U-PB DETRITAL ZIRCON SIGNATURE OF THE OUACHITA OROGENIC BELT

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Abstract

The Late Paleozoic Ouachita fold-and-thrust belt extends from the southern terminus of the Appalachian thrust belt in eastern Mississippi up through central Arkansas, southeastern Oklahoma, and Texas terminating in northeastern Mexico. A series of Carboniferous foreland basins were formed sequentially to the thrust front. The interaction between the Laurentian craton and the Appalachian-Ouachita orogenic belts controlled sedimentation in the southern mid-continent region throughout the Paleozoic. In contrast to the Appalachian orogenic belt to the east, the Ouachita orogenic belt and associated sediments remain poorly documented and less constrained.

In this study, seven Ordovician to Mississippian aged clastic units from the Ouachita Mountain in central Arkansas were sampled and tested using U-Pb detrital zircon geochronology. Three major age peaks are prominent, including the Grenville Province (~0.95-1.2 Ga), the Granite-Rhyolite Province (~1.3-1.5 Ga), and the Superior Province (>~2.5 Ga) in Ordovician to Silurian aged rocks. A change in this signature becomes clear at the beginning of the Carboniferous from Early Mississippian Stanley Group samples showing the additional Paleozoic age peak (~490-520 Ma) potentially derived from the Appalachian orogenic belt to the east, and/or from peri-Gondwanan terranes accreted to Laurentia just before the collision with Gondwana. This stratigraphic variation of detrital zircon age signature suggests that the transition from a passive to an active margin in the Ouachita trough started, at the latest, in early Mississippian times. Results of this study is the first systematic study of the U-Pb detrital zircon signature of the Ouachita orogenic belt and have important implications in sediment dispersal, provenance interpretations, and paleogeography reconstructions in North America, especially in the southern mid-continent and surrounding areas.

Introduction

The late Paleozoic Ouachita thrust belt extends from where it meets the Appalachian thrust belt in eastern Mississippi up through Arkansas, Oklahoma, and Texas then terminates in northeastern Mexico (Fig. 1) (Flawn et. al., 1961). There are seven foreland basins adjacent to the thrust front: the Arkoma, Black Warrior, Fort Worth, Kerr, Val Verde, Marathon and Marfa Basins (Denison, 1989). Strata within these basins are Late Cambrian to Pennsylvanian deep-water shale, carbonate, and siliciclastic rocks thrusted over shallow water carbonates and siliciclastics (Flawn, 1961). There is debate on provenance of the Ordovician to Pennsylvanian siliciclastic rocks in the Ouachita thrust belt foreland basins. Varying proportions of sediment stemming from the craton to the north, the continental arc system to the south, and the Appalachian orogeny to the east have been proposed (Morris, 1974a; Graham *et al.*, 1976; Thomas, 1985; Sutherland, 1988; and Gleason *et al.*, 1994).

The Ouachita trough is an early Paleozoic offshore depositional basin that is bordered to the north by the North American craton and the south by a passive margin and/or the converging Gondwana craton (Morris, 1974). The Ouachita trough is the result of rifting during the precambrian and an island arc system that formed to the south during the Cambrian creating a topographic barrier that closed the southern part of the trough (Fig. 1,2) (Lowe,1985).

The Ouachita trough accumulated sediments from Cambrian until its closure in the early Pennsylvanian. Deposition of primarily shallow water marine carbonates was occurring on the shelf that had established in the northern part of the Ouachita trough. Deep marine shales were forming off the shelf to the south in the basin center from the Cambrian until Silurian time (Flawn, 1961). From Silurian until closure of the trough in the Pennsylvanian, the trough shows a change from shale and carbonate deposition to carbonate and novaculite. This is due to an interpreted basin wide sea level drop during this time favoring a carbonate factory throughout the Ouachita trough and an increased amount of silica dissolved in the water column (Thomas, 1976; Haq and Schutter, 2008,). Flawn (1961) recorded that the pre-Mississippian strata show no depositional interruptions or angular unconformities. Silisiclastic units are only deposited in the Ouachita trough during the Ordovician, Silurian, and Mississippian.

Closure of the Ouachita trough began in the Early Pennsylvanian and completed in the Late Pennsylvanian, thrusting the deep-water deposits northward onto the shallow marine deposits, creating the Ouachita orogen (Morris, 1974a). Limited tectonic activity has occurred in this orogen since the Permian, and weathering and erosion are responsible for the present mountains.

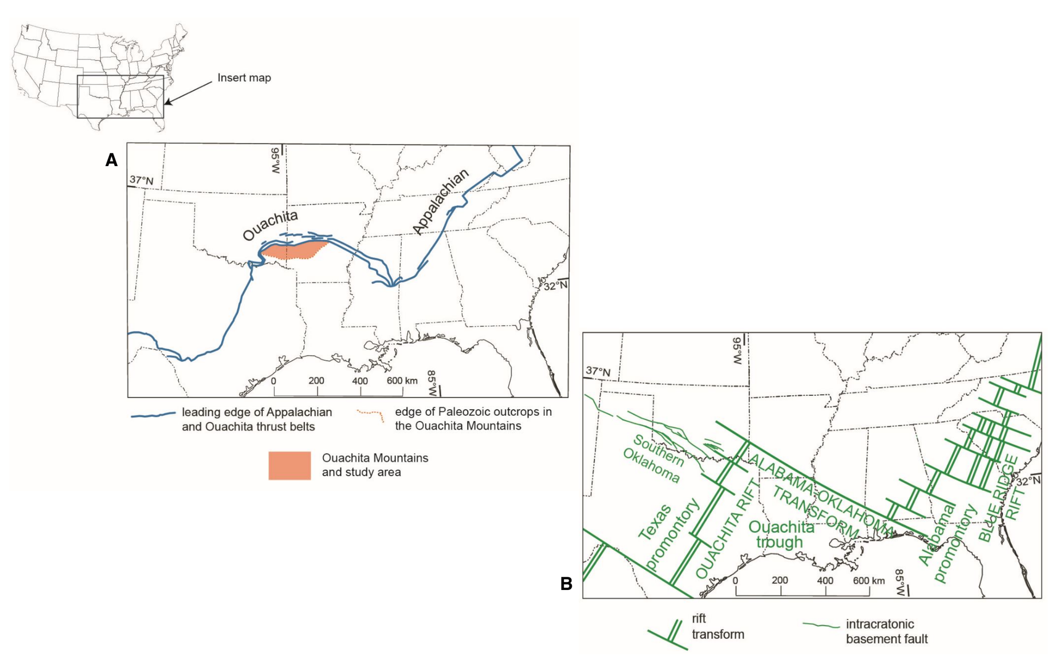

Figure 1. (A) Map of Appalachian/Ouachita frontal thrust belt showing the study area. (B) Map of Iapetan rifted margin of southern Laurentia, showing rift margins, transform faults, and synrift intracratonic basement fault system of the southern Oklahoma aulacogen (modified from Thomas (2010)). Note the Alabama-Oklahoma transform and the Ouachita rift create the Ouachita trough geometry.

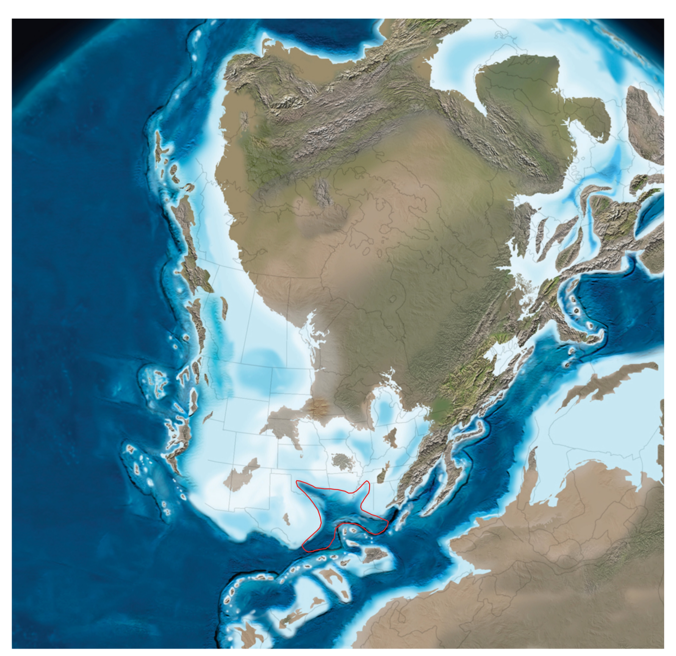

Figure 2. Paleogeographic reconstruction of North America from the early Mississippian showing the Ouachita trough outlined in red. Modified from Blakey (2011).

Methods

- U-Pb detrital zircon geochronology is an analytical technique of producing crystallization ages of zircon grains to aid in sandstone sediment provenance interpretations.
- Seven samples were processed for analysis.
- Standard crushing and heavy liquid separations techniques as described by Gehrels et. al. (2008) was used in obtaining zircon grains for analysis.
- Zircons were analyzed at the University of Arizona LaserChron Center using the laser-ablation multicollector inductively coupled plasma mass spectrometer (LA-MC-ICPMS)

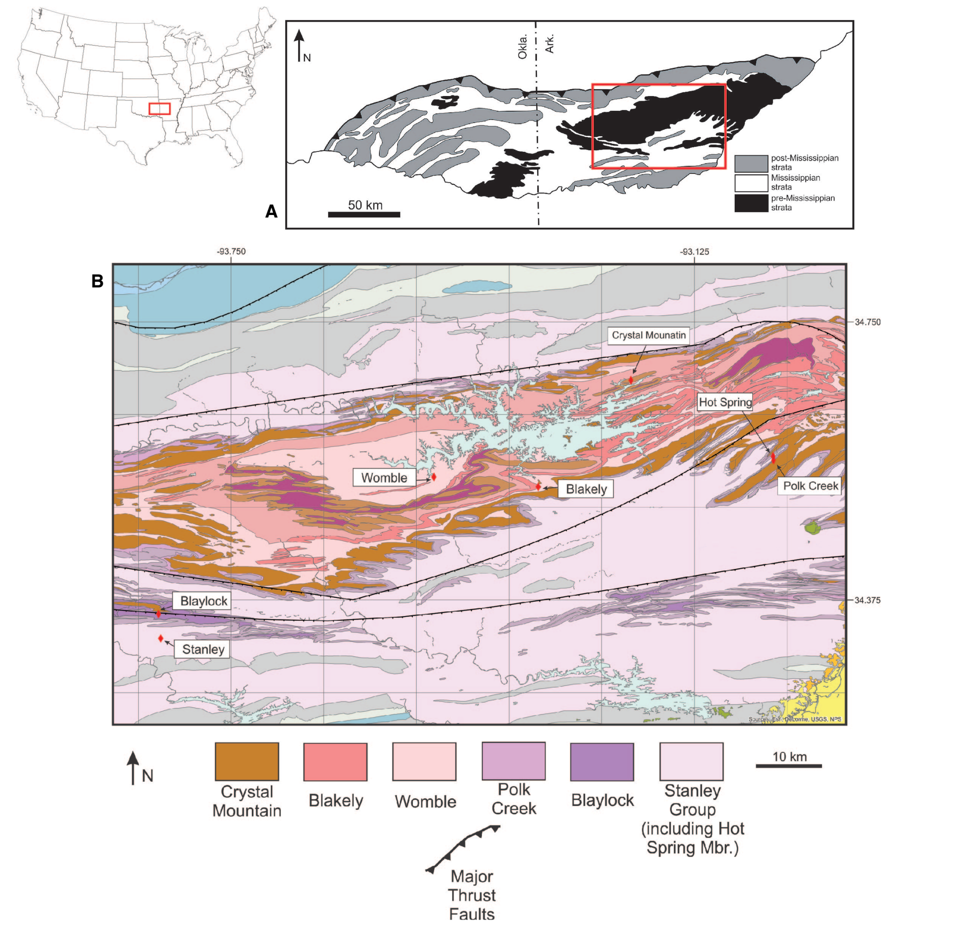

Figure 3.(A) Map of the Ouachita Mountain area in Oklahoma and Arkansas showing the pre-Mississippian (black), Mississippian (white), and post-Mississippian (gray) strata. Modified from Gleason et al. (2002). (B) Sample locations (red diamonds) displayed on the geologic map of the Ouachita Mountains with only the major thrust faults displayed. Legend only shows colors of sampled formations. To reference other colors, see map

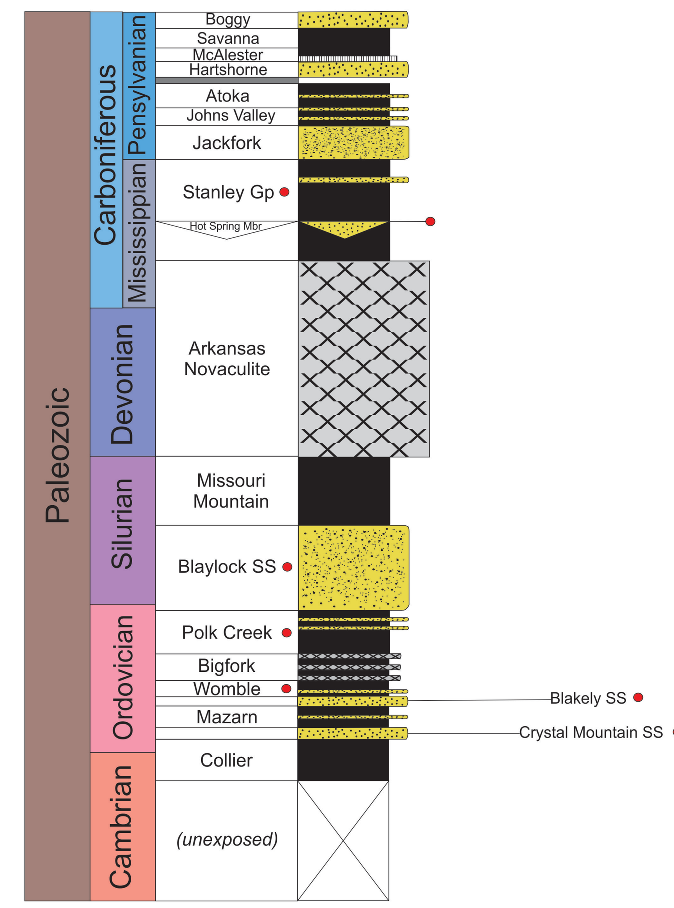

Figure 4. Stratigraphic and lithologic column of the Paleozoic rocks in the Ouachita Mountains and Arkoma Basin. Red dot represents sampled sand bodies. Gray represents unconformity. Black represents shale, yellow is sandstone, grey with (x) is microcrystalline quartz, white with texture (in McAlester) is coal. This figure only depicts depositional time and lithology. Column does not represent formation thickness.

Results

The five Ordovician to Silurian samples (fig. 4) show age peaks at ~0.9-1.2 Ga, ~1.3-1.5 Ga, and > ~2.5 Ga excluding the Womble Shale and Blaylock Sandstone which are missing the ~2.5 Ga peak. The Mississippian samples from the Stanley Group undifferentiated and the Hot Spring Member show additional peaks at ~490-520 Ma. The Stanly group sample shows more less prominent peaks at ~750-900 Ma and ~1.85-2.0 Ga. Analyses that are >5% discordant or >5% reverse discordant were not used in the final interpretation. These tight cutoffs were selected as only 71 of 970 grains analyzed did not fit the constraints. All probablylity age plots and concordia diagrams were produced using software provided by the University of Arizona LaserChron Center.

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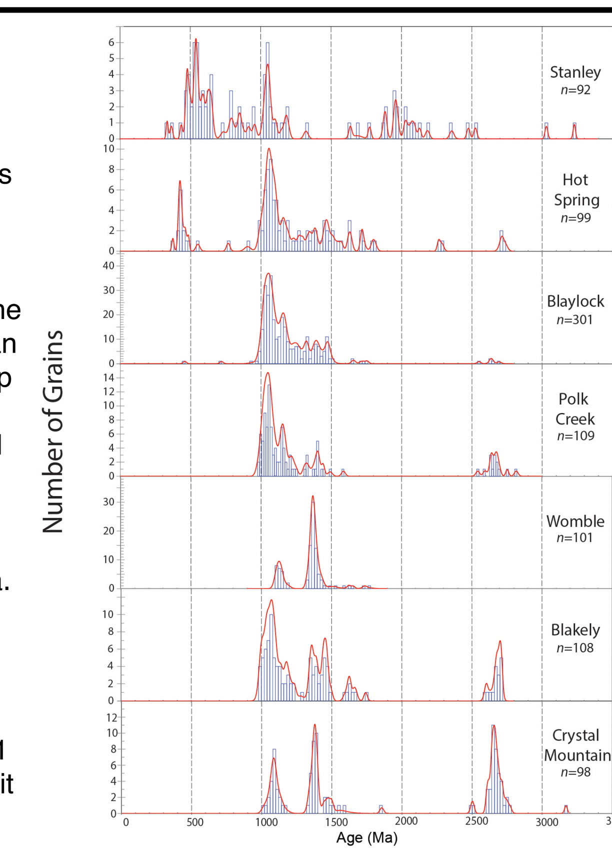

Figure 5. Relative age probability plot with histogram for all seven samples.

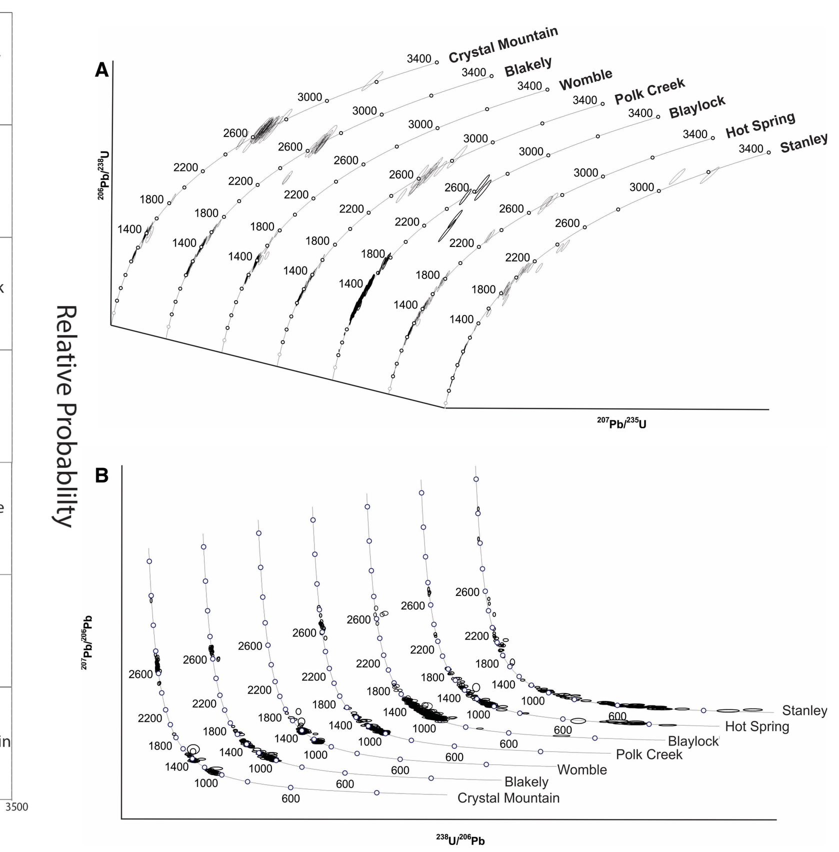

Figure 6. (A) Normal U-Pb concordia diagram. (B) U-Pb concordia diagram plotted as Tera-Wasserberg distribution.

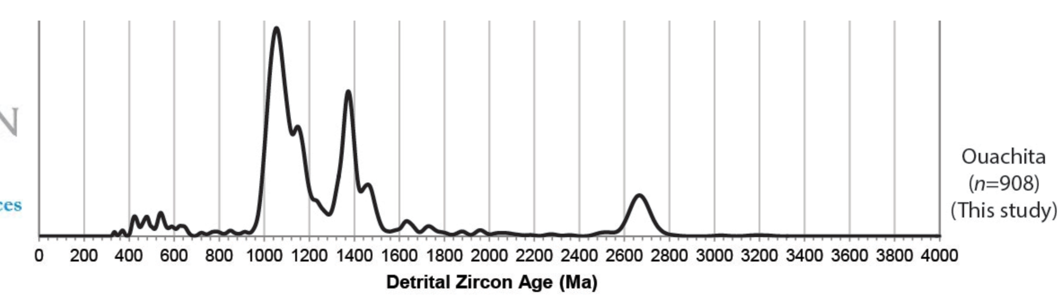

Figure 7. Normalized probability age plot comparing the combined Ouachita data representing all of the Ordovician-Mississippian samples (Ouachita signature).

Discussion

Potential Sources

- **Archean/Paleoproterozoic**
  - Superior (>2.5 Ga) (Archean craton)
  - Trans-Amazonian (~1.9-2.1 Ga)
  - Trans-Hudson/Penokean (~1.8-1.95 Ga)
  - Yavapai/Mazatzal (~1.6-1.8 Ga)
- **Mesoproterozoic**
  - Mid-Continent Granite-Rhyolite (~1.35-1.5 Ga)
  - Grenville (~950-1250 Ma)
- **Neoproterozoic**
  - Suwanee (~540-700 Ma)
- **Paleozoic**
  - Wichita Igneous Province (~530 Ma)
  - Taconic (~410-500 Ma)
  - Acadian (~340-410 Ma)
  - Allleghanian (~260-340 Ma)

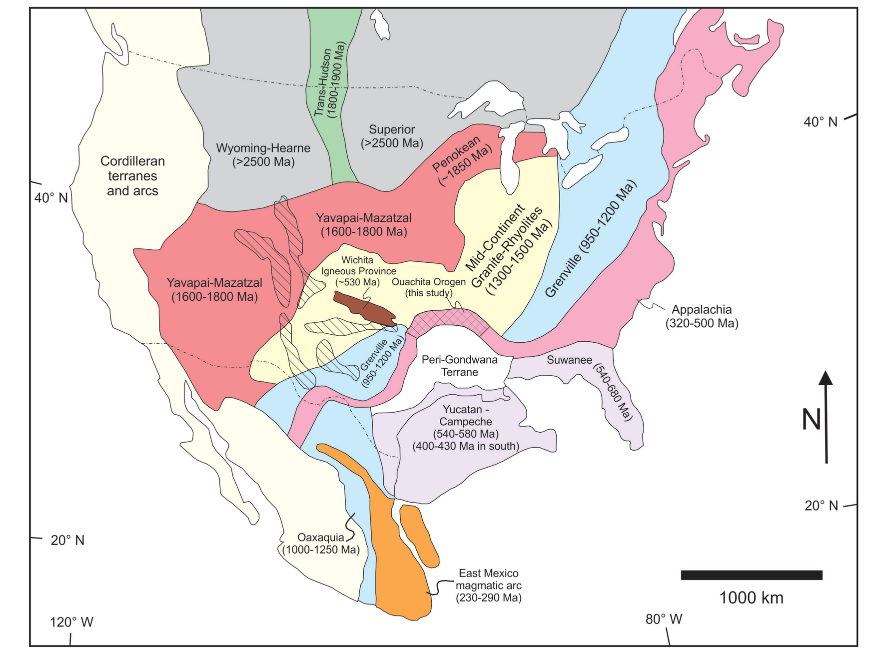

Figure 8. Map showing pre-Mesozoic major age belts of North America. The hachured areas represent the Ancestral Rocky Mountains. Modified from Gehrels et al. (2011).

Interpretation

Sedimentation to the Ouachita trough

During the Ordovician time, the Ouachita trough is receiving sediments from three major provinces (Figs. 5, 9); the Superior Province (>2500 Ma), Granite-Rhyolite Mid-Continent Province (1360-1600 Ma), and the Grenville Province (950-1350 Ma).These strong peaks are thought to be a result of exposed Mid-Continent Granites- Rhyolites and Grenville crust from the opening of the Iapetus Ocean in the late Precambrian (Fig. 1) (Thomas, 2006; Viele and Thomas, 1989). However, it is difficult further constrain if the Superior peak is due to primary deposition or recycled deposition, but nonetheless, there is a decreased influence from the Superior Province through the Ordovician to the Ouachita trough. There is also an increase in the Grenville peak while the Granite-Rhyolite peak decreases through the Ordovician, with the exception of the Womble. This ratio shift in the Grenville and Granite-Rhyolite is interpreted to indicate that the exposed Granite-Rhyolite crust from the break apart of Rodinia was probably completely covered by the coastal to shelf carbonate rocks to the north of the Ouachita trough. Meanwhile, the trough continued to receive influence of the Grenville crust from the east and northeast due to the active tectonism of the Taconic orogeny uplifting Grenville crust during the Ordovician in the Appalachian area. During the Silurian, the Blaylock continues to record the emerging dominance of Grenville aged zircons being supplied to the Ouachita trough with the decrease of mid-continent influence (Figs. 5, 6, Table 2). Additionally, the Silurian Blaylock Sandstone is interpreted to represent the initial sediment influence from newly accreted Appalachians terrane to the Ouachita trough area. This is consistent with Gleason and others (2007) study that the arrival of orogenic clastic sediment from the Appalachians was ~455 Ma. The Blaylock Sample has one grain with an age of 458 ± 11 Ma, which can be correlated with the Taconic orogeny to the east.

The Mississippian samples record a major shift in the sedimentation to the Ouachita trough, as 32% of the grains analyzed in these samples are <900 Ma. These grains could be attributed to primary deposition sourced from the Pan-African-Brasiliano orogenic event and Peri-Gondwana terranes (Coahuila, Sabine, Suwanee, and/or Yucatan) (~400-700 Ma) shortly after the collision of Laurentia and Gondwana (Lopez et al., 2001; Weber et al., 2006), or recycled orogenic detritus from the Appalachian foreland (~320-500) with influence from the Wichita Igneous Province (~530) (Becker et al., 2005; Hanson and Eschberger, 2014). The Trans-Amazonian age grains (1950-2200 Ma) found in the Stanley suggest influence from the Gondwanan side of the suture, but it is most likely a combination of all three potential sources due to the Ouachita trough being located at the intersection of these several tectonic provinces. Nonetheless, this shift in the detrital zircon age population represents the transformation from a passive to an active margin south of the Ouachita trough and the suturing of Laurentia and Gondwana.

Ouachita Detrital Zircon Signature

The new detrital zircon data suggest that the Ouachita source is characterized by a strong Grenville and Granite-Rhyolite peak with minor contributions from the Superior and <950 populations (Fig. 7).This data set provides an Ouachita source signature to compare and assess the Ouachita orogen as a sediment source.The detrital zircons of the pre-Pennsylvanian rocks from the Ouachita thrust represent the sediment source of the Ouachita orogen (Fig. 7). Overall, the Ouachita source has roughly ½ Grenville grains, ¼ Granite-Rhyolite grains, and the other ¼ being a combination of <950 Ma and Superior aged grains. The dominant population correlates to the Grenville Province and makes up more than half of the total population (53%) with a major peak at ~1060 Ma and a minor peak at ~1140 Ma (Fig. 7). The second dominant population is the Granite-Rhyolite Province making up 22% with a major peak at ~1380 Ma and a minor peak at ~1450 Ma, and the Superior Province is the third major population and makes up 9% peaking at ~2660 Ma. Additionally, there are about 7% of the grains within <950 Ma age range.

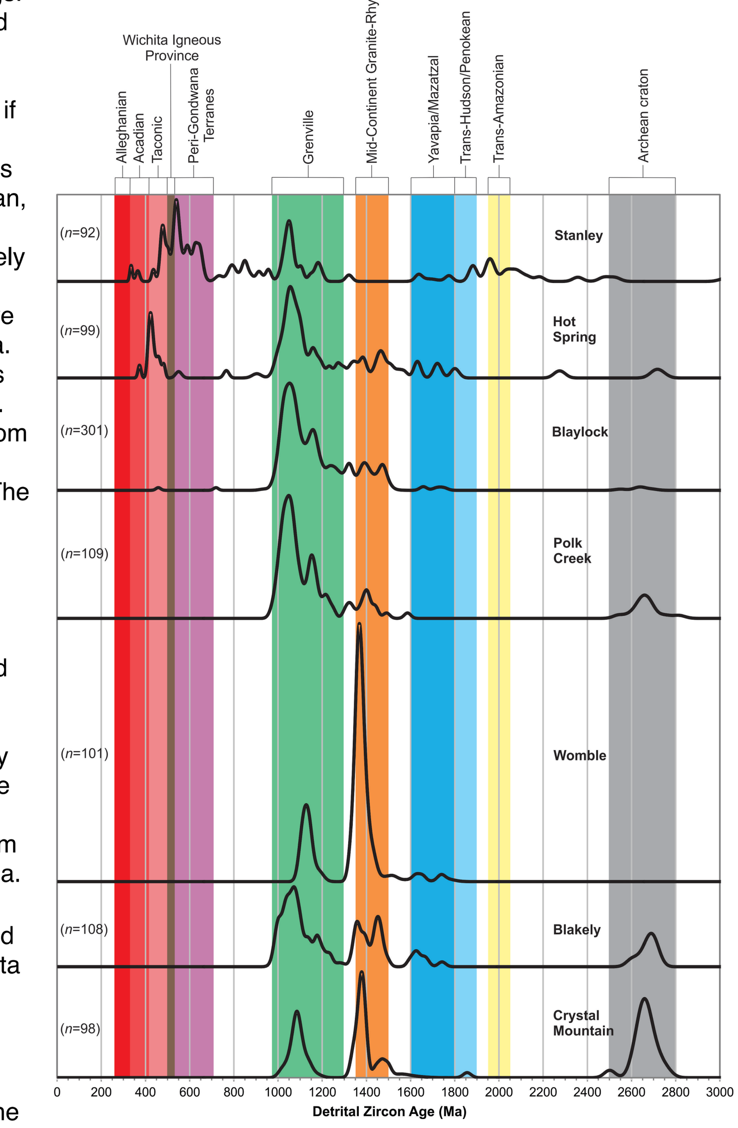

Figure 9. Normalized probability age plot with known source terrains shaded in color.

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