Pore-fluid migration and the timing of the 2005 M8.7 Nias earthquake

Kristin L.H. Hughes1,*, Timothy Masterlark1,*, and Walter D. Mooney2,*

1DEPARTMENT OF GEOLOGICAL SCIENCES, UNIVERSITY OF ALABAMA, 201 7TH AVENUE, TUSCALOOSA, ALABAMA 35487, USA
2U.S. GEOLOGICAL SURVEY, 345 MIDDLEFIELD ROAD, MENLO PARK, CALIFORNIA 94025, USA

ABSTRACT

Two great earthquakes have occurred recently along the Sunda Trench, the 2004 M9.2 Sumatra-Andaman earthquake and the 2005 M8.7 Nias earthquake. These earthquakes ruptured over 1600 km of adjacent crust within 3 mo of each other. We quantitatively present poroelastic deformation analyses suggesting that postseismic fluid flow and recovery induced by the Sumatra-Andaman earthquake advanced the timing of the Nias earthquake. Simple back-slip simulations indicate that the megapascal (MPa)–scale pore-pressure recovery is equivalent to 7 yr of interseismic Coulomb stress accumulation near the Nias earthquake hypocenter, implying that pore-pressure recovery of the Sumatra-Andaman earthquake advanced the timing of the Nias earthquake by ~7 yr. That is, in the absence of postseismic pore-pressure recovery, we predict that the Nias earthquake would have occurred in 2011 instead of 2005.

The M9.2 Sumatra-Andaman earthquake and subsequent great tsunami of 26 December 2004 ruptured over 1200 km of crust, lasted ~8 min, and killed over 250,000 people in 12 countries surrounding the Indian Ocean (Ammon et al., 2005; Bilek, 2007; Vigny et al., 2005). Three months later, on 28 March 2005, a M8.7 earthquake centered off the coast of Nias Island just west of northern Sumatra ruptured over 400 km of crust, killed over 1300 people, and caused a minor tsunami (Fig. 1) (Ammon et al., 2005; Banerjee et al., 2007). Here, we present poroelastic deformation analyses that suggest postseismic fluid flow and recovery induced by the Sumatra-Andaman earthquake advanced the timing of the later M8.7 Nias earthquake.

We constructed finite-element models (FEMs) to simulate the coseismic stress and pore (fluid) pressure fields of the Sumatra-Andaman

Figure 1. Seismotectonic setting of the Sumatra-Andaman subduction zone (adapted from Hughes et al., 2010). Harvard centroid moment tensor (CMT) focal mechanisms are given for the Sumatra-Andaman earthquake and Nias earthquake. Aftershock epicenters (orange dots), spanning 26 December 2004 through 28 March 2005 and transparent orange area, illuminate the surface projection of the Sumatra-Andaman earthquake rupture (http://neic.usgs.gov). The rupture initiated on the southeast portion of the fault and propagated ~1200 km northward. The blue transparent area represents the surface projection of the Nias earthquake rupture (http://neic.usgs.gov). The sharply truncated aftershock distribution, shown with a northeast-trending dashed line (red) that bisects Simeulue Island, marks the boundary between rupture of the Sumatra-Andaman earthquake and subsequent Nias earthquake and represents the seismic barrier between the two earthquakes. Black triangles are nearfield global positioning system sites (Gahalaut et al., 2006; Subarya et al., 2006). The tectonic configuration is modified from Bird (2003) and overlies a shaded relief image of global relief data (http://www.ngdc.noaa.gov). Abbreviations: AI—Andaman Islands, BP—Burma plate, IAP—Indo-Australian plate, NI—Nicobar Islands, SI—Simeulue Island, GSF—Great Sumatran fault, SP—Sunda plate, and WSF—West Sumatra fault.

*E-mails: klhhughes@gmail.com; masterlark@ua.edu; mooney@usgs.gov.
Changes in Coulomb stress—defined as \( \Delta \sigma = \sigma_s + f(\sigma_n + \Delta P) \), where \( \sigma_s \) is Coulomb stress, \( \sigma_n \) is shear stress, \( f \) is friction, \( \sigma_n \) is normal stress, and \( P \) is pore pressure (Wang, 2000)—quantify the change in tendency for frictional slip, i.e., 10^6 Pa (Stein, 1999). Furthermore, these changes in Coulomb stress near the Nias earthquake hypocenter were significantly greater than changes attributed to either afterslip (McCloskey et al., 2005; Chlieh et al., 2007; Prawirodirdjo et al., 2010) or postseismic viscoelastic relaxation (Pollitz et al., 2006). Simple back-slip simulations (Savage, 1983) using the FEMs suggest that the 2.0 MPa pore-pressure recovery is equivalent to 7 yr of interseismic accumulation of Coulomb stress (0.22 MPa) near the Nias earthquake hypocenter—a result that suggests post-pore-pressure recovery of the Sumatra-Andaman earthquake advanced the timing of the Nias earthquake by ~7 yr. Therefore, instead of occurring in 2011, the Nias earthquake occurred in 2005 due to pore-pressure recovery. The results of this study indicate that the analysis of pore-pressure recovery is significant in addressing earthquake triggering at subduction zones worldwide.

**ACKNOWLEDGMENTS**

We thank two anonymous reviewers for insightful comments and suggestions. This work is supported in part by the National Aeronautics and Space Administration (NASA) under award NNX06OF10G, National Science Foundation (NSF) Geophysics grant EAR-0911466, and the W. Gary Hooks Endowed Geology Fund. Academic licensing and technical support for Abaqus software is provided by Simulia Inc., Dassault Systèmes.
REFERENCES CITED


