Nd isotopes link Ouachita turbidites to Appalachian sources

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ABSTRACT

New Nd isotopic data suggest that Paleozoic turbidites in the Ouachita fold belt (Arkansas and Oklahoma) had a dominantly Appalachian provenance after Middle Ordovician time. We infer a long-lived sedimentary dispersal system of isotopically homogeneous detritus linked to Appalachian tectonics. By Carboniferous time, both the continental surface and the closing Ouachita trough were apparently flooded with sediment derived from the Appalachian collisional orogen.

INTRODUCTION

The provenance of thick (>10–12 km) Carboniferous turbidites of the Ouachita fold belt has long been uncertain. Sediment sources to the north (craton), south (oceanic or exotic continental arc), and east (Appalachian orogen) have all been proposed, in varying proportions by different authors (Morris, 1974, 1989; Graham et al., 1975, 1976; Mack et al., 1983; Thomas, 1989). Understanding the ultimate provenance of this classic sequence bears on the paleogeography and tectonic setting of the Ouachita orogen and the evolution of the Appalachian-Ouachita suture between Laurasia and Gondwana. In this paper, we present new Nd isotopic data representing the complete Paleozoic Ouachita sequence, and several foreland and interior basins of the Appalachian-Ouachita region, and discuss their implications for provenance models. We interpret the new data to indicate a dominantly Appalachian provenance for post–Middle Ordovician Ouachita turbidites and suggest that Ouachita depositional systems were linked to Appalachian tectonic events beginning in Late Ordovician time.

TECTONIC SETTING

The Ouachita fold belt, an extension of the Appalachian-Mauretanide (Hercynian) collisional system (Dickinson, 1988), stretches 2000 km from the southern Appalachians to Mexico along the southern margin of North America (Viele, 1989). Carboniferous turbidites within the Ouachita fold belt are interpreted as a deep-marine flysch sequence (Cline, 1970), thrust over platform strata of the continental margin during the Ouachita orogeny (Viele and Thomas, 1989).

Graham et al. (1975) inferred that the Ouachita orogeny was produced by closure of a remnant ocean basin resulting from the collision of an island arc or microcontinent with North America. Though the inferred suture (and part of the southern landmass) now lies buried beneath younger sedimentary deposits of the Gulf Coastal Plain (Viele and Thomas, 1989), the scarcity of igneous rocks in the Ouachita fold belt, plus subsurface geophysical and drill-hole evidence to the south, has led to general acceptance of a model involving a south-dipping subduction zone for the Ouachita orogeny (Graham et al., 1975; Wickham et al., 1976; Viele and Thomas, 1989).

MODELS FOR TURBIDITE PROVENANCE

From regional facies relations and petrographic studies, Graham et al. (1975, 1976) proposed that the Ouachita flysch basin occupied a tectonic setting analogous to the Bay of Bengal, a modern-day remnant ocean basin being filled by Bengal Fan turbidites derived from the Himalayan and Indo-Burman ranges (Dickinson, 1988). In an analogous way, the Ouachita flysch is inferred to have been derived mainly from the Appalachian collisional orogen via deltaic complexes located in the Black Warrior basin within the Appalachian-Ouachita syntaxis. In this model, longitudinal dispersal systems deliver sediment over great distances from the site of collision-belt tectonics. An important implication of the model is that basin filling proceeded from east to west as submarine fans prograded down the basin axis ahead of the collisional suture (Moiola and Shanmugam, 1984; Link and Roberts, 1986).

Petrographic studies and subsurface facies patterns have also been interpreted to imply delivery of sediment into the Black Warrior basin and the Ouachita trough from a proto-Ouachita arc orogen lying to the

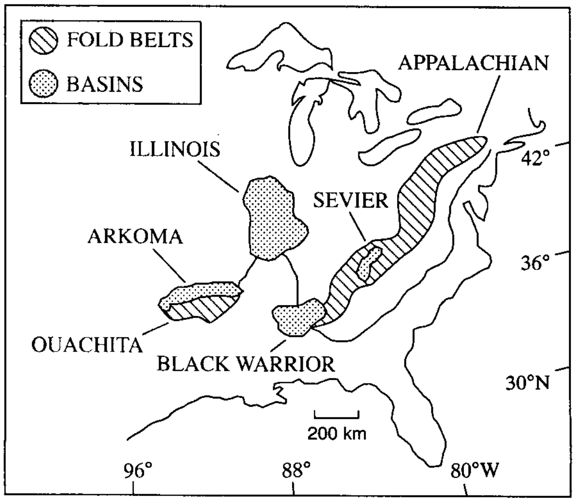

Figure 1. Paleozoic basins and fold belts of Appalachian-Ouachita region discussed in this paper. North American Great Lakes and Coastal Plain boundary are shown for reference.

south (Mack et al., 1983; Thomas, 1989). Provided that closure of the Ouachita remnant ocean basin was diachronous from east to west, a proto-Ouachita source also allows for westward progradation of submarine fans. Inferred tectonic elements of this source include a foreland fold-thrust belt and subduction complex more proximal to sites of deposition than the arc itself. Finally, sediment may have entered the Ouachita trough from the craton to the north (Morris, 1974, 1989).

Nd ISOTOPIC APPROACH TO PROVENANCE

There are many published examples of the application of Nd isotopes to problems of sedimentary provenance (e.g., Miller and O'Nions, 1984; Nelson and DePaolo, 1988; Frost and Coombs, 1989; Basu et al., 1990). Nd isotopes are ideal for establishing provenance differences because of (1) their sensitivity to differences in crustal age, (2) the coherent behavior of rare earth elements (REEs) in clastic sediments during transport (Taylor and McLennan, 1985), and (3) the low mobility of REEs during diagenesis and metamorphism.

Because average upper crust evolves by approximately -1 epsilon Nd (ϵ_{Nd}) unit every 100 m.y., average (crustal residence) age differences between terranes of just a few hundred million years are easily resolved by the Nd isotopic system. Nd isotopic studies thus complement petrographic and trace element approaches to provenance interpretation by providing age information on potential source terranes. An important point is that this information reflects an *average* of contributing source components and does not imply an ability to determine unique provenance. However, with a large enough data base, composed of analyses from well-chosen units and integrated with other regional provenance indicators (petrographic, paleocurrent, trace element), alternate hypotheses can be tested.

Although there is some indication that modern turbidites may be subject to REE fractionation and hydraulic unmixing of Nd isotopic components as a function of grain size (McLennan et al., 1989, 1990) and there is some indication of diagenetic effects on REE distribution in sediment (Ohr et al., 1991), our data do not show these effects. Of nine sandstone-shale pairs in our data set, all exhibit differences in ϵ_{Nd} of <1, and four have differences of <0.5, with very uniform Sm/Nd ratios. Although we see no evidence for significant diagenetic redistribution of REEs in our samples, we have chosen to plot the ϵ_{Nd} values as a function of their stratigraphic age (the most likely time of diagenesis), thus downplaying the importance of model ages.

ISOTOPIC PROVENANCE: DATA AND DISCUSSION

The data include 55 whole-rock Nd isotopic analyses of unmetamorphosed shale and sandstone representing the complete Paleozoic Ouachita sequence of Arkansas and Oklahoma, the Carboniferous of the Arkoma, Illinois, and Black Warrior basins, and the Middle Ordovician of the Sevier basin (Figs. 1, 2A). The following three observations lead us to conclude that most of the Ouachita sequence had a dominantly Appalachian provenance:

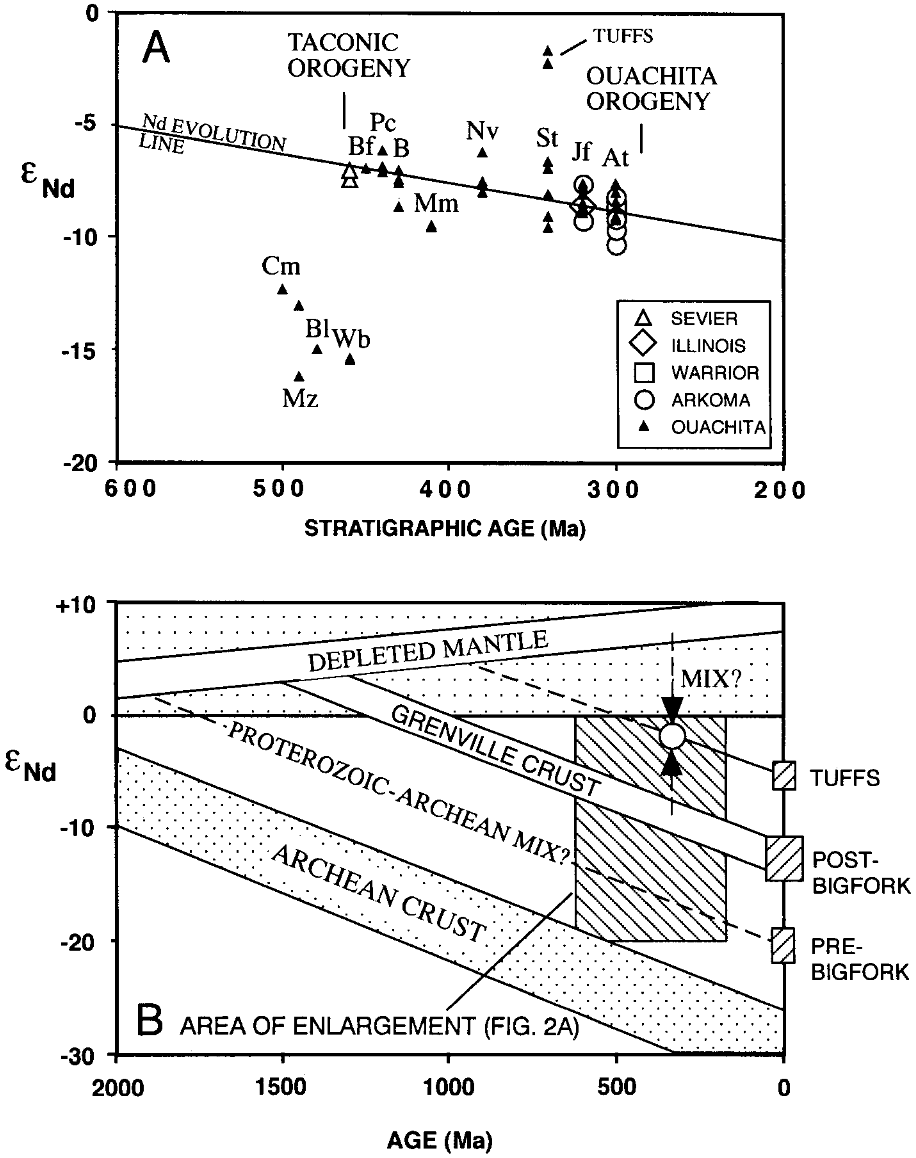

Figure 2. Nd isotope evolution diagrams. A: Note (1) shift in ϵ_{Nd} of Ouachita sediment in Late Ordovician (450 Ma); (2) similarity in ϵ_{Nd} between Carboniferous Ouachita turbidites and nonmarine strata of Illinois, Black Warrior, and Arkoma basins; and (3) similarity in ϵ_{Nd} between turbidites of Sevier Taconic foredeep (eastern Tennessee) and Bigfork–Polk Creek–Blaylock succession in Ouachitas (see text). Ouachita formations abbreviated as follows: At—Atoka, Bf—Bigfork, B—Blaylock, Bl—Blakely, Cm—Crystal Mountain, Jf—Jackfork, Mm—Missouri Mountain, Mz—Mazarn, Nv—Novaculite, Pc—Polk Creek, St—Stanley, Wb—Womble. Slope of Nd evolution line represents average upper-crustal evolution path (position is equivalent to Grenville crustal evolution band in Fig. 2B). Analytical procedures followed Patchett and Ruiz (1987). B: Schematic evolution bands represent Stanley Tuffs (interpreted as mix of depleted mantle and Precambrian crustal components), sediments younger than Bigfork Chert (isotopically equivalent to Grenville age crust), and sediments older than Bigfork Chert (interpreted as mixture of Proterozoic and Archean sources). Average Archean crust and depleted mantle shown for reference, with Grenville crustal evolution from Patchett and Ruiz (1989).

1. A Late Ordovician isotopic shift of 8 ϵ_{Nd} units (Fig. 2A) within the Ouachita sequence follows closely upon the Middle Ordovician Taconic event in the Appalachians (Rast, 1989). The timing of this shift (~450 Ma) and its abruptness are quite surprising within an off-shelf passive-margin sequence of deep-marine cherts and shales. Shales of the Womble Formation (Middle Ordovician), which are within the most negative isotopic population ($\epsilon_{\mathrm{Nd}} = -16$ to -13) of turbidites and hemipelagites, are overlain by the Bigfork Chert, which belongs to a significantly more positive population ($\epsilon_{\mathrm{Nd}} = -6$ to -10) that includes *all* succeeding sedimentary strata. We interpret the more negative population to reflect an older provenance of mixed Archean and Proterozoic cratonal sources to the north (Fig. 2, A and B, Fig. 3A). Sandy turbidites, which prograded over cherts and graptolitic shales of the Bigfork and Polk Creek formations in Early Silurian time (Blaylock Formation), may represent the distal fan facies of an Appalachian Taconic clastic wedge (Satterfield, 1982). To test this hypothesis, we analyzed Middle Ordovician turbidites of the Sevier basin (Tellico Formation) in eastern Tennessee, which represent foredeep clastic sediment shed from the Taconic highlands (e.g., Shanmugam and Walker, 1980). The Nd isotopic signature ($\epsilon_{\mathrm{Nd}} = -7$ to -8) of these rocks is indistinguishable from that of the Bigfork–Polk Creek–Blaylock sequence (Fig. 2A), lending support to the hypothesis. A possible pathway for delivery of Taconic sediment to the Ouachita region could have been via a proto–Black Warrior basin lying south of the continent (Fig. 3B).

2. To test the hypothesis that Ouachita Carboniferous turbidites had Appalachian sources (Graham et al., 1975), we analyzed Pennsylvanian nonmarine sandstones and shales from (1) the Arkoma basin (foreland of the Ouachita orogen, inferred to have been fed by dispersal paths from the north and east [Morris, 1974; Houseknecht, 1986; Sutherland, 1988]), (2) the Illinois basin (continental interior basin that received sediment from northern Appalachian [Pottsville-Alleghanian] clastic wedges [Pryor and Sable, 1974]), and (3) the Black Warrior basin (foreland basin situated within the cusp of the Appalachian-Ouachita syntaxis, inferred to have received sediment from southern Appalachian and/or proto-Ouachita clastic wedges [see discussion above]). In addition, we analyzed 14 samples representing the Ouachita Pennsylvanian flysch sequence (Jackfork and Atoka formations). The remarkable coherence in epsilon Nd ($\epsilon_{\mathrm{Nd}} = -8$ to -10) for the whole Pennsylvanian sample group (Fig. 2A) implies that all these major Pennsylvanian depositional systems had the same Appalachian provenance. No other known geologic province could have delivered such a large volume of recycled sedimentary and metasedimentary detritus to such a wide regional spectrum of basins within and near the continental landmass. The narrow range of isotopic values and model ages (1.4 to 1.7 Ga) also implies extremely effective homogenization of sediments from sources with evolved upper-crustal composition, consistent with a collisional belt provenance. The observation that all Pennsylvanian sediments analyzed in this study are isotopically indistinguishable from Grenville age crust (Fig. 2B)—the dominant basement in the Appalachian region (Rast, 1989)—suggests that these sources were in the Appalachian fold-thrust belt.

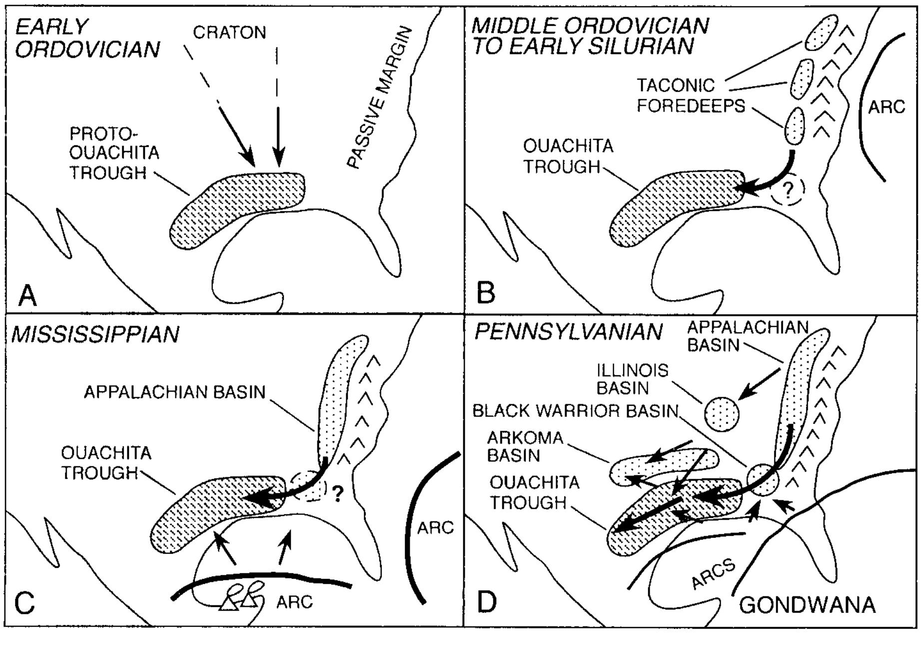

Figure 3. Evolution of Ouachita clastic dispersal systems as interpreted from this study, with arrows showing dominant sedimentary transport directions (see text for discussion).

3. The Mississippian Stanley Formation displays significant isotopic variation ($\epsilon_{\mathrm{Nd}} = -2$ to -9; Fig. 2A) because of the presence of silicic ash-flow tuffs (Niem, 1977), which have Nd isotopic compositions distinct from the rest of the Ouachita sequence (Fig. 2A). Their isotopic composition ($\epsilon_{\mathrm{Nd}} = -2$) is consistent with a continental-margin arc source (Loomis, 1992) and can be modeled as the result of mixing of depleted mantle and an older (Precambrian) crustal component (Fig. 2B). The well-documented southern source of these tuffs (Niem, 1977) thus fingerprints the arc terrane to the south of the Ouachita flysch basin as a continental mass, not an oceanic island arc (Fig. 3C). Though arc material represented by the tuffs could be a significant component (up to 30%) of a small proportion of Stanley turbidites, this material is *not* a significant component of the main (Pennsylvanian) Ouachita flysch represented by the Jackfork and Atoka formations.

We suggest that whereas the arc was largely submerged throughout Carboniferous time and the tuffs therefore represent extraordinary events, the main volume of Carboniferous turbidites came from Appalachian sources. The data also indicate no discernible difference in provenance for the more quartzose sandstones, as compared to the more lithic sandstones, in the Ouachita flysch sequence, and are therefore inconsistent with the former being derived from older cratonal sources to the north of the Ouachita flysch basin. Note, however, that our isotopic method would not detect subregional recycling of Appalachian-derived sediment, following deformation of sea-floor strata into a subduction complex along the flank of a proto-Ouachita orogen as it approached North America.

SUMMARY AND CONCLUSIONS

The isotopic data presented above imply common sources for the Ouachita flysch and several Carboniferous interior and foreland basins of the Appalachian-Ouachita region and suggest a dominantly Appalachian provenance for the Ouachita flysch. They also establish that Ordovician-Silurian Ouachita and Appalachian Taconic turbidites probably had similar sources, implying that dispersal systems transported sediments from the Appalachian region to the Ouachita region beginning early in Paleozoic time. Once the Appalachian orogen was uplifted high enough to be a sediment source at the time of the Taconic orogeny, it evidently remained a positive element throughout the remainder of the Paleozoic. We suggest that the Appalachian collisional orogen of Pennsylvanian age produced a large, continent-scale sedimentary dispersal system that effectively overwhelmed all other available sources within the Appalachian-Ouachita region of North America, flooding the surface of the continent and its margins with sediment of a single homogenized isotopic signature (Fig. 3D).

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