Time-Variable Deformation in the New Madrid Seismic Zone

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At plate boundary faults, a balance is achieved over <1000 years between the rates at which strain accumulates and is released in large earthquakes. Whether this steady-state model, which forms the basis for seismic hazard estimation, applies to continental plate interiors, where large earthquakes are infrequent, is unresolved. The New Madrid Seismic Zone (NMSZ, Fig. 1A) in North America is a focus for this issue. Large-magnitude ($M > 7$) earthquakes in 1811 and 1812 make hazard estimation a priority. Recent geodetic results have shown motions between 0 to 1.4 mm year^{-1}, allowing opposite interpretations (*1*) (Fig. 1B). The upper bound is consistent with steady-state behavior, in which strain accumulates at a rate consistent with a repeat time for magnitude ~ 7 earthquakes of about 600 to 1500 years, as seen in the earthquake record. However, the lower bound cannot be reconciled with this record, implying that the recent cluster of large-magnitude events does not reflect long-term fault behavior and may be ending.

New analysis including 3 additional years of Global Positioning System (GPS) data and three additional sites (*2*) shows root mean square (RMS) velocities relative to the rigid interior of North America of less than 0.2 mm year^{-1} (Fig. 1C). These residual velocities are below their uncertainties at 95% confidence (Fig. 1A). A simulation shows that even these residuals can be explained as nontectonic artifacts (*2*), so the observations do not require motions different from zero during this time. Our results correspond to strain rates lower than 1.3×10^{-9} year^{-1}, less than predicted by a model in which large earthquakes occur because the NMSZ continues to be loaded as a deeper weak zone relaxes (*3*).

At steady state, a rate of 0.2 mm year^{-1} implies a minimum repeat time of 10,000 years for low $M = 7$ earthquakes with ~2 m of coseismic slip and one longer than 100,000 years for $M = 8$ events (Fig. 1D). In contrast, the geologic data show a series of large earthquakes between 300 ± 200 Common Era and present and an additional cluster between 2200 and 1600 Before the Common Era (*4*). This implies an average repeat time of at most 900 years over that interval, much shorter than the geodetic data imply. Strain in the NMSZ over the past several years has therefore accumulated too slowly to account for seismicity over the past ~5000 years, hence excluding steady-state fault behavior.

Elsewhere throughout the plate interior, GPS data also show average deformation less than 0.7 mm year^{-1} (*5*), and paleoseismic records show earthquake migration and temporal earthquake clustering (*6*).

These data imply that fault loading, strength, or both vary with time in the North American continental interior. Time variations in stress could be due to local loading and unloading from ice sheets or sediments or after earthquakes on other faults. Alternatively, midcontinent faults may be loaded at a constant rate too small to be detected geodetically yet but sufficient to accumulate strain released in clustered events. In this hypothesis, clustering and migration could reflect time variations in fault strength (*7*).

Earthquake hazard estimates assuming that recent seismicity reflects long-term steady-state behavior may thus be inadequate for plate interiors and may overestimate the hazard near recent earthquakes and underestimate it elsewhere.

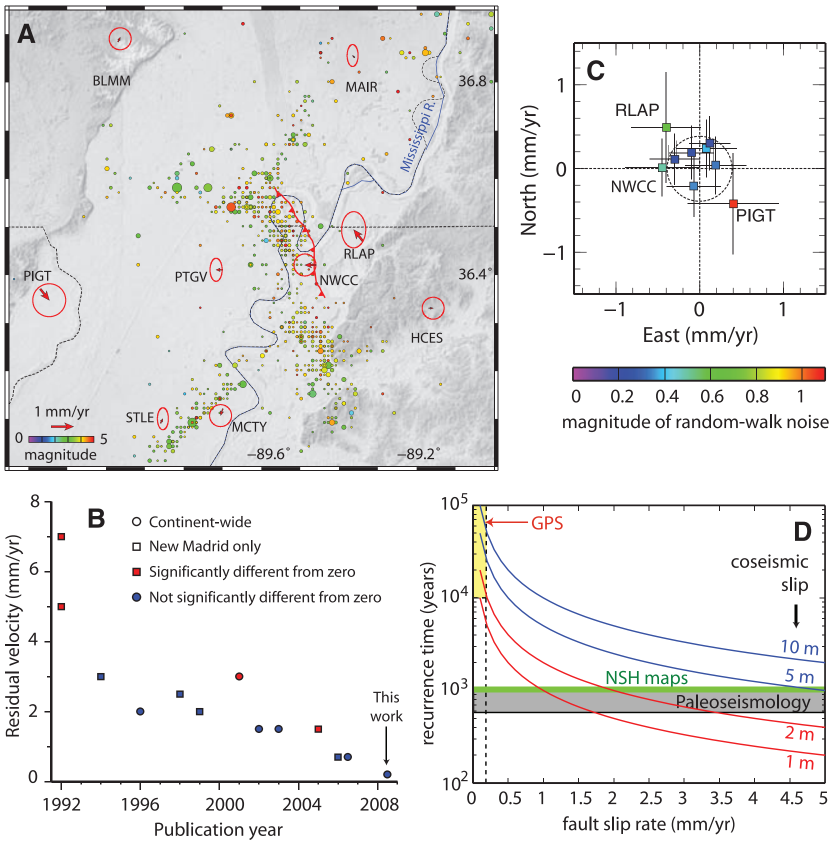

Fig. 1. (**A**) GPS site velocities in the NMSZ relative to North America and uncertainties (95% confidence). Circles show earthquake epicenters since 1974. Red line shows the Reelfoot fault. BLMM, HCES, MAIR, MCTY, NWCC, PIGT, PTGV, RLAP, and STLE indicate the names of the continuous GPS stations used in this work (*2*). (**B**) Maximum permissible deformation rates in the NMSZ as a function of publication year. References are listed in (*2*). Circles show continent-wide studies; squares show NMSZ studies. Red are publications claiming rates significantly different from zero; blue are upper bounds for publications claiming rates not significantly different from zero. The decrease in rates as a function of time reflects more-precise site velocity estimates because of both more precise site positions and the longer time span of observations. (**C**) Scatter plot of residual velocities. Sites are color-coded by the level of noise in their position time series. Bars show 95% error in velocities. Dashed circle shows 1-σ RMS of the data set. Note that sites with the largest noise have the largest residuals. (**D**) Earthquake recurrence interval as a function of slip rate across the fault in a steady-state model, with two end-member values of coseismic slip for magnitude 7 (red curves) and magnitude 8 (blue curves) earthquakes. The GPS and paleoseismology domains do not overlap. NSH indicates National Seismic Hazard maps.

References and Notes

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Supporting Online Material

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Materials and Methods
Fig. S1
References and Notes

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