The landslide and local tsunami of 13 September 1999 on Fatu Hiva (Marquesas Islands; French Polynesia)

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Key words. – Tsunami, Landslide, French Polynesia, Marquesas Islands.

Abstract. – On 13 September 1999, a local tsunami, comprising two waves separated by a few minutes, hit the village of Omoa, on the island of Fatu Hiva, French Polynesia. It inflicted serious damages to structures built close to the seashore, in particular to the local elementary school. The tsunami was generated by the collapse of a basaltic cliff, located 3 km to the southeast of Omoa, along the coastline. The volume of the landslide is estimated to range from 2 to 5 million m³, of which 60 % fell into the sea. A preliminary simulation of the tsunami provides an acceptable explanation of wave amplitudes, as well as an estimate of the origin time of landslide.

L'éboulement et le tsunami local du 13 septembre 1999 à Fatu Hiva (îles Marquises; Polynésie française)

Mots clés. – Tsunami, Eboulement, Polynésie française, Iles Marquises.

Résumé. – Un tsunami local, comprenant deux vagues séparées de quelques minutes, s'est abattu le 13 septembre 1999 sur le village d'Omoa (île de Fatu Hiva, Polynésie française), infligeant de sérieuses destructions aux structures en bord de mer, et notamment à l'école communale du village. Ces vagues ont été engendrées par l'éboulement d'un pan de falaise basaltique, à 3 km au sud-est d'Omoa, le long de la côte. Le volume de l'éboulement est estimé se situer entre 2 et 5 millions de m³, dont 60 % ont pénétré en mer. Une simulation préliminaire du tsunami donne des valeurs acceptables pour l'amplitude des vagues à Omoa, et fournit une estimation de l'heure origine du phénomène.

INTRODUCTION

At approximately 22 : 40 UTC (13 : 10 local time) on 13 September 1999, a series of two waves inundated the beachfront of the village of Omoa, on the island of Fatu Hiva, which is part of the Marquesas group in French Polynesia (fig. 1), at low tide, and during an episode of calm weather and seas. The waves seriously damaged waterfront property, including the local school. The origin of this local tsunami was found to be a major subaerial rockslide in a cliff located 3 km southeast of the village, immediately east of Pointe Mahitoa. Yet, no precursory signal — seismic shaking or audible sound — was reported in Omoa.

The possibility that significant tsunamis could be generated by landslides was first proposed by Milne [1898], and Gutenberg [1939] actually suggested that landslides were the primary mechanism for generating large tsunamis. More recently, Keating and McGuire [2000] have reviewed the tsunamigenic properties of a number of landslides, in the general context of the destabilization of volcanic edifices, their size ranging from small rockfalls to massive slides, such as the Hawaiian mega-slides identified by Moore [1964], which reach up to 34,000 km³ [Rees *et al.*, 1993]. Among seismic events whose tsunamis were attributed by modern studies to underwater landslides are the fol-

lowing earthquakes : Amorgos, Greece, 1956 [Ambraseys, 1960]; Suva, Fiji, 1953 [Houtz, 1953]; Grand Banks, Newfoundland, 1929 [Hasegawa and Kanamori, 1987]; Kalapana, Hawaii, 1975 [Eissler and Kanamori, 1987]; and Papua New Guinea (PNG), 1998 [Synolakis *et al.*, 2002]. In addition, localized underwater landslides triggered by neighboring large earthquakes have been argued to explain locally enhanced values of tsunami runup [Plafker *et al.*, 1969; Imamura *et al.*, 1995]. Tsunamigenic underwater landslides have also occurred in the absence of perceptible seismic activity, *e.g.*, the 1979 Nice, France [Assier-Rzadkiewicz *et al.*, 2000] and 1994 Skagway [Plafker *et al.*, 2000] events.

In addition to such landslides originating underwater, a number of tsunamis have been generated by large, originally subaerial landslides which reached the coastline and eventually spilled into the ocean. Such scenarios have been documented during volcanic eruptions in the Eolian Islands [Tinti *et al.*, 1999] and in the Caribean [Heinrich *et al.*, 2001], and may have been involved at Augustine Volcano, Alaska [Waythomas, 2000]. Because they are directly observable, subaerial slides have been the subject of extensive study from the dynamic and seismological standpoint, the best example being perhaps the event accompanying the 1980 explosion of Mt. St. Helens [Kanamori *et al.*, 1984],

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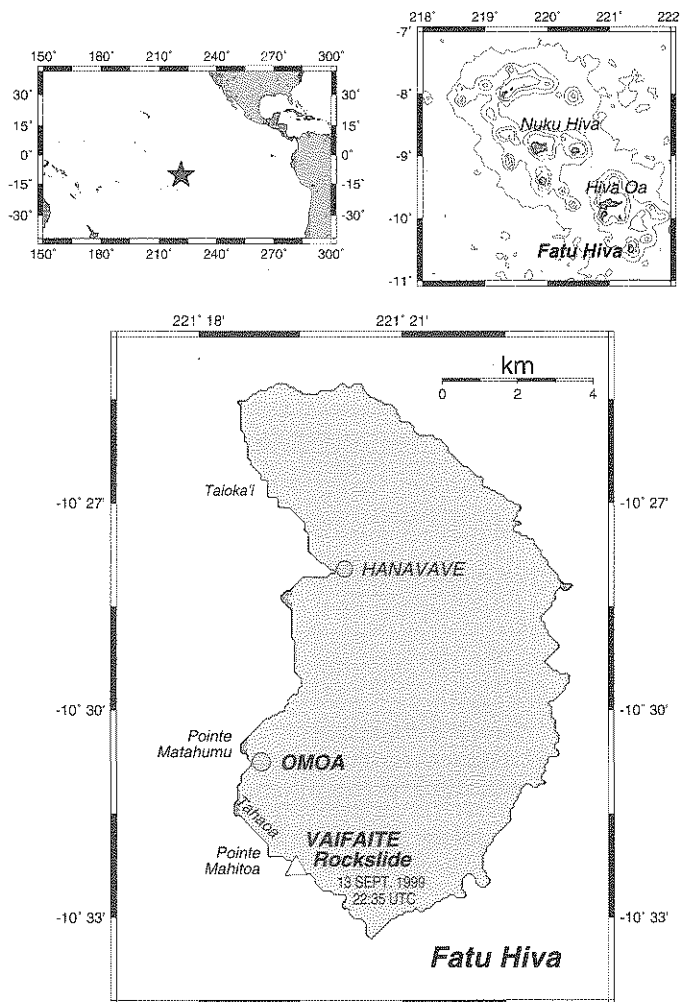[3] Department of Civil Engineering, University of Southern California, Los Angeles, CA 90089, USA.

FIG. 1. – *Top* : Maps locating the Marquesas Islands in the Pacific (left), and the island of Fatu Hiva within the Marquesas group (right). *Bottom :* Map of the island of Fatu Hiva, showing the two villages (circles) and the location of the Vaifaite cliff and rockslide (triangle). Other localities referred to in the text are identified.
FIG. 1. – *Haut : cartes localisant les îles Marquises dans le Pacifique (à gauche) et Fatu Hiva dans l'archipel (à droite). Bas : carte de Fatu Hiva, montrant les deux villages (cercles) et la position de la falaise éboulée à Vaifaite (triangle). Les autres lieux mentionnés dans le texte sont aussi identifiés.*

which, however, did not reach the ocean and thus generated no tsunami.

As will be detailed later, the 1999 Fatu Hiva landslide is unique in that it was generated above sea level, penetrated the ocean mass, but was most probably contained on the shallow, largely flat drowned beach.

ON-SITE SURVEY

Survey team

Fatu Hiva (77 km²) is the southernmost and youngest member of the Marquesas chain. Its last episode of volcanism has been dated at 1.3 Ma [Duncan and McDougall, 1974]. The island is kidney-shaped, and represents the remaining eastern half of the original volcanic edifice. Like all islands in the Marquesas, it is presently devoid of coral reefs, although drowned coral structures attest to their past existence.

tence. The population of Fatu Hiva is concentrated in two villages, Omoa (pop. ≈ 400) and Hanavave (pop. ≈ 200), at the mouth of the major valleys on the west coast.

In the aftermath of the disaster, a survey team consisting of the four authors of this paper was assembled and traveled to Fatu Hiva, reaching Omoa on 4 October 1999. The principal goal of the survey was to understand the origin of the local tsunami, and to build a database of runup and inundation values, to be used later for the purpose of numerical modeling. Because of the three-week delay between the tsunami and our visit, the quality of some watermarks had already started to erode; in addition, and understandably, a large clean-up effort had already taken place with most debris from the waves hauled away before our arrival.

Damage at Omoa

The most critical damage inflicted by the waves was at the local elementary school, located at the southern end of the waterfront (fig. 2). The school is built on a slight incline rising southward. The first wave totally destroyed the wall surrounding the school's playground, built of reinforced concrete; some of its blocks were carried a distance of 10 m, and rammed the doors to the principal's office at the northern and lower end of the building (fig. 3), which was then flooded and damaged. The school principal, wading waist-deep through the water, ordered the evacuation of the classrooms through the inland-facing back windows before the arrival of the second wave, a few minutes later. The teachers' room was also flooded and heavily damaged, with an estimated 20 cm of sand deposited on its floor. The classrooms, located progressively further south and slightly higher elevations, were also flooded, but with less damage.

Miraculously, no lives were lost, despite the fact that school was in session at the time (13 : 10 local time), with an estimated 85 children in attendance, the pre-schoolers (aged 3 to 6) taking their afternoon nap on the outside patio of their classroom, fortunately located at the southern (and higher) end of the school complex. Tragedy was avoided only through a combination of exceptional circumstances : the low tide (high tide would have added another meter to the runup), the arrival of the wave from the south, which resulted in the deflection of part of its energy by Motutapu (see below), and the immediate reaction of the school principal, acting with remarkable self-control and professionalism.

In addition to the school, the ice-making plant (fig. 2) was also severely damaged. While the concrete walls were left standing, the aluminum roof was carried away, and the refrigerating compressor unit was transported to the northern edge of the soccer field, a distance of approximately 60 m. Wooden sheds used to store pirogues (outrigger canoes), located between the soccer field and the Vaitopii river, were destroyed. Twelve pirogues were carried across the river and their wreckage left in the forest on the northern side. A copra-drying stand was also destroyed.

Based on our interviews, we were unable to gather evidence for any significant topographic or geomorphologic change in the affected areas.
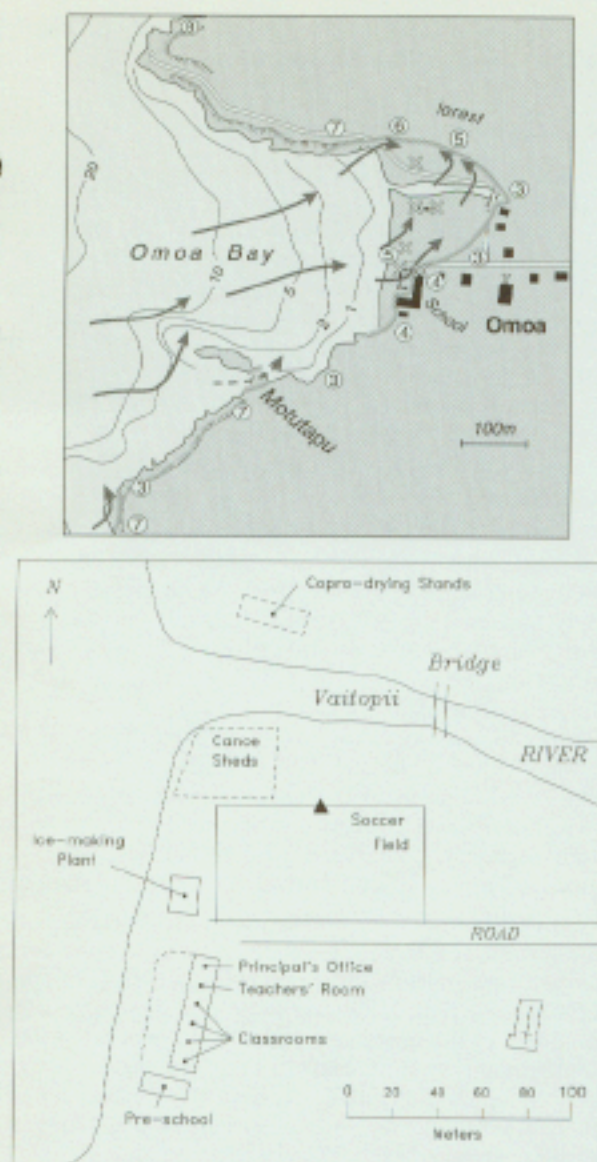
FIG. 2. – *Top :* Map of inundation around Omoa Bay. Circled numbers are runup amplitudes in meters, the thick line is the limit of penetration of the waves, and the arrows sketch the deflection of the waves by Motutapu. Crosses identify damaged or destroyed structures. Bathymetric contours in Omoa Bay are in meters. *Bottom :* Close-up map of the beach front of the village of Omoa. Dashed lines identify structures destroyed beyond repair. The school complex is detailed at lower left, including the destroyed wall around the school yard (dashed). The solid triangle shows the location where the compressor unit from the ice-making plant was deposited.

FIG. 2. – *Haut : carte de l'inondation de la baie d'Omoa. Les chiffres encerclés indiquent les hauteurs d'inondation (en m), le trait épais la limite de pénétration des vagues, et les flèches leur déflection par Motutapu. Les croix indiquent les structures détruites ou endommagées. Les contours bathymétriques sont en mètres. Bas : carte détaillée du front de mer à Omoa. Les pointillés indiquent les structures totalement détruites. Le complexe scolaire se trouve en bas à gauche, y compris le mur détruit qui entourait la cour (pointillés). Le triangle indique le lieu de dépôt du compresseur de l'unité réfrigérante.*

Runup and inundation measurements

A map of inundation (fig. 2) was compiled, using standard surveying techniques, and based on the recognition of water marks and testimony by witnesses. The methods used follow the experience gained during several post-tsunami surveys [Tsuji *et al.*, 1995; Synolakis *et al.*, 1998]. The runup

FIG. 3. – The damaged school at Omoa, photographed on 4 October 1999. *Top* (looking SSE) : The wall (A) has been totally destroyed around the playground. The principal's office and teachers' room (B) have been damaged and are now boarded up. Classrooms located at slightly higher elevations (C) were merely flooded. *Center* (looking SW) : The wall (A) used to extend all around the yard (to point D), and has been destroyed. Note the Motutapu promontory in the distance (E), which provided some protection to the southern part of the bay. *Bottom* (looking south) : (F) shows the location of the entrance gate through the wall. Note the slight incline to the south which lessened the impact of the waves on the more distant classrooms, and especially on the pre-school building (G; hidden beyond shrubbery).

FIG. 3. – *Dommages à l'école d'Omoa, photographiés le 4 Oct. 1999. Haut (vue vers le SSE) : mur de la cour de récréation (A) totalement détruit, bureau de la directrice et salle des maîtres (B) endommagés, fermés par des contreplaqués ; salles de classe légèrement surélevées (C), qui furent simplement inondées. Centre (vue vers le SW) : le mur détruit (A) entourait toute la cour, jusqu'au point D. Remarquer à l'horizon le rocher Motutapu, ayant accordé une protection partielle à la partie sud de la baie ; Bas (vue vers le S) : le portail d'entrée de la cour se trouvait en (F). Remarquer la légère pente vers le fond de la cour qui a atténué l'impact des vagues sur les salles de classe, en particulier sur la maternelle (G : derrière les arbustes).*

height was measured at 4 m at the school, 5 m at the ice-making plant, 5 to 7 m on the northern shore of the river, and up to 8 m immediately north of the launching dock at Pointe Matahumu. South of Omoa Bay, the runup reached 7 m along the elevated shoreline, but only 3 m between the school and Motutapu, an outgrowth of basalt reaching 10 m altitude and protruding 120 m into the sea (220 m at a depth of 10 m below sea level). We attribute the pattern of runup heights, and in particular the lower values on the southern half of the bay, to the presence of Motutapu, which barred the direct progression of the wave, in particular sheltering the school from a more severe attack. A further measurement (7 m) was taken at Tahaoa beach.

The extent of inundation was further documented by fine-grained coral sand deposits at the river bridge (fig. 2), at a distance of 130 m from the shore, and at an altitude of 3 m. According to residents of a nearby house, this corresponded to the limit of onland inundation; as observed universally in other tsunami scenarios, waves penetrate substantially farther inland along river beds.

At Hanavave, the second village of the island, located in the Baies des Vierges, 5.7 km NNE along the western coast (fig. 1), the runup reached only 1.9 m, and the waves penetrated a mere 12.5 m inland, based on witness reports. The waves were not recorded on the other Marquesan islands.

Origin of the waves

We established the origin of the local tsunami as the collapse, in a major subaerial rockslide, of a section of volcanic cliff, approximately 3 km south of Omoa (4.5 km along the coast). Figure 4 shows the Vaifaite cliff, as photographed from a speed boat on 5 October 1999. We were fortunate to be offered a photograph taken by a resident of Omoa at the exact same spot in 1996, which allows a "before-and-after" comparison of the landscape on figure 4. On this basis, we calculated the volume of the slide at between 2 and 5 million m^3. We estimate that about 60 % of the material entered the sea, displacing a volume of water of about 1 to 3 million m^3.

We note, however, that slide debris were deposited on the submerged beach extending 500 m offshore at Vaifaite, at depths not exceeding 50 m. In particular, some of the boulders remained partially exposed above the water line. This suggests that most of the slide material did not reach the steep slope leading to the abyssal plain, and thus did not generate a turbidity current, but rather was contained on the shallow shelf. This scenario would be somewhat reminiscent – albeit on a much reduced scale – of the giant slide at Lituya Bay, Alaska, following the Fairweather fault earthquake of 10 July 1958 [Tocher, 1960], which raised a gigantic wave in the bay, but left the body of the ocean essentially unaffected [Miller, 1960].

The testimony of a local resident, who was fishing offshore in Vaifaite, indicates that the cliff was intact as late as 12:30 local time (22 : 00 UTC) on 13 September, *i.e.*, 40 minutes prior to the inundation at Omoa. The existence of the slide, discovered on 14 September by fishermen, then leaves no doubt as to the origin of the waves. The location of the slide also explains the higher values of runup along

those segments of the shore (*e.g.*, the northern coast of Omoa Bay) facing the incoming waves.

Geological context

The rockslide at Vaifaite is part of the ongoing natural process of erosion of the island. Along the southern coast of Fatu Hiva, we have observed numerous dykes, which comprise about 10 % of the total volume of the cliffs. Many of these dykes have been almost completely altered to clays, and preferentially eroded, often leaving 10-50 cm wide cracks which rise from sea level to the cliff tops. The Vaifaite slide occurred after a 4-month drought during which Fatu Hiva received only traces of rainfall. We speculate that the dry conditions dewatered the clays, thus destroying the cohesion of the edifice and provoking spontaneous cliff collapse.

An identical mechanism appears to have been responsible for a calamity on Oahu, Hawaii on 9 May 1999. During a prolonged drought, a sheet of rock on the upper slopes of a deeply incised canyon gave way and fell into the plunge pool of Sacred Falls; eight hikers were killed [*Honolulu Star-Bulletin*, 1999]. A few days before this tragedy, during the ongoing drought in Hawaii, part of the sea cliffs along the north coast of Molokai collapsed into the ocean; that slide was 150 m wide and 800 m high [S. Martel, pers. comm., 1999]. The local tsunami that it must have generated was not observed because it occurred at night, along a deserted segment of coastline with the closest settlement, Kalaupapa, 8 km away, and protected behind a promontory.

Less than a kilometer northwest of the Vaifaite slide is Tahaoa ("the Long Beach"), which appears to have formed as the result of multiple slides which together have created a debris apron over a kilometer long, and deposited numerous boulders in the nearshore zone. More generally, the entire southern and western coast of Fatu Hiva is characterized by morphologies indicative of past landslides, featuring fan-shaped debris cones (in most instances overgrown with vegetation), arcuate headwalls, and run-out boulders.

At Taioka'i, 3.5 km northwest of Hanavave, is the scar of a recent landslide about 500 m across. Fatu Hiva traditions talk of the cliff giving way beneath a party of kava-drinking revelers, all of whom lost their lives. In the version of the story reported by Heyerdahl [1974, p. 116] the deaths occurred in a settlement below the cliff, but we were assured [T. Ihopu, pers. comm., 1999] that the settlement was already abandoned at the time of the landslide. Both versions of the story include a tsunami, which killed a group of people living in a cave near sea level just to the south. The skeletons are still in the cave and could, presumably, be dated. Boulders in the surf zone are even more common than at Tahaoa, suggesting that the Taioka'i slide is younger.

During Heyerdahl's visit in 1936, small rockfalls were common at Taioka'i and the talus slope was covered with "small brushwood and no real forest" [Heyerdahl, 1974, p. 116]. Now rockfalls are rare, and the forest well established. These changes suggest that the Taioka'i landslide occurred at most a few centuries ago.

On a much larger scale, Filmer *et al.* [1994] have documented the existence of a chaotic underwater compound estimated at 400 km^3, which may be the result of the collapse

BEFORE   (1996)
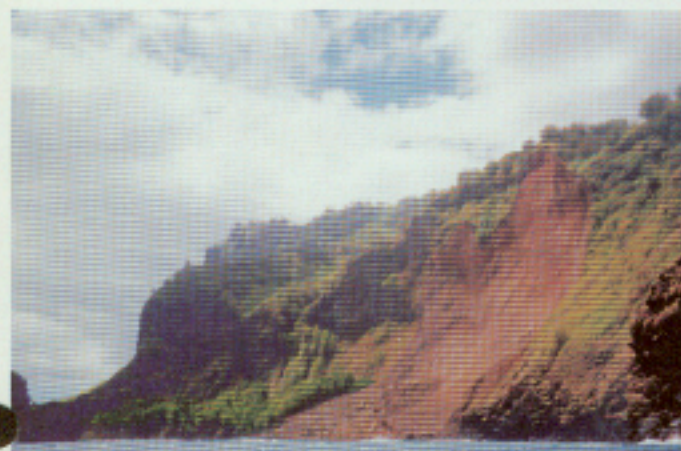
AFTER   (05 OCT 1999)

FIG. 4. – Before and after views of the Vaifaite cliff area. The slide is estimated to be 300 m in width and 250 to 300 m high.
FIG. 4. – *La falaise de Vaifaite, photographiée avant et après l'éboulement, dont les dimensions sont estimées à 300 m (largeur) et 250-300 m (hauteur).*

of the western half of the volcano, at about 1.40 Ma [Brousse *et al.*, 1990].

PRELIMINARY MODELING

A simulation of the wave's generation and propagation along the southwestern coast of the island was carried out using the MOST code which solves the nonlinear shallow water wave equations (NSW) in characteristic form [Titov and González, 1997; Titov and Synolakis, 1998]. MOST uses a splitting algorithm, *i.e.*, the equations in each of the two space dimensions are solved alternately. It involves no artificial viscosity or dissipation. The numerical solution uses a variable grid adjusted so that there is a fixed number of grid points per wavelength, and the scheme appears to have sufficient native numerical dissipation to realistically model the physical propagation and evolution of tsunamis. MOST was shown to be capable of reproducing the extreme inundation flows of the 1993 Hokkaido-Nansei-Oki tsunami [Titov and Synolakis, 1997], the 1996 Peru tsunami [Titov and Synolakis, 1998] and the laboratory data on soli-

tary waves of Synolakis [1987], of Briggs *et al.* [1995] and of Kanoglu and Synolakis [1998]. MOST calculates runup but differs in the shoreline computation methodology from the other widely used code TUNAMI-N2 of Imamura [1996]. As opposed to earlier threshold models that placed a vertical wall at some arbitrary offshore threshold depth, both TUNAMI-N2 and MOST allow the wave to pass through the initial shoreline. However, where TUNAMI-N2 calculates runup by evaluating the maximum of the time variation of surface elevation at the last wet grid point seaward of the initial shoreline, MOST extends the calculation by following the evolution of the moving shoreline up the coastline and by finding the last wet point up the slope, arguably a more realistic approach. When compared under identical initial conditions [Plafker *et al.*, 2000], MOST and TUNAMI-N2 produce comparable results, except in cases of extreme runup, where the different dissipation characteristics produce different estimates.

While we realize that the detailed dynamics of the penetration of the slide into the ocean and of the displacement of the water mass can significantly affect the characteristics

of the resulting tsunami waves [Heinrich *et al.*, 1998], our purpose at this preliminary stage is to explain the propagation of the wave to Omoa and the surrounding shores and to model an order of magnitude of the observed runup, rather than to propose an exact simulation of the generation of the wave. In this respect, we choose here the very simple *ad hoc* source model of a tapered bulge of water spreading over a base radius of 250 m, with a maximum height of 40 m, and a total volume of 3 million m^3. These dimensions account for the volume of displaced water estimated above while containing the source on the shallow beach.

Figure 5 simulates the propagation of the wave on the southern coast for approximately 5 minutes following the slide. The particular timing of the selected snapshots was chosen to illustrate the fundamental features of the simulation. Frames A-C show that this source generates two major waves, separated by approximately 50 seconds. This is in agreement with eyewitness testimonies describing two (and only two) waves. Perhaps the most crucial aspect of the propagation of the tsunami is illustrated on frame D. While to the southeast of the source area, the waves quickly die off, those propagating northwest are strongly refracted around the western tip of the island by the underwater ridge which prolongs, at depths as shallow as 100 m, the main watershed in the south of the island, both features being remnants of the rim of the ancient caldera. On frame E, the first wave penetrates Omoa Bay, followed about 50 s later by the second wave (frame F).

On figure 6, we give two time series of simulated gauges in Omoa Bay, located respectively above isobaths 2.5 and 15 m, as well as a runup profile taken at the shoreline, indicating an amplitude approaching 3 m at the center of Omoa Bay, directly in front of the ice-making plant (see fig. 2). These numbers provide an excellent order of magnitude for the runup values measured at the school (4 m) and at the ice-making plant (5 m), the difference being possibly attributable to the interaction of the wave with built-up structures such as the front wall of the ice house. Other, smaller dimensions of the source bulge were also tested, but they produced runup heights not exceeding 1 m at Omoa.

Similarly, we obtained simulated gage amplitudes of 4 to 6 m along segments of the Tahaoa Beach (no runup computed), where we surveyed a 7-m runup, and of up to 8 meters near Pointe Mahitoa, whose shore we could not access, but where we suggest a runup of 10 m, based on a survey of the line of destroyed vegetation, as estimated remotely from the speedboat. By contrast, our simulation predicts only an amplitude of 25 cm at the center of Hanavave Bay, above the 4.4 m isobath.

The conclusion of this effort is that our simulation, however preliminary and based on a very crude *ad hoc*
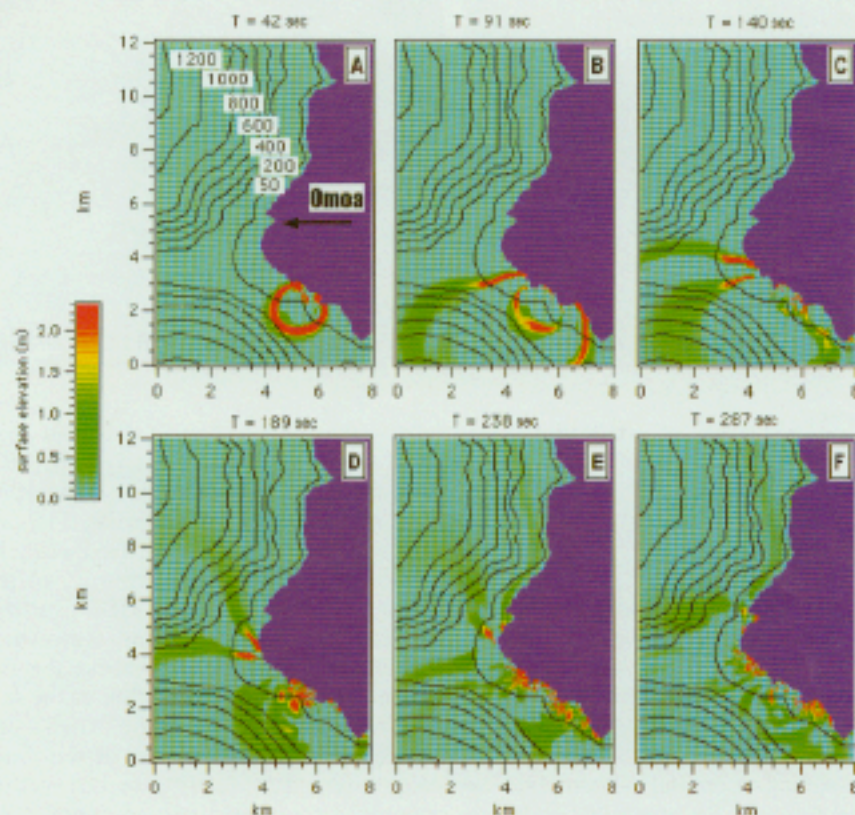

FIG. 5. – Snapshots of the simulated surface of the ocean at selected times following the onset of the wave. Bathymetric contours on frame A are in meters. Only positive wave heights are shown. Note the general confinement of large amplitudes to the shallowest portions of the ocean, and the refraction of the waves around the westernmost tip of the island (frames *(C)* and *(D)*), which flings their energy towards Omoa. As the two waves approach Omoa Bay, their amplitude is about 2 meters.

FIG. 5. – *Instantanés simulés de la surface de l'océan, aux temps indiqués mesurés après le déclenchement de la vague. Les contours bathymétriques (planche A) sont en mètres. Seules sont représentées les vagues d'amplitude positive. Remarquer que les plus grandes amplitudes sont concentrées dans les zones de moindre profondeur. Noter aussi la réfraction des vagues par la pointe Sud-Ouest de l'île (C et D), qui rabat leur énergie vers Omoa, où l'amplitude des vagues est de l'ordre de 2 m.*
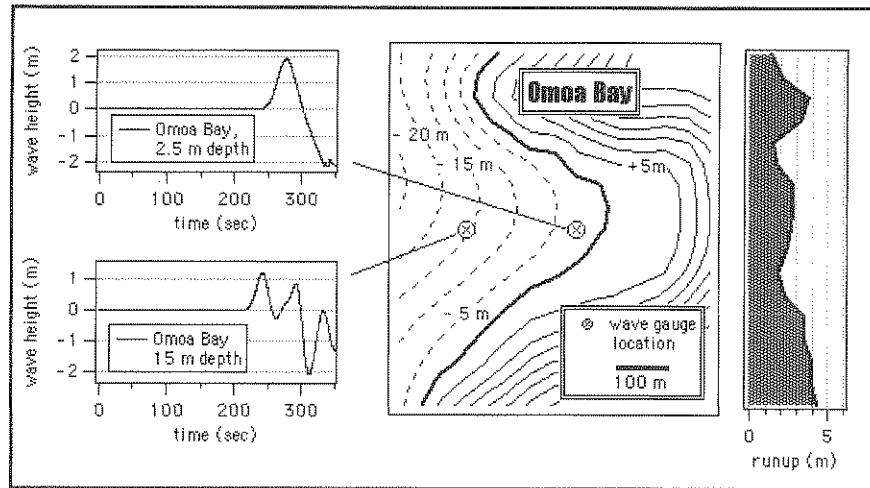
FIG. 6. – *Left :* Time series resulting from the simulation at two virtual gauges located in the center of Omoa Bay, along isobaths 2.5 m (top) and 15 m (bottom). *Center :* Close-up of the bathymetric model of Omoa Bay used in the simulation. *Right :* Profile of maximum runup obtained along the shoreline in Omoa Bay. Note an amplitude on the order of 3 meters in the center of Omoa Bay.
FIG. 6. – *A gauche : marégrammes simulés pour deux jauges virtuelles placées au centre de la baie d'Omoa, aux isobathes 2,5 m (haut) et 15 m (bas). Au centre : détail de la bathymétrie utilisée dans la simulation. A droite : profil de l'inondation maximum le long de la côte à Omoa. Remarquer l'amplitude de l'ordre de 3 m au centre de la baie.*

model of initial conditions, yields a reasonable description of the runup observed at key locations along the coast of the island. It explains the relatively large amplitude of the waves at Omoa through refraction by an underwater ridge, and provides an acceptable order of magnitude of their amplitudes at Omoa and Hanavave. Finally, it estimates a travel time of ≈ 5 minutes from Vaifaite, which in turn suggests an origin time of 13:05 local (22:35 UTC) for the slide.

Based on this estimate, an extensive search was conducted in the hope that the rockslide might have generated hydroacoustic signals (*T* waves) which could have been detected at various hydrophone and island seismographic sites in the Pacific Basin [Okal, 2001]. Due to the combination of masking by various island structures and, unfortunately, down time at several critical stations (Pitcairn, Easter), no conclusive detection could be identified. The absence of *T* waves may also be due to the containment of the slide on the flat, shallow drowned beach, well above the SOFAR channel.

FINAL PERSPECTIVE AND RECOMMENDATIONS

Tsunami damage in the Marquesas Islands during the 20th century was principally the fact of transpacific events generated by large subduction zone earthquakes. The 1946 Aleutian and 1960 Chilean tsunamis wrought considerable destruction on all islands, the former killing two people on Hiva Oa [Okal *et al.*, 2000]. Also, resonance in the ports of Atuona (Hiva Oa) and Hakahau (Ua Pou) damaged several boats during the 1995 Chilean and 1996 Peruvian tsunamis [Guibourg *et al.*, 1997; Heinrich *et al.*, 1998]. As the result of the development of tsunami warning procedures [Reymond *et al.*, 1991, 1996], some level of warning had been in effect during the latter two events.

By contrast, the 1999 event at Fatu Hiva serves as a reminder of the very serious risk posed by locally generated tsunamis in volcanic high islands, in particular those, like the Marquesas, without the relative protection of a coral reef. Although only 3 km away in a straight line (4.5 km by sea), the landslide was neither felt nor heard by the residents of Omoa, who were thus left without any advance warning.

It is particularly unfortunate that a critical structure such as a school should be built on an unprotected waterfront. Had the tide merely been high at the time of the landslide, the increment in wave height could have led to a horrific human tragedy, essentially wiping out the next generation of the population of the village. Yet, our experience on other islands reveals that, in about half of the valleys, the school is built in the vicinity of the shoreline, and most importantly, within the zone of destruction of large historical transpacific tsunamis [Okal *et al.*, 2000]. In many instances, other community centers such as town halls, post offices, and most regrettably, infirmaries and hospitals, also are built on the waterfront. This situation is probably related to the availability of a strip of public real estate, derived from a statute known as "les 50 pas du Roi" [Rougon, 1877], enacted upon colonization of the Marquesas by France in 1842. The development of beachfront property is relatively recent in the history of the islands, going back only a few decades. Before western influence, villages in the Marquesas were always set back several hundred meters from the coast because of the Marquesan tradition of "fishing", *i.e.*, raiding other valleys for human sacrifices [Dening, 1980]. Since the raids would come at night and by canoe, the ocean was to be avoided in choosing house sites. It is not clear whether the danger from tsunamis contributed to this avoidance, as suggested in Cascadia [Hutchinson and McMillan, 1997] or New Zealand [Goff and McFadgen, 2001] following catastrophic tsunamis, but the effect was to remove people from harm's way. At any rate, the practice of living away from the shore suggests a lesson in wisdom from ancient generations, which should be heeded.

We call on the responsible government agencies to immediately start developing plans to relocate critical community facilities such as schools and hospitals outside of the waterfront zones at risk of inundation during future tsunamis.

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