New Madrid seismic zone fault geometry

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ABSTRACT

The New Madrid seismic zone of the central Mississippi River valley has been interpreted to be a right-lateral strike-slip fault zone with a left stepover restraining bend (Reelfoot reverse fault). This model is overly simplistic because New Madrid seismicity continues 30 km southeast of the stepover. In this study we have analyzed 1704 earthquake hypocenters obtained between 1995 and 2006 in three-dimensional (3-D) space to more accurately map fault geometry in the New Madrid seismic zone. Most of the earthquakes appear to align along fault planes. The faults identified include the New Madrid North (29°, 72° SE), Risco (92°, 82° N), Axial (46°, 90°), Reelfoot North (167°, 30° SW), and Reelfoot South (150°, 44° SW) faults. A diffuse zone of earthquakes exists where the Axial fault divides the Reelfoot fault into the Reelfoot North and Reelfoot South faults. Regional mapping of the top of the Precambrian crystalline basement indicates that the Reelfoot North fault has an average of 500 m and the Reelfoot South fault 1200 m of down-to-the-southwest normal displacement. Since previously published seismic reflection profiles reveal reverse displacement on top of the Paleozoic and younger strata, the Reelfoot North and South faults are herein interpreted to be inverted basement normal faults. The Reelfoot North and South faults differ in strike, dip, depth, and displacement, and only the Reelfoot North fault has a surface scarp (monocline). Thus, the Reelfoot fault is actually composed of two left-stepping restraining bends and two faults that together extend across the entire width of the Reelfoot rift.

INTRODUCTION

The New Madrid seismic zone, beneath the central Mississippi River valley, is undergoing considerable study as it is the most seismically active area in the eastern United States and also because it experienced at least three devastating earthquakes in 1811–1812 (Nuttli, 1982; Penick, 1981; Johnston, 1996; Johnston and Schweig, 1996; Tuttle et al., 2002) (Fig. 1). This seismicity has been attributed to reactivation of basement faults within the subsurface Cambrian Reelfoot rift (Zoback, 1979; Kane et al., 1981; Braile et al., 1986; Thomas, 1989; Dart and Swolfs, 1998). The Reelfoot rift (Mississippi Valley Graben) is a major basement structure mapped from gravity, magnetic, seismic refraction, seismic reflection, and a few deep petroleum exploration wells (Fig. 2) (Hildenbrand, 1982; Hildenbrand et al., 1982; Hamilton and Zoback, 1982; Howe and Thompson, 1984; Howe, 1985; Hildenbrand and Hendricks, 1995; Dart and Swolfs, 1998; Parrish and Van Arsdale, 2004; Csontos et al., 2008) that is covered by up to 6 km of Phanerozoic sediments. New Madrid seismic zone seismicity is occurring along these rift faults primarily between depths of 4 and 14 km within the Cambrian and Precambrian section (Chiu et al., 1992; Pujol et al., 1997; Van Arsdale and TenBrink, 2000). The seismically most active fault within the New Madrid seismic zone is the Reelfoot reverse fault that extends northwest from near Dyersburg, Tennessee, to New Madrid, Missouri (Figs. 1 and 2) (Van Arsdale et al., 1995a, 1999). A surface scarp (monoclinal flexure) due to Reelfoot fault propagation folding (Champion et al., 2001) can be traced from the southwestern margin of Reelfoot Lake, Tennessee, where it is ~3 m high north to a maximum of 10 m where the scarp is truncated by the Mississippi River, to less than 3 m high where the scarp is again truncated by the Mississippi River near New Madrid, Missouri (Van Arsdale et al., 1999) (Fig. 3). Holocene uplift rate on the Reelfoot fault is 1.8 mm/yr (Van Arsdale, 2000), and global positioning system (GPS) data reveal a horizontal convergence rate across the fault of 2.7 mm/yr (Smalley et al., 2005). These high rates have been explained as Holocene initiation of the New Madrid seismic zone or as a burst of Holocene seismic activity on an old fault (Pratt, 1994; Schweig and Ellis, 1994; Van Arsdale, 2000).

In this study we define the geometry of New Madrid seismic zone fault planes by analyzing the distribution of earthquake hypocenters as has been done in studies conducted along the San Andreas fault system (e.g., Carena and Suppe, 2004; Pujol et al., 2006) and previously along the Reelfoot fault (Chiu et al., 1992; Liu, 1997; Pujol et al., 1997; Mueller and Pujol, 2001). In this study, however, we use an additional 1704 earthquake hypocenters from 1995 through 2006 and state-of-the-art, 3-D viewing capabilities to better evaluate their distribution. When viewing New Madrid seismic zone earthquake hypocenters with stereoscopic 3-D software, it is evident that the New Madrid seismic zone earthquakes occur within discrete zones (fault planes). Delineation of these fault planes provides geometric constraints for future kinematic analysis of the Reelfoot rift fault system and its earthquakes (e.g., Gomberg and Ellis, 1994; Johnston and Schweig, 1996). As presented below, we also believe that the Reelfoot rift illustrates the association of structural inversion and intraplate seismicity that may apply to other intraplate seismic zones.

Geology of the New Madrid Seismic Zone Region

The southeastern United States is underlain by several Precambrian terranes welded together to form the North American craton. The Precambrian terrane that underlies the Reelfoot rift is the 1470 ± 30 Ma Eastern Granite Rhylolite Province (Atekwana, 1996; Van Schmus et al., 1996, 2007). Drill-hole samples reveal that these rocks consist of granite, granite porphyry, and dioritic gneiss (Thomas, 1988; Dart, 1992; Dart and Swolfs, 1998).

The Reelfoot rift (Fig. 2) is interpreted to be a Cambrian intracratonic rift associated with the opening of the Paleozoic Iapetus Ocean (Ervin and McGinnis, 1975; Thomas, 1989, 2006). Reelfoot rifting occurred along northeast-striking
Figure 1. Reelfoot rift bounded by black lines and Mississippi embayment bounded by purple line. Microearthquake activity as colored dots with stars at estimated locations of the 16 December 1811 (south), 23 January 1812 (north), and 7 February 1812 (central) earthquakes.
normal faults (Howe and Thompson, 1984; Nelson and Zhang, 1991) that are segmented by northwest-striking vertical faults (Stark, 1997; Csontos et al., 2008). During rifting, the Reelfoot rift accumulated up to 8 km of Cambrian sediment, while outside the rift 1.5 km of Cambrian sediment accumulated (Howe and Thompson, 1984). Late Cambrian to Middle Ordovician regional subsidence of the rift and surrounding area (Howe and Thompson, 1984; Howe, 1985; Dart and Swolfs, 1998) resulted in deposition of the thick, shallow-marine Ordovician Knox (Arbuckle) carbonate Supergroup (Thomas, 1985; Lumsden and Caudle, 2001).

Tectonic landforms within the central Mississippi River valley are directly linked to the underlying Reelfoot rift faults (Fig. 3) (Mihills and Van Arsdale, 1999; Csontos et al., 2008). Quaternary displacement has been documented along the Eastern Rift Margin (Cox et al., 2001, 2006), Western Rift Margin (Van Arsdale et al., 1995b; Baldwin et al., 2005), Axial (Van Arsdale, 1998; Guccione et al., 2000), and Reelfoot fault (Russ, 1982; Kelson et al., 1996; Mueller et al., 1999; Van Arsdale et al., 1999; Champion et al., 2001). In addition, the Lake County uplift (essentially coincident with the seismicity between the central and northern 1811–1812 earthquakes in Fig. 1), Reelfoot Lake basin (Fig. 3), a segment of the eastern Mississippi Valley bluff line (located in westernmost Tennessee between the dark-green uplands and pale-green Mississippi River floodplain in Fig. 1), southern half of Crowley’s Ridge, the Big Lake and Lake Saint Francis Sunklands area, and Joiner Ridge are interpreted to be tectonic or tectonically influenced landforms (Fig. 4) (Csontos et al., 2008). New Madrid seismic zone faults have also modified Mississippi River gradients and influenced sedimentary processes during the Quaternary (Spitz and Schumm, 1997; Guccione et al., 2002; Guccione, 2005; Holbrook et al., 2006). Johnston and Schweig (1996) have proposed that the Bootheel lineament produced one of the major earthquakes of the 1811–1812 sequence, and Guccione et al. (2005) report Quaternary displacement on the Bootheel fault (lineament). However, Csontos (2007) mapped the Precambrian basement unconformity and the Pliocene-Pleistocene unconformity surfaces within the Reelfoot rift, and there is no evidence
Figure 3. Pliocene-Pleistocene unconformity on top of the Eocene section with vertical projection of Reelfoot rift faults from the top of the Precambrian unconformity. Contour interval—2 m; elevation relative to sea level. B—Big Lake; S—Lake Saint Francis; J—Joiner Ridge; GRTZ—Grand River Tectonic Zone; CMTZ—Central Missouri Tectonic Zone; OFZ—Osceola Fault Zone; BMTZ—Bolivar-Mansfield Tectonic Zone; WRFZ—White River Fault Zone; EM—Eastern Rift Margin faults; AF—Axial fault; WM—Western Rift Margin fault; RF—Reelfoot fault; CR—Crowley’s Ridge (from Csontos et al., 2008).
Figure 4. Deformation of the Pliocene-Pleistocene unconformity surface. Black lines—faults; J—Joiner Ridge; GRTZ—Grand River Tectonic Zone; CMTZ—Central Missouri Tectonic Zone; OFZ—Osceola Fault Zone; BMTZ—Bolivar-Mansfield Tectonic Zone; WRFZ—White River Fault Zone; EM—Eastern Rift Margin faults; AF—Axial fault; WM—Western Rift Margin fault; RF—Reelfoot fault. Inset map showing a restraining bend (from Csontos et al., 2008).
of vertical displacement or hypocenter alignment along the Bootheel fault. This lack of vertical displacement may be due to a very young Bootheel fault experiencing relatively minor displacement, and/or the displacement is strike-slip. However, in this study we focus on seismogenic faults and identified deformation and therefore do not consider a possible aseismic Bootheel fault.

New Madrid Seismic Zone Faults

Many of the Reelfoot rift faults (Fig. 2) have large normal displacements within the crystalline basement and Cambrian section (Howe 1985; Parrish and VanArsdale, 2004; Csontos et al., 2008). The Western Rift Margin fault is a steeply eastward-dipping normal fault, displacing the Precambrian surface up to 3 km (Howe, 1985; Nelson and Zhang, 1991). The Eastern Rift Margin faults consist of two down-to-the-northwest steep normal faults with as much as 3 km of normal displacement on the western fault, and 0.5 km on the eastern fault (Howe, 1985; Parrish and VanArsdale, 2004).

Several seismogenic faults have been mapped within the Reelfoot rift (Figs. 1–3). The Axial fault, which trends down the center of the rift, is a near vertical fault (Howe, 1985; Sexton and Jones, 1986; Stephenson et al., 1995; Csontos, 2007). The southwest-dipping Reelfoot reverse fault produces most of the New Madrid seismic zone seismicity (Sexton, 1988; Chiu et al., 1992; Pujol et al., 1997; Mueller and Pujol, 2001). The Reelfoot fault appears to be a segment of the Grand River tectonic zone, and the Reelfoot fault has been interpreted to form the northern margin of the Reelfoot rift (Fig. 2) (Csontos et al., 2008). The third major fault along which earthquakes are occurring is the New Madrid North fault (Baldwin et al., 2005), which is a portion of the Western Rift Margin fault north of New Madrid, Missouri (Fig. 5).

METHODS

The earthquake hypocenters used in this study were obtained from two data sets. One included 568 events recorded between October 1989 and August 1992 using a portable seismic network (PANDA, Chiu et al., 1992). This is the data set used in Mueller and Pujol (2001). The second data set includes 1136 events recorded from 2001 to 2006 by stations of the New Madrid seismic zone permanent network (data available through the Center for Earthquake Research and Information of the University of Memphis). The earthquakes in the two data sets were located using the joint hypocentral determination (JHD) technique described in Pujol et al. (1997). This technique removes the effect of the unconsolidated sediments of the Mississippi embayment, which changes in thickness under the two networks.

This change in thickness and the low P- and S-wave velocities of the post Paleozoic Mississippian embayment sediments introduce errors in the earthquake locations when the earthquakes are located individually. The error in depth, in particular, may be as large as 1 km. The errors that may affect JHD locations have been estimated by analyzing synthetic data generated for a velocity model that includes the variations in thickness of the unconsolidated sediments (Pujol et al., 1997). Based upon this JHD analysis, it was found that the average depth errors are likely to be less than 0.5 km, with the epicentral error considerably smaller.

Earthquake hypocenters were imported into Landmark’s GeoProbe™ and Schlumberger’s Petrel™ for 3-D point rendering using a personal computer (PC) workstation. Active stereo vision in GeoProbe™ and Petrel™ was achieved using Sharper Technology’s CrystalEyes stereo goggles and emitter. The 3-D image was also projected onto a screen for large-format viewing using a DepthQ Stereo3D projector. Earthquake hypocenters appearing to lie on planes (as visible in the 3-D model) were placed into separate data subsets. These subsets were exported to ArcMap™ and Zmap™, and a first-order trend surface (fault plane) was calculated for each hypocenter subset. In this way, location, strike, dip, and r² value (a statistical measure of how well the plane fits the hypocenter distribution) were calculated for each fault plane in the New Madrid seismic zone. The faults and earthquakes were then imported into a 3-D GeoProbe™ scene to ensure goodness of fit to the calculated plane and to determine if there were any outliers. Any obvious hypocenter outliers were removed from the subset, and a final planar trend surface (fault plane) was then created.

To create Reelfoot fault cross sections, the top of the crystalline Precambrian basement was taken from Figure 2, and the top of the Paleozoic and Cretaceous sections were obtained from VanArsdale et al. (1998) and Purser and VanArsdale (1998).

NEW MADRID SEISMIC ZONE FAULTS

The majority of New Madrid seismic zone seismicity falls along three major trends (Figs. 1 and 5). The longest trend is the 100-km-long southern section, extending northeast along the Axial fault (Chiu et al., 1992; Stephenson et al., 1995). The second trend extends 70 km northwest from near Dyersburg, Tennessee, to New Madrid, Missouri, and corresponds to the Reelfoot fault (Chiu et al., 1992; Pujol et al., 1997; VanArsdale et al., 1999; Mueller and Pujol, 2001). The third major seismicity trend, called the New Madrid North fault (Johnston and Schweig, 1996; Baldwin et al., 2005) appears to occur along a segment of the northwestern Reelfoot rift margin. A closer look at the earthquake hypocenters reveals that there is also a seismicity trend extending west from New Madrid herein called the Risco fault for the town of Risco, Missouri, and that the Reelfoot fault actually consists of three discrete, seismically defined segments (Fig. 5).

Five faults and a diffuse earthquake zone were delineated based upon 3-D earthquake hypocenter trend surface analyses (Animation 1). The Axial fault (r² = 0.9752) is essentially vertical, and so a regression line fit to the earthquakes defines a fault that strikes 46°. The New Madrid North fault strikes 29° and dips 72° SE (r² = 0.9452), and the Risco fault strikes 92° and dips 82° N (r² = 0.49). Planes were fit to the two segments of the Reelfoot fault—the Reelfoot North fault, 167°, 30° SW (r² = 0.4485), and Reelfoot South fault, 150°, 44° SW (r² = 0.9121). A diffuse zone of seismicity, with no apparent structure, divides the Reelfoot North and Reelfoot South faults at the intersection with the Axial fault.

DISCUSSION

The Reelfoot Rift and the Reelfoot Fault

Based primarily on gravity and magnetic data (Hildenbrand et al., 1982), the Reelfoot rift steps up (shallows) at the Reelfoot fault and appears to close to the north toward the Rough Creek graben (Fig. 2). This step is interpreted to be the result of Cambrian down-to-the-southwest displacement on the Grand River tectonic zone (Csontos et al., 2008). Since the Reelfoot fault essentially overlies the Grand River tectonic zone, we believe that the Reelfoot fault, within the Cambrian and Precambrian section, has down-to-the-southwest normal separation (Fig. 6) (Csontos et al., 2008). However, seismic reflection profiles reveal that the Reelfoot fault displaces the post-Paleozoic section ~70 m in a reverse sense (Sexton, 1988; VanArsdale et al., 1998; Champion et al., 2001). To alleviate this apparent contradiction, we propose that the Reelfoot fault was a rift-margin normal fault during Cambrian extension that was subsequently inverted into a thrust and reverse fault in late Paleozoic-Appalachian Orogeny and younger compression.

The Axial fault separates the differently oriented Reelfoot North and Reelfoot South faults. At the level of the top of the Precambrian, the Reelfoot North fault has 500 m of throw, whereas the Reelfoot South fault has 1200 m of
Figure 5 (continued on next page). (A) New Madrid seismic zone seismicity with faults mapped by Stephenson et al. (1995) within the zone of diffuse seismicity. A–A’ is line of cross section for B. Cross-section B–B’ and C–C’ located in Figure 6.
Figure 5 (continued). (B) Northwest-southeast A–A’ Reelfoot thrust faults showing earthquake foci. Reelfoot fault segments—orange and blue; Axial fault—red; and the arcuate diffuse zone—black. Dashed lines denote primary depth to seismicity coincident with depth to change in dip on Figure 6.
throw (Fig. 6). Thus, the Axial fault experienced down-to-the-southeast displacement during Cambrian rifting (Csontos, 2007).

New Madrid Seismic Zone Earthquakes

Trend surface analyses of earthquake hypocenters illustrate that most earthquakes within the New Madrid seismic zone occur along well-defined fault planes (Figs. 3–5, Animation 1). Specifically, earthquakes define the Reelfoot North, Reelfoot South, Axial, Risco, and New Madrid North faults.

The deep, seismically active portion of the Reelfoot fault is divided into the Reelfoot North fault that dips 30° SW and the Reelfoot South fault that dips 44° SW (Fig. 6). However, seismic reflection data reveal that the Reelfoot fault dips 73° (Van Arsdale et al., 1998) to perhaps as much as 80° (Champion et al., 2001) at depths less than 1 km, and the change in fault dip has been placed at the top of the Precambrian crystalline basement (Purser and Van Arsdale, 1998). This fault dip change was estimated by Purser and Van Arsdale (1998) to be at 4 km depth, which compares reasonably well with the footwall elevation of the Precambrian surface defined in Figure 6. The elevation of the top of the Precambrian in the hanging wall of the Reelfoot normal fault is −3700 m across the Reelfoot North fault and −4800 m across the Reelfoot South fault. It is also apparent that the minimum depth of seismicity on the Reelfoot South fault is deeper than on the Reelfoot North fault (Fig. 5). In both of these faults the seismicity is occurring on the deeper shallow-dipping portion of the fault planes. An additional major difference between the Reelfoot North and Reelfoot South faults is that there is no surface scarp along the Reelfoot South fault (Van Arsdale et al., 1999). The relatively low regression ($r^2 = 0.4485$) value for the Reelfoot North fault plane has at least two possible explanations. The Reelfoot North fault may be slightly curved (Animation 1), which would show a poor fit to a single planar surface. Alternatively, the Reelfoot North fault may be more complex than presented and may contain more than one fault plane. In summary, the Reelfoot North and Reelfoot South faults differ in strike, dip, basement displacement, surface deformation, and earthquake depths.

The seismicity of the Axial fault, where it divides the Northern and Southern Reelfoot

![Animation 1](image)

Animation 1. Three-dimensional model of New Madrid seismic zone with best-fit fault planes. You will need Adobe Acrobat or Adobe Reader Version 8 or later to view and rotate this file. If you are viewing the PDF of this paper or reading it offline, please visit [http://dx.doi.org/10.1130/GES00141.S1](http://dx.doi.org/10.1130/GES00141.S1) (Animation 1) or the full-text article on www.gsjournals.org to view Animation 1.

![Figure 6](image)

Figure 6. Generalized cross-section B–B’ of the inverted Reelfoot fault across the Reelfoot North fault segment. Generalized cross-section C–C’ of the inverted Reelfoot fault across the Reelfoot South fault segment. Cross-section scales are 1:1 and are located in Figure 5. Minor hanging-wall deformation is not shown due to scale.
faults, is a structureless cloud of earthquakes (Fig. 5). The only seismicity pattern within this zone is a 15-km-wide arched distribution around the intersection of the Axial and Reelfoot faults. This cloud of seismicity corresponds with the northeast-striking vertical basement Axial fault, which locally includes the unnamed, Cottonwood Grove, and Ridgely faults mapped within the overlying Phanerozoic section (Stephenson et al., 1995; Van Arsdale et al., 1998), apparently reflecting a wide zone of distributed shear (Oдум et al., 1998). However, this zone of structureless seismicity is wider than these four faults, thus suggesting that additional parallel right-lateral strike-slip faults may exist southeast of the Ridgely Ridge fault and northwest of the Axial fault within this zone (Fig. 5).

The Risco fault was defined by fitting a plane to the earthquake hypocenters west of New Madrid (Fig. 5). Based on these hypocenter locations, this fault strikes 92° and dips 82° N. Fault plane solutions (Johnston and Schweig, 1996) reveal left-lateral strike-slip motion on the Risco fault.

CONCLUSIONS

New Madrid seismic zone seismicity is occurring along Cambrian fault planes of the Reelfoot rift. Below ~4 km, the Reelfoot fault is interpreted to be the reactivation of a Cambrian down-to-the-southwest normal fault that may form the northern boundary of the Reelfoot rift. More specifically, the Reelfoot North, Reelfoot South, and Axial faults bound Reelfoot rift subbasins (Fig. 2). Earthquakes are occurring primarily between 4 and 14 km along the 30°-dipping Reelfoot North and 44°-dipping Reelfoot South faults. However, above 4 km, both of these faults dip ~90°, are largely aseismic, and have reverse displacement. We believe that these faults at depth are normal faults that have been structurally inverted probably initially during Paleozoic Appalachian-Ouachita Orogeny continental compression.

The New Madrid seismic zone has been explained to be a right-lateral shear zone with a compressional left stepover (Russ, 1982; Schweig and Ellis, 1994). The faults within the current model are the seismogenic right-lateral Axial fault, the compressional Reelfoot reverse fault (our Reelfoot North fault), and the right-lateral New Madrid North fault. This model requires that crustal rock is sliding northeast along the Axial fault and being forced over and around the Reelfoot North fault to continue sliding northeast along the New Madrid North fault. Indeed, in trench excavations across the Reelfoot North fault scarp, Kelson et al. (1996) cite evidence of right-lateral slip. This is important for two reasons. If there is a significant component of strike-slip on the Reelfoot North fault, then the ~1.8 m of coseismic reverse slip (Merritts and Hesterberg, 1994; Mueller and Pujol, 2001) determined for the 7 February 1812 Reelfoot fault earthquake may be only a component of greater oblique slip. Secondly, this “crowding” around the Reelfoot North fault may be responsible for the Risco fault. We believe that the left-lateral Risco fault is an escape fault caused by this crowding around the Reelfoot North fault stepover (Csontos, 2007).

Right-lateral shear on the New Madrid North and Axial faults explains the Reelfoot North fault (Oдум et al., 1998) but does not explain the seismicity occurring southeast of the Axial fault on the Reelfoot South fault. It is necessary to modify the current model for the New Madrid seismic zone. We propose that the Reelfoot South fault is also a compressional left stepover between the right-lateral Axial fault and the right-lateral Eastern Margin Margin faults (Cox et al., 2001, 2006; Csontos et al., 2008). This is supported by the right-lateral fault plane solutions for the Axial and Eastern Margin faults and the reverse fault plane solutions for the Reelfoot South fault (Chiu et al., 1992, 1997; Liu, 1997). The contemporary stress field for the eastern United States is a horizontal maximum compressive stress oriented N60°E with some central Mississippi River valley measurements indicating due east (Zoback and Zoback, 1989; Zoback, 1992; Ellis, 1994). This stress field, and resultant right-lateral shear on the N45°E-oriented Reelfoot rift faults, has led numerous authors to invoke right-lateral shear as being responsible for the New Madrid seismic zone. However, we believe that contemporary right-lateral shear is not restricted to the Axial–Reelfoot North–New Madrid North fault system, but is occurring over the full width of the Reelfoot rift at its northeastern end (Oдум et al., 1998; Csontos et al., 2008). We also believe that recent GPS data support these conclusions (Smallley et al., 2005).

Perhaps most difficult to explain in our proposed New Madrid seismic zone shear model are parts that at first glance appear to be missing. For example, the southeastern Reelfoot rift margin is only moderately active, but commensurate with our model, the portion north of Memphis is most active (Fig. 1). If the Axial fault is acting as a right-lateral fault for the Reelfoot South fault stepover, then the Axial fault should extend northeast of the Reelfoot faults. Van Arsdale et al. (1998) have proposed that the Cottonwood Grove and Ridgely faults may extend northeast of the Reelfoot fault (Fig. 5), and Figures 4–5 and Animation 1 suggest right-lateral displacement of the Reelfoot North fault with respect to the Reelfoot South fault. Our model also suggests that there should be earthquakes along a northeastern continuation of the Axial fault beyond the Reelfoot faults. To this we can only speculate that the northeastern extension of the Axial fault is currently aseismic or that the displacement is occurring as reverse movement on the Reelfoot North fault.

Van Arsdale et al. (1999) and Mueller and Pujol (2001) argue that the Reelfoot fault is continuous from New Madrid, Missouri, south to near Dyersburg, Tennessee. However, our research indicates that the Reelfoot North and Reelfoot South are discrete fault segments that may not rupture as one fault. These faults differ in strike, dip, depth, area, basement displacement, and the Reelfoot South fault does not have a surface scarp. Absence of a fault scarp along the Reelfoot South fault could be due to the fact that this fault is east of the Mississippi River floodplain and to displace the ground surface the fault would have to pass through an additional 30 m of unconsolidated sediment including a thick loess deposit. Although this may be an important factor as to why there is no scarp along the Reelfoot South fault, we believe this is not the primary reason.

The Reelfoot North fault scarp (fault propagation fold) is symmetric in that it diminishes in structural amplitude north and south (Van Arsdale et al., 1999) from its maximum fault amplitude of 11 m to the northwest of Reelfoot Lake (Champion et al., 2001). The fold amplitude is less than 3 m within the large Mississippi River bend (Kentucky Bend) area of Figure 3 and at its southern end where it intersects the Axial fault (Van Arsdale et al., 1999). Van Arsdale et al. (1999) argue that the southern end of the Reelfoot scarp may have been erodingly removed by Mississippi River flood waters prior to the construction of the Mississippi River levees. Although we agree with this, when we extrapolate a diminishing fold amplitude (scarp height) south from its maximum of 11 m, the fold would diminish to near zero at the eastern edge of the Mississippi River floodplain. If the Reelfoot fault has ruptured over its entire 70 km of its mapped bedrock length as one fault plane during its Holocene history, we would not expect the fold amplitude (scarp height) to diminish to zero at the southern end of the Reelfoot North fault. Quite the contrary: if the Reelfoot fault is truly continuous and has ruptured along its entire 70 km length during the late Quaternary, we would expect its fault propagation fold amplitude to be a maximum near its center (Van der Pluijm and Marshak, 2004) where the Reelfoot North and Reelfoot South faults meet.

Van Arsdale et al. (1999) document sable tectonic geomorphic features along the Reelfoot
South fault and the short-lived impoundment of the Ohio River during the 12 February 1812 New Madrid earthquake that may have been caused by fault displacement. However, based on the above arguments, we believe that the paleoseismic history documented along the Reelfoot North fault (Kelson et al., 1996; Mueller et al., 1999) probably does not apply to the South fault. We close by speculating that the Holocene earthquake history of the Reelfoot South fault may have begun with the 12 February 1812 earthquake and that ongoing seismicity reveals that this southeastern stepover zone is an area of strain accumulation (Cox et al., 2001, 2006).

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South fault and the short-lived impoundment of the Ohio River during the 12 February 1812 New Madrid earthquake that may have been caused by fault displacement. However, based on the above arguments, we believe that the paleoseismic history documented along the Reelfoot North fault (Kelson et al., 1996; Mueller et al., 1999) probably does not apply to the South fault. We close by speculating that the Holocene earthquake history of the Reelfoot South fault may have begun with the 12 February 1812 earthquake and that ongoing seismicity reveals that this southeastern stepover zone is an area of strain accumulation (Cox et al., 2001, 2006).

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