New York–Alabama lineament: A buried right-slip fault bordering the Appalachians and mid-continent North America

Mark G. Steltenpohl¹, Isidore Zietz², J. Wright Horton, Jr.², and David L. Daniels²
¹Department of Geology and Geography, Auburn University, Auburn, Alabama 36849, USA
²U.S. Geological Survey, National Center, 12201 Sunrise Valley Drive, Reston, Virginia 20192, USA

ABSTRACT
The New York–Alabama (NY-AL) lineament, recognized in 1978, is a magnetic anomaly that delineates a fundamental though historically enigmatic crustal boundary in eastern North America that is deeply buried beneath the Appalachian basin. Data not in the original aeromagnetic data set, particularly the lack of any information available at the time to constrain the southern continuation of the anomaly southwest of Tennessee, left the source of the lineament open to conjecture. We use modern digital aeromagnetic maps to fill in these data gaps and, for the first time, constrain the southern termination of the NY-AL lineament. Our analysis indicates that the lineament reflects a crustal-scale, right-lateral strike-slip fault that has displaced anomalies attributed to Grenville orogenesis by ~220 km. Palinspastic restoration of this displacement rearranges the trace of the Grenville belt in southern Rodinia and implies only passive influence on later-formed Appalachian structures. The precise timing of dextral movement on the NY-AL structure is not resolvable from the existing data set, but it must have occurred during one of, or combinations of, the following events: (1) a late, postcontractional (post-Ottawan) stage of the Grenville orogeny; (2) late Neoproterozoic to Cambrian rifting of Laurentia; or (3) right-slip reactivation during the late Neoproterozoic–Cambrian rifting of Laurentia, or during Appalachian movements. Our palinspastic reconstruction also implies that the host rocks for modern earthquakes in the Eastern Tennessee Seismic Zone are metasedimentary gneisses, and it provides an explanation for the spatial location and size of the seismic zone.

Figure 1. Aeromagnetic maps (from North American Magnetic Anomaly Group, 2003): hot colors (reds) are aeromagnetic highs and cool (blues) are lows. A: Eastern North America illustrating position of New York–Alabama (NY-AL) lineament (gray line); white dot separates northern segment reported by King and Zietz (1978) from southern continuation that we describe (dotted yellow square is area of Fig. 2). Early to late Cambrian syn-lapetan rift faults (white lines) and grabens: MV—Mississippi Valley, BG—Birmingham graben, RC—Rough Creek graben, RT—Rome trough; Appalachian faults (pink lines): BZ—Brevard zone, CPS—central Piedmont suture, SS—Suwannee suture (modified from Johnson et al., 1994; Thomas, 2006). A—feature described in the text; C—Clingman lineament (solid orange line); OB—Ocoee Block (from Johnston et al., 1985). Dashed orange contour is area with greatest likelihood of undergoing earthquake with particle velocities of 70 mm/s that have 10% chance of being exceeded in 50 yr (MM intensity VII is ~30 mm/s; Frankel, 1995). State abbreviations: AL—Alabama, FL—Florida, GA—Georgia, KY—Kentucky, MS—Mississippi, NC—North Carolina, NJ—New Jersey, NY—New York, OH—Ohio, PA—Pennsylvania, SC—South Carolina, TN—Tennessee, VA—Virginia, VT—Vermont, and WV—West Virginia. B: Retrodeformation of 220 km right-slip displacement along the NY-AL structure (see text).

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(Fig. 1A), the lineament separates a mottled pattern of magnetic highs and lows associated with the midcontinent granite-rhyolite province and Neoproterozoic mafic bodies to the northwest, from northeast-trending magnetic lineaments of the Appalachian orogen to the southeast.

Its near continent-wide extent, clear crustal penetrative nature, and position bordering the mid-continent and the Appalachians identify the NY-AL lineament as a fundamental tectonic boundary, yet after 30 yr of scientific scrutiny its origin and geologic significance remain uncertain. King and Zietz (1978) suggested that the lineament is not an age boundary because Grenville basement is found on both sides of it; they speculated that because the NY-AL lineament is similar in its great length, linearity, and orogenic position to the Altn Tagh fault of Tibet, that it may be an escape strike-slip fault related to Grenvillian contractional orogenesis. The suggestion of large strike-slip displacement was hypothetical, however, because no offset markers were known to constrain displacement along the NY-AL lineament (King and Zietz, 1978). Hopkins (1995) interpreted the NY-AL lineament to represent the axis of anatectic melting following continental collision during the Grenville orogeny. Thomas (2006) suggested that the NY-AL lineament may reflect an intra-Grenville suture formed either by accretion along a straight trace of the pre-Grenville rifted margin, which had already been smoothed by the accretion of terranes, or by orogen-parallel strike-slip movement across that margin.

Other studies focused on the relation of the NY-AL lineament to modern seismicity in the Eastern Tennessee Seismic Zone (Fig. 1A), which exhibits the second-highest release of seismic strain energy in the United States east of the Rocky Mountains; only the New Madrid zone has been more seismogenic (Johnston et al., 1985; Powell et al., 1994; Chapman and Powell, 1996). Eastern Tennessee Seismic Zone earthquake foci do not correlate to surface geology, but occur beneath allochthonous Appalachian rocks in a basement crustal block, the Ocoee block, which contains a distinct N15°E magnetic grain and is bound by the NY-AL lineament (King and Zietz, 1978) combined with our interpretation for the missing southwestward continuation through Alabama. The ~300 km Tennessee-Alabama segment of the lineament now is imaged in fine detail in the digitally reprocessed aeromagnetic map in Figure 2. Features that are characteristic of the NY-AL lineament north of Tennessee, for example, fine- and coarse-scale crustal domains, their internal structure and boundaries, and the steep linear gradient between mottled midcontinent granite-rhyolite province patterns to the northwest and broadly structural and plate tectonic framework. Though our approach is simple, we believe that our findings are compelling and have far-reaching implications that range from reactivation and/or rejuvenation of continent-scale structures inherited from the Neoproterozoic construction of Rodinia to modern seismicity in eastern North America.

ANALYSIS

Figure 1A depicts the original trace of the NY-AL lineament northeast of Tennessee (King and Zietz, 1978) combined with our interpretation for the missing southwestward continuation through Alabama. The ~300 km Tennessee-Alabama segment of the lineament now is imaged in fine detail in the digitally reprocessed aeromagnetic map in Figure 2. Features that are characteristic of the NY-AL lineament north of Tennessee, for example, fine- and coarse-scale crustal domains, their internal structure and boundaries, and the steep linear gradient between mottled midcontinent granite-rhyolite province patterns to the northwest and broadly structural and plate tectonic framework. Though our approach is simple, we believe that our findings are compelling and have far-reaching implications that range from reactivation and/or rejuvenation of continent-scale structures inherited from the Neoproterozoic construction of Rodinia to modern seismicity in eastern North America.
Appalachian ones to the southeast, clearly are maintained along the segment from Tennessee through Alabama. On a finer scale, the distinct N15°E magnetic grain of the Ocoee block maintains its characteristic oblique, ~25° angle to the NY-AL lineament. Likewise, modern seismicity follows the same pattern as seen in the Eastern Tennessee Seismic Zone (Fig. 2). Instrumentally located earthquake epicenters in Alabama for the period between 1965 and 1985 (Powell et al., 1994) are predominantly southeast of our trace of the NY-AL lineament with larger magnitude events concentrated near it.

Several key relationships are revealed through inspection of the NY-AL lineament in its newly found entirety (Fig. 1A). The great extent and remarkable linearity of the NY-AL lineament now is even more impressive than originally reported by King and Zietz (1978). Combined with the clear crustal penetrative nature of the lineament, documented by seismic-reflection profiles indicating a vertical structure extending to Moho depths (Hopkins, 1995, p. 73 and seismic profile FM), we agree that it most likely is a strike-slip fault zone. Figure 1A depicts a distinct, more northward-trending, linear magnetic high-low pair on the northwest block in West Virginia, known as the Amish anomaly (Culotta et al., 1990) that appears to have been displaced and dragged in a right-slip sense and truncated by the NY-AL lineament. Our analysis in Figure 2 documents a matching, virtually identical scale and trending magnetic high-low pair in the southeast block in Tennessee, Georgia, and Alabama that is also dextrally dragged and truncated by the NY-AL lineament. Assuming strike-slip movement along the NY-AL lineament, we used scissors to cut finer-resolution (1:1,000,000 scale) maps that we generated along the entire length of the lineament to visually match these two magnetic markers (Fig. 1B), and found ~220 km of right-slip separation. Our restoration (Fig. 1B) also matches aeromagnetic lineaments argued by Culotta et al. (1990) to be the trace of the Grenville front to a set of linear magnetic markers with similar trends, scales, and magnitudes on the southeast block in Alabama. Overall, Figure 1B documents a consistent series of matches across the restored NY-AL structure while also providing an explanation for how the N15°E trends of the Ocoee block became truncated against it (Fig. 1A).

We also employed overlays of surface and subsurface geological maps (not all shown in Fig. 1) to compare surface structural and lithologic trends to the NY-AL lineament. There is obvious parallelism between the lineament and fundamental right-slip Appalachian fault zones, including the Brevard zone (BZ in Figs. 1A and 1B). Outstanding correspondence is found between the lineament and segments of the system of early to late Cambrian, intracratonic, syn-lapetan rift basins and their margins (Johnson et al., 1994; Gao et al., 2000; Thomas, 2006; Fig. 1A). Linear fault segments that border the Rome trough parallel and locally coincide with the NY-AL lineament (see A in Fig. 1A). The southeast border fault to the Rome trough parallels the lineament for nearly 250 km from eastern Kentucky to southwestern Pennsylvania. It generally is located 7–15 km west of the NY-AL lineament (Sattler, 2000), but converges with the lineament in southern West Virginia (Gao et al., 2000). Hence, this segment of the lineament was a normal fault that underwent west-side-down, dip-slip displacement during formation of the Cambrian rift basin. Aside from the faults of the more eastward-trending Rough Creek graben, most of the major faults of this system are subparallel to the NY-AL lineament.

DISCUSSION AND CONCLUSIONS

Tectonic Implications

Assessing the timing and tectonic significance of dextral movement inferred along the NY-AL lineament is difficult given that it is completely buried. Traditionally, the lineament was considered to separate crust to the southeast that was intensely deformed during Appalachian orogenic events from crust to the northwest that was not (King and Zietz, 1978). Crust northwest of the lineament appears to have behaved as a rigid, somewhat coherent block, and its sharp boundary against the anomaly implies the edge of this competent crustal block. In Figure 1B, N15°E magnetic trends northwest of the NY-AL lineament, including Culotta et al.’s (1990) Grenville front and Amish anomaly, continue southward across the Ocoee block to disappear into the Clingman lineament. The Clingman lineament parallels the Brevard zone (Fig. 1A), and we interpret the lineament to generally mark the northwestern edge of anomalies attributed to Appalachian contraction. The source of the NY-AL lineament, therefore, had to postdate contraction during the Grenville orogeny.

Pervasive, northeast-trending, right-slip shear zones exposed in parts of New York, New Jersey, and Pennsylvania overprint contractional structures related to the last stage of the Grenvillian orogeny (the Otawanti stage), and are dated at between 1008 and 876 Ma (Gates, 1995; Gates et al., 2004). If the NY-AL structure is a latest Grenvillian right-slip fault, then palinspastic restoration of 220 km of displacement (Fig. 1B) requires that the Grenville belt had extended farther south in Laurentia than is indicated in reconstructions of Rodinia.

Close geographic and geometric correspondence between the NY-AL lineament and late Neoproterozoic–Cambrian rift structures (Fig. 1A) suggests that some rift faults were localized along an earlier-formed, pre-rift NY-AL fault, and/or that right-slip strains later exploited and reactivated existing rift faults. Bartholomew and Tolto (2004) documented large-scale (hundreds of kilometers) right-slip translation of outboard terranes in eastern Laurentia that initiated during late Neoproterozoic to early Cambrian rifting, compatible with the movement along the NY-AL structure. Cambrian rift faults of the Rough Creek graben appear to splay westward off of the NY-AL lineament where the Amish anomaly is truncated in southern West Virginia (Fig. 1A), compatible with a release (extensional) fault bend in the dextral NY-AL fault zone. Most other Cambrian rift faults are southwest of this hypothetical release bend, coincident with the area of major dextral separation of the Amish marker. This geometry and kinematic plan are appropriate for the riftings of the Argentine Precordillera out of the Ouachita embayment at precisely that time (Thomas and Astini, 1996). Cambrian dextral movement along the NY-AL structure and its far-cratonward position would require its involvement in either the development of promontories and embayments along the Laurentian margin or the displacement of existing ones.

The NY-AL lineament partitions seismicity today in the Eastern Tennessee Seismic Zone, but faults formed during either of the events described above would have been even more favorably oriented for reactivation during the Paleozoic, when dextral transtensive strains produced the pervasive system of Appalachian right-slip fault zones (Fig. 1). Seismic-reflection profiles are interpreted to indicate that early Cambrian (Rome and Conasauga Formations) and younger strata have overstepped the NY-AL structure, suggesting that the largest right-slip displacement occurred earlier, but the absence of resolvable evidence for a narrow, vertical strike-slip fault strand above this level in a few published profiles that cross the structure (e.g., Gao and Shumaker, 1996, their figure 8) does not constitute evidence for its absence. Hibbard and Waldron (2009) reported that Appalachian right-slip faulting in the central and southern Appalachians has displaced the Virginia promontory ~200–250 km relative to the Laurentian margin; this is compatible with the geometry, kinematics, and magnitudes of displacement that we report for the NY-AL structure.

Relation of the NY-AL Lineament to Modern Seismicity

If our right-lateral correlation of magnetic anomalies in Figure 1B is correct, then the pronounced N15°E magnetic low anomaly in the Ocoee block on the southeast side of the NY-AL lineament (Fig. 1A) is the southern continuation of the Amish anomaly. The most intense seismicity in the Eastern Tennessee Seismic Zone coincides with this continuation.
Geophysical studies, the NY-AL lineament makes approachable only through deep borehole and Combined with the fact that the structure appears unusual and long record of continental dynamics. but it makes the NY-AL structure stand out as an between the mid-continent and the Appalachians, pattern likely is the result of its dynamic position a billion years ago. This temporal and kinematic tral motion along the NY-AL lineament as early as fi eld is compatible with the one that initiated dex- 

Earthquakes that exceed the historical record opened during any of the tectonic events described above and during later Mesozoic rifting could control the spatial pattern of modern seismicity. Regardless of any earlier history, Powell et al. (1994) attributed this seismicity to strike-slip reactivation of a fault system, because the earthquake focal mechanisms consistently indicate dextral motion on NNE-trending planes and sinistral motion on east-trending planes, the dextral motion on NNE-trending planes and quake focal mechanisms consistently indicate reactivation of a fault system, because the earth-quake focal mechanisms consistently indicate dextral motion on NNE-trending planes and sinistral motion on east-trending planes, the geometry and kinematics of the former being the same as we interpret for the NY-AL structure. Chapman and Powell (1996) suggested that this pattern of modern seismicity occurs along northeast- and east-striking sets of conjugate faults. Modern eastern North American intraplate stresses today appear to be concentrating seismicity even nearer to the NY-AL lineament with time, implying the potential emergence of a throughgoing fault with future large earthquakes that exceed the historical record (Powell et al., 1994).

Our analysis suggests that this modern stress field is compatible with the one that initiated dextral motion along the NY-AL lineament as early as a billion years ago. This temporal and kinematic pattern likely is the result of its dynamic position between the mid-continent and the Appalachians, but it makes the NY-AL structure stand out as an unusual and long record of continental dynamics. Combined with the fact that the structure appears approachable only through deep borehole and geophysical studies, the NY-AL lineament makes a timely target for the eastward-migrating EarthScope seismic array (http://www.earthscope.org/observatories/usarray).

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