Geology

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William A. Thomas, James D. Gleason, P. Jonathan Patchett, William R. Dickinson and Joaquin Ruiz

Geology 1995;23;93-95
doi:10.1130/0091-7613(1995)023<0093:NILOTT>2.3.CO;2

FORUM

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COMMENT

William A. Thomas
Department of Geological Sciences, University of Kentucky, Lexington, Kentucky 40506-0053

That "Nd isotopes link Ouachita turbidites to Appalachian sources" (Gleason et al., 1994) poses two problems. First, Nd isotopes yield neither sediment-dispersal vector nor provenance location; instead, sediment dispersal is interpreted primarily from sedimentologic-stratigraphic data (distributions of facies, thickness, depositional systems, and stratigraphic architecture). Second, provenance characterization from the Nd isotopic data needs elaboration.

An Appalachian provenance for Ouachita turbidites leads to the derivative that sediment was transported westward across the Black Warrior basin as in Figure 3 of Gleason et al. (1994); however, westward transport of Mississippian-Pennsylvanian clastic sediment is contrary to interpretations of sedimentologic-stratigraphic data from more than 1500 wells in the western Black Warrior basin and outcrops around the eastern part of the basin (bibliographies in Sartwell and Bearden, 1983; Thomas, 1988; Pashin, 1993). For example, Mississippian limestone in eastern Alabama (near stippled circle and question mark in Fig. 3C of Gleason et al., 1994) partitions a westward-prograding clastic wedge in the southern part of the Appalachian basin from a northeastward-prograding clastic wedge in the Black Warrior basin (Thomas, 1988). A synthesis includes northeastward sediment dispersal into the Black Warrior basin from a Ouachita arc-continent collision orogen beginning in middle Mississippian time and addition of northwestward sediment dispersal from the Alabama Appalachian orogen in Pennsylvanian time (summary in Thomas, 1988). Alternative interpretations of Mississippian sediment dispersal have proposed southward transport from cratonic sources and northwestward transport from the Alabama Appalachians, but I am not aware of any data-based study that has proposed westward transport of Mississippian sediment across the Black Warrior basin. West-dipping cross beds previously were interpreted to indicate westward dispersal of Pennsylvanian sediment in the eastern (outcrop) part of the basin, but that work pre-dates recognition of the significance of depositional environments in paleocurrent interpretations.

Contrast of Nd isotopes in the Ouachita Stanley tuffs with those in Mississippian-Pennsylvanian clastic rocks is inferred to reflect an insignificant volcanic contribution to the Ouachita strata (Gleason et al., 1994); however, the sandstones contain volcanic lithic grains (Graham et al., 1976; Mack et al., 1983). Sandstone-shale pairs of samples exhibit only minor differences in Nd isotopes (Gleason et al., 1994). Why is the volcanic component of the sandstones invisible in Nd analyses? Are masking effects similar in sandstones and shales?

An Appalachian provenance is inferred from the Nd data because (1) of implications of a Grenville source and (2) "no other known geologic province could have delivered such a large volume of . . . detritus" (Gleason et al., 1994). Both inferences require further consideration. First, although Grenville rocks form the Appalachian basement, most of the present Appalachian surface is on latest Precambrian–Paleozoic sedimentary, metasedimentary, metavolcanic, and plutonic rocks, including accreted non–North American (non-Grenville) terranes (Horton et al., 1989). How much Grenville basement had been unroofed by Mississippian time? Second, perhaps an "unknown" geologic province was the sediment source, but where are the candidates? Grenville-age rocks are distributed around southeastern North America as far west as Texas and Mexico; apparently the Nd model (Fig. 2 in Gleason et al., 1994) represents Texas (not Appalachian) Grenville. Petrography of Black Warrior basin sandstones indicates a subduction-complex and volcanic-arc provenance but does not discriminate between oceanic or continental-margin arc (Mack et al., 1983); Nd data favor a continental-margin arc (Gleason et al., 1994). Geophysical data show a fragment of continental crust now deep beneath southern Louisiana (Mickus and Keller, 1992), south of an arc that faced North America. That continental crust may be Grenville (as shown in the mixing model for Stanley tuffs; Fig. 2, Gleason et al., 1994). Sediment dispersal from the "southern continent" to the Black Warrior basin and Ouachita region is consistent with both the sedimentologic-stratigraphic data and Nd data.

Abrupt change from "Archean and Proterozoic cratonal sources" to an "Appalachian Taconic" source in Middle Ordovician time is inferred to indicate initiation of westward sediment transport across the "proto–Black Warrior basin" (Gleason et al., 1994), which was then a passive-margin carbonate shelf (Thomas, 1988). Given wide distribution of Grenville rocks around southeastern North America and a mixed source inferred for the older Ouachita strata, the abrupt change in the Middle Ordovician may reflect elimination of Archean contributions to the mix rather than a different provenance. If a Taconic source is invoked, a more reasonable route may be devised by tracing Middle Ordovician clastic rocks along the Appalachian thrust belt (palinspastically restored), possibly continuing over the southwest side of the passive-margin shelf. That the Appalachians "remained a positive element throughout the [post-Taconic] . . . Paleozoic" is not supported by proximal-foreland stratigraphy which indicates episodic sediment progradation.

With a more broadly integrative approach, new Nd data may provide insights into Ouachita sediment sources; however, westward sediment transport from the Appalachians across the Black Warrior basin has not received credence from detailed sedimentologic-stratigraphic studies, a fact not addressed by Gleason et al. (1994). Scientific method, of course, does not require acceptance of previously published *interpretations*, but it does require explanation of all (both "new" and "old") *data* in any new interpretation. Therefore, either the existing sedimentologic-stratigraphic data must be explained in terms of westward sediment transport across the Black Warrior basin, or alternative provenance locations must be identified in concert with all data. Sedimentologic-stratigraphic data indicate a supply of Mississippian-Pennsylvanian sediment from south of North America; the Nd data simply suggest that the southern source included Grenville rocks.

ACKNOWLEDGMENTS

I thank David P. Moecher and Brian M. Whiting for helpful discussions.

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REPLY

James D. Gleason, P. Jonathan Patchett, William R. Dickinson, Joaquin Ruiz
Department of Geosciences, University of Arizona, Tucson, Arizona 85721

We appreciate the thoughtful comments by Thomas, and the opportunity to clarify our ideas about the ultimate provenance of clastic detritus in Ouachita turbidites. Although we readily concede that Nd isotopes yield no direct information about specific provenance or dispersal path, facies trends and stratigraphic architecture also reveal little about provenance location where dispersal routes tap distant sources. That Nd isotopes in sediments represent mixtures of variously recycled crustal components contributes to ambiguity in their interpretation, but this property can be put to advantage where regional dispersal systems are being studied.

We argued that the petrographic character of both Silurian and Carboniferous turbidites implies recycling of sedimentary and metasedimentary debris, probably from fold-thrust belts. Their Nd isotopic signature is compatible with ultimate derivation of that recycled material from Grenville-age crust and is indistinguishable from the Nd isotopic signature of Carboniferous sediment transported across intracratonic depocenters from the Appalachian orogen. We noted, 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." Our data emphatically do not preclude contributions of recycled detritus to the Ouachita trough from a proto–Ouachita subduction complex. The much different Nd isotopic signature of Mississippian tuffs suggests, however, that any contributions of arc detritus from beyond the subduction complex were minor. Major contributions from older sources are possible but would have required mixing in unique proportions to give the same Nd isotopic signature as detritus derived from the Appalachian orogen. Any supposition that Grenville or other basement south of the arc contributed any significant amount of detritus encounters the additional difficulty that magmatic arcs generally form drainage divides.

Although volcanic rock fragments do occur in Carboniferous Ouachita turbidites, they are notable for their paucity, not their abundance. Summary compilations (Morris et al., 1979, $n = 654$; Morris, 1989, $n = 456$) give the average content of volcanic rock fragments in the Ouachita flysch as only a trace. Our point counts (including the data of Graham et al., 1976) suggest that the framework percentage of volcanic rock fragments in Carboniferous Ouachita turbidites averages about 1.0%, where total lithic fragments are 20%–30% (vs. Morris average of 12.8%). There are also 2%–3% feldspar grains in our samples, with approximately equal proportions of K-feldspar and plagioclase. If half the feldspar is volcanic, then perhaps 2.5% of the sandy detritus might be of volcanic derivation. Using Nd isotopic values for the Mississippian tuffs as a guide, this proportion of volcanic debris would shift Nd isotopic values for the turbidites by only 0.1–0.2 epsilon Nd, an effect not detectable within the inherent variability observed. Framework modes of arc-derived sandstones are typically 20%–45% feldspar (median 30%–35%), and the ratio of volcanic rock fragments to total lithic fragments (Lv/Lt) is typically 0.35–1.0 (median 0.6–0.7), or roughly an order of magnitude higher in each case than for Ouachita rocks (Dickinson and Suczek, 1979; Dickinson, 1982). Morris et al. (1979) reported somewhat more feldspar (6%–8%) than we have observed, but also reported more K-feldspar than plagioclase, a relation unknown for arc-derived sandstones.

We thus regard our inference that volcanic detritus is minor in Ouachita turbidites as robust, and lack of evidence from Nd isotopes for its presence as fully expected on petrographic grounds. Thomas calls attention to a clastic wedge he interprets as having been transported into the Black Warrior basin from proto-Ouachita sources to the southwest. In this sequence, volcanic rock fragments derived from arclike sources increase up section in relative abundance, with Lv/Lt ratios 0.05 or less in Mississippian Parkwood sandstones, but 0.05–0.35 for Pennsylvanian Pottsville sandstones, with median values of 0.15 and 0.20–0.25 for lower and upper Pottsville, respectively (Mack et al., 1983). These Pottsville Lv/Lt ratios are still lower than typical for arc-derived sandstones, but in any case are well above the even lower Lv/Lt ratios observed throughout the Ouachita succession.

In our judgment, there are reasons to doubt that progradation of a clastic wedge into the Black Warrior basin from the southwest blocked all egress of Appalachian-derived detritus westward toward the Ouachita region in Carboniferous time. On the basis of more than 500 mostly unimodal paleocurrent measurements from apparently fluvial sandstones, many of them containing conglomerate lenses, Schlee (1963) inferred westerly to southwesterly sediment transport from Appalachian sources throughout exposures of the Pottsville Formation in Alabama. Moreover, Liu and Gastaldo (1992) described the discovery, within a Pottsville channel sandstone in Alabama, of log-transported pebble to boulder gravels composed of phyllite, quartzite, schist, gneiss, and granodiorite of Appalachian Piedmont aspect. The occurrence of this gravel suite within strata regarded as part of the clastic wedge prograding into the Black Warrior basin from the southwest led them to question that concept. Perhaps some volcanic rock fragments in sandstones under discussion here were derived from the Carolina Slate Belt of the Appalachian orogen.

By using the phrase "proto–Black Warrior basin lying south of the continent," we did not mean to imply that Taconic detritus in Blaylock turbidites of the Ouachita orogen was transported across the buried carbonate shelf beneath the present Black Warrior basin, but rather along the seafloor beyond the continental margin, which lay farther south (the arrow we drew schematically "through" the Black Warrior basin for Mississippian sediment transport should be interpreted as passing south of the subsurface carbonate platform). We think it unlikely (see Thomas's Comment) that sources on the craton could fortuitously supply Blaylock detritus with a Nd isotopic signature identical to that of Tellico turbidites in the Taconic foreland.

In supposing that parts of the Appalachian orogen remained positive elements through post-Taconic Paleozoic time, we rely on lack of evidence for burial and subsequent unroofing of the orogen in the intervals of time prior to either the Acadian or Alleghanian orogeny. Our Nd isotopic results indicate that the surface of the craton and the Ouachita trough were both flooded by detritus compatible with Appalachian sources by Pennsylvanian time, and we have difficulty envisioning how an alternate sediment source could have been either voluminous enough or positioned strategically enough to achieve this regional pattern of widespread sediment delivery. We thus derive the general insight that major collisional orogens tend to dominate sediment dispersal over large segments of the globe for long intervals of time. Combined tectonic and sedimentary recycling through subduction complexes and foreland fold-thrust belts can be viewed as simply integral parts of geologically complex dispersal systems.

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