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Genetic relationship of rift-stage crustal structure, terrane accretion, and foreland tectonics along the southern Appalachian-Ouachita orogen

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Abstract

Abrupt along-strike variations in tectonostratigraphic composition, internal structural style, and detachment level in the southern Appalachian and Ouachita foreland thrust belts are defined at a large-scale bend in strike and a truncation of Ouachita structures by the frontal Appalachian thrust fault. The along-strike variations correspond to differences in the pre-orogenic rifted Laurentian margin, in the history and nature of terrane accretion, and in the response of the foreland to these differences. Within the Ouachita embayment of the Laurentian margin, diachronous arc-continent collision migrated northwestward along a rift-stage transform margin from the Black Warrior foreland basin on the southeast in Late Mississippian time to a short-wavelength, high-amplitude foreland basin (Arkoma basin) on the northwest in front of the Ouachita thrust-belt salient in Early-Middle Pennsylvanian time. Off-shelf, deep-water strata of both passive-margin and synorogenic facies comprise an accretionary prism and subduction complex, and the Ouachita allochthon consists of mud-dominated thrust sheets that are internally disharmonic and folded. The allochthon of off-shelf strata was thrust over the passive-margin carbonate shelf, which remains in the Ouachita footwall. Along the southeast side of the Alabama promontory of the Laurentian margin, passive-margin shelf carbonates are imbricated in the Appalachian thrust belt, which is characterized by internally coherent thrust sheets and high-amplitude frontal ramps. The palinspastic extent of shelf-carbonate rocks corresponds to the extent of structurally shallow basement rocks on the upper-plate rift-stage margin of the Alabama promontory of Laurentian crust. Terranes accreted to the Laurentian margin during the Taconic and Acadian orogenies were driven over the shallow basement by continent-continent collision of Laurentia with Africa (Gondwana). Emplacement of the thrust-translated terranes tectonically stripped and replaced the shelf carbonate. The frontal thrust fault of the Appalachian thrust belt truncates the southeastern end of the slightly older frontal Ouachita thrust belt, as well as the southeastern part of the greater Black Warrior basin in the Ouachita foreland. Shallow basement beneath the Appalachian thrust belt extends cratonward beneath the low-amplitude Appalachian foreland basin.

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1. Introduction

A large-scale curve in strike of the late Paleozoic Appalachian-Ouachita orogenic belt in southeastern North America (Fig. 1A) corresponds to along-strike changes in tectonostratigraphic composition, internal structural style, and detachment level of the foreland thrust belt (e.g., Thomas, 1989). The purpose of this article is to consider the relationship of along-strike changes in the foreland thrust belt and foreland basins to significant contrasts in the structure of rift-stage crust and the history of terrane accretion along the hinterland.

Late Paleozoic thrust-belt structures of the Appalachian Mountains extend along strike southwestward beneath the Gulf Coastal Plain in central Alabama, and thrust-belt structures of the Ouachita Mountains extend eastward beneath the Gulf Coastal Plain in central Arkansas (Fig. 1A) (e.g., Thomas et al., 1989a). In the subsurface beneath the Gulf Coastal Plain, the strikes of both thrust belts curve dextrally (clockwise), and the two sets of thrust-belt structures reach a junction in central Mississippi (Thomas, 1973, 1989). Late Paleozoic deformation and foreland subsidence along the Appalachian Mountains is assigned to the Alleghanian orogeny (Late Mississippian to Permian); late Paleozoic deformation in the Ouachita Mountains (the Ouachita orogeny, Late Mississippian to Middle Pennsylvanian) was approximately, but not exactly, coeval with the Alleghanian orogeny (Thomas, 1977).

2. Southern Appalachian Alleghanian orogeny

Southern Appalachian imbricate thrust sheets contain a succession of sedimentary rocks of Cambrian to Pennsylvanian age, including (1) Lower to Middle Cambrian late synrift, fine-grained clastic rocks, which host the regional décollement; (2) a massive Upper Cambrian to Lower Ordovician passive-margin carbonate succession, which is the dominant stiff layer in the thrust sheets; (3) a relatively thin, laterally variable succession of Middle Ordovician to Lower Mississippian dominantly shallow-marine facies; and (4) Upper Mississippian to Lower Pennsylvanian synorogenic clastic wedges of shallow-marine to deltaic facies (summary in Thomas, 1988; Thomas and Osborne, 1995). The thrust sheets are detached at a regional décollement in the Lower-Middle Cambrian fine-grained clastic rocks near the base of the Paleozoic sedimentary cover succession above Precambrian crystalline basement rocks. The structure is characterized by large-scale frontal ramps and internally coherent, extensive thrust sheets, in which the geometry is controlled by the Upper Cambrian-Lower Ordovician carbonate stiff layer (Thomas and Bayona, in press).

Southeast (on the hinterland side) of the sedimentary thrust belt, the Talladega Slate belt (Figs. 1A, 2) is a distinctive thrust sheet of greenschist-facies metasedimentary rocks including a Cambrian to Lower Ordovician stratigraphic succession similar to that in the sedimentary thrust belt; however, the post-Ordovician Talladega succession differs markedly from that in the sedimentary thrust belt (Tull, 1998). In the Appalachian Piedmont southeast of the Talladega Slate belt, thrust sheets of higher grade metamorphic rocks represent accreted terranes (Figs. 1A, 2) (e.g., the Jefferson, Inner Piedmont, and Carolina terranes; Horton et al., 1989). In the southeasternmost exposed Piedmont, the Pine Mountain internal basement massif (Figs. 1A, 2) includes Grenville basement rocks and a metasedimentary cover sequence of passive-margin quartzite and marble (Steltenpohl, 1992).

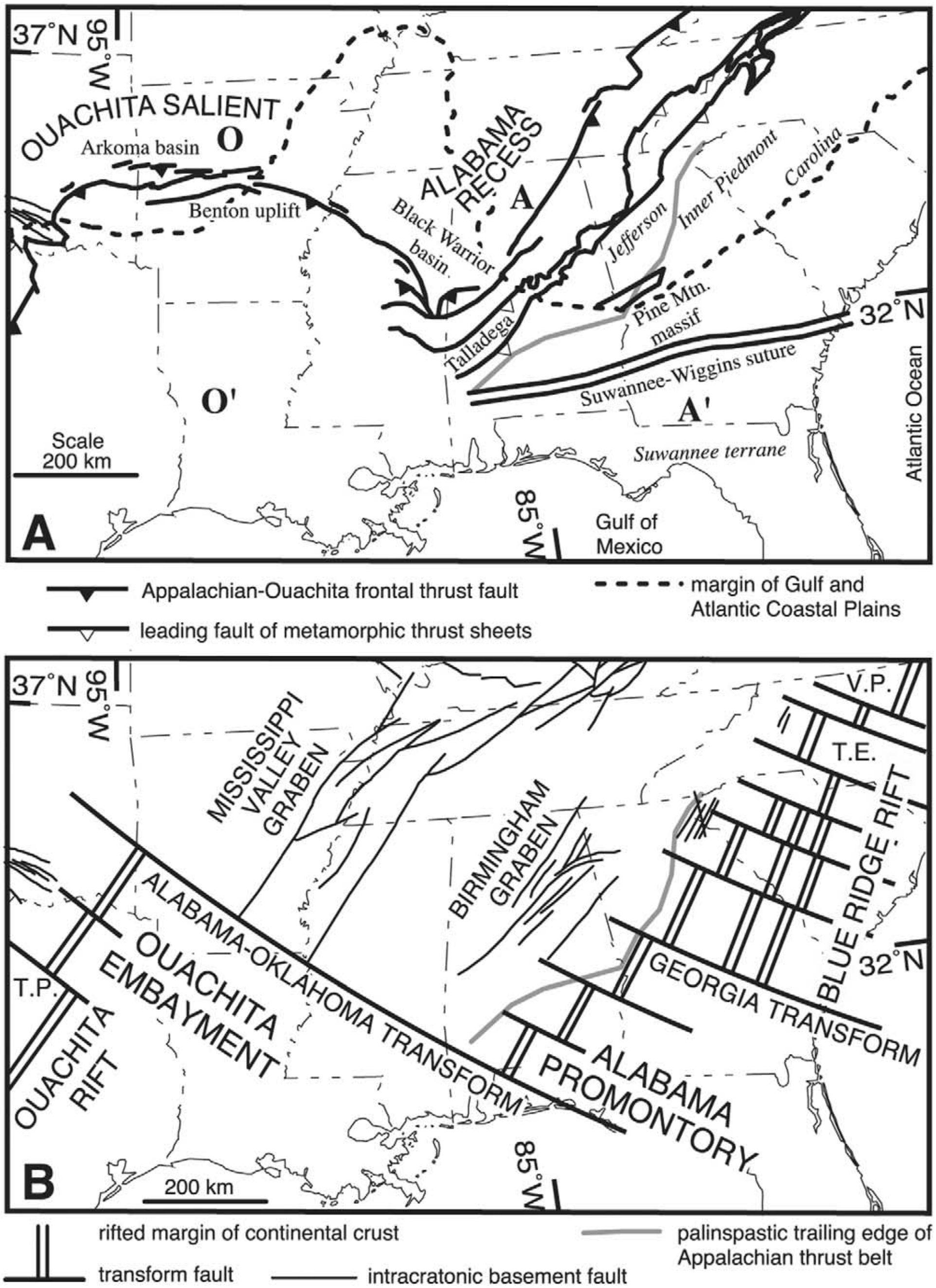

Fig. 1. Outline maps of Appalachian-Ouachita orogenic belt. A. Map of present traces of Appalachian and Ouachita structures, combining outcrop geologic map and paleogeologic map beneath the Gulf and Atlantic Coastal Plains; approximate locations of accreted terranes are shown by labels in italics. B. Outline map of interpreted trace of late Precambrian-Early Cambrian rifted margin of southern Laurentia and intracratonic grabens (from Thomas, 1991, 1993); abbreviations: T.P. = Texas promontory, T.E. = Tennessee embayment, V.P. = Virginia promontory. Both maps show palinspastic location of trailing edge of Appalachian sedimentary thrust belt (from Thomas and Bayona, in press). End points of cross sections in Fig. 2 are shown in Fig. 1A.

The top of autochthonous Precambrian crystalline basement rocks dips southeastward at a low angle from the Appalachian foreland to the Pine Mountain internal massif (Fig. 2) (COCORP seismic reflection profile GA-23; Nelson et al., 1985). Seismic reflection profiles show that the average elevation of the top of basement descends gradually from approximately −2 km on the northwest beneath the Appalachian foreland to approximately −7 km beneath the Pine Mountain massif (Fig. 2) (Nelson et al., 1985; Thomas and Bayona, in press). Beneath the Appalachian thrust belt, steep faults with >2 km of vertical separation break the basement into a horst and graben system, and Appalachian thrust faults ramp over the sub-décollement basement faults (Fig. 2) (Thomas, 1985, 1990; Thomas and Bayona, 2002, in press).

Southeast of the Pine Mountain massif, the outboard limit of Laurentian continental crust is marked by the Suwannee-Wiggins suture zone at the leading edge of the Suwannee terrane of African (Gondwanan) crust and sedimentary cover (Figs. 1A, 2) (Thomas et al., 1989b). The southeast-dipping suture zone is imaged as a thick package of seismic reflectors that dip from the pre-Mesozoic surface to the M-discontinuity (Fig. 2) (Nelson et al., 1985). The layered reflectors suggest a suture zone of mylonitic and gneissic rocks, mostly beneath the cover of the Gulf Coastal Plain; the tectonic fabric of the layered reflectors is indicated by mylonites (Goat Rock fault zone) and gneisses (Uchee Complex) at the southern limit of outcrop south of the Pine Mountain internal basement massif (Osborne et al., 1988).

Palinspastic reconstruction of the sedimentary thrust belt shows that the passive-margin carbonate shelf originally extended approximately to the margin of Laurentian crust near the present location of the Pine Mountain internal basement massif at the leading edge of the Suwannee-Wiggins suture zone (Fig. 1) (Ferrill and Thomas, 1988; Thomas and Bayona, in press). The restored extent of the carbonate-shelf strata in the sedimentary thrust belt indicates that the Pine

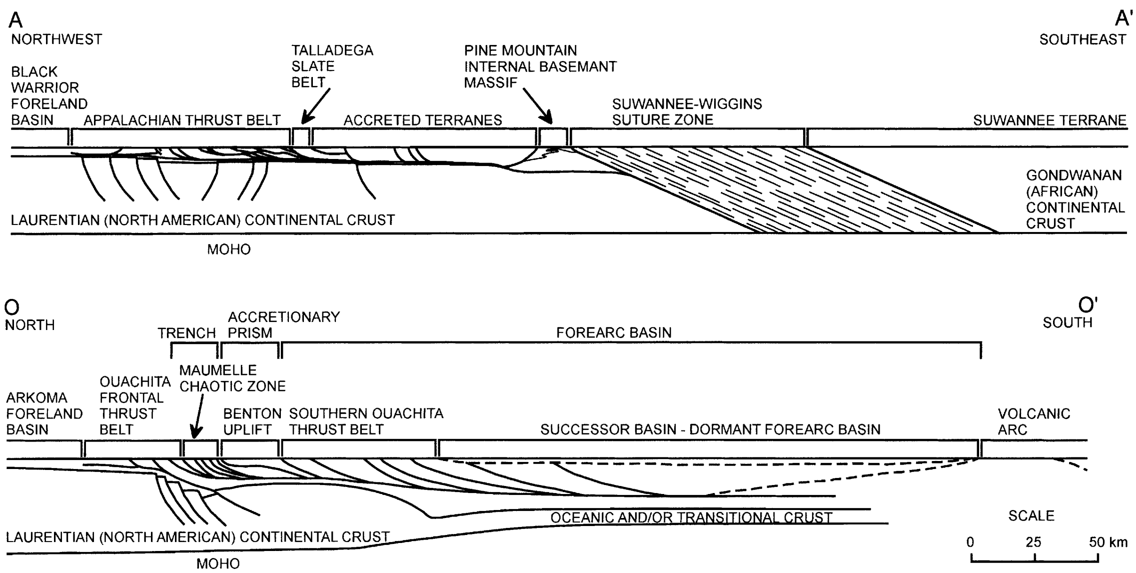

Fig. 2. Structural cross sections of Appalachian (A–A′) and Ouachita (O–O′) orogenic belts. End points of cross sections are shown in Fig. 1A. Datum is palinspastically restored pre-Triassic surface beneath Gulf and Atlantic Coastal Plains merged with present topography of Appalachian and Ouachita outcrops.

Mountain basement massif and perhaps the Talladega Slate belt are palinspastically restored farther outboard either on the Laurentian rifted margin or on microcontinents that were rifted from and later re-accreted to Laurentia (e.g., Thomas, 1977; Bayona, 2003). The metamorphosed accreted terranes in the Appalachian Piedmont cover a wide expanse of Laurentian crust that was originally covered by the passive-margin shelf carbonates, indicating that the carbonate-shelf succession was tectonically stripped away and replaced by the metamorphosed thrust terranes during Alleghanian thrusting (Fig. 2).

3. Ouachita orogeny

The Ouachita thrust belt (Figs. 1A, 2) of internally disharmonic folded thrust sheets consists of off-shelf facies, both Cambrian to Lower Mississippian passive-margin continental-slope-and-rise deposits, and Upper Mississippian to Pennsylvanian synorogenic turbidites (Viele and Thomas, 1989). Fine-grained clastic rocks dominate the stratigraphy, and the succession lacks a dominant structural stiff layer. The allochthonous, off-shelf rocks are thrust over the temporally equivalent, passive-margin shelf-carbonate and distal shallow-marine synorogenic facies (Fig. 2). In notable contrast to the Appalachian structures, the lower Paleozoic passive-margin carbonate succession remains in the autochthonous footwall of the Ouachita structures. In the subsurface beneath the Ouachita thrust belt, small-magnitude thick-skinned thrust faults displace the passive-margin strata and underlying basement; otherwise, the allochthon of deep-water facies is thrust over the pre-orogenic shelf edge at the margin of Laurentian continental crust (Fig. 2) (Jusczuk, 2002).

The Ouachita orogen comprises an arc and subduction complex, in which the leading part includes an accretionary prism and the hinterland includes a forearc basin and remnants of an arc (Viele and Thomas, 1989). The central Benton uplift (Figs. 1A, 2), where the oldest Paleozoic off-shelf strata are exposed, is interpreted to be the uppermost part of an accretionary prism. On the foreland (north) side of the Benton uplift, large-scale cratonward-directed Ouachita frontal thrust faults propagated into a thick synorogenic clastic wedge in the Arkoma foreland basin (Figs. 1A, 2). Along the boundary between the Benton uplift and the frontal thrust belt farther north, the Maumelle chaotic zone (Fig. 2) comprises blocks of sandstone in shale, representing a subduction complex (Viele and Thomas, 1989). Mississippian-Pennsylvanian clastic-wedge rocks north of the Benton uplift are interpreted to be the fill of a trench and peripheral foreland basin (Arkoma basin) that formed as the subduction complex overrode the southern edge of Laurentian crust. South of the Benton uplift in the southern Ouachita thrust belt, a thick succession of southward-dipping thrust-imbricated Mississippian-Pennsylvanian turbidites is interpreted to be forearc-basin deposits (Fig. 2). South of the Ouachita Mountains beneath the Gulf Coastal Plain, thrust-deformed turbidites as young as Atokan are overlain unconformably by nearly undeformed, fluvial to shallow-marine, successor-basin deposits of Desmoinesian to Permian age (Fig. 2) (Woods and Addington, 1973; Nicholas and Waddell, 1989; Thomas et al., 1989a). The successor-basin deposits above the angular unconformity are interpreted to be the fill of a dormant forearc basin that has been preserved intact, suggesting that subduction stopped shortly after the leading edge of the subduction complex rode onto continental crust (Viele and Thomas, 1989). Seismic velocity data show that the southern edge of Laurentian continental crust in the deep subsurface is <100 km south of the leading edge of the subduction complex (Fig. 2) (Keller et al., 1989).

In the southern part of the forearc complex, some wells have penetrated volcanic rocks (rhyolite porphyry and tuff), suggesting proximity to the arc (Nicholas and Waddell, 1989). Seismic velocity and gravity modeling indicate a block of continental crust along the south side of the arc (Mickus and Keller, 1992). Lack of drill penetration precludes more specific characterization of the continental crust; however, volcanic rocks and tuff beds within the Ouachita synorogenic clastic wedge suggest a continental-margin arc and continental terrane accreted off the Laurentian margin.

4. Subsurface junction of Appalachian and Ouachita thrust belts

Deep wells and seismic reflection profiles show that Ouachita structures extend eastward beneath the post-orogenic cover of the Gulf Coastal Plain from the outcrops in Arkansas (Fig. 1A). In the subsurface, the Ouachita thrust belt curves dextrally (clockwise) to a south-southeast strike in eastern Mississippi (Thomas et al., 1989a,b). The frontal Ouachita structures parallel a system of down-to-southwest basement faults, and the frontal thrust faults ramp over the basement faults. The curve in the Ouachita thrust front mimics a bend in the basement fault system (Thomas et al., 1989a). The north-northwest-striking segment of the Ouachita thrust front and underlying basement faults have been interpreted as a transpressional zone (Hale-Erlich and Coleman, 1993); however, seismic reflection profiles show down-to-southwest separation on the basement faults and northeast-vergent frontal thrust ramps.

Appalachian structures extend southwestward beneath the Gulf Coastal Plain in central Alabama (Fig. 1A). In the subsurface, the Appalachian thrust belt curves dextrally (clockwise) to a westerly strike, and the Appalachian frontal thrust fault truncates the south-southeast-striking Ouachita thrust-belt structures in eastern Mississippi (Fig. 1A) (Thomas, 1973; Thomas et al., 1989a,b). The structural truncation defines the abrupt change from Appalachian to Ouachita structural style, detachment level, and tectonostratigraphic composition.

5. Controls on along-strike differences between the Appalachian and Ouachita thrust belts

The regional curve in strike of the late Paleozoic thrust belt from the Alabama recess to the Ouachita salient corresponds to the bend in the pre-orogenic continental margin from the Alabama promontory to the Ouachita embayment (Fig. 1) (Thomas, 1977). The differences in tectonostratigraphic composition between the Appalachian and Ouachita orogens suggest controls by the outline and structure of the pre-orogenic rifted Laurentian margin, by the history of terrane accretion, and by the response of the foreland to these differences.

5.1. Rifted and passive margin

Late Precambrian to Early Cambrian diachronous rifting outlined the Alabama promontory and Ouachita embayment of the Laurentian margin (Fig. 1B) (Thomas, 1991). In the context of locus of curves in the late Paleozoic thrust belts, the Alabama-Oklahoma transform fault frames the northeast margin of the Ouachita embayment, whereas the southeast margin of the Alabama promontory is an upper-plate rifted margin (Thomas, 1993).

A transform continental margin generally is characterized by a narrow zone of transition from full-thickness continental crust to oceanic crust (e.g., Keen and Haworth, 1985). The Alabama-Oklahoma transform fault margin of the Ouachita embayment is documented by a wide-angle reflection/refraction seismic survey (Keller et al., 1989). Laurentian continental crust has a full thickness of ~38 km beneath the Ouachita foreland. The transition from continental crust to highly attenuated continental crust and/or oceanic crust is ~25 km wide (Fig. 2) (Keller et al., 1989).

The rifted southeastern margin of the Alabama promontory is interpreted to represent an upper-plate setting in a low-angle-detachment, simple-shear continental rift (Thomas, 1993). Transform faults partition the Blue Ridge rift, separating the Alabama promontory, Tennessee embayment, and Virginia promontory (Fig. 1B). The Georgia transform between the Alabama promontory and Tennessee embayment also bounds domains of upper-plate (Alabama promontory) and lower-plate (Tennessee embayment) rift structure. A lack of thick synrift sedimentary deposits along the rifted margin characterizes the upper-plate margin of the Alabama promontory, in contrast to the thick synrift deposits (Ocoee Supergroup) on the lower-plate margin of the Tennessee embayment (Thomas, 1993). The upper-plate margin has a more narrow zone of transitional crust than does the lower-plate margin. The top of basement rocks extends at shallow levels into the craton from near the upper-plate margin (Fig. 2).

Intracratonic grabens (Mississippi Valley and Birmingham) extend northeastward from the Alabama-Oklahoma transform fault and parallel the Blue Ridge rift (Fig. 1B) (Thomas, 1991). Late-stage extension associated with opening of the Ouachita rift margin of the Texas promontory is recorded in thick graben-fill successions of Lower and Middle Cambrian fine-grained clastic rocks. Clastic graben-fill facies grade upward into passive-margin carbonate facies from lower to middle Upper Cambrian. A similar basal clastic succession grades upward to the passive-margin carbonate succession near the Blue Ridge rift margin on the southeastern part of the Alabama promontory, but the basal clastic succession generally thins northwestward and is very thin northwest of the Mississippi Valley graben.

Deposition on an extensive carbonate shelf accompanied post-rift thermal subsidence around the margins of the Alabama promontory and Ouachita embayment (e.g., Thomas and Astini, 1999). Diachroneity of rifting and of post-rift thermal subsidence is reflected in lateral variations in the time of the upward transition from clastic facies to passive-margin carbonate-shelf deposits. The average thickness of passive-margin carbonates is not significantly different from the Alabama promontory to the Ouachita embayment.

5.2. Taconic and Acadian orogenies

The Taconic (Middle Ordovician-Middle Silurian) and Acadian (Middle Devonian-Early Mississippian) orogenic events modified the Appalachian rifted and passive margin (e.g., Drake et al., 1989; Osberg et al., 1989). In contrast, during the same time, the Ouachita margin remained tectonically passive; mud-dominated, off-shelf, slope-and-rise facies border the carbonate shelf (Viele and Thomas, 1989).

The primary manifestation of the Taconic orogeny along the Alabama promontory is a dominantly deep-water, synorogenic clastic wedge in the more southeasterly (interior) thrust sheets (Drake et al., 1989; Bayona, 2003). In palinspastic location (to restore Alleghanian shortening), the Taconic foreland basin is near the rifted margin of continental crust, and synorogenic clastic-wedge facies (e.g., Athens Shale) prograded only a short distance toward the craton onto the carbonate shelf. No Taconic thrust faults have been recognized within the presently preserved thrust belt, suggesting that the front of Taconic compressional deformation did not reach the palinspastic location of the trailing part of the thrust belt, which is near the pre-Taconic rifted margin.

In the Appalachian thrust belt on the Alabama promontory, very thin Devonian clastic deposits (Chattanooga Shale) may be the most distal parts of a synorogenic clastic wedge centered farther north in the Appalachians (Thomas, 1977). The sedimentary succession in the Talladega Slate belt contains locally thick Devonian clastic rocks, but the distribution suggests a transtensional pull-apart basin or a fault-bounded basin associated with either compressional or extensional faults (Ferrill and Thomas, 1988; Tull, 1998). Regardless of the deformation mechanism in the palinspastic location of the Talladega Slate belt, during the Acadian orogeny, no deformation, tectonic loading, foreland subsidence, or thrust propagation reached the palinspastic location of the present sedimentary thrust belt.

Although the lack of foreland deformation defines limits to Taconic and Acadian deformation, the Taconic clastic wedge and Acadian Talladega stratigraphy indicate orogenic activity near or at the rifted margin of Laurentia. The orogenic history includes assembly and accretion of multiple terranes along the eastern margin of Laurentia during the Taconic and Acadian orogenies (e.g., Hatcher, 1989, 1999; Hibbard, 2000). Widespread bentonite (volcanic ash) beds in Ordovician cratonic facies indicate a source from the present southeast, suggesting that terrane accretion was accompanied by continental-margin-arc volcanism (Kolata et al., 1996, 1998). The lack of foreland deformation and the restriction of synorogenic clastic sediment suggest that the accreted terranes were not translated onto the passive-margin shelf but remained at or southeast of the rifted margin of Laurentian crust.

6. Foreland subsidence

Thickness and sedimentary facies of synorogenic clastic wedges document both time and geometry of foreland-basin subsidence (e.g., Jordan, 1995). Along-strike variations in the times of foreland subsidence document diachroneity of tectonic loading of the margin of continental crust around the Alabama promontory and Ouachita embayment (Fig. 3). Along-strike variations in amplitude:wavelength ratios of the foreland basins correspond to along-strike differences in pre-orogenic crustal structure and in the style of terrane accretion.

In the Black Warrior foreland basin, an abrupt upward transition from open-shelf, passive-margin carbonates to siliciclastic facies denotes initiation of the late Paleozoic orogeny along the transform margin between the Alabama promontory and Ouachita embayment (Fig. 3A) (Thomas, 1988, 1989; Pashin, 1993). Barrier-island to shallow-marine sandstone and mudstone facies (Pride Mountain and Hartselle formations) overlie the youngest part of the passive-margin carbonate facies (Osagean Fort Payne Chert and Meramecian Tuscumbia Limestone). Differing interpretations of sediment dispersal and provenance (cf., Thomas, 1988; Thomas and Mack, 1982; Pashin, 1993; Pashin and Rindsberg, 1993) converge on the conclusion that these deposits record the initial, tectonically driven subsidence of the Black Warrior basin. The siliciclastic facies pinch out northeastward within a Mississippian carbonate succession (Monteagle and Bangor Limestones) in northeastern Alabama (Fig. 3A) (Thomas, 1972).

In the Upper Mississippian of the Black Warrior basin, tongues of carbonate rocks (Bangor Limestone) pinch out southwestward into synorogenic siliciclastic facies (Floyd and Parkwood formations), indicating temporal variations in sediment supply, subsidence rate, and water depth in the foreland basin (Thomas, 1988; Pashin, 1993; Mars and Thomas, 1999). Through the Upper Mississippian and Lower Pennsylvanian succession, siliciclastic sedimentary facies (Parkwood and Pottsville Formations) thicken and generally coarsen southwestward toward the Ouachita thrust front, indicating that the tectonic load of the Ouachita orogen drove foreland subsidence and supplied clastic sediment (Mack et al., 1983; Thomas, 1988; Whiting and Thomas, 1994).

In the Ouachita embayment, an abrupt increase in sedimentation rate in off-shelf deep-water deposits (Stanley Shale) corresponds in age to the initiation of clastic-wedge progradation in the Black Warrior basin (Viele and Thomas, 1989). Although some clastic sediment spread onto

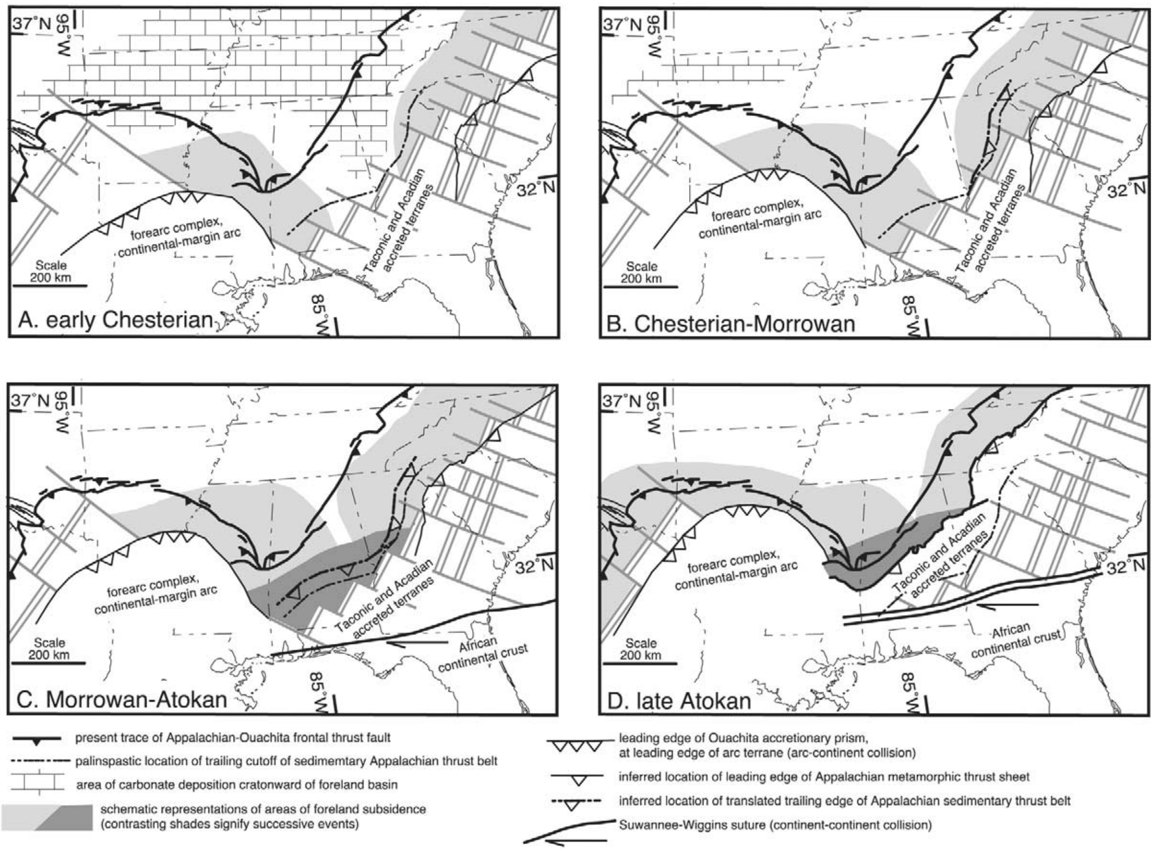

Fig. 3. Sequential maps illustrating history of arc-continent collision and foreland subsidence in Ouachita embayment, and continent-continent collision, foreland subsidence, thrusting of previously accreted terranes, and tectonic replacement and imbrication of passive-margin shelf strata on the Alabama promontory.

the passive-margin shelf in the Ouachita embayment, sedimentary facies and thickness show no significant tectonic subsidence through the Mississippian (Fig. 3A). By Atokan time, however, very rapid subsidence of the Ouachita foreland (the Arkoma basin) is documented by a very thick clastic succession that shallows upward from deep-water turbidites (Fig. 3D) (Houseknecht, 1986; Sutherland, 1988). The clastic wedge thins abruptly northward onto the foreland across a system of down-to-south synsedimentary normal faults. The large-magnitude normal faults frame a high-amplitude, short-wavelength foreland basin in the Ouachita embayment.

The difference in time of initial subsidence in the Black Warrior and Arkoma basins demonstrates diachronous tectonic loading that advanced from southeast to northwest along the Alabama-Oklahoma transform margin as a result of oblique convergence of the Ouachita accretionary prism with the margin of Laurentian continental crust (Fig. 3). Accretion of the arc complex evidently stopped when the accretionary prism ran aground on continental crust, although a diachronous termination of deformation cannot be documented because of lack of preservation of Atokan sediments in the Black Warrior basin.

Along the southeastern side of the Alabama promontory, tectonically independent of the nearly coeval initial clastic-wedge progradation in the Black Warrior basin, Upper Mississippian clastic sediment prograded westward over a Lower Mississippian carbonate facies (Fort Payne Chert) in northeastern Georgia (Fig. 3A) (Thomas and Cramer, 1979). Two separate Upper Mississippian clastic facies prograded from the northeast and southwest (Black Warrior basin) over a coeval carbonate facies (Bangor Limestone) that persisted on a shallow platform in northern Alabama. The oppositely directed clastic wedges merged around the southeastern edge of the carbonate platform along the southeast margin of the Alabama promontory. By the beginning of Pennsylvanian time, the clastic wedges from opposite directions overstepped the youngest of the carbonate facies and merged in a barrier-island complex (Hobday, 1974).

Along the present Appalachian thrust belt in Alabama, the Mississippian and lowermost Pennsylvanian succession thickens and coarsens southwestward, and the Upper Mississippian carbonate facies (Bangor Limestone) pinches out southwestward into the clastic facies (Fig. 3) (Thomas, 1972, 1995). The sedimentary gradients along the present strike of the Appalachian structures are similar in orientation and scale to sedimentary gradients in the Black Warrior foreland basin, indicating down-to-southwest subsidence and northeastward clastic-wedge progradation in the palinspastic location of the Appalachian thrust sheets as part of the Ouachita foreland in the greater Black Warrior basin. Abrupt southeastward thickening and northeastward deflection of facies indicate down-to-southeast reactivation of a northeast-striking basement fault system, which partitioned the Ouachita foreland (greater Black Warrior basin), and which is now beneath the Appalachian thrust belt (Thomas, 1995).

Beginning in Early Pennsylvanian time (upper Pottsville Formation), down-to-southeast subsidence of the Appalachian foreland is documented by southeastward thickening and facies distribution of an additional clastic wedge (Fig. 3C) (Mack et al., 1983; Sestak, 1984; Pashin et al., 1991; Pashin, 1994; Whiting and Thomas, 1994). The down-to-southeast subsidence in the Appalachian foreland imposed an interference pattern on down-to-southwest subsidence of the greater Black Warrior foreland basin toward the Ouachita thrust load. The later down-to-southeast subsidence indicates the emplacement of a separate tectonic load, which is genetically linked to subsequent propagation of the northwest-directed, northeast-striking Appalachian thrust belt.

7. Ouachita terrane accretion

Accretion of the arc terrane in the Ouachita embayment began along the southwest margin of the greater Black Warrior basin when the accretionary prism at the leading edge of the subduction complex first tectonically loaded the margin of Laurentian crust (Fig. 3A). Continued southward subduction of Laurentian crust led to diachronous migration of the initiation of tectonic loading westward along the Laurentian margin to the Arkoma basin (Fig. 3B–D). Emplacement of the accretionary prism onto the Laurentian passive-margin shelf was accompanied by a brittle component (normal faults) of high-amplitude, short-wavelength flexural subsidence, perhaps because of reactivation of rift-stage, transform-related faults as normal faults. The short wavelength of the Arkoma basin may be a manifestation of the rift-stage crustal structure of the transform margin. The longer wavelength of flexural subsidence in the Black Warrior basin is consistent with a greater magnitude of translation of the tectonic load onto Laurentian crust, inboard from the transform continental margin.

Along strike of the diachronous, oblique arc-continent collision, subduction evidently stopped shortly after the accretionary prism was emplaced over the shelf edge. Small-magnitude compressional faults shortened the continental crust and overlying passive-margin carbonate cover, but most of the shortening in the Ouachita thrust belt resulted from translation of off-shelf facies over the shelf (Fig. 2). Much of the Ouachita thrust belt consists of off-shelf, mud-dominated facies in the accretionary prism and subduction complex. Imbrication of the relatively narrow foreland-basin fill involves a thick succession dominantly of turbidites (Atoka Formation). Interpretation of seismic velocity (Keller et al., 1989) shows that deformed forearc-basin sedimentary rocks fill the space between the margin of Laurentian continental crust and the magmatic arc (Fig. 2).

8. Appalachian terrane accretion

Alleghanian thrusting detached the passive-margin carbonate-shelf succession from the shallow continental basement and imbricated the sedimentary cover in the foreland thrust belt. Thrust translation of metamorphosed accreted terranes tectonically replaced the imbricated sedimentary cover. The accreted terranes now in the Appalachian Piedmont were evidently accreted to the Laurentian margin during Taconic and Acadian orogenic events; however, initial accretion concentrated the terranes at or southeast of the margin of Laurentian crust (Hatcher, 1999). Continent-continent collision of Laurentia with Africa (Gondwana) was completed at the Suwannee-Wiggins suture zone, and that collision drove the older accreted terranes onto the shallow Laurentian basement on the Alabama promontory. The shallow basement on the Alabama promontory responded to tectonic loading with long-wavelength, low-amplitude foreland subsidence. Frontal thrust ramps propagated upward over basement normal faults of the Birmingham graben system. The frontal Appalachian thrust fault truncated the southeastern end of the slightly older frontal Ouachita thrust belt, as well as the southeastern part of the greater Black Warrior basin in the Ouachita foreland.

9. Conclusions

Along the Ouachita thrust belt, both passive-margin off-shelf facies and synorogenic turbidites were thrust over the shelf edge and over parautochthonous passive-margin carbonate-shelf facies; lack of a dominant stiff layer in the mud-dominated successions resulted in disharmonic, folded thrust sheets. The tectonostratigraphic composition and structural style record subduction of the Laurentian margin beneath an accretionary prism and forearc complex; present crustal structure indicates no collision with continental terranes along the Ouachita margin. A brittle component of foreland subsidence, documented by large-magnitude synsedimentary normal faults, suggests reactivation of rift-stage, transform-related shear zones along the Alabama-Oklahoma transform fault. Compensation for the tectonic load across the large normal faults produced a short-wavelength, high-amplitude peripheral foreland basin (Arkoma basin). Deep subsidence, along with a lack of earlier Paleozoic accreted terranes at the continental margin, set the geometry for translation of the accretionary prism over the passive-margin carbonate shelf and for lack of thrust imbrication of the carbonate-shelf strata.

Along the Appalachian thrust belt, the Alleghanian continent-continent collision of southeastern Laurentia with Africa (Gondwana) drove previously accreted (Taconic and Acadian) terranes onto the Laurentian shelf, where the passive-margin carbonate cover was imbricated and tectonically replaced. A broader zone of crustal transition and less pervasive synrift faults on the upper-plate rift margin of the Alabama promontory contrast with the narrow zone of transition along the Alabama-Oklahoma transform. The contrast in rift-stage crustal structure is reflected in contrasts in wavelength and amplitude of the Ouachita and Appalachian forelands.

The earlier initiation of tectonic loading of the Alabama-Oklahoma transform margin led to interference in flexural subsidence down-to-southwest in the Ouachita foreland (greater Black Warrior basin) and later down-to-southeast in the Appalachian foreland in Alabama. The later northwest-directed Appalachian thrust faults imbricated the southeastern part of the greater Black Warrior basin and truncated the older Ouachita thrust faults. The contrasting structural styles, tectonostratigraphic composition, and detachment level of the Appalachian and Ouachita thrust belts were juxtaposed by the late-stage thrusts that were driven by continent-continent collision on the southeast side of the Alabama promontory.

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