Why We Have Earthquakes in the Eastern United States

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Abstract

There are only two types of naturally-occurring earthquakes anywhere on the Earth: 1) those associated with the dynamics of plate tectonics and 2) those associated with the dynamics of the hydrologic cycle. The first type is characteristic of an INTERplate setting (like the San Andreas Fault in California). The second is characteristic of an INTRAplate setting (like the Virginia magnitude 5.7 earthquake of August 23, 2011, or the earthquakes of the New Madrid, MO, seismic zone). This second type is caused by the dynamics of groundwater recharge, hurricanes, and typhoons, which trigger the intraplate earthquakes. The Earth's crust is generally accepted to be in a self-organized critical (SOC) state and generally fractured with connected hydraulic continuity from the surface down to 15-18 km. Thus, the fluid (meteoric water) filling the cracks is under hydrostatic, not lithostatic pressure. It is generally accepted that it takes only 0.01-0.1 MPa (0.1-1.0 bar) of pore-fluid overpressure (pressure above hydrostatic) to trigger an intraplate earthquake.

The central Virginia seismic zone (CVSZ), New Madrid, MO, seismic zone, and the central Oklahoma intraplate seismic zone are all bisected by major river systems. A hydrograph separation to obtain baseflow (recharge) was obtained at gauging station 02.0350.00 in the CVSZ. The derivative of the response of the crust to a unit step function increase in pore-fluid pressure at the surface of the Earth (by groundwater recharge) is, by definition, the impulse response of a hydraulically conductive crust. The time sequence of groundwater recharge (baseflow) can then be convolved with the impulse response to give the pore-fluid overpressure (pressure above hydrostatic) at depth.

The key characteristic of the hydraulic impulse response is that, unlike a seismic wavelet, it never (theoretically) goes to zero for long periods of time. Thus, the Earth's crust retains a memory of earlier pressure transients. Each recharge-day contributes to the pore-fluid pressure at depth. It is assumed that an earthquake is triggered when the pore-fluid pressure reaches a peak. Successive groundwater recharge elements send down impulses that always constructively interfere (a convolution), shifting the peak in pore-fluid pressure toward later times and gradually building up the peak until an earthquake is triggered by a reduction in effective stress.

Finite element models (FEMs) are useful as a way to examine the buildup of pore-fluid pressure in fracture zones due to groundwater recharge from the surface of the Earth. Results of FEM modeling using COMSOL Multiphysics® are consistent with the assumptions of

"hydroseismicity", which attributes intraplate seismicity to the dynamics of the hydrologic cycle, and supports the suggestion of Costain and Bollinger (2010) [1] that naturally-occurring earthquakes fall into just one of two categories: 1) those associated with the dynamics of plate tectonics, or 2) those associated with the dynamics of the hydrologic cycle. The triggered intraplate earthquakes typically follow surface disturbances in pore-fluid pressure by 60-90 days.

Reference

[1] John Costain and G.A. Bollinger, G.A., Review: Research results in Hydroseismicity from 1987 to 2009, Bulletin Seismological Society America, v.100, 1841-1858 (2010).

Figures used in the abstract

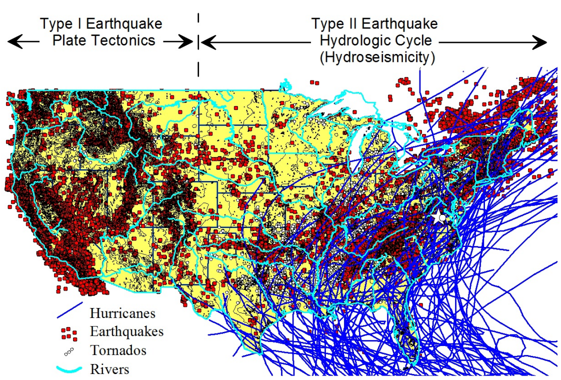

Figure 1: The elements of the hydrologic cycle that are reponsible for groundwater recharge into a hydraulically diffusive crust up to depths of 15 km where increases in pore-fluid overpressure trigger intraplate earthquakes.

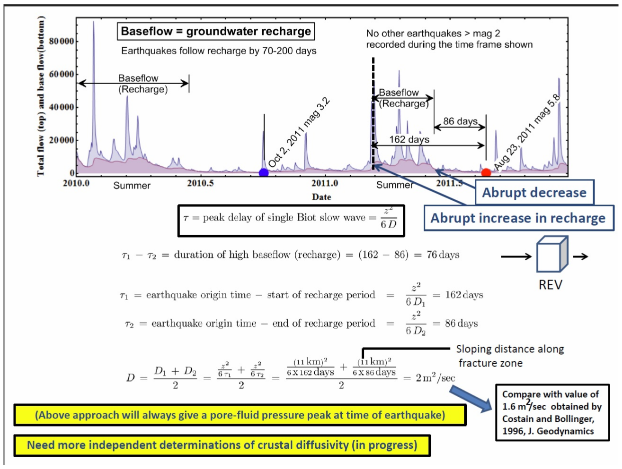

Figure 2: A hydrograph separation used to separate groundwater recharge (base flow) from total streamflow. The duration of base flow of 76 days (162-86) shown on the figure is the source function for the COMSOL FEM calculations. This groundwater recharge is believed to have triggered the magnitude 5.7 earthquake near Mineral, VA, on August 23, 2011 at a depth of 8 km.

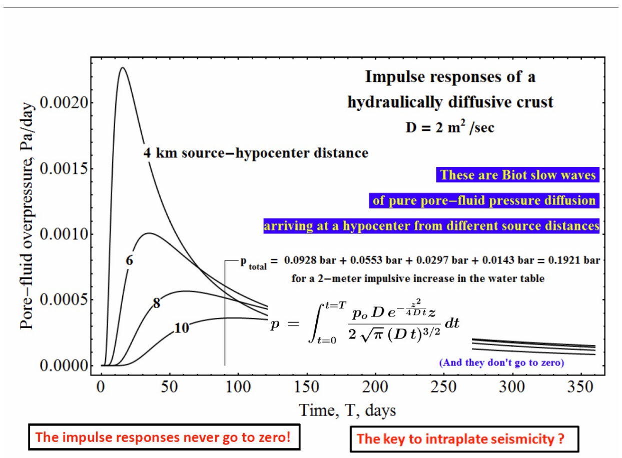

Figure 3: Biot slow waves of pure pore-fluid pressure diffusion in a poroelastic crust showing severe attenuation and dispersion. The pore-fluid pressure at the depth of the earthquake can be thought of as the convolution of waves like these with the surface recharge source function obtained from the hydrograph separation.

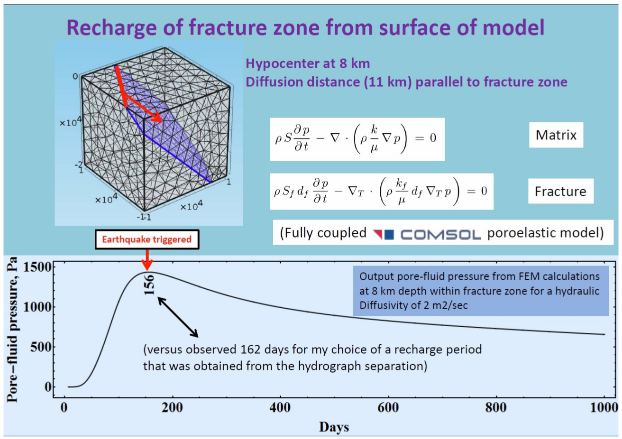

Figure 4: Diffusion of groundwater recharge from the surface down along the fault zone triggers the earthquake when the pore-fluid pressure reaches a peak after a delay of about 160 days after the start of recharge.