

fault slip rate, the strain rate is directly dependent on the distance between the two sites across the fault. In the NMSZ, ongoing earthquake activity along the Reelfoot fault (Figure 1) suggests that this is the case near the two sites used in the Smalley paper.

To better illustrate the issue, the model curves in Figure 1 show fault-normal shortening and the resulting strain rate for a simplified fault analogous to the Reelfoot thrust. Slip is scaled to approximate the 10^{-7} per year strain rate at two sites about 5 kilometers from the fault, inferred by Smalley *et al.* [2005]. However, depending on changes in the measurement distance, strain rates decrease dramatically away from and increase rapidly very near the fault. Specifically, when measurements are made 100 kilometers from the fault, the resultant strain rate decreases by 2 orders of magnitude. However, as measurements are made right up to the fault, strain rates become infinitely large, as the distance between measurements goes to zero. Thus, it is clear that a direct comparison of strain rates alone from different fault systems is not useful for describing relative activity along faults, let alone their seismic hazard. It is

better to either directly compare relative velocities at certain distances or compare the best models that describe such activity. In this case, the measured convergence suggests that there is active slip along the fault, consistent with ongoing microseismicity.

A significant consideration to be made here is whether or not ongoing active slip along a fault suggests increased seismic hazard, as has been suggested by Smalley *et al.* [2005]. It has generally been observed that along active faults, the regions that are not actively slipping are instead locked and thus able to build strain energy for possibly catastrophic release. These locked regions, identifiable by significant far-field and little to no near-field strain, have the greatest potential for moderate to large earthquakes [e.g., Scholz, 2002]. Thus, ongoing slip on a fault may suggest lower immediate danger because the fault is accumulating little if any strain energy for future events. In the NMSZ, if the relative motion is real, it may be due to postseismic relaxation within the asthenosphere due to past earthquakes [Rydelek, this issue], which causes transient motions near the fault rather than accumulating slip for future earthquakes.

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New Madrid Strain and Postseismic Transients

PAGES 60, 61

A crucial issue for the assessment of earthquake hazard in the New Madrid Seismic Zone (NMSZ) of the central United States is whether the small motions inferred from geodetic measurements are actually the result of strain accumulation that will eventually be released in damaging earthquakes. The interpretation of these measurements has led to an ongoing debate over the associated seismic risk and hazard assessment in the NMSZ [Zoback, 1999; Schweig *et al.*, 1999; Newman *et al.*, 1999a, 1999b; Stein *et al.*, 2003]. The gist of the debate is whether or not models of high seismic hazard in this region are supported by the geodetic data and historic earthquake data.

A recent report by Smalley *et al.* [2005] on GPS measurements across the Reelfoot fault suggested a relatively high strain rate, of the order of 10^{-7} per year, comparable to that normally associated with convergence at plate boundaries. To some, these measurements seemingly ended the debate since they were taken to be the result of rapid strain accumulation that could unleash a large, devastating earthquake, which in turn prompted a general public warning from a top U.S. Federal Emergency Management Agency (FEMA) official [Brown, 2005]. Others, however, believe that the debate is not yet settled [Calais *et al.*, 2005]; it has been argued that these GPS measurements show no statistically significant motion and instead

reveal a puzzling offset in one of the GPS time series [Calais *et al.*, 2006].

Smalley *et al.* [2005] offered several explanations for their observations, one of which was long-term postseismic relaxation following the 1811–1812 sequence of three large earthquakes that occurred in this seismic zone. Clearly, relaxation is fundamentally different from accumulation. Postseismic relaxation is due to the coupling of the rigid elastic crust to the underlying viscoelastic asthenosphere. An earthquake generates stresses that are relieved by both an immediate elastic response (coseismic effect) and a long-term viscoelastic relaxation (postseismic effect) that will persist for many decades because of the enormous value of the viscosity of the asthenosphere, on the order of 10^{20} pascal seconds. The long-term effects of postseismic relaxation were found to include migrations in seismicity [Rydelek and Sacks, 2001] and the triggering or inhibition of remote seismicity [Rydelek and Sacks, 1990; Pollitz and Sacks, 1997; Rydelek and Sacks, 2003].

It is odd that Smalley *et al.* [2005] did not pursue the possibility of postseismic effects, since it was previously shown by Rydelek and Pollitz [1994] that a large-magnitude strike-slip earthquake in 1811 along the Bootheel lineament in the NMSZ could generate a localized high rate of strain in the present day. This rate may resemble some features of the Reelfoot GPS measurements if that observation were indeed the result of steady strain deformation.

To investigate postseismic effects specific to a large thrust earthquake, model calculations [Pollitz, 1992] were done for a $M_w = 7.8$ event in 1812 along the Reelfoot fault shown in Figure 1 and with fault parameters given in Table 1. This earthquake was the last, and largest, of the three events that occurred in the winter of 1811–1812. A viscoelastic Earth model [Rydelek and Pollitz, 1994] believed to be appropriate for this region of the central United States was used, and the calculations were run to span the time interval 2000–2005, that is, results for 5 years of postseismic viscoelastic relaxation that correspond to the times and regions of the GPS measurements of Smalley *et al.* [2005].

Figure 1 shows the model results for the engineering strain $\gamma = \epsilon_{EE} - \epsilon_{NN}$, where ϵ_{EE} and ϵ_{NN} are the compressional components of the strain tensor. Calculated strain rates of order 10^{-7} per year are found in the vicinity of the Reelfoot fault, and the corresponding

Table 1. Fault model parameters for 1812 Reelfoot Earthquake. Uniform slip on the fault plane is assumed.

Latitude =	36.64°
Longitude =	-89.55°
Strike =	158°
Length =	58 km
Width =	27 km
Dip =	40°
Rake =	90°
Slip =	11.0 m
M_w =	7.8 (computed from fault parameters)

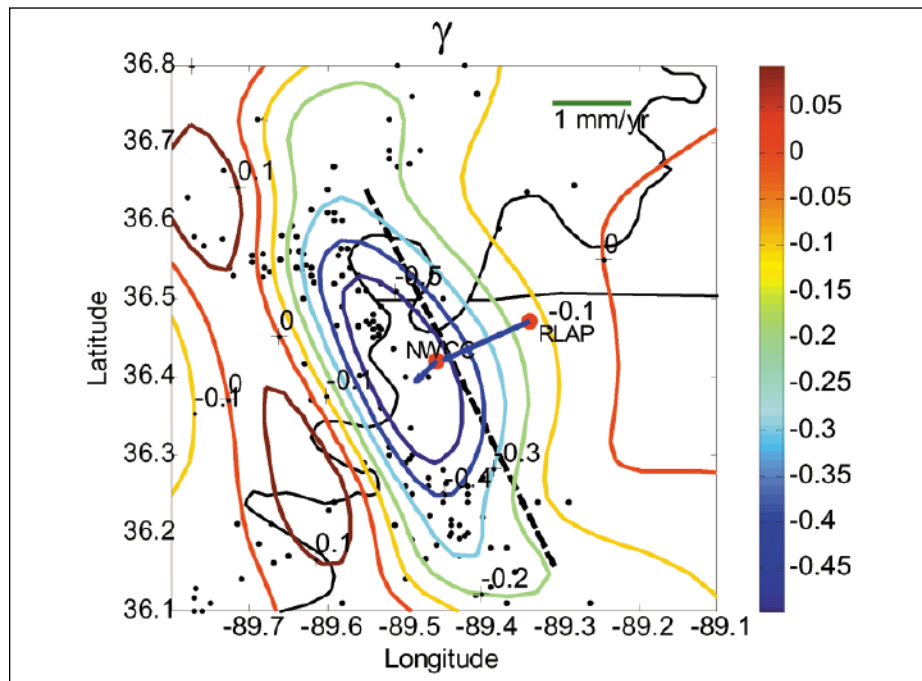


Fig. 1. Contours show the compressional components of the strain field from postseismic viscoelastic relaxation that would occur in 2000–2005 from a $M_w = 7.8$ thrust earthquake on the Reelfoot fault (dashed line) in 1812. Averaged over the 5-year span, the maximum strain rate is of order 10^{-7} per year on the hanging-wall side of the fault; the relative baseline shortening of GPS stations NWCC and RLAP is about 1 millimeter per year. The black dots are cataloged earthquakes with $M \geq 2.5$ in the New Madrid Seismic Zone. Color scale is in units of microstrain.

convergence velocity of approximately 1 millimeter per year of the GPS locations across the fault is comparable to that reported.

Given the similarities between the deformation from the modeling of postseismic viscoelastic effects and the suggested scale of motions from the recent GPS measurements [Smalley *et al.*, 2005], it would seem premature to conclude that the apparent high rate of strain in this region is due entirely to accumulation, and therefore portends a significant hazard risk, until further data and analysis verify that this is not just a local effect of long-term postseismic relaxation. On the other hand, any offset in the GPS time series [Calais *et al.*, 2006] would be difficult to explain by

either the steady accumulation of strain or the release of strain from long-term postseismic relaxation. Clearly, the modeling of postseismic viscoelastic effects and its interpretation may have important consequences for seismic hazard assessment in the central United States and should be considered in the unsettled and ongoing debate.

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