A giant landslide on the southern flank of Tahiti Island, French Polynesia

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A giant landslide on the southern flank of Tahiti Island, French Polynesia

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Abstract. We present evidence for an ancient and voluminous subaerial landslide of the southern flank of Tahiti, Society Islands. During a marine geophysical survey in 1996, submarine mass wasting deposits were mapped as far as 60 km from the southern shore of the island. Acoustic imagery reveals a surface of 2950 km^2 of debris avalanche and hummocky terrain. Based on bathymetric data, the volume of the debris is estimated to be 1150 km^3. In comparison with Hawaiian and other oceanic island landslides, it can be classified as a giant, rapid and cataclysmic event. Tahiti morphology and the distribution of volcanic ages over the island strongly suggest that the slope failure initiated near the top of the southern island flank, between 650 and 850 ka. The landslide scar was subsequently filled by eruptions. The estimated volume of the subaerial removed material exhibits a large discrepancy with the volume of the submarine deposits that can be explained by recurrent slide events.

Introduction

Submarine landslides are major events in the history of oceanic islands. Studies of Hawaiian Islands have shown that there are two general types [*Walker*, 1988]: (1) lateral collapses due to listric faults; (2) lateral collapses along a deep decollement. They usually occur during the period of volcanic activity of the island [*Moore et al.*, 1989] and are thought to be a response to magma intrusion into the volcano [e.g., *Swanson et al.*, 1976; *Moore et al.*, 1989; *Denlinger and Okubo,* 1995]. Both types produce giant landslides which can be characterized by a scarp at the head and a displaced mass [*Hampton et al.*, 1996]. *Moore et al.* [1989] have described their differences: a slow moving of a part of the island along a deep decollement is a slump, whereas listric faults produce debris avalanches. A slump is characterized by thick deposits (up to 10 km) with steep toes, and debris avalanche by thin deposits (0.05 to 2 km) with hummocky terrain in its lower part. Giant landslides are well documented on the Hawaiian Ridge [*Moore*, 1964; *Fornari et al.*, 1979; *Moore et al.*, 1989], in the Canary Islands [*Holcomb and Searle*, 1991; *Watts and Masson*, 1995; *Stillman*, 1999], and at Réunion Island [*Lénat et al.*, 1989; *Gillot et al.*, 1994].

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We present here the first evidence of a large submarine landslide in French Polynesia, on the southern flank of Tahiti Island. Its characteristics are first determined from an analysis of multibeam bathymetric and acoustic imagery data gathered during the ZEPOLYF1 cruise in December 1996 by the French R/V L'Atalante [*Bonneville et al.*, 1997]. We use subaerial dating and the topographic map of Tahiti Island to estimate its source area and its age.

Geological context

Tahiti Island is located on the Pacific plate, in the South central Pacific ocean (Figure 1). It is the main island of the Society Island chain, resulting from the activity of the Society hotspot [*Duncan and McDougall*, 1976]. The island is made of two coalescent volcanoes, Tahiti Nui to the northwest and Tahiti Iti to the southeast. Tahiti Nui is a shield volcano where the subaerial volcanism is dated between 1.4 and 0.2 Ma [*Duncan and McDougall*, 1976; *Diraison et al.*, 1991; *Duncan et al.*, 1994; *Leroy*, 1994]. Figure 2 shows the distribution of K-Ar ages from *Leroy* [1994]. This author proposed that eruptive breccias on Tahiti Nui define two stages of shield construction, the main one from 1.4 to 0.87 Ma and a second one from 0.85 to 0.45 Ma.

Acoustic imagery

In addition to multibeam bathymetric data, the Simrad EM12-D echo sounder on board the R/V L'Atalante provides acoustic imagery data corresponding to the backscattering strength of the echo sounder beams. South of Tahiti Island, the speckled pattern of the acoustic imagery (Figure 3) is typical of the rugged morphology of landslide deposits [*Moore et al.*, 1989; *Watts and Masson*, 1995]. The acoustic signature of hummocks more than 1 km in size is a dark horseshoe shape. Owing to the presence of hummocky terrain in the lower part, a debris avalanche origin could be invoked. Drainage patterns are observed all around the island in the upper submarine flanks except in the area south of Papara and Mataiea. This suggests that the landslide deposits resurfaced this part of the submarine flank. Present day submarine channels are diverted to the west at Papara, and to the south at Tahiti Iti because of the topographic high due to the landslide deposits. If we consider that the speckled pattern corresponds to the area covered by the landslide, we can then estimate the surface of this area to be 2950 km^2. The shape of the upper boundary indicates that the head of the landslide is probably to the north of the acoustic data, i.e. near or above the sea level.

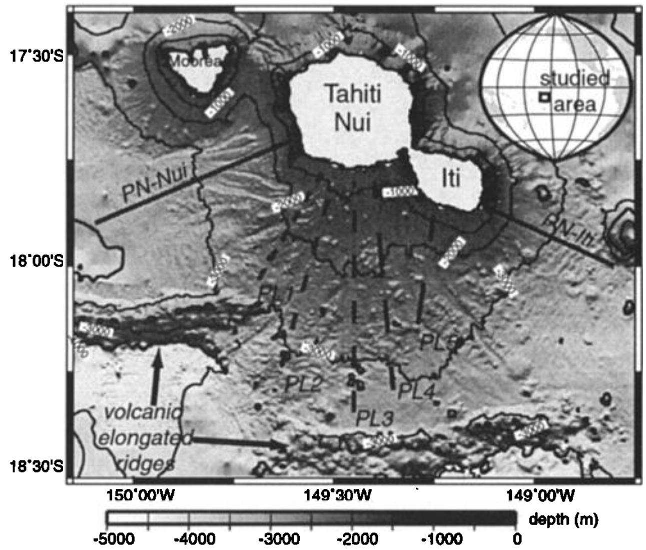

Figure 1. Multibeam bathymetric map around Tahiti Island; 1000-m contour interval. The location of the studied area in the Pacific ocean is shown in the upper inset. Profiles across (PL1 to PL4) and outside (PN-Nui and PN-Iti) the landslide deposits used to compute the volume of the deposits are drawn (see figure 4).

Bathymetry

We have extracted four bathymetric profiles on the landslide itself, perpendicular to the main slope, and two profiles outside the landslide deposits (Figure 4). We assume that the difference between on-slide profiles and off-slide profiles represents the thickness of the deposits. This thickness reaches a maximum value of 1000 m at a distance of 30 km away from the coral reef and vanishes 60 km away. This relatively small thickness is in good agreement with a debris avalanche origin. The slope of the deposits is roughly linear on the 4 main profiles (Figure 4). Note that beyond about 20 km, profiles 1 and 2 are consistently deeper (by ~ 250 m) than profiles 3 and 4. The slope gives a good estimate of the mobility of the slide, and is, in the case of Tahiti landslide, $H/L = 0.05$. This value is high compared to Hawaii [0.0125, *Prior and Coleman,* 1979]. This could be caused by the relatively low value of the horizontal extension L, which could be due to the presence of the submarine ridges (Figure 1), more than 1000 m high above the seafloor, which were acting as natural barriers for the debris flow.

To compute the volume of the deposits, we have generated a theoretical bathymetric grid by replacing values inside the deposit area deduced from the acoustic imagery by the values observed off-slide. The difference between these two grids can be considered as a good estimate of the thickness of the landslide deposits. The resulting volume is then computed with GMT tools [*Wessel*, 1998] to be 1150 km^3. This confirms that the Tahiti landslide is a giant submarine landslide, comparable to those of the Hawaiian Ridge or Canary Islands.

On-land origin of the landslide

Acoustic imagery strongly suggests that the landslide could originate from land. Erosional valleys radiate from the central part of the island on the eastern, northern and western flanks (Figure 2). On the southern flank however, the valleys are elongated along a north-south direction and are flanked by two "planezes", remnants of the original shield. The planezes were built up before 870 ka whereas the ages of the north-south valleys range from 450 to 650 ka. We propose that the submarine landslide comes from this area during an event that took place between 650 and 850 ka. The lack of prominent amphitheatre as observed on the Hawaiian Ridge could be explained by the later filling of lava flows.

To compute the volume of the slide scar, we have first evaluated the surface comprised between the inferred preexistent subaerial slopes of the Tahiti Nui volcano and a presumed listric fault. A listric fault can be described by the function $y = 2.76\, e^{-ax}$ where 2.76 is the top of the fault in km and a is a coefficient adjusted so that the exponential curve is tangent to the profiles extracted from the landslide area, at a place where they could correspond to the scarp. In our case, a=1.5 and the bottom of the fault is at sea level because, as can be seen from figure 2, the later lava flows stop before the shore. The line crest length, D, is 18.5 km, thus the volume is $V = D \times S = 299\, km^3$. This is less than a third of the volume of the submarine deposits. A slight difference would be expected because: (1) disorganized landslide material must occupy a larger volume than the cohesive material of the volcano; (2) the landslide may have incorporated sediments from the submarine slope by abrasion; (3) gravitational collapses can be triggered by an overload of the volcanic flanks, caused by secondary cones, for example. However, these processes cannot explain the large difference between the subaerial and submarine computed volumes.

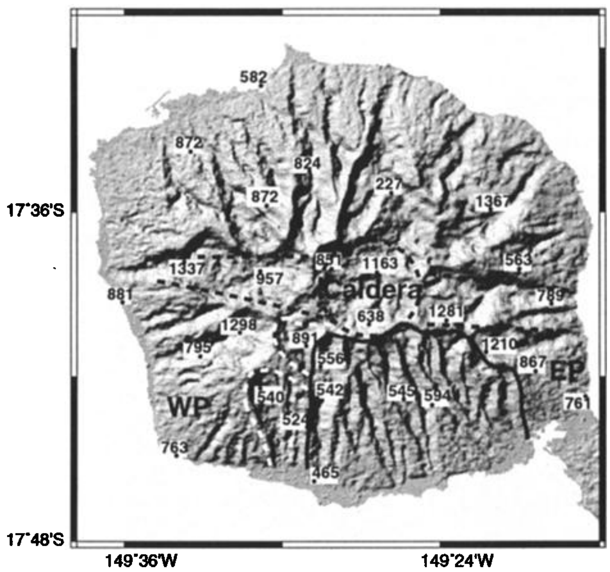

Figure 2. Shaded view of Tahiti topography and location of K-Ar radiometric ages from *Leroy* [1994] in thousands of years (ka). WP stands for Western "Planeze", and EP for Eastern "Planeze". The location of the inferred caldera is represented by a dashed circle. Dashed lines correspond to the main rift zones. The limits of the slide headwall are drawn: the black line indicates a collapse area which may be common to several events; the northern white dashed line indicates an old event and the southern white dashed line a more recent event.

Discussion

In order to explain the large discrepancy in volume between the inferred subaerial scar and submarine deposits, several hypotheses can be proposed:

(1) the submarine volume has been overestimated. If the seafloor were on average 300 m higher, the volumes would match. However, it seems unlikely that the initial slope of Tahiti southern submarine flank could have been so different than elsewhere on the island.

(2) the subaerial volume has been underestimated. This could be the case if the bottom of the listric fault was deeper. To account for the submarine volume, the depth of the bottom plane should lie at 1500 m beneath the sea level. However, such a deep slide plane seems to be incompatible with the morphology of the upper submarine slopes.

(3) the submarine volume is the result of successive collapses from the south flank of Tahiti Nui. Such phenomena have been noticed in Hawaii [*Moore et al.*, 1989], in Réunion Island [*Gillot et al.*, 1994] and in Fuerteventura [*Stillman*, 1999]. From figure 2, we can suppose that the headwalls of the western part of the collapse were also the headwalls of one or several previous events.

Hence, the hypothesis of several landslides is probably the most likely. What could be the cause? Lateral collapses can be the result of massive magma intrusion within the volcano. These intrusions use the rift zones as preferential pathways to the surface and, indeed, Hawaiian landslide directions of motion trend normal to the rift zones [*Moore et al.*, 1989]. In the case of Tahiti, the crest line, which represents the headwall of the landslide, is the main rift zone of the island [*Gillot et al.*, 1993]. Since the last landslide postdates the main caldera collapse, the last landslide could be related to the beginning of the late shield stage marked by intense activity along the rift zone. Moreover, one could suppose that a first landslide occurred during the shield building and, despite the filling of the scar by lava flows, the slide slip plane persisted and enabled subsequent landslide(s). Indeed a 250-m difference in the debris pile appears beyond 20 km between the eastern and the western bathymetric profiles (Figure 4). It could indicate that at least two landslides occurred and that the last landslide flow beyond 20 km only covered the central and eastern part of the deposit area. This interpretation is consistent with the acoustic data (Figure 2), which exhibit a more chaotic pattern in the central and eastern part.

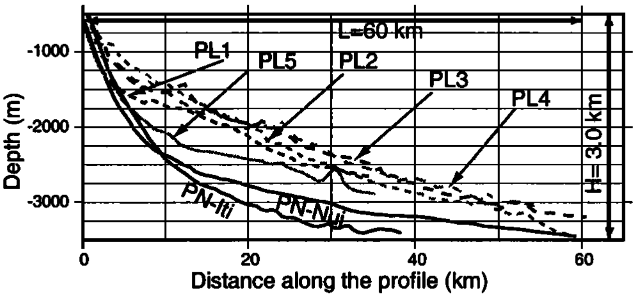

Figure 4. Bathymetric profiles across the landslide deposits (PL1 to PL4) and bathymetric profiles of Tahiti Nui and Tahiti Iti in an area not covered by landslide deposits (PN-Nui and PN-Iti).

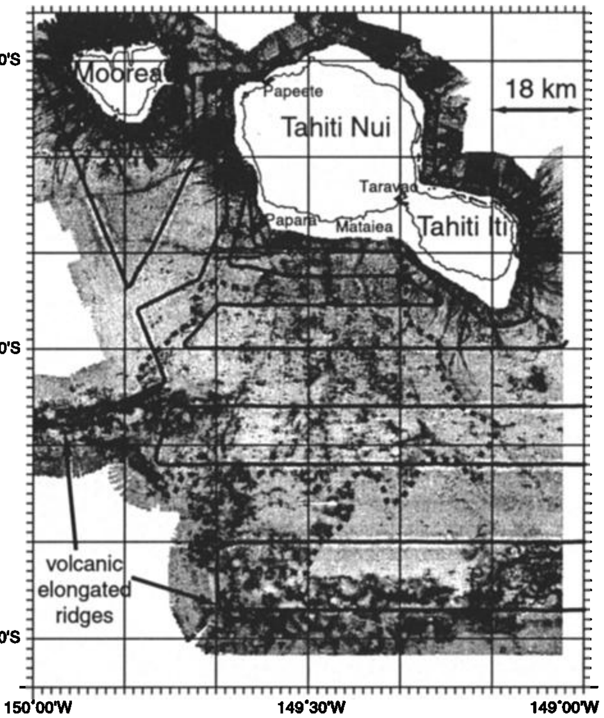

Figure 3. Acoustic imagery of the south of Tahiti and Moorea Islands (EM12-D backscatter). The black line is the navigation track. The dashed thick line is the boundary of the deposits. High reflectivity is in dark gray, and weak reflectivity in light gray. Two volcanic elongated ridges have a black and white acoustic facies.

Conclusion

The first giant submarine landslide described in the Society Island archipelago belongs to the debris avalanche type, and probably occurred between 650 and 850 thousand years b.p. The total volume of submarine deposits is estimated to be 1150 km^3 and covers an area of 2950 km^2. The head of the landslide is aerial, and parallel to the island main rift zone. The whole southern subaerial flank of Tahiti disappeared into the sea. The discrepancy between the volume of the subaerial scar and of the submarine deposits can be explained by a series of events caused by repeated intrusions of magma into the rift zones, the last event occurring at the beginning of the late shield stage.

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