17 Deciphering the Mystery of the Great Indian Ocean Earthquakes

Kelly Wiseman and Roland Bürgmann

17.1 Introduction

On April 11, 2012, there were two magnitude 8+ earthquakes off the west coast of northern Sumatra, Indonesia. The first was a magnitude 8.6 and the second was a magnitude 8.2, two hours later. Both of these earthquakes were a result of strike-slip faulting within the oceanic lithosphere of the broadly distributed India-Australia plate boundary zone. Unlike the nearby 2004 magnitude 9.2 Sumatra megathrust earthquake that produced a disastrous tsunami, these earthquakes involved mostly horizontal motion and initiated more than 380 km from the Sumatra mainland, thereby limiting the shaking and tsunami damage. Although these earthquakes quickly faded from the news once the tsunami warnings were canceled, the magnitude 8.6 mainshock is incredibly significant as it holds the distinction of being both the largest instrumentally recorded strike-slip earthquake and the largest earthquake within the interior of a tectonic plate. Early geophysical studies have revealed another noteworthy aspect of these events, that the mainshock involved sequential ruptures of multiple fault planes oriented nearly perpendicular to each other. Here we discuss the unusual geological conditions within the Indian Ocean basin that allow for such a large, complex intraplate earthquake and relate the timing of these events to the 2004 megathrust earthquake.

17.2 Relation to the 2004 Sumatra-Andaman earthquake

The 2004 Sumatra megathrust earthquake fundamentally changed the stress state in the surrounding lithosphere and seismicity rates have been enhanced throughout Southeast Asia in the years following the great earthquake. The yellow and blue beach balls in Figure 2.34b,c (www.globalcmt.org) depict the focal mechanisms for all of the strike-slip earthquakes in the incoming Indian and Australian plates, west of the Sunda trench, during the years between the 2004 and 2012 earthquakes. The mechanisms are very similar to the focal mechanisms for the two April, 2012 earthquakes (shown in red), and are consistent with either left-lateral strike-slip motion on the N-S oriented fractures, or right-lateral motion on E-W oriented planes.

The 2012 mainshock initiated at 20 km depth and the aftershock pattern (gray dots in Figure 2.34a, USGS NEIC catalog), along with preliminary back-projection rupture propagation models (Meng et al., 2012), suggests complex rupture on multiple fault planes. It appears that the mainshock started with bilateral shear away from the hypocenter on an E-W oriented plane (red fault segment in Figure 2.34a) and then bilaterally ruptured a N-S oriented plane to the west of the hypocenter (yellow segment labeled 2). It ended with slip on two additional E-W oriented segments to the south, near the eventual magnitude 8.2 aftershock (yellow segments labeled 3 and 4) (Delescluse et al., 2007). The 2012 mainshock was able to grow to such a large magnitude because it was able to continue rupturing beyond the initial E-W fault plane, on multiple nearby faults in the weak, heavily fractured northern Wharton Basin. This complex rupture scenario is similar to the second largest Wharton Basin earthquake, a magnitude 7.9 earthquake in June 2000, that started as left-lateral strike-slip motion on a
N-S plane and ended as oblique motion on an E-W plane (Abercrombie et al., 2003). Half of the focal mechanisms for the 2012 aftershocks show oblique motion, indicating that the magnitude 8.6 earthquake may have included an oblique sub-event as well.

We have calculated the stresses induced by the 2004 (Chlieh et al., 2007) and 2005 (Konca et al., 2007) megathrust earthquakes at the hypocenter of the magnitude 8.6 earthquake in order to determine if the 2012 earthquakes were triggered events. We modeled the static, coseismic stress perturbations from the two nearby megathrust ruptures and the time-dependent perturbations resulting from postseismic relaxation of the upper mantle following the megathrust events. The 2004 earthquake contributed most of the stress changes at the 2012 hypocenter and further to the north spanning the zone of enhanced strike-slip activity. The rate of strike-slip activity in the northern Wharton Basin increased greatly in the initial months following the 2004 earthquake (yellow beach balls in Figure 2.34b,c), and continued at a lower level up until the 2012 earthquakes. The combined coseismic stress perturbation from the 2004 and 2005 earthquakes was ~18 kPa at the hypocenter (Figure 2.34b), with similar values when resolving stress on either the E-W or N-S fault plane orientation. The additional stress perturbations from postseismic deformation can explain the continued strike-slip activity during the years following the 2004 earthquake (blue beach balls in Figure 2.34b,c). By April 2012, the postseismic stress perturbation from the megathrust earthquakes was ~4 times larger than the induced coseismic stresses at the 2012 hypocenter, highlighting the importance of postseismic deformation for triggering earthquakes away from the coseismic rupture plane. (Figure 2.34c). A magnitude 7.2 foreshock, ~25 km NE of the mainshock in January 2012, involved right-lateral slip on an E-W oriented fault and added a final push before the April events.

17.3 Discussion

The high strain-rates within the Wharton Basin enable strike-slip earthquakes over a wide portion of the plate interior, and the stresses imparted to the oceanic lithosphere by the 2004 earthquake induced a spike in these strike-slip earthquakes. This behavior is particular to the Equatorial region of the Indian Ocean basin, as we did not see triggered strike-slip earthquakes in the Pacific plate following the 2011 Tohoku earthquake. The 2012 magnitude 8+ events were the latest in this collection of post-2004 strike-slip earthquakes and the additional stress imparted to the lithosphere from the postseismic deformation can explain the time delay between the 2004 and 2012 earthquakes. The 2012 mainshock was so large because it was able to rupture multiple weak spots within the oceanic lithosphere, including four separate fault planes. The annual moment rate for the entire Wharton Basin, that actively deforms down to 20°S, is ~ 3.5 x 10^{19} \text{Nm/yr} (Delescluse and Chamot-Rooke, 2007), and these two magnitude 8+ strike-slip earthquakes released ~270 years of accumulated seismic moment. The northern portion of Wharton Basin is the highest straining region in the diffuse India-Australia boundary zone, accommodating roughly 1 cm/yr of N-S left-lateral shear (Delescluse and Chamot-Rooke, 2007), so this region should have shorter earthquake repeat times, on the order of 500-1000 years, than the rest of the region. Over the past millennia, the megathrust earthquake periodicity for the southern end of the 2004 rupture has been roughly 400-600 years (Meltzner et al., 2010), therefore these great oceanic strike-slip earthquakes may coincide with the great Sunda megathrust earthquakes every 1-2 cycles. Although these 2012 earthquakes did not cause much damage or casualties, they highlight the risk that very large earthquakes can occur within the interior of a plate, and that unexpected events can be triggered well after great megathrust earthquakes.

17.4 Acknowledgments

This work is supported by the National Science Foundation grant EAR 0738299.

17.5 References


