Coordinated strike-slip and normal faulting in the southern Ozark dome of northern Arkansas: Deformation in a late Paleozoic foreland

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ABSTRACT

Structures that formed on the southern flank of the Ozark dome, in the foreland of the late Paleozoic Ouachita orogeny, have received little modern study. New mapping of the western Buffalo River region of northern Arkansas identifies diversely oriented faults and monoclinal folds that displace the generally flat lying Mississippian Boone Formation over a 180 m elevation range. Kinematic measurements and spatial relations reveal the presence of both east-striking normal faults and broader northeast-striking dextral strike-slip fault zones that acted in a coordinated fashion to accommodate constrictional strain, in which north-south extension was balanced by vertical and east-directed shortening. North-south extension in the Buffalo River region probably reflects Pennsylvanian–Early Permian deformation within the flexural forebulge of the developing Ouachita orogeny, which closed progressively westward along the southern margin of the craton.

Keywords: foreland, strike-slip faults, normal faults, Ozark dome, Ouachita orogeny.

INTRODUCTION

Although strain in continental foreland regions is low compared to adjoining marginal orogenic belts, foreland structures are important because of their potential controls on (1) syntectonic sedimentation, (2) paths of hydrocarbon and mineralizing fluids driven from orogenic belts, and (3) distribution of groundwater resources. Foreland deformation may also provide valuable insight into the tectonic history of a cratonic margin, particularly if preservation of the adjacent orogen is incomplete.

The Ozark dome is in the foreland of the late Paleozoic Ouachita fold-and-thrust belt, which flanks the southern margin the of North American craton (Fig. 1). From a crest in the Salem Plateau and St. Francois Mountains, the dome passes southwestward into the Arkoma foreland basin and Ouachita fold-and-thrust belt. In regional syntheses, the southern flank of the Ozark dome in northern Arkansas is typically portrayed as a simple, south-dipping homocline that is broken by a series of normal faults (Haley et al., 1976). Although faults and open folds have long been recognized in northern Arkansas (Purdue and Miser, 1916; Croneis, 1930; McKnight, 1935; Haley et al., 1976), their kinematics have received little study. Faults in northern Arkansas strike east-west, northeast, northwest, and, less commonly, north (Fig. 1). These faults are generally portrayed as normal faults (Croneis, 1930; Haley et al., 1976), but strike-slip (McKnight, 1935) and reverse (Lucas, 1971) movements have been locally noted or inferred.

Several explanations have been offered for the diverse trends of faults in northern Arkansas. Glick (1997) attributed diverse structural trends to differential solution and compaction over paleotopography in the Precambrian basement. Ancillary to their discussion of foreland flexure in the Arkoma basin, Bradley and Kidd (1991) inferred that diversely oriented faults in northern Arkansas formed in different stress regimes over time, before development of the foreland basin. Alternatively, this study suggests that many of these structures were coeval, accommodating triaxial strain by a combination of normal, strike-slip, and/or reverse faults and folds having different strikes.

STRUCTURAL GEOMETRY AND KINEMATICS

The western Buffalo River region of northern Arkansas exposes an ~500-m-thick sedimentary sequence of Ordovician, Mississippian, and

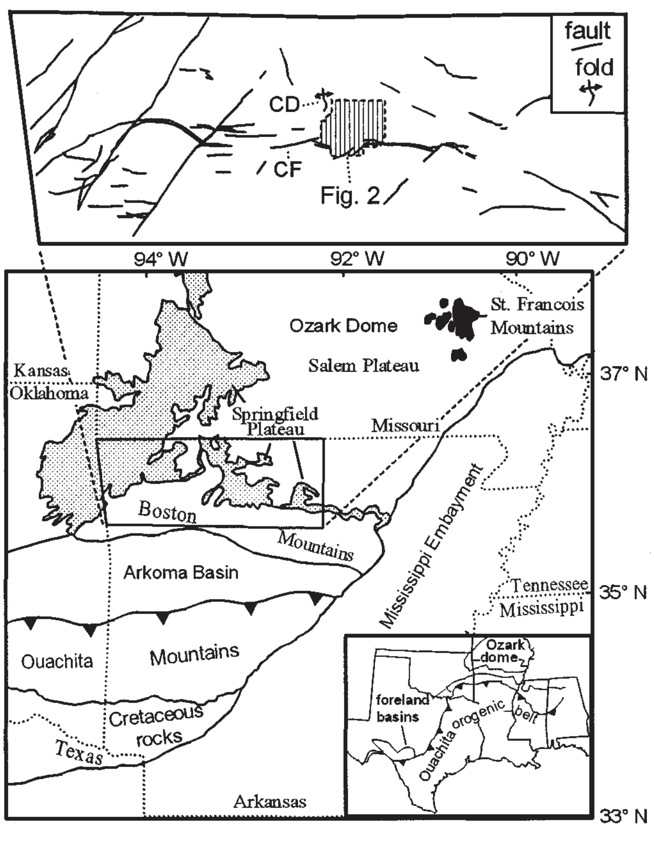

Figure 1. Generalized tectonic and physiographic provinces of Arkansas and adjacent regions. Large-scale map shows major faults in Ozark Mountains of northern Arkansas (from Haley et al., 1976). CD, Carrollton dome; CF, Compton fault. Inset shows front of Ouachita orogenic belt, flanking foreland basins, and Ozark dome (modified from Viele and Thomas, 1989).

Pennsylvanian carbonate and clastic strata deposited on and near the southern shelf of North America. Within this Paleozoic sequence, the 120-m-thick cherty limestone of the Mississippian Boone Formation is a distinctive unit, the upper and lower contacts of which usually can be located to a 6 m elevation accuracy. Variation of these widespread markers over a 180 m elevation range provides a basis to identify a system of faults and folds (Fig. 2).

Two principal fault sets, striking east and northeast, are present in the study area. East-striking faults are typified by faults that bound the Braden Mountain graben. Northeast-striking faults are represented by the Elmwood fault zone, upper Flatrock Creek fault, and the Carlton and Stringtown Hollow fault zones. Exposures of fault surfaces that retain slip lineations are sparse but are key to understanding the deformation. Most kinematic measurements are from small-displacement faults because exposures of map-scale faults are typically poor. Slip data demonstrate the presence of both normal and strike-slip faults (Fig. 3). In general, east-striking faults have normal slip, whereas northeast-striking faults have dextral strike slip or normal-oblique dextral strike slip. Small-scale, west-northwest– to northwest-striking sinistral faults are also present as a subordinate subset of strike-slip faults. Reduced paleostress tensors, calculated using the methods of Angelier (1990), suggest that both fault sets were active under a north-south–directed least principal stress (Fig. 3).

At map scale, normal and strike-slip fault zones differ in overall geometry (Fig. 2). Normal faults comprise discrete planes or narrow fault zones. For example, where it is well exposed along the Buffalo River, the southern bounding fault of the Braden Mountain graben consists of two 75°N dipping strands separated by <10 m. Dips of small-scale normal faults mostly range from 65° to 75°. In contrast, map-scale strike-slip faults tend to form broader, more complex zones. Where it is best exposed at its southwestern end, the Elmwood fault zone is about 1 km wide and contains en echelon fault strands oriented about 15° clockwise to the overall N60°E strike; these are interpreted as Riedel shears. Strata on both flanks of this fault zone dip gently inward, giving it an overall geometry of a fault-cored trough. Farther south, the Carlton and adjacent Stringtown Hollow fault zones each enclose fault blocks, uplifted and downdropped, respectively. Dips of small strike-slip faults in the study area are typically >75°. Sparse small-scale, open to tight folds were observed locally within both the Elmwood and Carlton dextral fault zones; their axes trend slightly counterclockwise (13° average) to the overall fault strikes.

Strata in the study area were also deformed by several broad monoclinal folds having axial trends that range from west-northwest to northeast. These monoclines displace beds as much as 40 m and have limbs that mostly dip 5°–10°. Several observations suggest that these monoclines formed by drape over buried faults. The alignment of the Hoskins Creek monocline with the Elmwood fault system, which has a similar sense of throw, provides direct evidence that some faults die into monoclinal folds. Small-scale strike-slip faults were observed within the northwest-dipping limb of the Hoskins Creek monocline, illustrating that this fold accommodated strain from an underlying fault that had lateral as well as vertical displacement. Small strike-slip and normal faults also were observed locally within the north-facing Web monocline, suggesting that it probably formed over a west-northwest–striking transtensional fault.

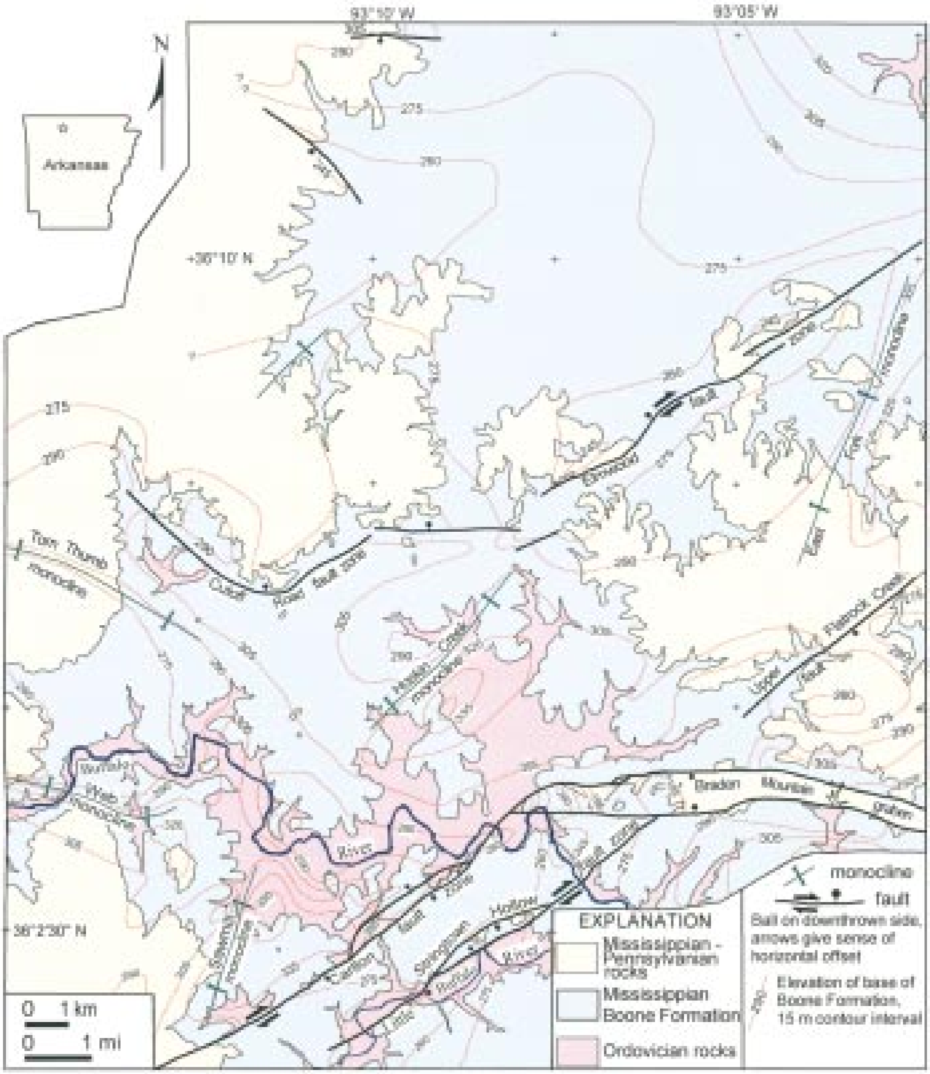

Figure 2. Generalized geologic map of western Buffalo River region. Structure contours are on base of Mississippian Boone Formation, including basal St. Joe Limestone Member.

Strain Transfer and Coeval Faulting

The spatial distribution of structures indicates that there was strain transfer between the normal and strike-slip faults in the study area, providing strong evidence for their kinematic coordination. Purdue and Miser (1916) recognized both the east-striking northern Braden Mountain fault and the northeast-striking Carlton fault at the western end of the Braden Mountain graben. New mapping establishes that these faults merge (Fig. 2). Both the northern and southern Braden Mountain faults have normal slip, whereas the Carlton fault has dextral-normal oblique slip. Throw on the base of the Boone Formation decreases westward in Braden Mountain graben between the intersections of the Stringtown Hollow and Carlton faults (Fig. 2). Together, these relations indicate that extension within the Braden Mountain graben was transferred to northeast-striking normal-oblique dextral faults at its western end.

Strain transfer between strike-slip and normal faults is also indicated by spatial relations among the Elmwood and Cutoff Road fault zones and the Hoskin Creek monocline. The change of the dextral Elmwood fault zone into the Hoskin Creek monocline coincides with the intersection of the east-striking Cutoff Road normal fault.

These relations suggest that strain along the Elmwood fault zone was partly transferred onto the Cutoff Road normal fault zone and, due to decreased displacement past this intersection, adjacent strata were flexed rather than ruptured over a buried southwestern continuation of the Elmwood fault zone.

STRAIN PATTERN: CONSTRICTIONAL NORTH-SOUTH EXTENSION

Map relations and kinematic data (Figs. 2 and 3) indicate that normal and strike-slip faults in the Buffalo River area were coeval and acted in a coordinated fashion to accommodate north-south extension. Arbitrarily separated into normal and strike-slip fault subsets, the paleostress inversions (Fig. 3) give directions of greatest principal stress axes that are vertical and east-west, respectively. Coordinated activity of the normal and strike-slip faults, however, suggests that the overall strain regime was constrictional, with north-south extension balanced by components of both vertical and east-west shortening.

The presence of the East Fork and Sawmill Creek monoclines that strike more northerly than recognized normal and strike-slip faults lends support for a component of east-west shortening. Analogy is made to the Carrollton dome (Purdue and Miser, 1916; Lucas, 1971), a north-northwest–trending structure located about 5 km northwest of the map area (Fig. 1). A near doubling of Boone Formation thickness encountered in an exploration well on the Carrollton dome was interpreted to reflect stratal repetition by a north-striking reverse fault (Lucas, 1971), requiring east-west shortening. Within the study area, it is notable that the north-northeast–trending Sawmill monocline bounds the west flank of a dome developed next to the dextral Carlton fault. Moreover, the north end of this monocline aligns with the termination of the Hoskin Creek monocline, which is probably underlain by the buried Elmwood dextral fault zone. These relations suggest that east-west shortening was taken up across the Sawmill Creek monocline and that this strain was spatially associated with offset on dextral faults.

North-south extension accommodated by faults in the Buffalo River region contrasts with north to north-northwest shortening that has been determined from studies of calcite twinning in northern Arkansas (e.g., Chinn and Konig, 1973). This north-south shortening has typically been attributed to final closure of the Ouachita orogenic belt. No map-scale structures related to north-south shortening are recognized within the map area. However, 8 km to the west the east-northeast–striking Compton normal fault (Fig. 1) was probably reactivated under north-south compression, based on a pattern of adjacent fractures (Hudson, 2000). Thus, north-south shortening probably followed north-south extension.

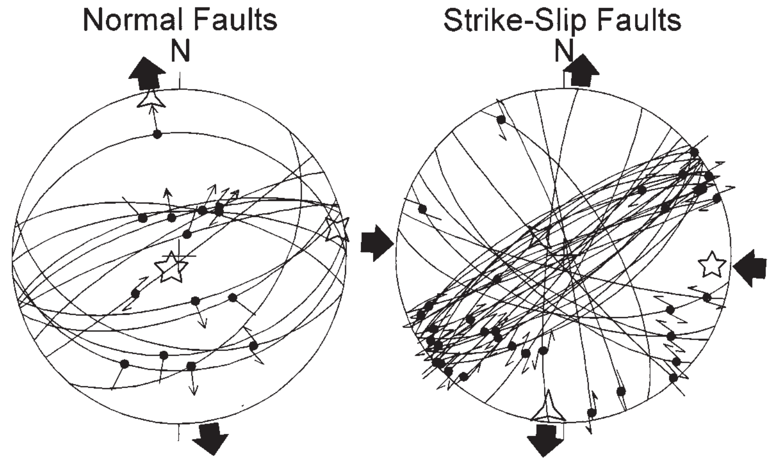

Figure 3. Equal-area projections of fault data from Buffalo River map area broken into sets of dominantly normal (rake >45°) and strike-slip (rake <45°) sense. Fault planes are arcs and slip striae are dots. Arrows give slip sense, increasing head ornamentation representing increasing certainty of sense determination. Stars with five, four, and three points, respectively, represent axes of greatest (σ1), intermediate (σ2), and least (σ3) principal stress determined using method of Angelier (1990). Black arrows indicate azimuths of σ1 (converging) and σ3 (diverging) axes.

AGE OF DEFORMATION

Local and regional geologic relations suggest that most deformation in the northern Arkansas region occurred during Pennsylvanian to Early Permian time. Within the map area, the full Ordovician through Lower Pennsylvanian (Morrowan) stratigraphic sequence is equally offset by faults of the Braden Mountain graben and the connecting Carlton fault. These structures formed after Early Pennsylvanian time. In other areas, however, the Pennsylvanian strata appear to vary less in elevation than Upper Mississippian strata. For example, the 30-m-high, west-northwest–trending Tom Thumb monocline affects both the Boone Formation and the Upper Mississippian Pitkin Limestone, but it is not evident in a well-exposed Morrowan sandstone of the Bloyd Formation that caps the sequence (Hudson, 1998). Over the Carrollton dome, Chesterian Fayettville Shale is greatly thinned and Morrowan strata were uplifted only about a quarter of the >120 m uplift of Mississippian strata (Croneis, 1930; Lucas, 1971). Thus, some structures in northern Arkansas had probably begun to develop by earliest Pennsylvanian time.

The end of faulting is suggested by the localization of late Paleozoic lead-zinc mineralization along faults in northern Arkansas (McKnight, 1935). Widespread lead-zinc mineralization in the Ozark dome has been linked to northward flow of mineralizing brines out of the Arkoma basin (Leach and Rowan, 1986). This flow was mostly focused along basal Cambrian clastic strata, but lead-zinc deposits in northern Arkansas mineral districts occupy Middle Ordovician and Lower Mississippian strata near faults. These relations indicate that faults in northern Arkansas formed before mineralization and acted to divert mineralizing fluids upsection (Erickson et al., 1988). Late Pennsylvanian to Early Permian ages for the mineralization have been determined from isotopic dating (Brannon et al., 1996) and paleomagnetic studies (e.g., Pan et al., 1990).

TECTONIC SETTING

Deformation in the Buffalo River area was coeval with and likely linked to development of the Ouachita orogeny. Regionally, the time span of the Ouachita orogeny is bracketed between the start of offshelf synorogenic sedimentation in middle Mississippian time and final uplift of core areas in Permian time (Thomas, 1989; Viele and Thomas, 1989). Suturing of the Ouachita orogenic belt to the continental margin was diachronous, however, beginning in Alabama and moving obliquely through Arkansas and finally the Marathon region of west Texas (Thomas, 1989). Structural relations in the Buffalo River region support the conclusion of Croneis (1930) that deformation on the southern flank of the Ozark dome in northern Arkansas was linked to development of the adjacent Arkoma foreland basin. Extension in the Buffalo River area permissibly overlapped early Middle Pennsylvanian movement on south-dipping growth faults in the Arkoma Basin (Houseknecht, 1986). Due to their diverse trends, Bradley and Kidd (1991) inferred that faults in the Ozarks probably were older than foreland basin faults, yet structural relations in the Buffalo River region illustrate that they accommodated a common north-south extension. Thus, north-south extension in northern Arkansas probably reflects flexure of the cratonic margin due to a developing load in the Ouachita orogen.

Extensional faults have been well documented in both contemporary and ancient foreland basins such as the Timor trough (Veevers et al., 1978) and the Alpine (Sinclair, 1997) and Taconic (Bradley and Kidd, 1991) forelands. Deformation in northern Arkansas, however, differs in

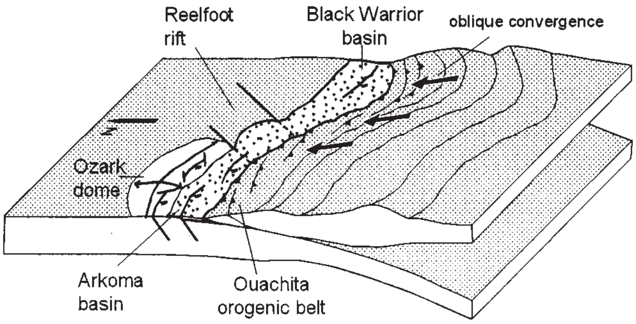

Figure 4. Tectonic setting of foreland deformation in southern Ozark dome (unpatterned). Foreland basins are indicated by dotted pattern.

some respects with that in other foreland basins. Whereas extensional flexure in most foreland basins is restricted to the depositional foredeep (Bradley and Kidd, 1991; Sinclair, 1997), faulting in the Buffalo River area is north of the Arkoma basin, a foredeep defined by abrupt thickening of early Middle Pennsylvanian strata (Houseknect, 1986). In this context, north-south extension in the Buffalo River region may represent flexural failure that occurred within the forebulge of the foreland system (Fig. 4).

The diverse structures that accommodated triaxial extensional strain in the Buffalo River area also differ from typical plane strain depicted in other foreland basins. We speculate that the constrictional nature of strain may reflect oblique closure of the Ouachita orogenic belt. Analogous to models of indentors (e.g., Houseman and England, 1986), initial impingement of the Ouachita orogenic belt at its eastern end (present-day Alabama) may have caused axes of maximum horizontal stress to radiate toward parallelism with the free-face side of the orogeny farther west. In the southern Ozark dome, east-west compression was superimposed on extension related to continental margin flexure caused by thrust loading, driving overall triaxial extension within a developing forebulge.

CONCLUSIONS

Foreland deformation in northern Arkansas, associated with the Ouachita orogeny, is more complicated than a simple homocline dipping southwestward from the Ozark dome. Deformation in the western Buffalo River region was accommodated by a mixture of normal and strike-slip faults and monoclinal folds. Northeast-striking dextral faults and east-striking normal faults were coeval and acted in a coordinated fashion to accommodate north-south extension. In addition to vertical shortening associated with normal faulting, east-west shortening was accommodated by strike-slip faulting and folding along some north-trending monoclines. Extension occurred during Early to Late Pennsylvanian time and it was mostly likely related to flexure in the foreland of the Ouachita orogenic belt, which obliquely closed along the southern margin of the craton.

ACKNOWLEDGMENTS

This study was conducted as part of a cooperative project between the U.S. Geological Survey and National Park Service. Helpful technical reviews were provided by R. Cox, W. Day, R. Harrison, K. Kellogg, N. Mancktelow, and U. Ring. Software developed by J. Angelier was used for display and analysis of fault slip data.

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Manuscript received December 6, 1999
Revised manuscript received March 1, 2000
Manuscript accepted March 9, 2000