Journal of the Arkansas Academy of Science

Volume 56 Article 27

2002

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Sullivan, Robert A. and Boss, Stephen K. (2002) "Revised Bedrock Geology of War Eagle Quadrangle, Benton County, Arkansas," *Journal of the Arkansas Academy of Science*: Vol. 56 , Article 27.
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Revised Bedrock Geology of War Eagle Quadrangle, Benton County, Arkansas

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Abstract

A digital geologic map of War Eagle quadrangle (WEQ) was produced at the 1:24000 scale using the geographic information system (GIS) software ArcView® by digitizing geological contacts onto the United States Geological Survey (USGS) digital raster graphic (DRG). The geology of WEQ consists of sedimentary rocks of Ordovician (Cotter, Powell, and Everton Formations), Devonian (Clifty Formation and Chattanooga Shale), and Mississippian (St. Joe-Boone, Batesville, and Fayetteville Formations) systems. Impoundment of Beaver Lake in 1966 inundated most Ordovician rocks cropping out in WEQ, but all three formations were present in isolated outcrops along the present shoreline of the lake. The St. Joe Limestone was mapped as a separate unit from the Boone Formation throughout WEQ and all four members of the St. Joe Limestone were observed, lending credence to suggestions that the St. Joe Limestone should be elevated to formation status. The Hindsville Member of the Batesville Formation and the Fayetteville Formation were mapped in an isolated outcrop along the extreme eastern boundary of WEQ. All formations withinWEQ were highly fractured, and some prominent lineaments may represent faults with minor displacement. Several new normal faults were mapped in the central-eastern portion of the quadrangle, and the most prominent structural feature in the quadrangle was the northward extension of the Fayetteville Fault (also know as the Price Mountain Fault), which bisects the quadrangle from southwest to northeast.

Introduction

War Eagle quadrangle (WEQ) is located in the southeastern corner of Benton County, Arkansas. The quadrangle lies from 36° 22' 30" to 36° 15' 00" North latitude and from 94° 00' 00" to 93° 52' 30" West longitude (Fig. 1). The quadrangle was named for War Eagle Creek and War Eagle Mill, each located near the southern boundary of the quadrangle (Fig. 2). Previous mapping within the quadrangle was conducted prior to inundation of the White River valley to create Beaver Lake in the northern half of WEQ (Fig. 2). In the 40 years since the last mapping effort in WEQ (Staley, 1962), changes in stratigraphic nomenclature reassigned some stratigraphic members to different formations whereas other members were nominated to be elevated to formation status. Thus, revised mapping in WEQ was undertaken with the aim of delineating field relations of exposed sedimentary strata in the context of modern stratigraphic nomenclature. In addition, geologic structures within WEQ were reinterpreted in the context of the plate tectonic paradigm and its relation to the geologic history of Arkansas (Houseknecht, 1986; Hudson, 2000) and the Ozark Plateaus. This report presents results of field mapping and revision of the geology of War Eagle quadrangle. A new, digital geologic map was produced from field data utilizing the geographic information system (GIS) software ArcView.

Branner (1940) and Croneis (1930) described the Ozark Plateaus physiographic province of northwest Arkansas. The Ozark Plateaus province comprises the Salem, Springfield, and Boston Mountain plateau surfaces (from oldest and topographically lowest to youngest and topographically highest). The Salem Plateau and Springfield Plateau are separated by the Eureka Springs escarpment, which rises 137 m above the general level of the Salem Plateau. The Boston Mountains escarpment separates the Springfield and Boston Mountain Plateaus (Croneis, 1930; Fig. 3). WEQ is located mostly on the Springfield Plateau with a small portion of the White River valley at the extreme northern limit of the quadrangle within the Salem Plateau. The Ozark Plateaus province is a portion of a structural dome believed to have been formed by regional tectonic warping during the assembly of Pangea in the late Paleozoic (Guccione, 1993; Hudson, 2000). Though structurally a part of the Ozark Dome, the Salem and Springfield plateaus consist of nearly horizontal beds of Paleozoic sedimentary rocks. Ordovician rocks form the foundation of the Salem Plateau, whereas Mississippian and Devonian rocks form the Springfield Plateau (Guccione, 1993; Fig. 4).

The topography of WEQ is controlled by the type of rock cropping out in the area. Steep, regolith-covered slopes

Published by Arkansas Academy of Science, 2002

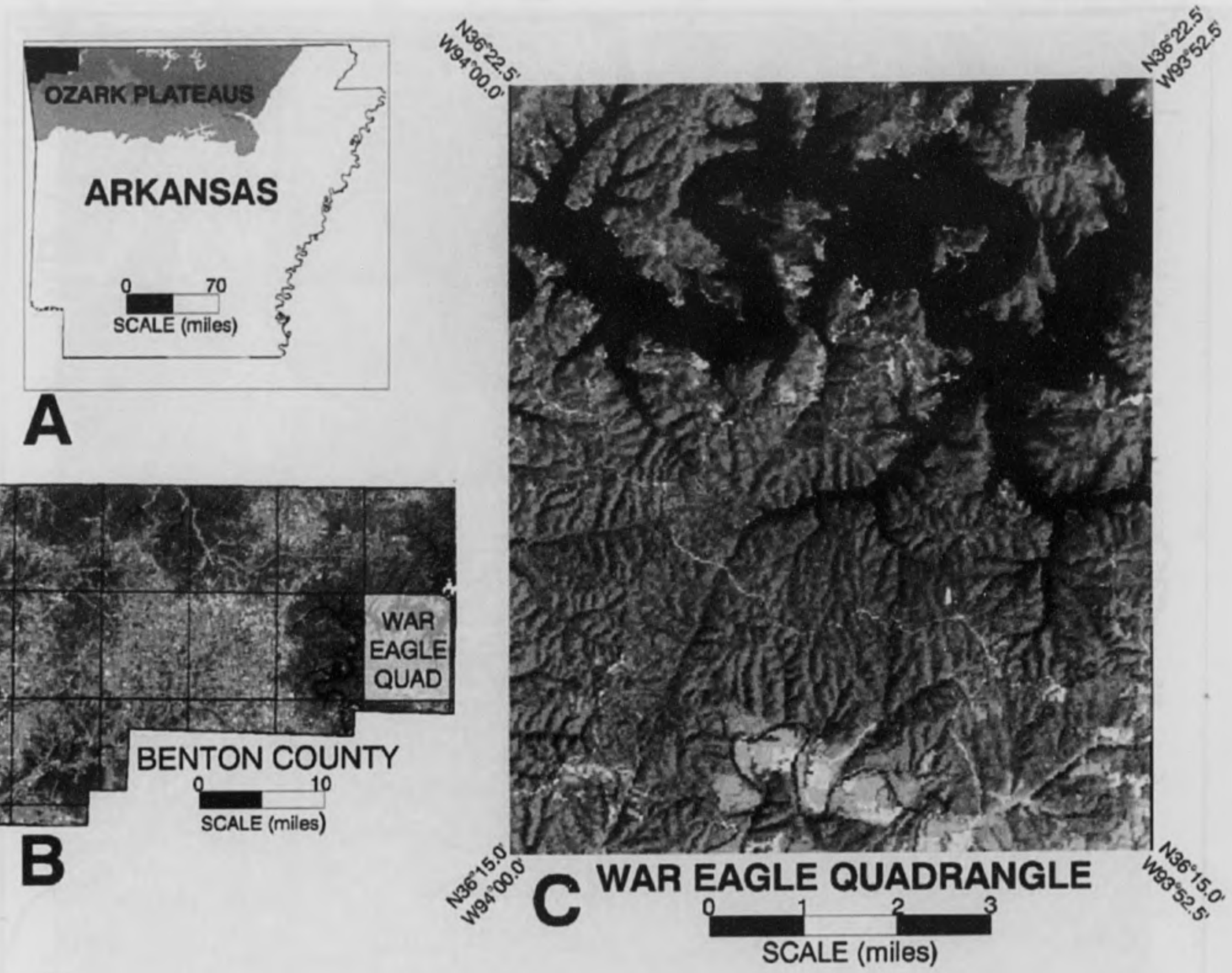

Fig. 1. Location of A) Benton County in northwest Arkansas (black) within the Ozark Plateaus physiographic province; B) location of War Eagle quadrangle (shaded) within Benton County, Arkansas; C) Landsat image of War Eagle quadrangle (from Arkansas Interactive Mapper, http://www.cast.uark.edu/local/mapper).

are typically developed within the Boone Formation (Mississippian), and near-vertical to overhanging cliffs are typically associated with outcrops of the St. Joe Formation. The Chattanooga Shale (Devonian) forms gentle slopes and broad terraces, whereas the Everton, Powell and Cotter Formations (Ordovician) form both gently and steeply sloped terrains.

Most stream valleys within WEQ are v-shaped and carry mainly intermittent or disappearing streams. Exceptions to this are the Van Hollow Creek, Rambo Creek, Devil's Gap Creek, War Eagle Creek, and two unnamed streams feeding War Eagle Creek. The entire quadrangle is located in the drainage basin of the White River.

Previous Investigations.--Branner (1891) discussed topographic features, hydrology, and the stratigraphy of Benton County, Arkansas. Croneis (1930) provided a similar stratigraphic description, but also outlined the major structural features (e.g., Price Mountain Fault, now known as the Fayetteville Fault and Glade Fault) located within the study area.

The geology of the WEQ is known only from the 1:500,000 geologic map of Arkansas (Haley et al., 1976), Eureka Springs-Harrison 30 minute quadrangle folio at

Fig. 2. USGS Digital Raster Graphic (DRG) of War Eagle quadrangle, Benton County, Arkansas.

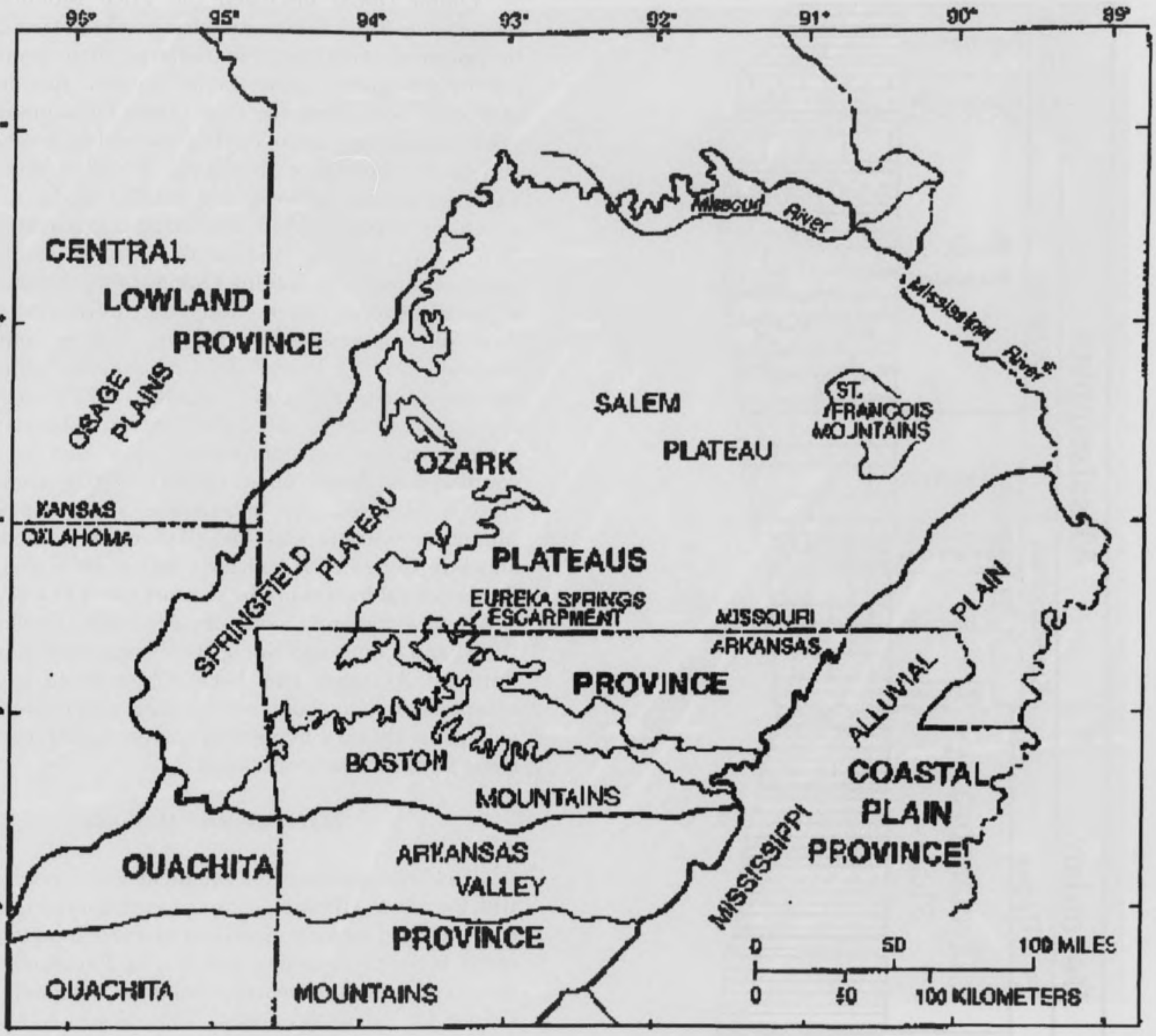

Fig. 3. Physiographic provinces of Arkansas (modified from Adamski et al., 1995). Note: Province divisions only show general boundary locations.

1:100,000 scale (Purdue and Miser, 1916), and an unpublished geologic map (Staley, 1962) at 1:24,000 scale.

In 1962, Staley mapped WEQ as a master's thesis project in the Department of Geology at the University of Arkansas (Fayetteville). A geologic map and cross-section were produced, but the map was never published; the only known copy of Staley's (1962) WEQ geologic map was located after an extensive search of holdings in the Department of Geosciences and the University of Arkansas library. Staley's (1962) map was important to this study because it predated construction of Beaver Dam and inundation of the White River Valley to create Beaver Lake (Black, 1979). Thus, the single remaining copy of his map was the only detailed source of information regarding geology and stratigraphy of areas of WEQ now inundated by Beaver Lake. For the map produced in the present study, sub-lake geology was taken directly from Staley's (1962) map. The accuracy of Staley's (1962) work was evaluated by comparing his mapped formations in areas still above lake level to those mapped during the present study.

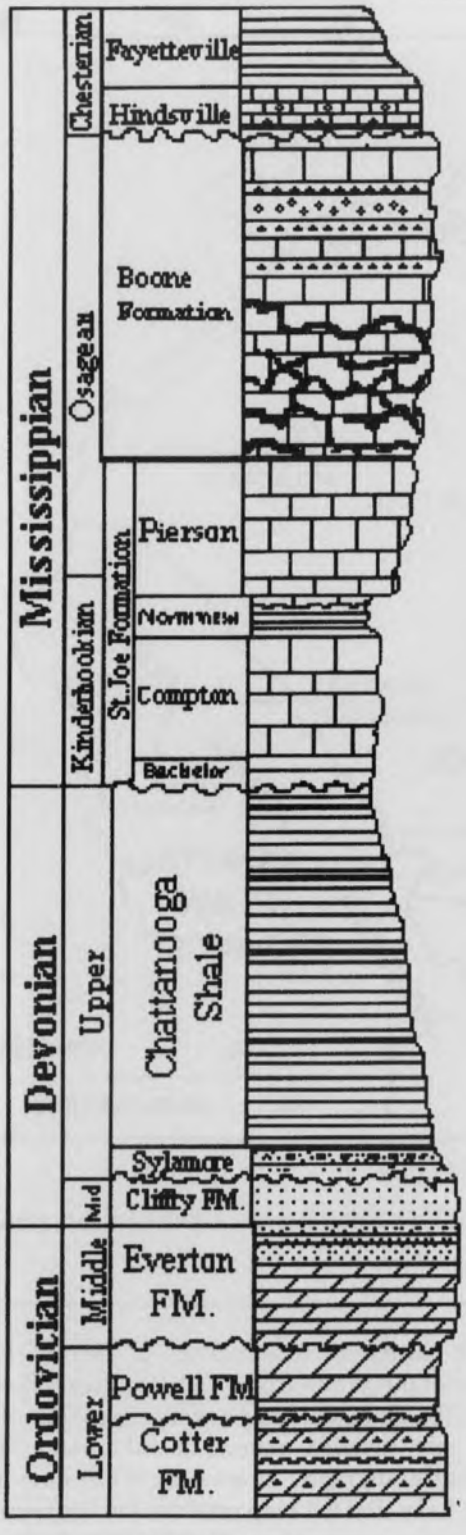

Fig. 4. Generalized stratigraphic column of War Eagle quadrangle.

Quinn (1963) discussed the Price Mountain Fault (Fayetteville Fault) along with other northeast trending faults in northern Arkansas. He believed that groundwater movement along these faults caused dissolution of carbonate beds along the fault plane. Dissolution opened voids that allowed the overlying material to slowly subside and form “subsidence structures”. He also believed that anticlines existed between and parallel to the subsidence structures. Gibbons (1962) concluded that fractures striking N70°E and N7°E indicated a northwest-southeast compressional force, leading Quinn (1963) to conclude that a compressional force from the northwest-southeast direction was responsible for the faulting and folding observed in WEQ. In addition, Gibbons (1962) documented another system of fractures trending N30°W and N55°E that were not cut by the earlier system. Gibbons believed these fractures were indicative of a later north-south compression. Based upon Quinn's (1963) work, Clardy (1964) discussed the subsidence structures of Price Mountain Syncline and the relationship with a parallel anticline (Cove Creek Anticline). Staley (1962) also included this structural framework in his work on WEQ.

In a petrographic study of calcite twin lamellae, Chinn (1967) and Chinn and Konig (1973) suggested that rocks of northern Arkansas had been subjected to north-south compression but could not identify conclusive evidence validating Quinn’s hypothesis for an earlier compressive stress from northwest-southeast.

Materials and Methods

Field reconnaissance throughout WEQ was performed with the aid of a Brunton compass, rock hammer, and digital camera. Field measurements were recorded on topographic maps, aerial photographs, and in a field notebook. Satellite imagery (Landsat Thematic Mapper) obtained from the Center for Advanced Spatial Technologies (CAST) at the University of Arkansas was also examined to help determine fracture and fault orientations (Fig. 5). Field investigations were completed by accessing WEQ by automobile, on foot, and by boat around the margins of Beaver Lake. Use of a boat to circumnavigate the lakeshore proved essential in mapping geologic contacts and investigating geologic structures; a number of new stratigraphic relationships and geologic structures (faults) were discovered from shipboard observations.

Digital Mapping and Geographic Information System.-- A digital geologic map of WEQ was developed for this project by digitizing geologic contacts and observed faults from field maps onto a digital raster graphic (DRG) of WEQ. The digitizing technique involved drawing contacts directly on the computer screen by moving the cursor over the DRG and clicking the mouse button at short intervals to

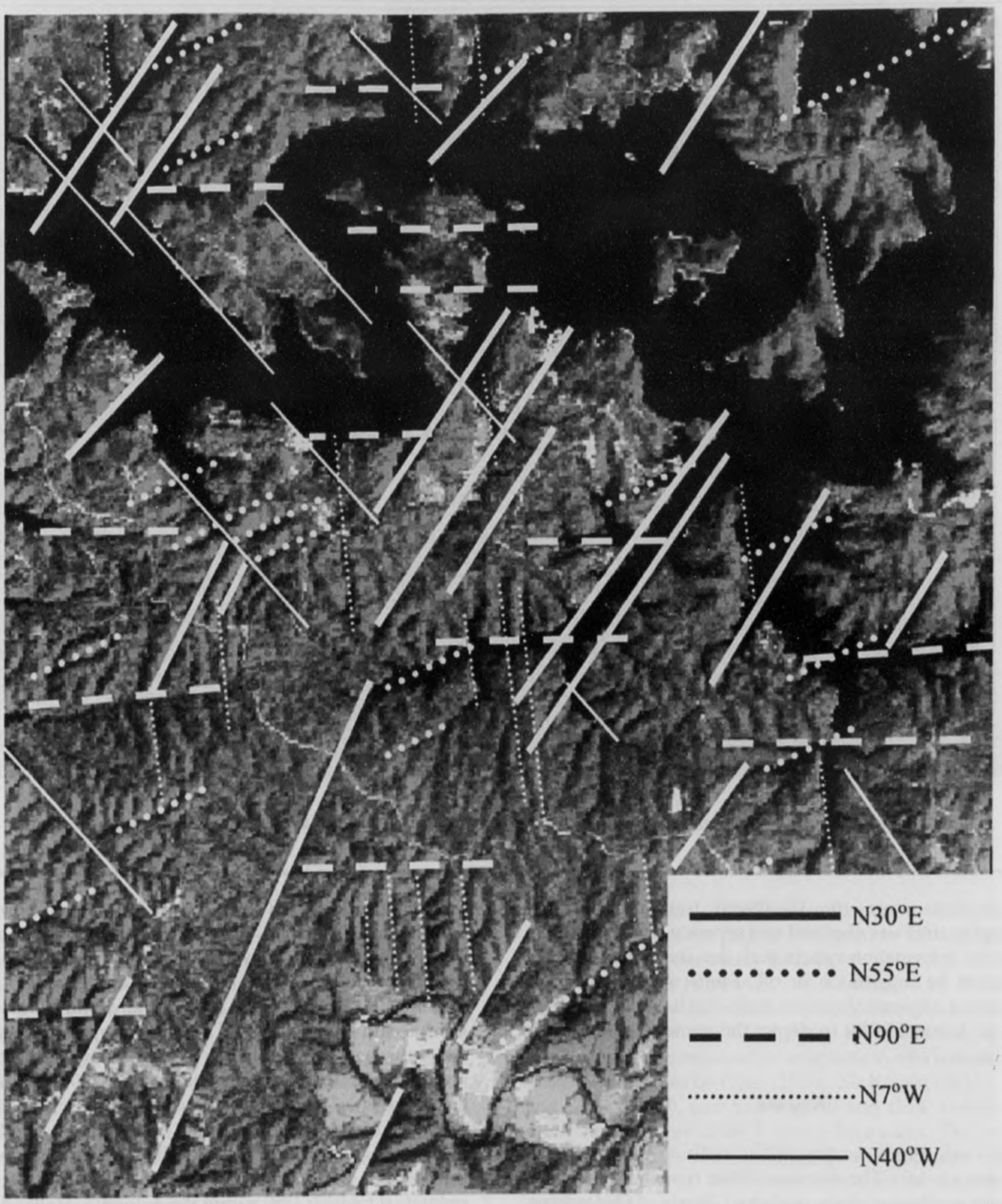

Fig. 5. Landsat Thematic Mapper image with prominent lineaments highlighted. Note there appear to be several superimposed sets of lineaments in this area. Image taken from Arkansas Interactive Mapper (http://www.cast.uark.edu/local/mapper) developed by the Center for Advanced Spatial Technologies, University of Arkansas.

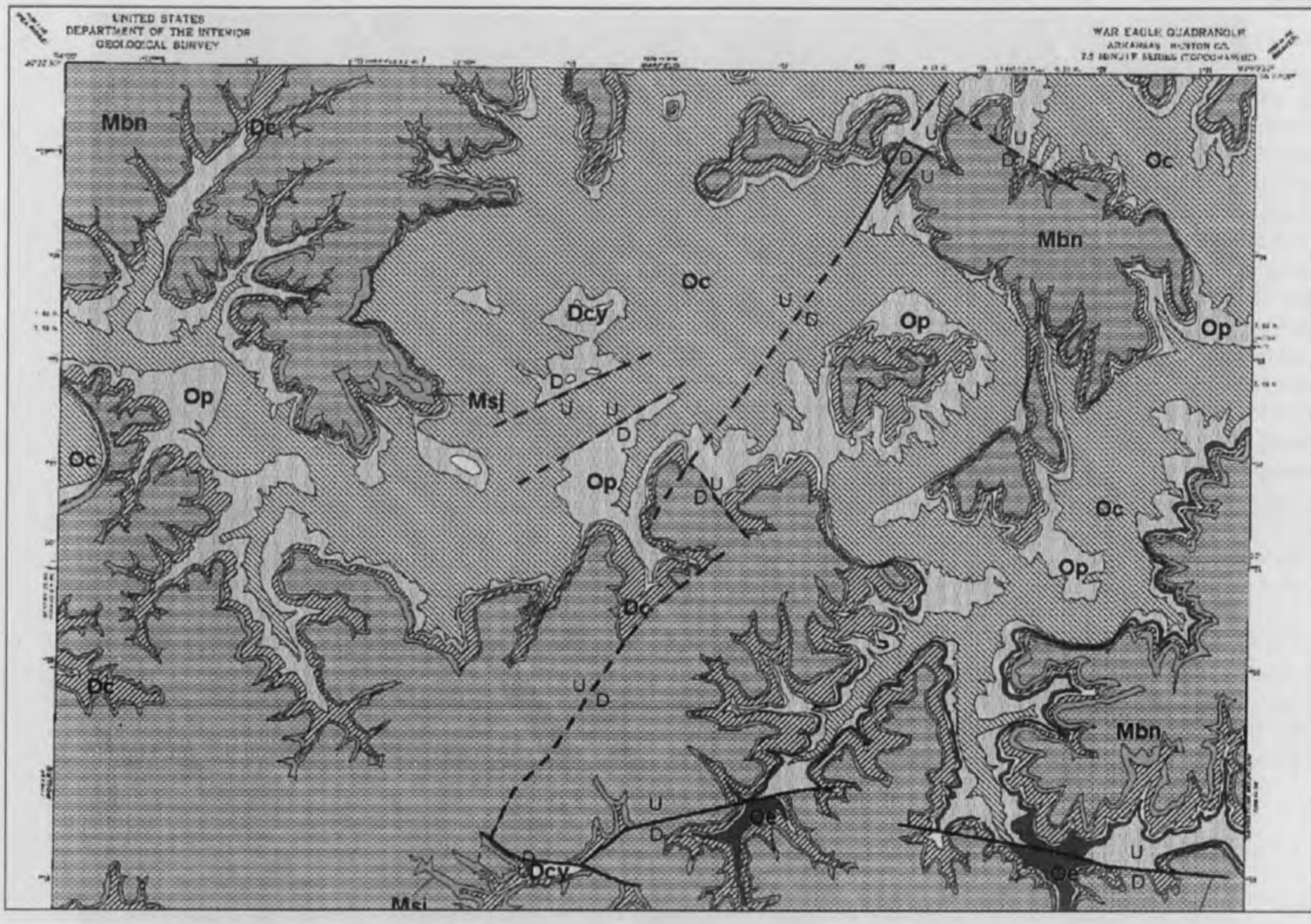

Fig. 6. Digital geologic map of the northern portion of War Eagle quadrangle, Benton County, Arkansas..

trace contacts onto the displayed topography. 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. Each layer was then displayed hierarchically to depict the geology of the study area (Figs. 6, 7, 8).

Results

All rock types cropping-out within WEQ are of sedimentary origin. The dominant lithic types are limestone, dolostone, sandstone, shale, and chert. Strata of Ordovician, Devonian, and Mississippian age were exposed throughout WEQ (Fig. 4). Silurian-age rocks are absent throughout the quadrangle as a result of erosion or non-deposition.

The Ordovician System in WEQ is represented by (in ascending order) the Cotter Formation, Powell Formation, and Everton Formation. The Cotter Formation is composed mostly of medium gray to light brown to bluish gray weathered dolomite with thin layers and nodules of chert (Simonds, 1891; Hopkins, 1893; Adams and Ulrich, 1904; Purdue and Miser, 1916). The chert ranges in color from white through diverse shades of gray. Many of the nodules are banded and a few are oolitic. Thin (<0.5 m) to thick (~ 8 m) beds of microcrystalline dolomite alternate with intervals of argillaceous, oolitic and quartz sand-bearing units throughout the formation. The sand intervals occur as thin lenses, thinly interbedded (<0 .5 m), or as thicker individual beds (> 1 m) within the dolomite (Holland, 1987). Stromatolitic mounds are sometimes present (Staley, 1962). Intraformational conglomerates (0.075 m to 4.5 m thick) of chert and dolomitic pebbles are sporadically distributed throughout the formation (Staley, 1962). Since

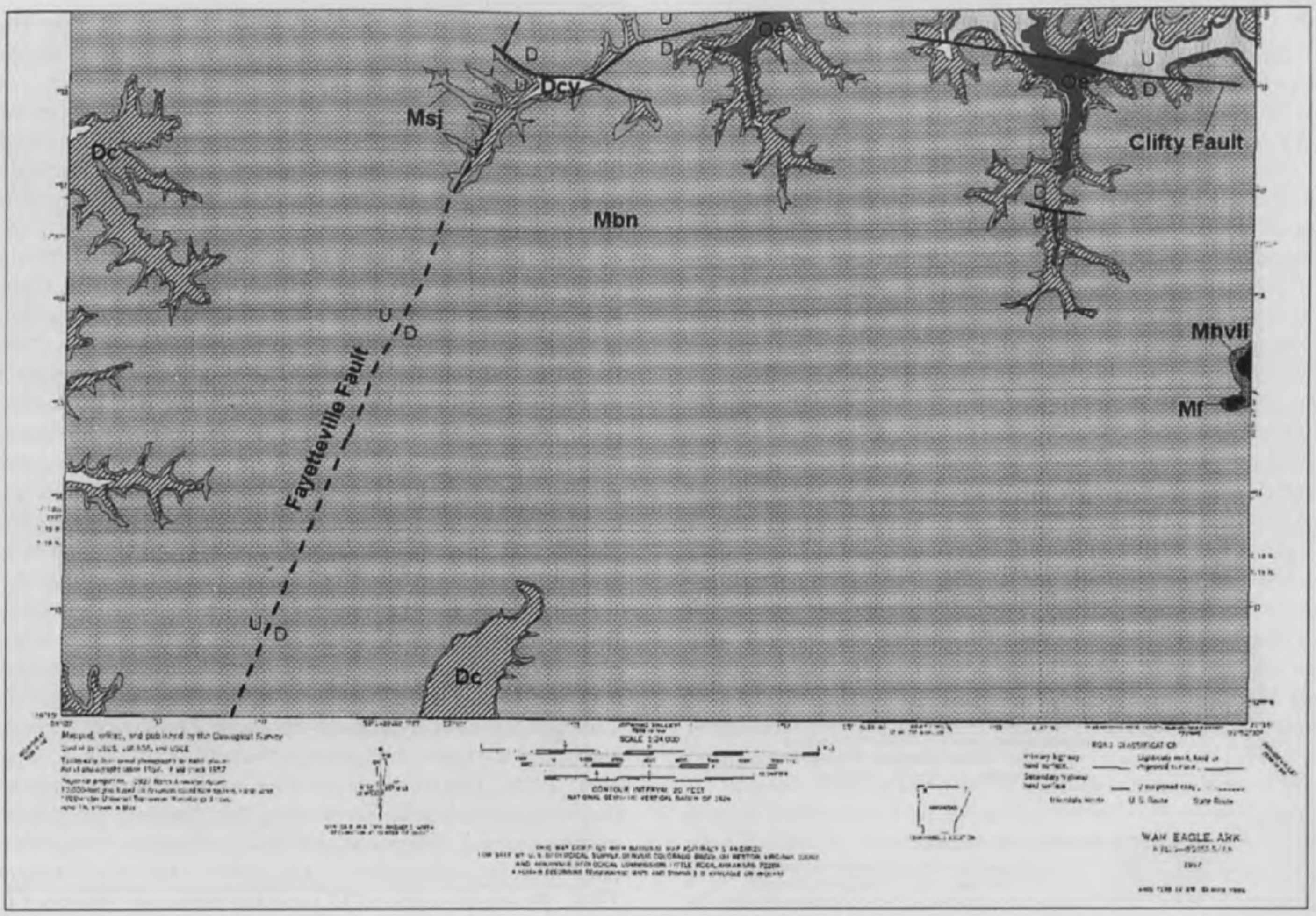

Fig. 7. Digital geologic map of the southern portion of War Eagle quadrangle, Benton County, Arkansas.

impoundment of Beaver Lake, only the uppermost 1 m to 12 m of the Cotter Formation are still visible in a few locations around the lake shore (Figs. 6 and 7).

The Powell Formation lies unconformably on top of the Cotter Formation. It is light gray to tan dolomudstone with orthoquartzite lenses. Shale is more abundant than in the underlying Cotter Formation. An undulating green shale layer, 0.05 m to 0.46 m thick, marks the base of the formation (Manger, 1988). Absence of chert in the Powell Formation helps differentiate it from the Cotter Formation. Like the Cotter Formation, Powell Formation outcrops in WEQ were limited to the northern half of the quadrangle where it commonly occurred near lake level (ca. 341 m above sea-level). The observed thickness of the interval ranged from 6 m to 24 m. Staley (1962) reported measurements up to 31 m, but the lower portions of this section are presently below lake level and therefore inaccessible. Staley (1962) also reported differences in elevation of outcrops that he attributed to folding, but more likely resulted from minor faulting.

The Everton Formation was subdivided by Purdue and Miser (1916) into three different members. These units are the Sneeds Limestone Lentil, Kings River Sandstone, and an upper member composed of magnesium-free limestone and sandstone. Studies by Giles (1930), McKnight (1935), Frezon and Glick (1959), and Suhm (1970 and 1974) redefined the different members of the Everton Formation. The only unit present in WEQ was the Kings River Sandstone Member. The Kings River Sandstone Member is thin bedded, saccharoidal, quartz sandstone cemented by calcium carbonate. Grains are subangular to rounded and fine- to medium-grained. Beds are friable to non-friable and are cross-bedded and often ripple marked with occasional channels. Sedimentary structures and stratal geometries

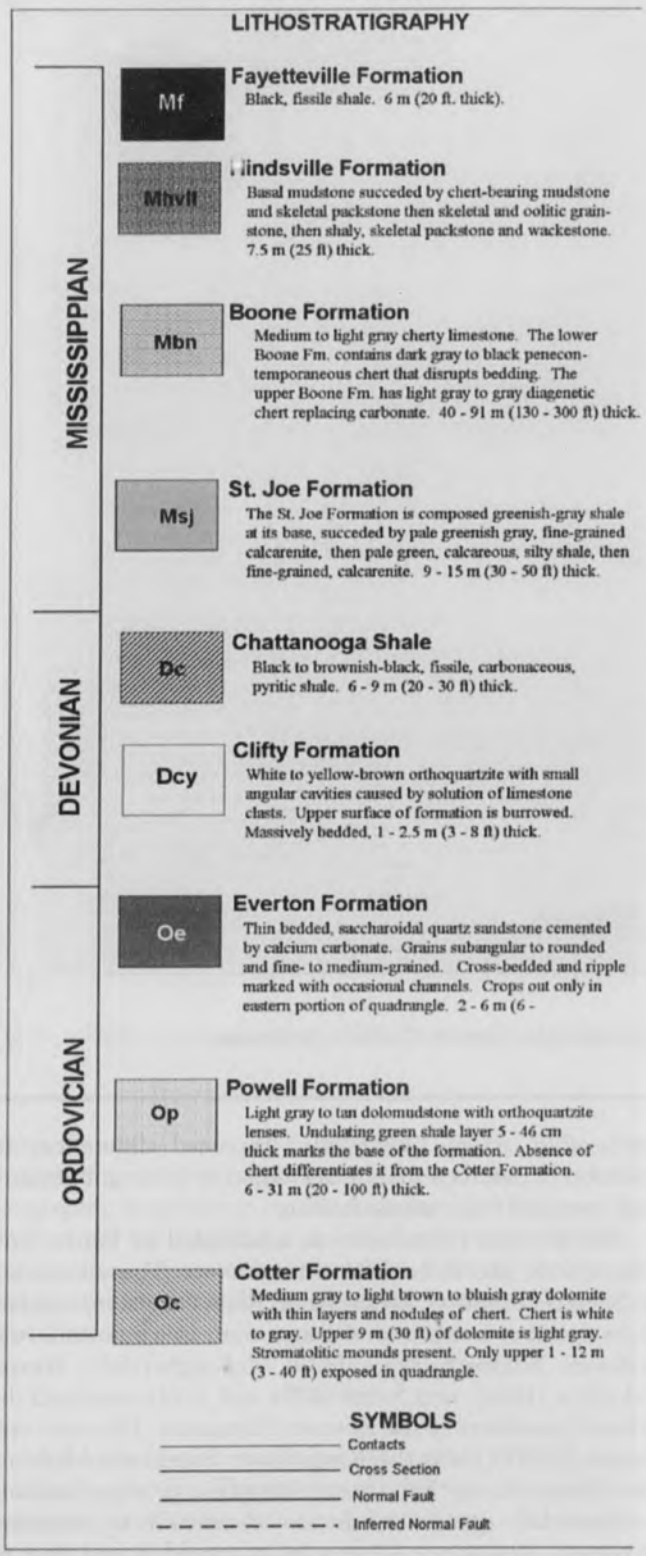

Fig. 8. Legend for geologic map of War Eagle quadrangle (Figs. 6 and 7).

suggested deposition in nearshore, beach, and coastal dune environments (Dr. D. Zachry, pers. comm., 1999). The creation of Beaver Lake inundated most outcrops of the Everton Formation in WEQ. Presently, outcrops are observed only along the lakeshore of the east-central portion of the quadrangle, and these average only 2 m thick (Figs. 6 and 7). Staley (1962) reported a maximum thickness of 12 m near Rambo Creek and an average thickness of approximately 5.5 m throughout WEQ.

The Devonian System in WEQ is represented by the Clifty Formation and the Chattanooga Shale. The Clifty Formation is white to yellow-brown orthoquartzite ranging in thickness from <1 m to 2.5 m. The surface of the Clifty Formation is heavily burrowed (Fig. 8) and represents a probable nearshore (shallow littoral) setting (Dr. D. Zachry, pers. comm., 1999). The Clifty Formation is widespread throughout the quadrangle except in the northwestern portion (Figs. 6 and 7). It is observed to be mainly massively bedded sandstone with discontinuous chert layers in a few places. It is unconformable with the Everton Formation or Powell Formation where the Everton Formation is absent.

The Chattanooga Shale is a black to brownish-black, fissile, carbonaceous, pyritic shale with a maximum observed thickness of 15 m and average thickness between 6 m and 9 m. The Chattanooga Shale correlates with the Chattanooga and Woodford Shale of Oklahoma (Frezon, 1962) and the type Chattanooga Shale of Tennessee (Cooper et al., 1942). The basal unit of the Chattanooga Formation is the Sylamore Member (a mature, thin bedded, phosphatic pebble-bearing orthoquartzite that commonly displays a chert breccia at its base; (Hall, 1978; Hall and Manger, 1978). Nowhere in the WEQ did the Sylamore Member lie in direct contact with the Everton Formation. It has been proposed that the Chattanooga Shale was deposited as shelf mud with the Sylamore Member sandstone representing an early transgressive, shallow-water, near-shore accumulation (Swanson and Landis, 1962).

The Mississippian System in WEQ is represented by the St. Joe Formation and the Boone Formation, the Hindsville Member of the Batesville Formation, and the Fayetteville Formation. The first appearance of the name St. Joe Limestone was in Hopkins (1893) for the basal chert-free unit within the Boone Formation. Girty (1915) assigned the St. Joe Limestone as a member of the Boone Formation. However, in 1934 Cline proposed to raise the St. Joe Member to formation status. While working on the Chouteau Group in Missouri (equivalent to the St. Joe in Arkansas), Mehl (1960) identified the following members (in ascending order): the Bachelor Member, the Compton Member, the Northview Member, and the Pierson Member. Subsequent work by McFarland (1975), Shanks (1976), Manger and Shanks (1977), and Shelby (1986) reordered the classification to bring the St. Joe Limestone to formation

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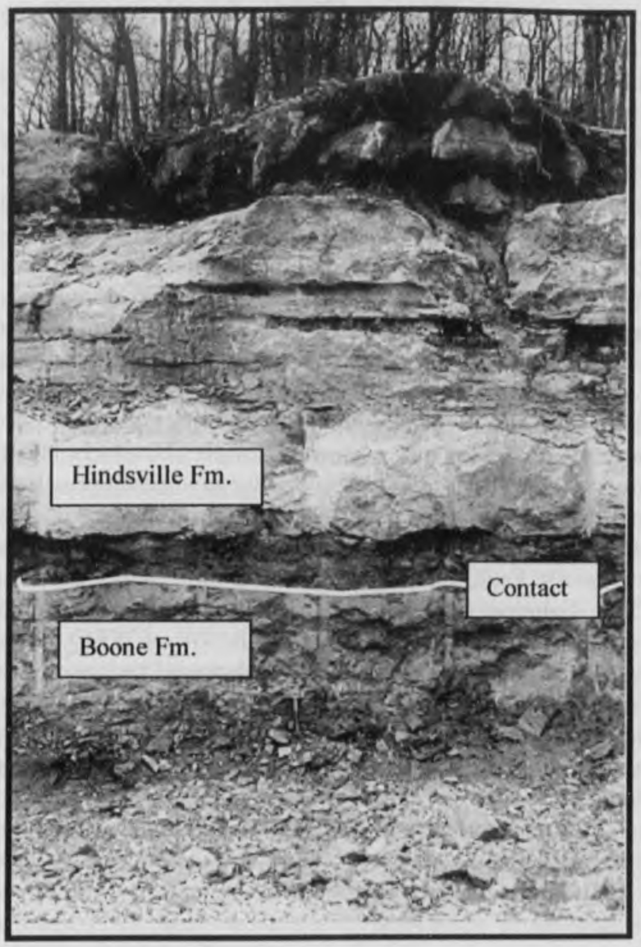

Fig. 9. Contact between the Boone and Hindsville Formations in Sec. 29, T19N, R27W.

status including the Bachelor, Compton, Northview, and Pierson as members. This convention was followed for this study. Staley (1962) did not recognize the St. Joe Limestone as a formation and subsequently did not map the formation, but included it with the overlying Boone Formation. For this study, the St. Joe Formation was mapped as a separate stratigraphic unit throughout WEQ (Figs. 6 and 7). The thickness of the St. Joe Formation ranges from 9 m to 15 m in WEQ. The St. Joe Formation formed near vertical to overhanging cliffs in the areas where it cropped out, especially along the margins of Beaver Lake. The contact between the Bachelor Member of the St. Joe Formation and Chattanooga Shale is an unconformity. The rest of the members of the St. Joe Formation are conformable (Manger, 1988).

The Boone Formation was named by Branner (1891) for exposures in Boone County, Arkansas. The classification scheme for northwest Arkansas divides the unit into two informal intervals and a capping oolitic member (Fig. 4). The two informal members are the Upper and Lower Boone. The type of chert development is the primary means for characterizing these units. The Lower Boone has dark gray to black penecontemporaneous chert that occurs in nodules and beds disrupting bedding of the limestone in an anastomosing fashion (Manger, 1988). The Upper Boone interval has light gray to gray diagenetic chert that was formed by silica replacing carbonate sediment after deposition. The Short Creek Oolite is the only formally recognized member of the Boone Formation. Development of the oolitic unit is sporadic throughout northern Arkansas (Shelby, 1986) and was not observed in WEQ. The Lower Boone Formation is a fine-grained, grain-supported, calcarenite consisting mainly of bryozoan detritus, while the Upper Boone is more grain-dominated than the Lower Boone (Shelby, 1986). The Boone Formation is the most widespread of the rocks cropping out in WEQ, occurring as the surface cover over 63% of the quadrangle. The Boone Formation has an approximate average thickness of 91 m. The Boone Formation displayed many karst features. Sinkholes and blind valleys with disappearing streams are present throughout the study area. Dissolution of the St. Joe Formation and subsequent collapse of the overlying Boone Formation formed these sinkholes.

The Hindsville Member of the Batesville Formation was named by Purdue and Miser (1916) for exposures located near Hindsville, Madison County, Arkansas. Grayson (1976) proposed the Hindsville Member be elevated to formation status in order to distinguish it from the Batesville Formation. However, because outcrops of Hindsville strata are restricted to a single locality in WEQ, there is insufficient evidence to permit evaluation of Grayson's (1976) proposal. Thus, Hindsville strata observed in WEQ are considered a member of the Batesville Formation. The contact between the underlying Boone Formation and Hindsville Formation is marked by a basal mudstone. Chert pebbles reworked from the Boone Formation are found throughout the lower portion of the formation. Hindsville Member limestones are light gray to gray in color. The only outcrop of the Hindsville Member in WEQ is located in Sections 29 and 32, T19N, R27W. A recent road cut provides an excellent exposure of an approximately 7.5 m section (Fig. 9) of the Hindsville Member.

Simonds (1891) named the Fayetteville Shale for exposures near Fayetteville, Washington County, Arkansas. At the type locality, the Fayetteville Shale consists of 1) a lower black, fissile, non-silty shale unit, 2) Wedington Sandstone Member, and 3) an upper interval of lighter colored, less fissile, silty to sandy shale. The only unit present in WEQ is the lower black, fissile shale (Handford

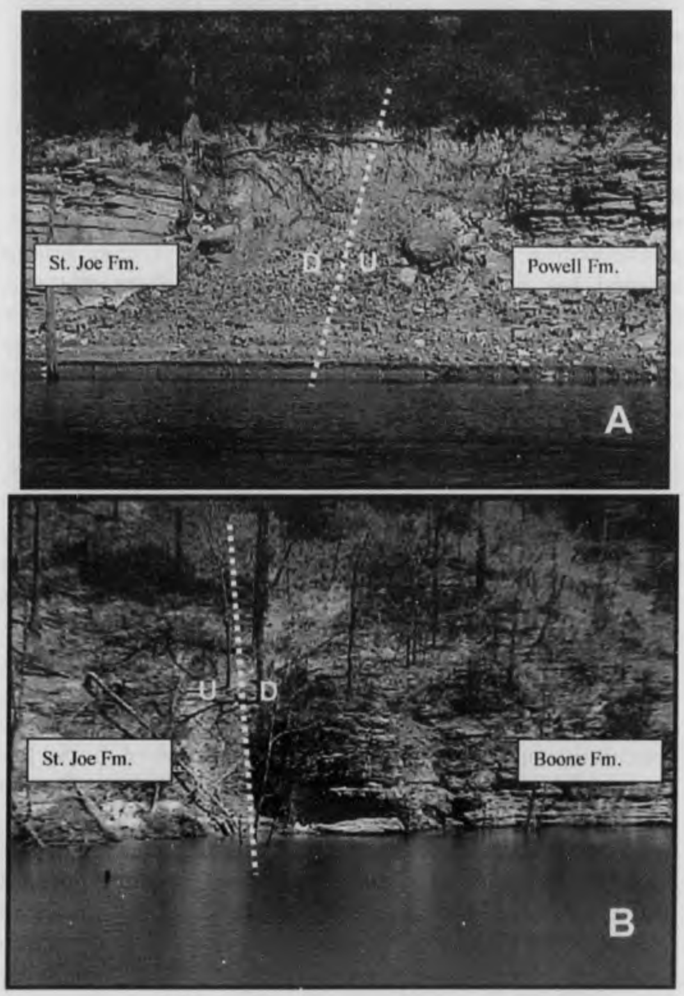

Fig. 10 A) St. Joe Formation to the left is faulted against the Powell Formation in Van Hollow (Sec. 14, T19N, R28W). This photograph was taken during a period of low water; B) St. Joe Formation to the right is faulted against the Boone Formation in Van Hollow (Sec. 22, T19N, R28W).

and Manger, 1990, 1993). The Fayetteville Shale lies uncomformably on the Hindsville Member of the Batesville Formation. The unit is approximately 6 m thick in WEQ.

Structural Geology.--Northwest Arkansas is situated on a sable midcontent craton that consists of a Precambrian basement of igneous rocks overlain by Paleozoic strata. The controlling influence on the structure in the southern portion of the craton was the assembly of Pangea during the latest Paleozoic, resulting in development of the Ouachita Mountains and Ozark Dome (Smith, 1977; Houseknecht, 1986; Hudson, 2000). Throughout the study area the geologic formations are typically horizontal with a slight dip to the south (<5°). Occasionally, a few disjunct blocks have dips greater than 5°, especially in the vicinity of faults. However, these are not representative of the regional dip.

Quinn (1959) proposed a system of northeast trending folds throughout northwest Arkansas that were presumed to result from compressional tectonics. Staley (1962) used Quinnís model of northeast trending folds by including the Cove Creek Anticline in the northwest portion of WEQ. However, Staley (1962) determined the existence of the Cove Creek Anticline from dip angles less than 2°. Field investigation during revised mapping of WEQ failed to produce evidence of the Cove Creek Anticline within WEQ. Quinn's (1963) later subsidence structure hypothesis involved karstification of underlying carbonates and subsequent subsidence along faults without the need for compressional tectonics. As an example, Simonds (1891) named the Price Mountain Syncline for inward dipping beds near Price Mountain, Washington County, Arkansas. The Price Mountain Syncline trends along the trace of the Fayetteville Fault, but appears to terminate before entering WEQ. Solution features are present near Rocky Branch Marina in Sections 11 and 2, T19N, R13W of WEQ. Thus, this area appears to have been down-dropped by dissolution of underlying carbonates. Resulting gravity faults bound this feature (Fig. 6). Clardy (1964) discussed similar structures associated with the Fayetteville Fault and Price Mountain Syncline.

Compression and tension have produced systematic joint and fault patterns in northwestern Arkansas. Analysis of satellite imagery shows a series of lineaments believed to be expressions of regional joint patterns (Fig. 5). Lineament trends measured in WEQ were N30°E, N90°E, N7°W, N40°W, and N55°E.

The Fayetteville Fault bisects WEQ from the southwest to the northeast (Figs. 6, 7), and is the most prominent structure in the quadrangle. Simonds (1891) named the Fayetteville Fault for a fault trace exposed in Fayetteville, Washington County, Arkansas. In WEQ the strike of the Fayetteville Fault is N30°E and the fault appears to be discontinuous along strike. The Fayetteville Fault is a near-vertical normal fault down-thrown to the southeast, but the vertical displacement is difficult to determine. The Fayetteville Fault is exposed in an area northwest of Rocky Branch Marina in Section 2, T19N, R28W (Fig. 6). In this area Staley (1962) did not discover the exposure of the fault and mapped it incorrectly to the southeast.

In the Glade Creek area (Sections 26 and 25, T20N, R28W), a normal fault is present (Fig. 6). This fault is downthrown to the northwest. Staley (1962) mapped this area before the Glade Fault was accepted to be a part of the Fayetteville Fault system. By mapping these faults separately it was necessary for Staley (1962) to incorporate additional faults to explain the stratigraphy, and this complicated the structural interpretation by adding additional faults without field evidence.

The Clifty Fault is located in the eastern quarter of the quadrangle (Figs. 6 and 7) and has a slightly curving east-west trend. The fault is downthrown to the south and is displaced approximately 15 m.

Van Hollow branch of Beaver Lake is located in the central portion of the map and is the location of two newly described normal faults (Figs. 6 and 7). The first fault trends in a curving northeasterly direction (approximately N70°E) and has an approximate displacement of 17 m (Fig. 10A). The fault is downthrown to the south. The second fault trends N60°W and is downthrown on the northern side with a displacement of approximately 4.5 m (Fig. 10B).

Another fault located along the Devil's Gap branch of Beaver Lake was identified during this project. The sense of displacement and strike of this fault are similar to the second fault in Van Hollow several kilometers to the west, suggesting these structures may be genetically related (Fig. 7).

Conclusions

Exposed stratigraphy within WEQ is Ordovician-Mississippian and generally horizontal (Figs 6 and 7). The impoundment of Beaver Lake covered much of the Ordovician section previously mapped by Purdue and Miser (1916), Staley (1962), and Haley et al. (1976). However, important revisions of the geologic map of Staley (1962) included 1) separating and mapping the St. Joe Formation as a distinct stratigraphic unit, 2) separation of the Bachelor Member from the Chattanooga Formation and assigning it as the basal member of the St. Joe Formation, 3) revision of fault locations and documentation of several new faults, 4) mapping the Hindsville Formation within WEQ, and 5) mapping the Fayetteville Shale within WEQ.

Observed jointing and faulting patterns coincide with previously mapped trends. The control of joint and fault patterns on topography and drainage patterns throughout the quadrangle was made apparent from satellite imagery. The Fayetteville Fault is discontinuous and was previously mapped incorrectly in the Rocky Branch Marina and Glade Creek areas. All of the faults in WEQ are normal faults (implying extensional tectonics) and are difficult to follow in the Boone Formation regolith.

Utilizing digital mapping techniques had many advantages over conventional styles of mapping. Once field-mapping data are entered into digital format and incorporated into a geographic information system, they are more easily manipulated and merged with geologic maps of adjoining quadrangles.

ACKNOWLEDGMENTS.—Field mapping of War Eagle quadrangle was completed with the aid of United States Geological Survey National Cooperative Geologic Mapping Program grant #98HQAG2074 and the Department of Geosciences, University of Arkansas, Fayetteville.

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Published by Arkansas Academy of Science, 2002

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