Soft Volcanic Sediments Compound 2006 Java Earthquake Disaster

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When the region south of Mount Merapi volcano in central Java, Indonesia, was struck by a magnitude 6.4 earthquake, the city of Yogyakarta and its suburbs were partly devastated. The event caused severe damage to the densely inhabited area, leaving about 6000 people dead, 50,000 injured, and between 500,000 and 1 million homeless. With over 155,000 houses totally destroyed and 200,000 damaged, more houses were affected in this earthquake area than in Aceh and Nias after the earthquake-tsunami disasters of 26 December 2004 and 28 March 2005 combined [*United Nations*, 2006].

Shortly after the earthquake, the Merapi volcano significantly increased its activity; the volume of the lava dome extrusion tripled, as did the number of pyroclastic flows [*Walter et al.*, 2007]. In addition, the volcano also may have indirectly augmented the scale of the earthquake disaster because damage was caused to those areas underlain by remobilized volcaniclastic deposits, as this brief report discusses.

Search for the Source

A global net of seismic stations allowed for automatic earthquake location (see http://www.gfz-potsdam.de/geofon/) and determination of the rupture mechanism (see http://www.globalcmt.org/CMTsearch.html and http://neic.usgs.gov/neis/eq_depot/2006). These data suggested that a fault with a southwest-northeast orientation ruptured with significant strike-slip motion, and that the location of the epicenter was close to the major Opak River Fault [*Rahardjo et al.*, 1977]. The disaster area was found along a 30-kilometer stretch of this fault, apparently confirming it as the source of the earthquake (Figure 1). However, field observations did not reveal a significant scale of movement along the fault or its nearby branches, implying that the source of the earthquake may have been located elsewhere.

In order to better understand the earthquake physics, just 6 days after the earthquake a rapid response team of the German Task Force for Earthquakes, together with the Seismological Division of Badan Meterologi and Geofisika and the Gadjah Mada University in Yogyakarta, had set up a temporary network of 12 seismic stations surrounding the earthquake area in an attempt to precisely measure aftershocks.

The recorded events provide important insights about the location and geometry of the earthquake rupture plane. We are using the HYPO71PC program [*Lee and Lahr*, 1972] and, in order to take a realistic velocity structure into account, a velocity layered crustal model derived by the 2004 Merapi Amphibious Experiment (MERAMEX) and a seismic tomography study [*Koulakov et al.*, 2007; *Wagner et al.*, 2007]. The results show that the aftershock hypocenters are not aligned along the Opak River Fault as originally thought, but rather are aligned at a previously unidentified fault farther to the east. Most of the aftershocks arrange in a northeast-southwest direction at a depth of 8–15 kilometers.

The result is surprising because the earthquake hypocenters are located in a region of minor damage at a distance of 15 kilometers from the disaster area, providing an explanation for the absence of primary fault displacement along the Opak River Fault.

Why, then, did this earthquake cause severe loss around Yogyakarta? Geologic data suggest that the earthquake caused damage to those areas underlain by young volcanic sediments [*Rahardjo et al.*, 1977]. The sediments are mechanically soft, mainly redeposited and altered volcaniclastics originating from the Merapi volcano to the north, and they probably reached thicknesses of about 200 meters near the Opak River. The sediment deposition is very large during rainy seasons, when pyroclastic material from the volcano is transported in the form of mudflows, or lahars. Lahars along individual rivers south of the volcano may deposit sediments that annually exceed 200,000 cubic meters per square kilometer at sedimentation rates of more than 3 centimeters per minute [*Lavigne and Thouret*, 2003]. These rapidly deposited sediments, which are unconsolidated, may have locally increased the seismic effects. A package of such soft sediments is thought to underlie the disaster area, amplifying the seismic waves due to resonance effects.

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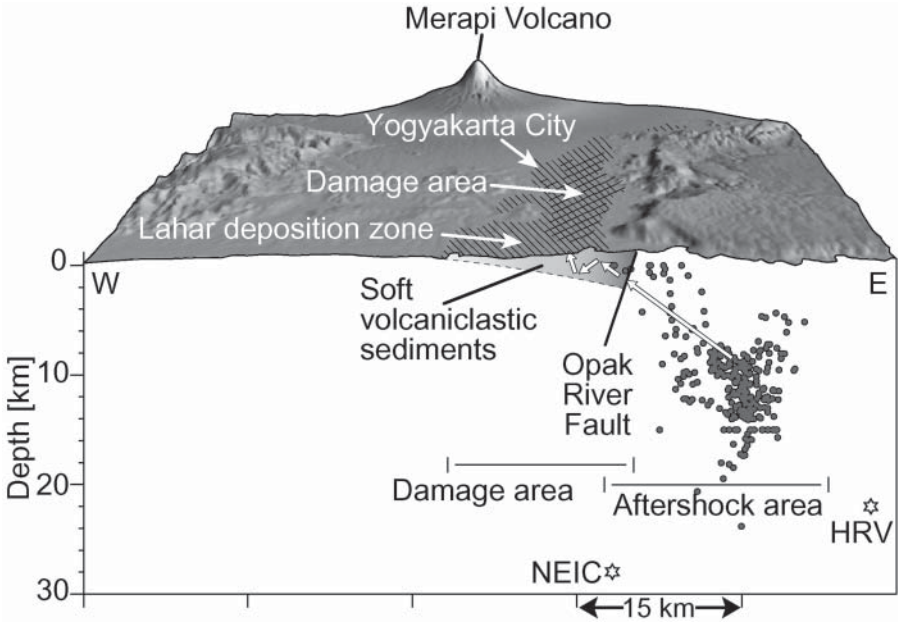

Fig. 1. Shaded relief topography map of the Yogyakarta district south of Merapi volcano. An east-west profile shows a projection of Task Force aftershock data from 0 to 30 kilometer depth located beneath an area without major damage. The earthquake disaster was most severe at 15 kilometers farther to the west. The damaged area is underlain by soft volcaniclastic sediments that may have amplified the ground shaking. Stars indicate teleseismic hypocenter locations.