THE 1998 PAPUA NEW GUINEA TSUNAMI : AN OVERVIEW

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On July 17, 1998, less than two months following the conclusion of the Paris Tsunami Conference, a catastrophic tsunami took place in the Sandaun province of Papua New Guinea, resulting in widespread destruction in the area of Sissano Lagoon, and killing upwards of 2100 persons. This figure makes it the second deadliest tsunami in the 20th century, surpassed only by the 3000 deaths reported during the great Sanriku tsunami of 1933. While many members of the tsunami community worldwide are still busy studying various aspects of this deadly event, it seems appropriate to include a short description of its main characteristics in the proceedings of the Paris conference, since they can be directly related to many themes developed in the present volume.

The parent earthquake of the Sandaun tsunami took place at 08:49 GMT (18:49, or a few minutes before sundown, local time) in the northwesternmost section of Papua New Guinea, approximately 35 km Northwest of the port city of Aitape (see Figure 1). The earthquake was relatively moderate by seismological standards, reaching magnitudes $m_b = 5.9$ and $M_s = 7.0$. Mantle magnitude estimates [*Okal and Talandier,* 1989] were immediately computed at Papeete and Northwestern University, yielding $M_m = 6.8$, in agreement with the seismic moment of $M_0 = 5.2 \times 10^{26}$ dyn-cm obtained by the Quick CMT algorithm at Harvard University. The main shock was followed by a number of aftershocks, the largest one taking place at 09:10 GMT and felt strongly at Aitape, an observation supporting a more Eastward location relative to the main shock (Figure 1).

The earthquake was followed within about 20 minutes by a series of three sea waves, which destroyed all communities located along a 25-km stretch of coastline (Figure 1). The damage was particularly heavy around Sissano Lagoon, a 30–km^2 body of water separated from the high seas only by sand spits no wider than a few hundred meters, which supported several villages. To a large extent, their residents, trapped between sea and lagoon, had nowhere to escape. Initial reports described wave heights of up to 10 m, by itself an exceptionally large figure given the size of the earthquake, and the basically flat, linear coastline. An additional and unusual feature of the destruction was its strong concentration along the coast with the amplitude of run-up diminishing to a benign 4 m only 15 km on each side from Sissano. In this respect, the Sandaun tsunami became intriguing as soon as early reports began trickling in from the epicentral area on July 18.

The slight discrepancy between body- and surface-wave magnitudes suggested early on that the earthquake may have had a slow source spectrum, and could be a new example of the so-called "*tsunami earthquakes*", similar for example to the 1992 Nicaraguan event. However, this was quickly ruled out by a further investigation at Northwestern University on July 18, through the computation of the estimated seismic energy in the body waves, E^E. *Newman and Okal* [1998] defined a slowness parameter, $\Theta = \log_{10} E^E / M_0$, expected to take the value −4.90 for regular seismic sources. The value obtained for the Sandaun earthquake, $\Theta = -5.50$, shows a slight deficiency in the high-frequency spectrum of the event, but remains significantly larger than for typical tsunami earthquakes (Nicaragua, 1992: $\Theta = -6.30$; Java, 1994: $\Theta = -6.01$). On this basis, it appeared as early as July 18 that the Sandaun tsunami could not simply be explained by a slow component to the earthquake source.

The devastated area was the subject of a detailed survey by an international team [*Kawata et al.*, 1999], from August 1 to August 6, 1999. More than 80 inundation data points, as well as 30 topographic transects, were measured along a stretch of 40 km of shoreline, from Aitape to Serai (see Figure 1), with several additional points obtained at Vanimo (on the Indonesian border, 100 km West of Sissano) and at Wewak (190 km to the East). In the most devastated area surrounding Sissano Lagoon, the average flow depth measured was 10 m, reaching 15 m at one point in Arop. Figure 2 presents a particularly evocative snapshot of a household bucket deposited in a tree branch, 7 m above ground at Sissano Lagoon. Sediment deposition thicknesses of 15 cm were commonly observed with current velocities inferred at 15–20 m/s.

On the other hand, we could not find any evidence of permanent deformation from the earthquake itself: no fault scarps or obvious changes in sea level could be identified; only at one site on the eastern spit, was an occurrence of liquefaction recognized. The only observable damage done by the earthquake was the collapse of a stack of tree trunks and a 40-m high rock slide in a highly weathered cliff, both located at the western end of the Serai lumber mill, which marks the transition from a flat coastal plain to higher relief along the coastline.

Efforts to model the data collected during the survey focused initially on the possibility of generation of the tsunami by the mainshock at 08:49 GMT. An initial inversion of the seismological characteristics of the main shock indicated a fault length of ~35 km, and a vertical motion of ~2 m. Hydrodynamic models based on these numbers are by themselves unable to explain the size of the tsunami [*Titov and González*, 1998; *Piatanesi and Heinrich*, pers. comm., 1999], which would require at least 8 m of displacement, an improbable slip for such a small seismic source. Similarly, the main aftershock at 09:10 ($m_b = 5.6$; $M_m = 5.75$; $\Theta = -4.80$) cannot be the source of the tsunami, a conclusion corroborated by the tentative timing of the arrival of the tsunami described by interviewed survivors.

In this context, speculation grew quickly (actually as early as July 19) that the source of the tsunami should be sought in an underwater landslide triggered by the mainshock. This suggestion was of course circumstantial in nature, but considerable support was obtained during cruises organized in December 1998 and January 1999 on Japanese research vessels. These marine surveys of the continental shelf off the coast of the Sandaun province revealed a fresh underwater slump centered around 2.85°S and 142.25°E, and covering approximately 60 km^2. While there is no firm evidence that the slump took place on July 17, it is nevertheless an excellent candidate for the source of the tsunami. Preliminary modeling by *Watts et al.* [1999] and *Piatanesi and Heinrich* [pers. comm., 1999] suggests that a slump source with a volume of ½ to 1 km^3 located on the continental slope would match the run-up heights observed at Sissano and along the coast.

An examination of the aftershocks immediately following the mainshock reveals two events detected teleseismically between the main shock at 08:49 GMT and the main aftershock at 09:10:02 ($m_b = 5.6$), the latter featuring a small precursor ($m_b = 5.3$) at 09:09:32: a small earthquake at 09:06:01 has poor longitudinal resolution, and an event with $m_b = 4.4$ at 09:02:06 relocates to the North of the fault zone, with its 95%-confidence ellipse intersecting the slump area (Figure 1). All shocks generated acoustic (T) waves in the ocean, well recorded at the Wake Island seismic station. Among them, the 09:02 earthquake features an intriguing T wave, lasting ~50 s, a considerable duration for such a small earthquake. While more research is warranted, it is tempting to speculate that the 09:02 seismic event is indeed the slump triggered by the earthquake and responsible for the generation of the tsunami. Its timing would result in the wave arriving at some shore locations before the main 09:10 aftershock, while it would reach other sites such as Aitape after the main aftershock, in general agreement with the best estimates of the timing of the tsunami reconstructed from interviews with survivors.

The identification of a slump as a probable origin of the Sandaun tsunami has considerably renewed our interest and sharpened the concern of the scientific and engineering community over the contribution of underwater slumps to tsunami hazard. The 1998 Papua New Guinea tsunami is a tragic illustration of the potential of relatively moderate earthquakes to raise lethal tsunamis in areas where generous sediment deposition may result in unstable accumulates. Few coastal areas would be immune to the relatively small (and hence possibly more frequent) class of earthquakes comparable to the Sandaun event of July 17, 1998, whose moment remained well below 10^{27} dyn-cm, a figure heretofore often quoted as a threshold for regional tsunami hazard.

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References

Kawata, Y., B.C. Benson, J.C. Borrero, J.L. Borrero, H.L. Davies, W.P. de Lange, F. Imamura, H. Letz, J. Nott, and C.E. Synolakis, The July 17, 1998 Papua New Guinea earthquake and tsunami, *Eos, Trans. Amer. Un.*, **80**, 101 and 104, 1999.

Newman, A.V., and E.A. Okal, Teleseismic estimates of radiated seismic energy: The E/M_0 discriminant for tsunami earthquakes, *J. Geophys. Res.*, **103**, 26885–26898, 1998.

Okal, E.A., and J. Talandier, M_m: A variable period mantle magnitude, *J. Geophys. Res.*, **94**, 4169-4193, 1989.

Titov, V., and F. González, Numerical study of the source of the July 17, 1998 PNG earthquake, *Eos, Trans. Amer. Geophys. Un.*, **79**, *(45)*, F572, 1998 [abstract].

Watts, P., J. Borrero, D. Tappin, E.A. Okal, J.-P. Bardet, S. Grilli, and C.E. Synolakis, The July 17, 1998 Papua New Guinea tsunami generated by a giant slump, *Science*, submitted, 1999.

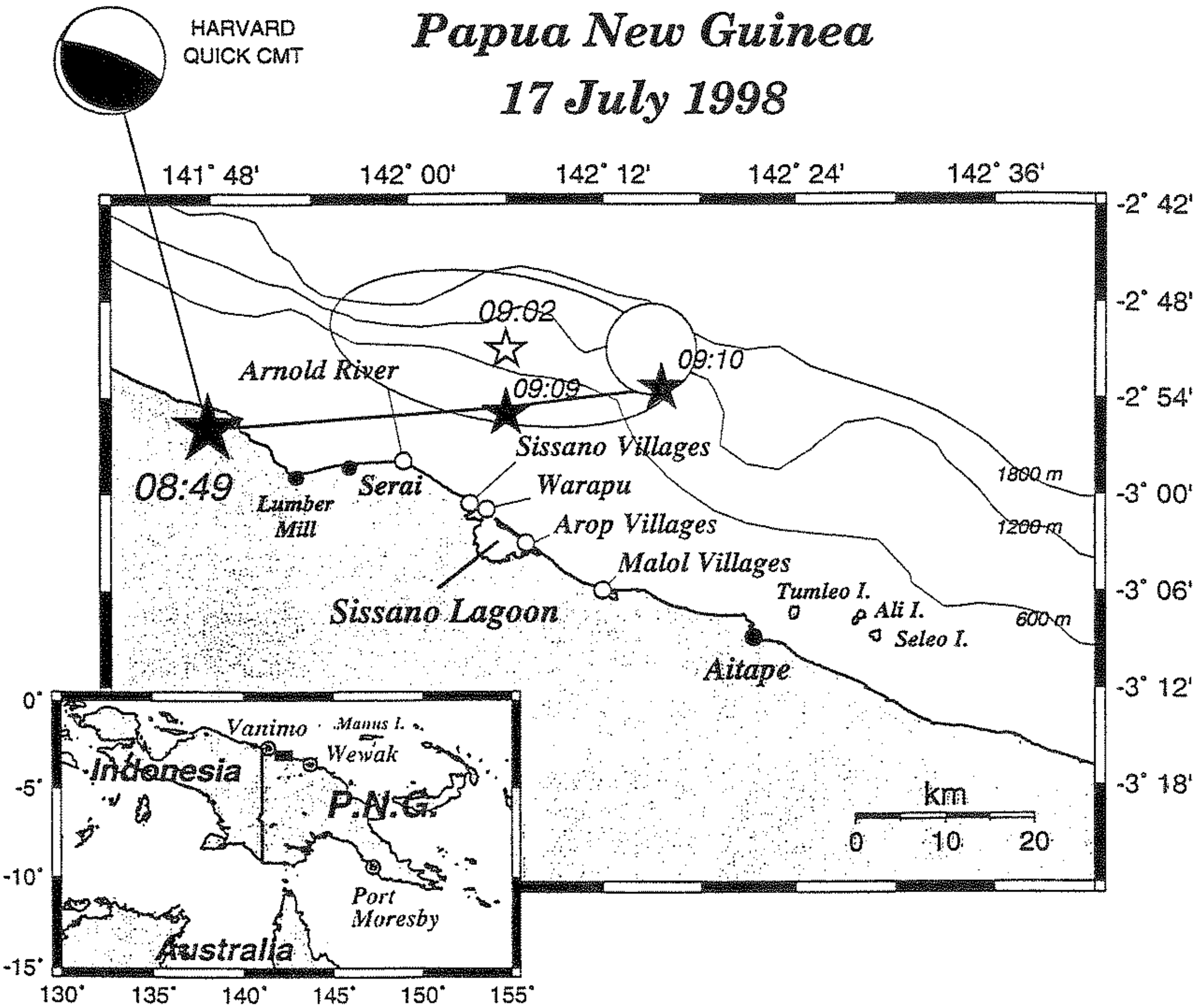


Figure 1. Map of the Sandaun coast of Northwestern Papua New Guinea (black rectangle in insert locates main map). Open circles on coastline identify devastated villages; full circles are other communities mentioned in text. The dark stars are epicenters of the mainshock (large symbol) and of the aftershock doublets (smaller symbols) at 09:09 and 09:10 GMT. The line joining them is the extent of the seismic rupture, as inferred from early seismological modeling. The light star is the relocated epicenter of the 09:02 seismic event (with error ellipse). The grey disk schematizes the location of the slump identified by the Japanese surveys.

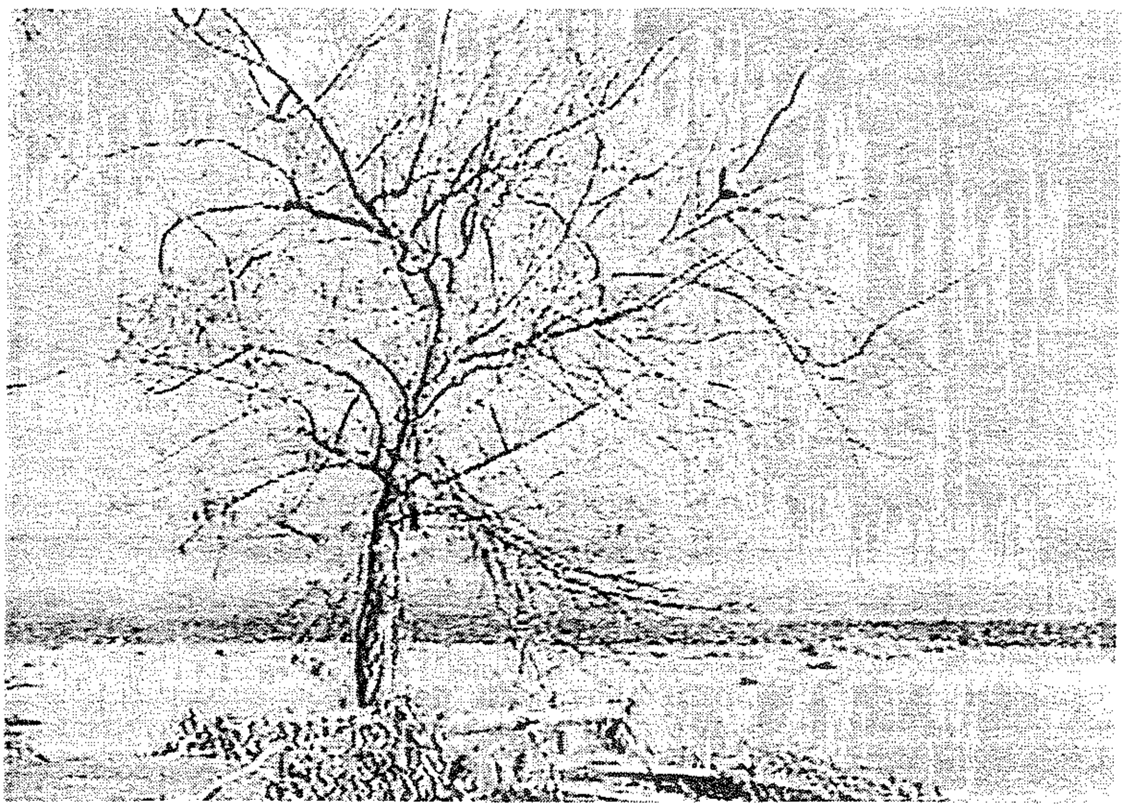
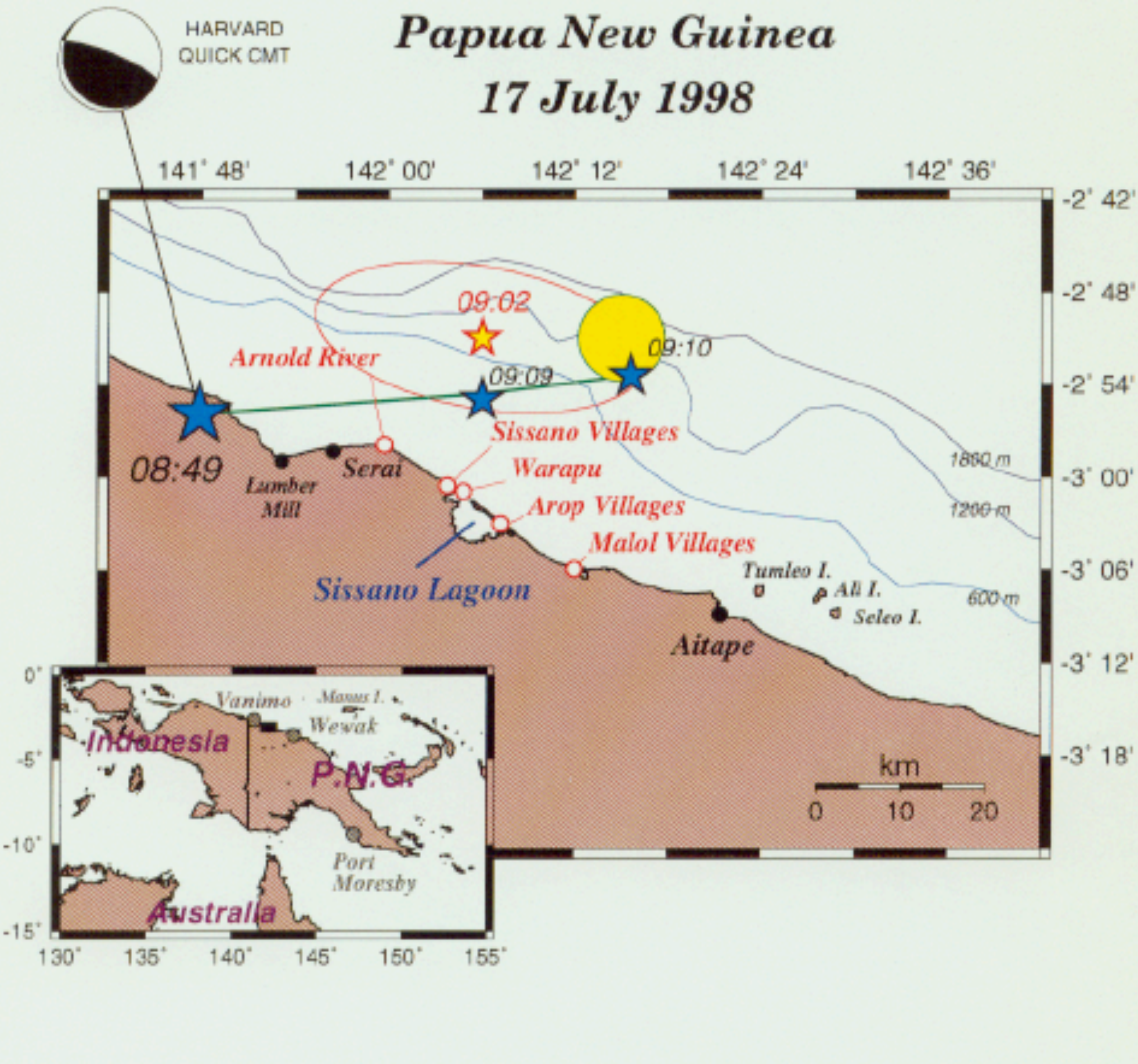


Figure 2. A tree left standing on the shore of Sissano Lagoon. Note the bucket deposited by the wave 7 m above ground. The view is South across Sissano Lagoon from the Eastern spit. [Photograph courtesy of J.C. Borrero, August 3, 1998.]



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