

A NOTE ON THE NEW MADRID SEISMIC ZONE: ARE WE OVERESTIMATING THE RISK?

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EDITOR'S NOTE: In March, AIR Currents published *New Thinking on Seismic Risk in the Central U.S.*, which explained why the United States Geological Survey changed its estimate of hazard in the New Madrid Seismic Zone (NMSZ) in its 2008 National Seismic Hazard Maps. The article also described how the development of new data has inspired new understandings of earthquakes in the NMSZ. Shortly after the AIR Currents article appeared, new research concerning the NMSZ was published in the scientific literature that attracted the interest of several AIR Currents readers and AIR clients—and also received popular press attention. Here Dr. Mehrdad Mahdyiar, author of the earlier article and AIR's Director of Earthquake Hazard Research, outlines the new research and places it into the context of the NMSZ as generally understood in the scientific community at this time.

By Dr. Mehrdad Mahdyiar

For at least the last decade, the scientific community has known that the rate of strain accumulation in the New Madrid Seismic Zone (NMSZ) is lower than expected for an area where large-magnitude earthquakes are thought to recur at roughly 500-year intervals. (The most recent event was a triplet of magnitude 7-8 earthquakes that took place two hundred years ago during the winter of 1811/1812.) The rate at which strain accumulates within a seismically active region is linked to the rate at which stress builds up on individual faults in the region. Eventually, the threshold of one fault is exceeded—triggering an earthquake and releasing the accumulated potential energy.

One way of determining the rate of strain accumulation is to monitor the earth's surface for movement in the region of interest. Using global positioning system (GPS) measurements, a team of researchers from Northwestern and Purdue Universities did just that for the NMSZ over a period of eight years. This past March they published their findings in *Science* in a paper titled, "Time-Variable Deformation in the New Madrid Seismic Zone"¹—which in

the popular media was translated as some variation of the more provocative title, "New Madrid Fault System May be Shutting Down."

THE RECENT GPS DATA

The findings presented in the *Science* article indicate that surface ground movement in the NMSZ relative to the rigid interior of North America is (with 95% likelihood) less than 0.2 millimeters per year (slightly less than 1/100th of an inch). The authors (Eric Calais and Seth Stein) go on to say: "At steady state, a rate of 0.2mm [per year] implies a minimum repeat time of 10,000 years for low $M = 7$ earthquakes..." For $M = 8$ events—which may have been the magnitude of one of the 1812 New Madrid events—they estimate that the return period would be over 100,000 years.

This new information—whose accuracy there is no reason to doubt—adds to long-standing puzzlement in the scientific community about the seismic nature of the NMSZ. On the one hand, we know from ample geological, paleoseismic

and historical evidence that earthquakes in the upper M7 to M8 range took place in the NMSZ in 1811/1812, and that similar large earthquakes occurred around 900 CE and around 1450 CE—or roughly every 500 years for at least the last two millennia. Thus, standard seismology would expect the recurrence of an earthquake in about 300 years give or take a few decades—or about 500 years after the 1811/12 events.

On the other hand, there also is evidence (now newly corroborated) that indicates that, given the present rate of deformation in the region, such earthquakes should not take place in the future.

So what is happening in the New Madrid Seismic Zone? This has been a major question among seismologists for the past 60 years, at least since plate tectonics was accepted as the driving force behind geology and geography. The question is not academic. It is important to everyday concerns because how it is answered affects how hazard and risk are estimated: whether there is a high probability of major earthquakes taking place in the NMSZ relatively soon or not for thousands—or even tens of thousands—of years.

PLATE TECTONICS, EARTHQUAKES, AND THE NMSZ

Very briefly, most earthquakes happen where two or more of the tectonic plates that make up the solid surface of the earth come together. These earthquakes are caused by the plates sliding against each other, butting into one another, or one plate slipping underneath another. The stresses and strain at these plate boundaries can also cause fracturing in the surrounding crust, which can, in turn, trigger nearby crustal earthquakes. The New Madrid Seismic Zone, however, lies in the middle of the North American plate; the nearest plate boundary is about 2,000 miles away. So there is no opportunity here for plates to slide against, butt into, or slip under one another.

So, if plate tectonics are not at work in the NMSZ, how are earthquakes produced there?

More than a few researchers have proposed mechanisms to answer this question, mechanisms that explain not only why and how earthquakes happen in the NMSZ at all, but also explain the present low regional strain accumulation rate. Among the contending explanations is one that a number of researchers find appealing and which is supported by some empirical data: that the lower crust and upper mantle

directly beneath the NMSZ are comparatively weak and contain material that is denser and more viscous than that of the surrounding material.

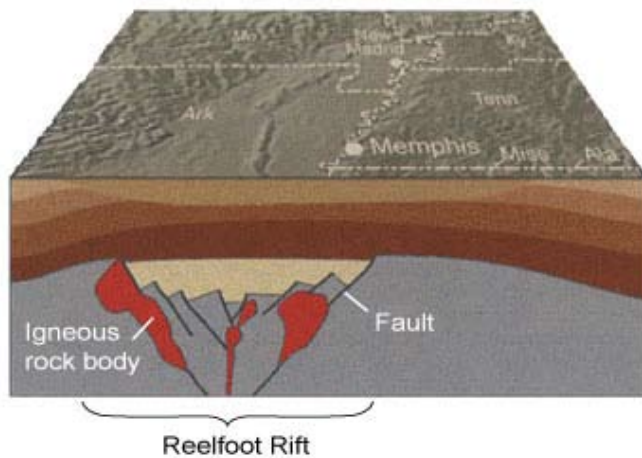
These conditions have set in motion a complex and dynamic interaction between the weak lower crust/upper mantle and the upper crust. This interaction causes the weak crust/mantle region below the NMSZ to undergo episodes of stress accumulation followed by episodes of relaxation. The episodes of stress accumulation causes stress to concentrate on the faults in the NMSZ—eventually resulting in earthquakes—while the episodes of relaxation create periods of low surface-strain accumulation rates.

Consequently, earthquakes in the NMSZ occur according to stress accumulation patterns different from those of typical faults near plate boundaries. The dynamic weak zone/upper crust interaction also creates a complex strain accumulation pattern throughout the region that similarly cannot be interpreted simply by using the standard strain accumulation patterns typical of plate-boundary regions.

BENEATH THE NMSZ

The key element in this proposed mechanism is the premise that beneath the NMSZ lies a region of lower crust and upper mantle that is weak. Both geological and geophysical data support an understanding of the NMSZ as the remnant of a rift that 600 million years ago failed to separate fully to form an ocean basin. Geologists have named the failed rift the “Reelfoot Rift” and, using a variety of geophysical and geodetic (earth-measuring) data and by tracing vestigial surface features, have mapped its general outlines.

The data also suggest that in some later geological period, large “mafic plutons”—masses of dense igneous rock that have a different composition from surrounding material—were deposited, miles below the NMSZ’s present surface, into the weakened lower crust/upper mantle region. High-resolution seismic and geopotential imaging data do indicate the presence of such mafic bodies. Among them, according to some researchers, is a lens-shaped, high density “rift pillow.” The greater density and relative weight of the rift pillow has been partially held up by the lower crust/upper mantle becoming compressed—much like the cushion of a sofa holding up the people sitting on it. Some researchers suggest that the pillow may also be attached to the upper crust, which thus contributes to supporting it (thereby creating stress within the upper crust).



Cross-section of the New Madrid Seismic Zone's Reelfoot Rift. Source: USGS

MANTLE/CRUST PERTURBATIONS

The rift pillow and other plutonic bodies presumably achieved some kind of equilibrium that remained stable for some time. Different researchers have suggested different possible scenarios for what might have happened next. One study, "Sinking Mafic Body in a Reactivated Lower Crust: A Mechanism for Stress Concentration at the New Madrid Seismic Zone" by Fred F. Pollitz et al.², points to the Laurentide Ice Sheet that covered most of what today is Canada and the northern United States during the last ice age (from about 95,000 to 20,000 years ago). At its peak, the ice sheet was miles thick in places and covered an area of millions of square miles. Its weight was so great that it depressed the Earth's crust.

Over a 10,000-year period leading into our current geological epoch (the Holocene), the Laurentide Ice Sheet underwent rapid deglaciation that reduced pressure (the weight of all that ice) on the lower crust and upper mantle. The Pollitz study sees this (relatively) sudden release of pressure as having caused the crust/mantle interface to weaken.

Beneath the NMSZ, these nearly continent-wide developments perturbed the equilibrium of the lower crust/upper mantle and the mafic plutons. The weakening of the crust/mantle reduced or removed support for the rift pillow and other mafic bodies. They began to sink, which, in turn, induced a downward pull on the upper crust—a downward pull that the Pollitz study understands to be the source of instability (and earthquakes) in the NMSZ.

Yet another recent study, "Descent of the Ancient Farallon Slab Drives Localized Mantle Flow below the New Madrid Seismic Zone" by Forte et al.³, attributes the instability in the NMSZ lower crust/upper mantle to the subduction of the ancient Farallon plate beneath the North American plate. This subduction began with the break-up of the supercontinent Pangea during the Jurassic period some 200 million years ago. It is thought that the Farallon plate subducted at a very shallow angle, thereby eventually creating the Rocky Mountains and also initiating the formation of the San Andreas fault. A large remaining fragment is believed to be in the mantle under the present eastern United States.

Using 3D seismic tomography, Forte et al. constructed a model of density, flow, and seismic wave velocity in the mantle below the NMSZ that is consistent with the most recent geophysical data concerning the region. The model suggests a complex downward mantle flow beneath the NMSZ because of the Farallon plate, which Forte et al. argue may be the source of the dynamic instability in the NMSZ.

ESTIMATING THE RISK

These studies and others suggest that the causative mechanisms for earthquakes in the New Madrid Seismic Zone may be different from the generally accepted mechanisms in active tectonic regions. The alternative models outlined here, which do not exhaust the contending solutions offered to date, provide very plausible—and quite different—physical explanations for earthquake dynamics in the NMSZ.

Thus, Calais and Stein's recent GPS data need to be evaluated within the context of the range of proposed physical models for the NMSZ. Explaining the origins, dynamic mechanisms, and probable recurrence rates of earthquakes in the NMSZ is an active research effort and only more data, new information that leads to new insights—and time—will determine which causative scenario is most likely.

At present, it is not possible to fully accept the assumption that the NMSZ acts like a typical plate boundary fault—and it is also not possible to fully refute all the proposed models for the NMSZ that describe a different mechanism at work. In law, one is innocent until proven guilty. With respect

to earthquakes, it is the opposite: a fault with a recent earthquake history is assumed to be guilty (i.e., active) until proven innocent (i.e., inactive).

Because the USGS seismic hazard maps are the basis for developing building codes that are designed to save lives and property, it is appropriate that they take a conservative approach. That is, until such time as the findings of Calais and Stein become part of a new consensus view among the scientific community, it is entirely appropriate and responsible for the USGS to acknowledge and incorporate the potential for large earthquakes in the NMSZ in their national seismic hazard maps.

The most important job of the scientists and engineers at AIR is to keep abreast of the scientific literature, evaluate the latest research findings and conduct original research of their own—to determine whether competing scientific approaches are credible and how much weight to assign to them.⁴ In accordance with this measured approach, AIR implemented a treatment of the NMSZ that is consistent with the USGS 2008 National Seismic Hazard Maps in the current update to AIR's Earthquake Model for the U.S.

1 CALAIS, ERIC, AND STEIN, SETH (2009); TIME-VARIABLE DEFORMATION IN THE NEW MADRID SEISMIC ZONE, SCIENCE, 323, 1442

2 POLLITZ, FRED F., KELLOGG, LOUISE, AND ROLAND BÜRGMANN (2001); SINKING MAFIC BODY IN A REACTIVATED LOWER CRUST: A MECHANISM FOR STRESS CONCENTRATION AT THE NEW MADRID SEISMIC ZONE, BULLETIN OF THE SEISMOLOGICAL SOCIETY OF AMERICA, 91, 6, 1882-1897

3 FORTE, A. M., MITROVICA, J. X., MOUCHA, R., SIMMONS, N. A., AND GRAND, S. P. (2007); DESCENT OF THE ANCIENT FARALLON SLAB DRIVES LOCALIZED MANTLE FLOW BELOW THE NEW MADRID SEISMIC ZONE, GEOPHYSICAL RESEARCH LETTERS VOL. 34, L04308, DOI:10.1029/2006GL027895

4 THIS TOPIC IS ADDRESSED IN MORE DEPTH IN THE AIR CURRENT THE DYNAMIC NATURE OF SCIENCE IN CATASTROPHE MODELING THE DYNAMIC NATURE OF SCIENCE IN CATASTROPHE MODELING

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