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COD. 1 Plate Tectonics of Ancestral...
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Plate tectonics of the Ancestral Rocky Mountains

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ABSTRACT

The Ancestral Rocky Mountains were intracratonic block uplifts that formed in Colorado and the surrounding region during Pennsylvanian time. Their development related to the collision of North America with South America–Africa, which produced the Ouachita-Marathon orogeny. In Early Pennsylvanian time, suturing was taking place only in the Ouachita region, and foreland deformation took place only in the mid-continent. By Middle Pennsylvanian time, the length of the suture zone had increased, and it was active from the Ouachita to the Marathon region. The extent of cratonic deformation also increased in intensity and in areal extent, culminating in the Ancestral Rocky Mountains. In Late Pennsylvanian time, suturing was taking place only in the Marathon region, and cratonic deformation decreased in extent and spread southward into New Mexico and West Texas. We suggest that the Ancestral Rocky Mountains, and related features over a broad area of the western United States, were formed while an irregularly bounded peninsula of the craton (including the transcontinental arch) was pushed northwestward by the progressive collision-suturing of North America and South America–Africa. This intraplate deformation is, in some respects, like the deformation of Asia in response to the Cenozoic collision with India.

INTRODUCTION

The Ancestral Rocky Mountains were Pennsylvanian uplifts in the region of Colorado and adjacent states (Eardley, 1951; Curtis, 1958; Mallory, 1972, 1975; Fig. 1). Evidence for these uplifts is inferred from unconformities and from coarse, arkosic sediments shed from them. In some areas, there is additional evidence for uplifts from fault zones that were active in Pennsylvanian time (Mallory, 1958, 1975; Howard, 1966; Szabo and Wengerd, 1975; Stone, 1977) and that are exposed today. The Ancestral Rockies were broad, block uplifts bounded by narrow zones of faults with complex movement histories. They are enigmatic in terms of plate-tectonics theory because they were located in an intracratonic and intraplate setting, as much as 1,500 km from any plate margin during the Pennsylvanian. The uplifts deformed shelf-type pre-Pennsylvanian sedimentary rocks and disrupted long-standing Cordilleran sedimentation trends (Curtis, 1958). In addition, the Ancestral Rocky Mountains were amagmatic (Curtis, 1958) and formed along trends that were at high angles to Pennsylvanian orogenic zones. It has been suggested that the Ancestral Rockies were of considerable topographic as well as structural relief (Mallory, 1958, 1972, 1975; DeVoto, 1980).

We propose a model that relates development of the Ancestral Rocky Mountains to events in the Ouachita-Marathon orogenic belt along the southern margin of North America. The basis for this model is a series of tectonic maps for intervals of time during the Late Mississippian through Early Permian; three of these maps are shown in Figure 2. These maps were compiled from published maps and from published data on age, thickness, and facies trends of Pennsylvanian sedimentary rocks and on faults active during that time. The maps shown in Figure 2 are highly generalized, but they serve to emphasize the tectonic patterns.

SYNTHESIS OF TECTONIC PATTERNS

Late Mississippian and Early Pennsylvanian

The tectonic pattern of uplifts and basins that dominated Pennsylvanian time in the west-central United States already had started to emerge sometime before earliest Pennsylvanian (Curtis, 1958; Merriam, 1963; Baars, 1966; Frezon and Dixon, 1975; Stewart, 1975; Crosby and Mapel, 1975; Bachman, 1975;

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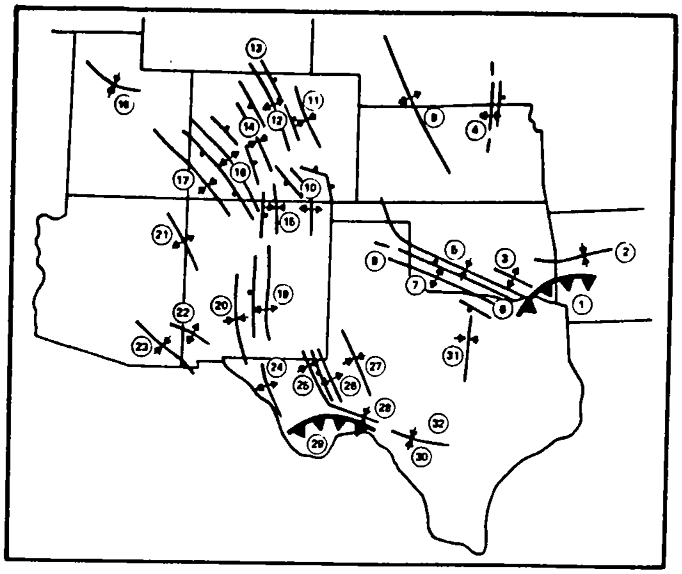

Figure 1. Location map for features discussed in text. (1) Ouachita trough and thrust belt; (2) Arkoma Basin; (3) Arbuckle Mountains; (4) Nemaha Uplift; (5) Anadarko Basin; (6) Criner Hills; (7) Wichita Uplift; (8) Amarillo Uplift; (9) Central Kansas Uplift; (10) Apishapa-Sierra Grande Uplift; (11) Denver Basin; (12) Frontrange Uplift; (13) Pathfinder Uplift; (14) Central Colorado Trough; (15) Rowe-Mora Basin; (16) Uncompahgre Uplift; (17) Paradox Basin; (18) Oquirrh Basin; (19) Pedernal Uplift; (20) Orogrande Basin; (21) Defiance Uplift; (22) Burro Uplift; (23) Pedregosa Basin; (24) Diablo Platform; (25) Delaware Basin; (26) Central Basin Platform; (27) Midland Basin; (28) Val Verde Basin; (29) Marathon trough and thrust belt; (30) Kerr Basin; (31) Fort Worth Basin; (32) Llano Uplift. Note: Delaware Basin-Central Basin Platform-Midland Basin form pre-Pennsylvanian Tobosa Basin.

Wilson, 1975; Gorham, 1975; Stone, 1977; Tweto, 1977; Evans, 1979; Moore, 1979; DeVoto, 1980). In general, the pre-Pennsylvanian precursory patterns in the Ancestral Rocky Mountains were subdued and only hinted at the rapid tectonic development that followed (Bachman, 1975; Crosby and Mapel, 1975; Mallory, 1975; Stewart, 1975). The mid-continent region east of the Ancestral Rocky Mountains, however, was undergoing rapid, intense deformation (Fig. 2A). There were rapid subsidence of the Anadarko Basin and rapid uplift of the Wichita–Criner Hills uplift trend (Tomlinson and McBee, 1959; Frezon and Dixon, 1975). Deformation is inferred to have gradually increased in the Ouachita region (Tomlinson and McBee, 1959; Flawn, 1961c; Goldstein, 1961; Frezon and Dixon, 1975). The intense folding and thrusting in the Ouachita region reached a climax late in the Early Pennsylvanian (late Atokan) (Goldstein, 1961) or early Middle Pennsylvanian (early Desmoinesian) (Frezon and Dixon, 1975). Deformation spread northwestward from the Anadarko Basin late in the Early Pennsylvanian and began to affect the Apishapa Uplift (Mallory, 1975) and the southeastern end of the Uncompaghre Uplift (Sutherland, 1972; Mallory, 1975).

Middle Pennsylvanian

The Ancestral Rocky Mountains developed rapidly and reached their greatest extent in Middle Pennsylvanian (Desmoinesian) time (Mallory, 1975; Wilson, 1975) (Fig. 2B). Rapid uplift took place in the Uncompaghre, Frontrange (written as one word, after Mallory, 1975, to distinguish it from the present-day Front Range), and Apishapa Uplifts (Mallory, 1972, 1975; Bachman, 1975; DeVoto, 1980). These uplifts provided an increasing flood of coarse arkoses, which filled the adjoining basins and maintained shallow-water or emergent conditions despite the rapid downwarping (Mallory, 1975).

The intense structural activity in the Ancestral Rocky Mountains accompanied deformation in the Ouachita and Anadarko regions (Goldstein, 1961; Frezon and Dixon, 1975). The activity also spread progressively southwestward from the Ouachita area, as the Llano region was uplifted rapidly (Freeman and Wilde, 1964). The Kerr, the Val Verde, the southern part of the Tobosa, and the Marathon Basins all subsided rapidly, as foredeeps, related to tectonic activity farther south (Crosby and Mapel, 1975).

Late in the Middle Pennsylvanian, tectonic activity began spreading southward in New Mexico (Pray, 1961; Bachman, 1975), and the Pedernal Uplift was raised to a level sufficient to provide arkoses to the surrounding basins (Kottlowski, 1969).

Late Pennsylvanian–Early Permian

Structural activity of the Ancestral Rocky Mountains and other areas on the craton continued through Late Pennsylvanian and Early Permian time (Fig. 1C), but at a gradually slower rate than in the Middle Pennsylvanian (Mallory, 1975; Wilson, 1975; DeVoto, 1980). However, the Uncompaghre Uplift continued to be uplifted throughout the Late Pennsylvanian (Mallory, 1975), as were the southern part of the Frontrange and Apishapa Uplifts (Wilson, 1975). Rapid structural activity apparently also spread westward from the Ancestral Rocky Mountains during this time. Parts of the Oquirrh Basin began subsiding more rapidly and began receiving an influx of coarser clastic material (Jordan and Douglass, 1980). Rejuvenation of areas within the Antler belt may also have taken place during this time (Roberts and others, 1965; Ketner, 1980; Skipp and Hall, 1980). In addition, the area of deformation continued to spread southward (Pray, 1961; Bachman, 1975). The Pedernal Uplift shed arkoses into the adjoining Orogrande Basin (Pray, 1961; Bachman, 1975), which was subsiding rapidly (Greenwood and others, 1977), as was the southern part of the Tobosa Basin (Adams, 1962). In very latest Pennsylvanian or Early Permian time, the Central Basin Platform and Diablo Platform in West Texas were rapidly uplifted (Galley, 1958; King, 1965; Crosby and Mapel, 1975), and the Pedregosa Basin rapidly subsided (Ross, 1979).

Structural activity along the Anadarko trend was still rapid, especially along the western, Amarillo-Wichita Uplift part of the trend (Tomlinson and McBee, 1959; Frezon and Dixon, 1975). Tectonic features in the Ouachita and mid-continent region were much less active than in Middle Pennsylvanian time. The notable exception to this general trend of reduced activity is the Arbuckle Mountains and related features, which were deformed rapidly during that interval (Tomlinson and McBee, 1959; Flawn, 1961b; Goldstein, 1961; Ham and Wilson, 1967; Frezon and Dixon, 1975).

The Marathon region was the site of intense northward thrusting and folding over rapidly subsiding foredeep basins during the Late Pennsylvanian and Early Permian, culminating late in the Virgilian or in the Wolfcampian (Flawn, 1961a). Thrusting in the Marathon region and large-scale, rapid deformation of the craton ended synchronously in the Early Permian (Wolfcampian or Leonardian).

INTERPRETATION

The pattern and timing of events shown in Figure 2 and summarized above suggest to us that the Ancestral Rocky Mountains were part of a complex, intraplate response of the foreland to events that produced the Ouachita-Marathon orogeny. The correlation in timing of deformation in the Ouachita-

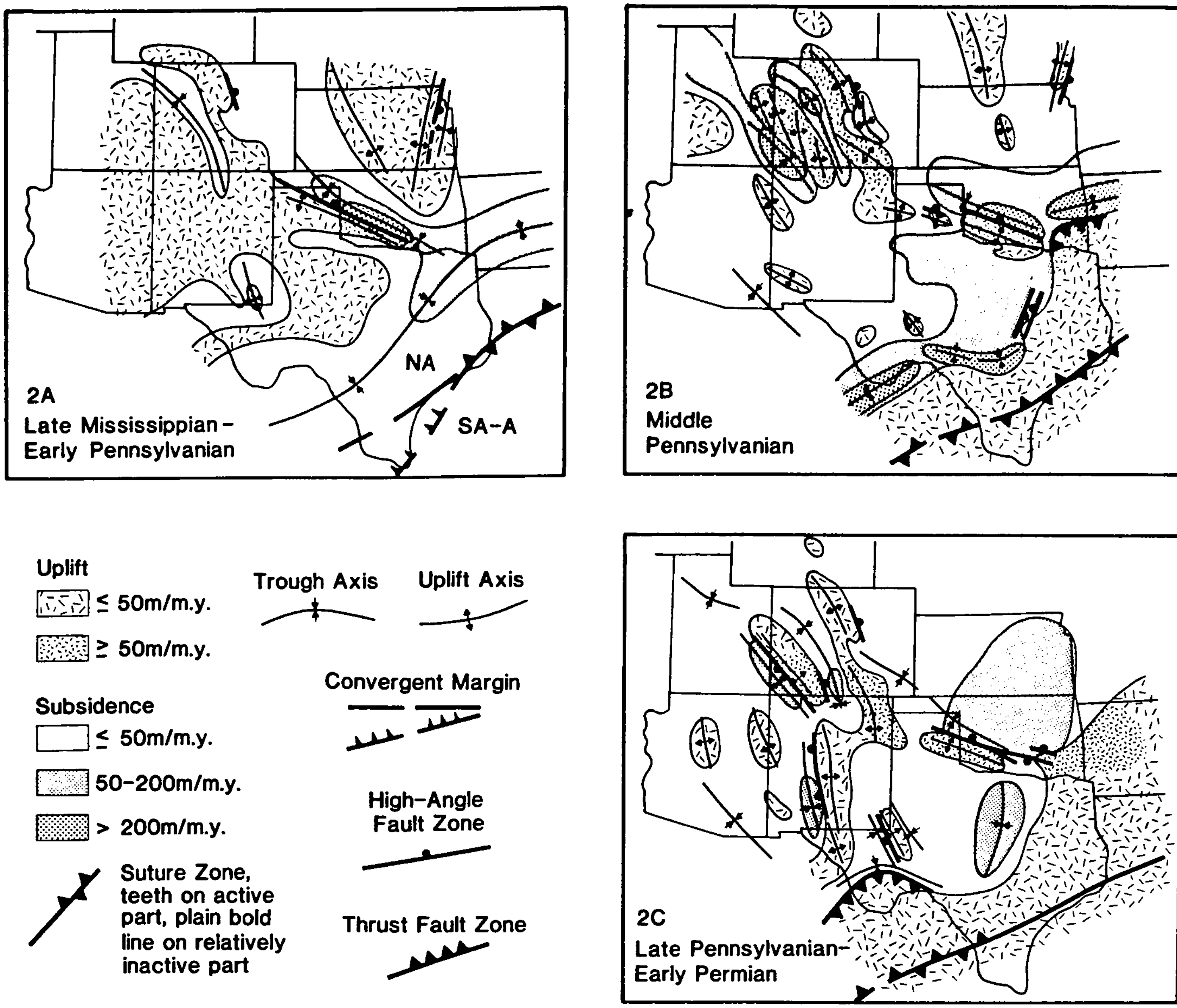

Figure 2. Paleotectonic maps for intervals of time in Pennsylvanian (modified after McKee and Crosby, 1975, Pl. 15; Moore, 1979). Note that position of suture zone is approximate. NA = North America, SA-A = South America-Africa.

Marathon region with that of the Ancestral Rocky Mountains is too close to be considered coincidental. The Antler orogeny ended along the western margin of North America before the development of the Ancestral Rocky Mountains began, and the Ancestral Rockies were tectonically quiet by the time the Sonoma orogeny began along the western margin (Burchfiel and Davis, 1972; Gilluly, 1967). Thus, this interpretation is preferred to any that might relate the Ancestral Rockies to events along the Pacific plate margin, because the Pennsylvanian was a period of relative quiescence there.

We assume that the Ouachita-Marathon orogeny was caused by a continent-continent collision along the southern margin of North America. There is some question, however, about the positions of the continents during Pennsylvanian time (compare Irving, 1977, and Scotese and others, 1979). We show a plate reconstruction (Fig. 2) after Scotese and others (1979) which is also suggested by geologic data such as that given by Ross (1979), in which South America is on the south side of the Pennsylvanian suture zone (Pangea A).

Early Pennsylvanian deformation of the craton is here related to the early deformational phases of the Ouachita orogeny. The Ouachita orogeny has been interpreted to reflect suturing of the North American and South American continents south of the Ouachitas (Dewey and Bird, 1970; Graham and others, 1975). Graham and others (1975) have interpreted the progressive, southwestward migration of rapid sedimentation through time along the southern margin of North America (Black Warrior, Arkoma, Fort Worth, Val Verde–Kerr, and Marathon Basins) as a response to the southwestward migration of the orogen through time. The southwestward migration of centers of rapid sedimentation and orogenic activity reflects the progressive southwestward migration of the suture zone between North America and South America–Africa through Pennsylvanian time (Graham and others, 1975).

As the suture zone between North America and South America–Africa lengthened southwestward, reflected in increased deformation of the Ouachitas and areas along the continental margin southwest of the Ouachitas, the deformation of the craton increased in intensity and areal extent. By Middle Pennsylvanian time, the collision zone was active from the Ouachita region to the Marathon region. The large-scale thrusting in the Ouachitas suggests a culmination of continental suturing to the south. Rapid subsidence and sedimentation in the Marathon region, by analogy with earlier phases of the Ouachita region, probably reflect an early stage of the suturing collision south of that region. At the same time, deformation of the craton region had spread northwestward. The Ancestral Rocky Mountains developed rapidly and shed coarse arkoses into adjacent basins. Later in the Pennsylvanian and in the Early Permian, as activity generally waned in the Ouachita region, reflecting a slowing of the collision suturing process, the Marathon region was experiencing intense folding and thrusting, suggesting an increase of activity along the suture to the south of that area. As the length of the actively closing suture zone decreased and moved southwestward along the margin, the intensity and extent of deformation of the craton decreased and spread southward and westward. A relationship between the Ouachita orogeny and deformation in the Anadarko Basin has been suggested by Ham and Wilson (1967), between the Wichita orogeny and the Ancestral Rockies by Tomlinson and McBee (1959), and between the Marathon region and New Mexico and West Texas by Ross (1979). We conclude that the deformation over an area of about 2.5×10^6 km^2 of the craton from Texas and Oklahoma to at least Wyoming and Utah can be related to this progressive suturing of the two continents.

In general, the foreland uplifts were block uplifts of great structural relief, with minor en echelon folding within the blocks (Curtis, 1958; Kottlowski, 1969; Mallory, 1975; Tomlinson and McBee, 1959). The fault zones that bound the blocks have characteristics of both normal and reverse faults (Merriam, 1963). Blocks within these fault zones have complex histories of reversals of relative movements (Merriam, 1963; Baars, 1966; Stevenson and Baars, 1977; Frezon and Dixon, 1975). In some areas, whole uplifts show a reversal of movement relative to surrounding areas (Crosby and Mapel, 1975; Frezon and Dixon, 1975; Tomlinson and McBee, 1959). In many areas, horizontal movements on specific zones have been documented or interpreted (Burgess, 1976; Flawn, 1961c; Harrington, 1963; Hills, 1970; Otte, 1959; Walper, 1977). It seems reasonable to us because of the large structural relief on these blocks that the largest component of movement along the faults bounding the uplifts was vertical. Because many of these zones also have characteristics common to strike-slip faults, we suggest that many of the zones also had at least some component of strike slip.

MODEL

The component of transcurrent movement suggested on the faults bounding the foreland block uplifts probably reflects the fact that the North American craton was undergoing wrenching (Coney, 1973, 1978) and some degree of internal translation due to the collision of South America–Africa with North America. We suggest that the large fault-block mountains formed when the southwestern, peninsular projection of the North American craton between the Cordilleran geosyncline and the Ouachita-Marathon geosyncline (including the transcontinental arch) was wrenched, pushed northwestward, and deformed as the collision progressed.

This wrenching and translation must have been by distributive shear of a large area of the craton such as that suggested by Hills (1970) for the Delaware Basin region of West Texas, because there is no evidence for large-scale throughgoing megashears in the Pennsylvanian or pre-Pennsylvanian rocks.

An additional factor that probably had a large role in the timing and pattern of the deformation of the craton was the inferred irregular southern margin of North America during the collision (Thomas, 1977). Salients such as the Llano region of central Texas and recesses such as the Anadarko-Arkoma Basins region probably had an effect on the stress-strain patterns and timing of deformation within the craton. The effect that such irregularities in the continental margin would have on the strain pattern produced during collisions has been discussed by Tapponier and Molnar (1976; Molnar and Tapponier, 1975), and on structural and sedimentary patterns by Dewey and Burke (1974). More specific data on the configurations of the continental margins of North America and South America–Africa are required before this effect can be fully evaluated.

The fact that no such large-scale foreland block uplifts are found during episodes of suturing farther northeastward along the Appalachian trend (Ham and Wilson, 1967) suggests that conditions there must have been unfavorable for their development. The collision along the Appalachian trend involved a relatively straight continental margin (Thomas, 1977) and involved the main mass of the Precambrian craton. The foreland deformation resulting from that phase of the collision is subdued compared to that farther west, where the weak peninsula of the craton with a more irregular margin was involved in the collision.

The crust had been fractured and weakened in late Precambrian time during a rifting event, in which its southern margin formed (Stewart, 1976), and probably during other, pre-Pennsylvanian tectonic events. When suturing started to affect the area south of the Ouachita-Marathon region, the peninsula of Precambrian crust of the North American craton was too weak and narrow to resist the effects of the collision. Pre-existing zones of weakness were reactivated by the collision in a complex, changing pattern that was controlled by the southwestward progressive suturing of the irregular margins. An example of this changing pattern is in the Delaware Basin of West Texas (Hills, 1970). Early faulting in that region probably relates to the Early Pennsylvanian collision in the Ouachita region. The Late Pennsylvanian fault patterns probably relate to the collision taking place in the Marathon region to the south. The general northerly component of the stress field that was set up in the craton by the collision resulted in large vertical components of movement on the zones of weakness and probably at least some strike-slip component.

One pre-existing zone of weakness appears to have been the Anadarko Basin, an aulacogen formed during a Precambrian rifting of southern North America (Hoffman and others, 1974). This zone of inherited marked structural discontinuity was weak enough to be deformed throughout the Pennsylvanian. In this model, the Arbuckle Uplift and related features, which developed in Late Pennsylvanian time, after the culmination of tectonic activity in the Ouachita region, are viewed as a block uplifted and folded by the late movements of left shear along the Anadarko zone in response to the combined effects of wrenching and compression caused by the suturing taking place to the southwest, in the Marathon area. Another inherited and reactivated zone of weakness is the fault zone along the southwest margin of the Uncompaghre Uplift. This zone has a long history of complex movements, including the Pennsylvanian deformation (Baars, 1966; Stevenson and Baars, 1977; Stone, 1977).

The deformation of the craton in Pennsylvanian time, including the Ancestral Rocky Mountains, as interpreted here, related to the collision of North America and South America–Africa in a way that is analogous in some respects to the deformation of Asia in response to the Cenozoic collision with India (Molnar and Tapponier, 1975). Both are intraplate deformational events related to continental collision. The analogy cannot yet be applied rigorously. There are differences in geometry of deformation and structural style between the two areas which may relate to differences in the age and complexity of the crust, plate geometries, and configuration of the colliding margins between the two areas (compare Dewey and Burke, 1974; Thomas, 1977).

SUMMARY

The timing, rates, and distribution of tectonic events, summarized here, suggest that the Ancestral Rocky Mountains were part of a complex intraplate response to the collision between North America and South America–Africa. This same collision produced the Ouachita-Marathon orogeny. It is suggested that the areal extent of the cratonic deformation is related to the length and activity along the suture zone between the continents. In Early Pennsylvanian time, the collision was taking place only south of the Ouachita region. At that time, foreland deformation was restricted largely to the Anadarko Basin and the mid-continent. By Middle Pennsylvanian time, the collision was taking place from south of the Ouachita region along the irregular margin into the area south of the Marathon region. The foreland deformation, in response to the collision, reached its greatest extent and intensity at this time, culminating in the Ancestral Rocky Mountains. During Late Pennsylvanian and into Early Permian time, the collision process generally slowed south of the Ouachitas, but it continued south of the Marathon region. As the length of the actively converging margin decreased, the areal extent of the deformation of the craton decreased and spread southward from the Ancestral Rocky Mountains into New Mexico and West Texas. Suturing, as reflected by thrusting in the Marathon region, and deformation of the craton ended synchronously in the Early Permian.

The Ancestral Rocky Mountains and related foreland uplifts do not have analogues elsewhere along the Appalachian-Ouachita-Marathon trend. This suggests that their tectonic setting was unique. We interpret this setting to be their position on the southwestward peninsular projection (including the transcontinental arch) of the North American craton. These foreland uplifts are a product of the continental collision along an irregular continental margin which tended to push the craton to the northwest. The Pennsylvanian deformation of North America is, in some general ways, analogous to the Cenozoic intraplate deformation of Asia in response to the collision with India.

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