

The Flores Island Tsunamis

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On December 12, 1992, at 5:30 A.M. GMT, an earthquake of magnitude M_s 7.5 struck the eastern region of Flores Island, Indonesia (Figure 1), a volcanic island located just at the transition between the Sunda and Banda Island arc systems. The local newspaper reported that 25-m high tsunamis struck the town of Maumere, causing substantial casualties and property damage. On December 16, television reports broadcast in Japan via satellite reported that 1000 people had been killed in Maumere and two-thirds of the population of Babi Island had been swept away by the tsunamis.

The current toll of the Flores earthquake is 2080 deaths and 2144 injuries, approximately 50% of which are attributed to the tsunamis. A tsunami survey plan was initiated within 3 days of the earthquake, and a cooperative international survey team was formed with four scientists from Indonesia, nine from Japan, three from the United States, one from the United Kingdom, and one from Korea.

Background

Flores Island is one of several large islands in the East Nusa Tenggara region of Indonesia, approximately 1800 km east of Jakarta (Figure 2a). The Indonesian region is located at the intersection of three lithosphere plates: the Indian-Australia plate, the Pacific plate, and the Asian continental plate. The Asian continental plate is fragmented into several deformed subplates. The Indian Ocean lithosphere subducts beneath the fragmented Asian continental subplates along the Sunda Trench and forms an arc system. Beyond the Sunda trench, the Banda sector continues eastward to where the oceanic arc collides with Australia. Detailed tectonic setting of this area was given by Hamilton [1988], for example.

The epicenters of the December 12 mainshock and the area of aftershocks were determined by the U.S. Geological Survey (see Figure 2b). The location of the epicenter is at 8.482°S , 121.930°E , approximately 50 km northwest of Maumere. The hypocenter was estimated to be 15 km deep. The fault parameters, based on seismic surface and body waves, were obtained from the Harvard University centroid moment tensor (CMT) solution (M121292y): strike direction 61° , dip

angle 32° , slip angle 64° , and seismic moment 6.4×10^{27} dynes-cm. The earthquake area is considered to be in a backarc region of the eastern Sunda arc or western Banda arc, a segment containing many active volcanoes. We conjecture that this is a backarc-thrust earthquake with tectonic setting (G. Plafker, personal communication, 1993); such a backarc thrust must be located between the existing Flores thrust and the minor thrust near the eastern peninsula of Flores Island (Figure 2b). The mechanism of this earthquake resembles the 1983 Nihonkai Chubu earthquake in the Sea of Japan, which also caused significant tsunami damage, and more recently, the 1991 Costa Rica earthquake, which also generated tsunamis [Plafker and Ward, 1992]. (The earthquake that struck Okushiri Island, Japan, on July 12, 1993, can be considered to be a back-arc earthquake.)

To make an initial estimate of the tsunami generation, a fault plane was determined based on the distribution of aftershocks directly related to the mainshock; those aftershock locations are shown in Figure 2b. The estimated fault plane is located in an area approximately 100 km long and 50 km wide. Using these parameters and assuming the value of rigidity = 4.0×10^{11} dynes/cm², the computed dislocation was found to be 3.2 m, and the maximum vertical displacement of the sea bottom was computed to be 1.3 m, which directly trans-

lates to the sea-surface magnitude of the initial tsunami formation. With this initial condition, a preliminary prediction of tsunami propagation and run-up was computed by the numerical simulation model [Shuto *et al.*, 1990]. The predicted tsunami run-up heights along the coast of Flores Island are shown in Figure 3a. The model indicates that the hardest hit area would be an approximately 100-km-long coastline east of Maumere with a maximum predicted height of 1.4 m at the north shore of the Hading Bay. Surveying efforts were focused on this area.

Tsunami Survey

Seventeen days after the earthquake, the team began its survey on Flores Island, gathering data from December 29 through January 5. The survey consisted of measurements of maximum tsunami run-up heights and distances, average run-up heights and areas of inundation, flow patterns of run-up and run-down, eyewitness accounts, and observations of subsidence, uplift, and landslides. In addition to the ground survey, the helicopter aerial survey was conducted with the cooperation of the Indonesian military.

The maximum tsunami run-up height is defined as the vertical water-surface elevation reached by the tsunamis above sea level. It is measured using standard surveying instrumentation. The run-up mark was determined visually based on water marks on structures and/or the ground, breakage of tree limbs, scratch-marks on trees or structures caused by waterborne objects, and/or location of waterborne debris. Every mark used for the run-up was photographed for archiving, and its location was identified using a global positioning system (GPS).



Fig. 1. Tsunami attack site in Riangkroko, looking toward inland. See Figure 3 for location. (Photo courtesy of H. Yeh.) [Original color image appears in the back of this volume.]

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