5% of the total depositional interval. Thus, if one takes into account other minor unconformities that may occur within some units (e.g. Brentwood Member of the Bloyd Formation), it is conceivable that the stratigraphic succession in Fayetteville Quadrangle represents as little as 25% to 30% of the total time interval; the remainder of the interval would be represented by the unconformities. Clearly, the stratigraphic succession in Fayetteville Quadrangle reflects relative sea-level oscillations driven by the interplay of tectonics and eustasy. The dominance of either tectonic or eustatic processes in controlling sea level cannot be definitively assessed based on available data. However, the relatively prolonged interval of emergence indicated by the regional unconformities (Boone Fm.–Batesville Fm. contact, Pitkin Fm.–Hale Fm. contact, Bloyd Fm.–Atoka Fm. contact) is suggestive of a tectonically modulated sea-level process. In addition, the relative amplitude of sea-level variation indicated by the different sedimentary facies developed in the stratigraphic succession is probably rather small, perhaps only a few 10's of meters. The predominance of shallow water limestone, shale, and marginal marine (i.e. tidal flat) facies indicates that Fayetteville Quadrangle was susceptible to emergence or inundation with relatively small amplitude sea-level fluctuations. There is no doubt that tectonic flexure capable of driving sea-level oscillations of the scale required to generate the observed stratigraphy was developing in this region associated with evolution of the Ouachita orogen and Arkoma Basin to the south (Thomas, 1989; Viele and Thomas, 1989; Hudson, 2000). Therefore, it seems most likely that relative sea-level changes recorded by the strata of Fayetteville Quadrangle were dominated by tectonic processes.

Supplementary Material Available.--Tables with locations and descriptions of the geologic sites recorded during this mapping project (Universal Transverse Mercator coordinate system relative to WGS 84 datum) are available from the authors upon request. These data are archived on CD-ROM in a spreadsheet format but can be generated in various ASCII formats if necessary.

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