Proc 8th Int Coral Reef Sym 2:1833–1838. 1997

SEDIMENTARY RECORDS OF HUMAN INDUCED ENVIRONMENTAL CHANGES IN THE TAHITI LAGOON

R. Fichez[1], P. Harris[2], R. Jouen[2], C. Badie[3] and J.-M. Fernandez[1]

[1] Centre ORSTOM de Nouméa, BP A5, 98848 Nouméa, New Caledonia
[2] Centre ORSTOM de Tahiti, BP 529, Papeete, Tahiti, French Polynesia
[3] IPSN-LESE, BP 519, Papeete, Tahiti, French Polynesia

ABSTRACT

Sediment cores were sampled in the Tahiti lagoon close to the city and harbor of Papeete. Results from one sediment core sampled at the mouth of the Papeava estuary are presented in this paper. Sediment dating was obtained by measuring the decrease in the activity of excess 210Pb radioisotope. Results were used to reconstruct the evolution of sediment deposition over the past 60 years and mainly to identify impacts of human induced changes in sediment inputs. We observed a rapid increase in sedimentation rates that corresponded to the period when the harbor was built (1963-1966). An artificial 2 km concrete sea-wall blocking ocean water inputs over the reef crest is obviously responsible for a decrease in the flushing of land derived inputs. The sediment level corresponding to the 1960-1966 period was clearly identified either by eye (sediment color) or by basic chemical analysis (carbonate content). The approach used clearly identified a major shift in environmental conditions due to human activities.

INTRODUCTION

There is growing evidence that the coral reef lagoon of Tahiti island is subject to significant environmental degradation (Gabrié et al., 1995a; 1995b). The city of Papeete and the surrounding area with 100,000 inhabitants is home to almost half the population of French Polynesia. The geomorphological structure of the mountainous island has constrained the population to the coastal fringe. The released waste waters are mainly composed of raw sewage and are either directly (coastal discharge) or indirectly (river) delivered to the lagoon. Concurrently, an increase in both population and living standards has resulted in significant terracing to provide building land on the mountain slopes of the island. This has resulted in enhanced land erosion leading to a significant increase in the runoff of terrigeneous material toward the lagoon.

The development of Papeete is closely linked to the presence of a easily accessed deep water harbor naturally protected by the barrier reef. During the years 1963-1966, a period that corresponded with the installation of nuclear testing facilities in Mururoa and Fangataufa atolls (Tuamotu Archipelago), there was an extensive investment to build artificial protective structures and to reclaim land from the lagoon. There has been several additions to the initial structures over the past decades. This economic development of this part of the island has been accompanied by large modifications in the coastal zone and it is therefore legitimate to question the extent of environmental changes since the middle of the twentieth century.

The ANTROPIC research program launched since 1995 by ORSTOM with the support of French Polynesia (Ministry of Research and Ministry of Environment) was designed to address issues related to the influence of anthropogenic inputs to the lagoon. To complement these general approaches to the environmental conditions in the lagoon or degradation of benthic populations, we developed a research project especially aimed at the study of sediments as potential recorder of past environmental conditions. The present paper mainly deals with preliminary results on sediment dating that proved to be a very informative tool in areas subject to strong changes in terrigeneous-anthropogenic influences. From the results it is possible to place studies on present day conditions in a wider historical context.

MATERIALS AND METHODS

Study site

Our study on anthropogenic influences on the Tahiti barrier reef lagoon logically focused on the area close to Papeete Harbor where population density was at a maximum. Sedimentary records of environmental changes are found in well stratified sediments (Valette-Silver, 1993). It is therefore necessary to find sedimentary areas with both limited hydrodynamic disturbance and limited bioturbation. We selected embayements or estuaries where i) reef protection and rapid deposition of organic rich sediments favored the formation of stratified anoxic sediments and ii) terrigeneous and anthropogenic inputs were of great significance. From the general study on environmental conditions we identified 4 main sites for sediment core study. The present paper mainly focuses on the PPV core located in the eastern Papeete Harbor basin (Figure 1). This core was especially interesting as it represented a lagoon area that had been artificially protected from oceanic influences by a concrete sea-wall built on the barrier reef while strongly influenced by the Papeava river that drains most of Papeete urban discharges.

Sampling

The sediment core was sampled at 33 m depth on a flat muddy bottom using a specially devised PVC corer operated by SCUBA divers. The corer was formed of a 1.2 m long PVC tubing 25 cm in diameter that had been cut in half from top to bottom. Both halves of the corer could be tightly attached for coring and transport then removed in the laboratory for core cutting. Underwater, the corer was forced down the sediment by hammering until it reached a depth of 1 m. The top end of the corer was then tightly closed by a cap. Sediment around the corer was pumped away using a small suction dredge. Water flow was supplied to the pipe from the surface by a motor-pump placed onboard a moored craft. Sediment removal was ensured until the base of the corer could be reached by hand. A bottom cap was then manually inserted below the corer and fixed. To avoid sediment loss the bottom cap was fixed to the lifting cables, the whole lifting force therefore applying to tighten the grip of this lower cap. The fully closed corer was then extracted from the sediment, lifted to the surface, lifted onboard and brought back to the laboratory. Even though it involved strong difficulties, this technique ensured minimum disturbance in the stratification of the sediment core. Back in the laboratory, the core was allowed to settle vertically for 2 hours then the top stopper was removed and the overlaying water pumped out. For the first very fluid sediment layers (5-7 cm) the core was kept vertical and 1 cm thick slices were extracted with a spatula by accessing from the top opening. After the more unstable top sediment layers were removed the corer was laid horizontally and the top half of the PVC tubing was removed. After a general examination and picture taking the whole core length was cut in 1 cm thick sediment slices. According to the planned analyses, sediment samples were frozen or directly dried in an oven.

Sediment analysis

Sediment samples were weighed before and after drying in an oven at 110 °C for 48 h. Weight difference gave the water content expressed as a % of the initial sediment dry weight.

Dried sediment samples were grounded and ignited for 48 hours at 550 °C. The weight loss due to ignition is commonly referred to as loss on ignition and considered

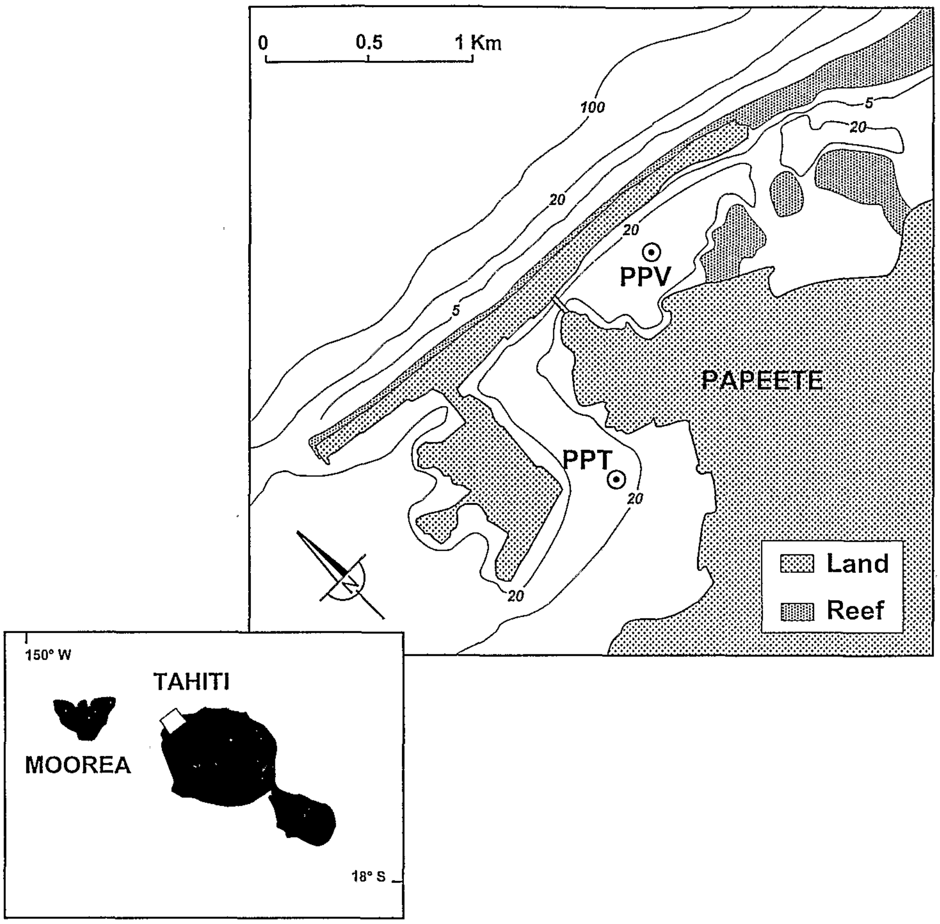

Fig. 1: Tahiti lagoon and location of the 2 sediment cores sampled in the Papeete harbor area ; results presented in this paper are from the sole PPV core located at the mouth of the Papeava river.

as an estimate of organic matter content. Attention must be given to the fact that ignition may remove water molecules that are too strongly bound to some particles to be removed by simple drying, therefore resulting in the over estimation of organic content.

Dried and ground sediment samples were weighed before being subject to digestion by hydrochloric acid. After one hour the sediment and the acid was washed with distilled water through a weighed filter and the filter was dried and weighed again. The fraction removed by acid attack (acid-soluble) is considered as carbonate while the remaining fraction (acid-insoluble) is considered as non-carbonate sediment.

Sediment dating

Sediment geochronology was obtained by analyzing natural and radiogenic radioisotopes (Faure 1986). The 210Pb activity was determined indirectly by measuring alpha radiation from its granddaughter isotope 210Po. 210Po was spontaneously deposited on aluminum planchets and the activity was counted using an alpha-spectrometer (Nittrouer et al., 1979). The excess or unsupported 210Pb activity may be calculated by subtracting 210Pb produced by the radioactive decay of 226Ra (supported 210Pb) to total 210Pb activity. We assessed supported 210Pb from gamma emitting 226Ra activity directly measured on a 85 % efficiency gamma-x spectrometer. 210Pb is known to decrease with time with a half-life of 22.3 years. When plotting the logarithm of excess 210Pb against sediment depth it is possible to look for linear parts of the plot. Calculation of the slope of corresponding linear fit gives the sediment deposition rate (Chanton et al., 1983; Zuo, 1991). For 210Pb extraction efficiency estimated by addition of 208Po was 98%. One sigma counting error is specific to each sediment sample and was generally around 3-4 % with 5 values among 32 being between 6 and 14 %.

RESULTS

Sediment core sampling by a piston coring technique was responsible for sediment compacting. For the PPV core we measured the sediment height in the core to represent 78.5 % of the *in situ* sampled sediment column. From radiographic analysis of a sister core it was possible to observe that at the contact of the core flanks friction during coring pushed the sediment downward. However, sediment stratification in itself was not significantly disturbed by the coring. Compacting decreased exponentially from top to bottom and mostly affected the top 30 cm of the core were sediments had a water content of more than 50 %. Correction for such compacting effects by considering mass depth instead of sediment depth have not been introduced in the present paper.

Sediment geochronology

Total 210Pb activity decreased with depth according to a logarithmic function The profile showed a very limited non-stratified homogeneous layer between 0 and 9 cm depth. Such a layer can be attributed to vertical mixing of sediments due to bioturbation. Underwater observation revealed burrows at the sediment-water interface and small crustaceans (Callianassidae) were occasionally retrieved. Below 9 cm 210Pb activity sharply decreased down to 42 cm. Below 42 cm 210Pb activity ranged between 20 and 40 mBq g-1 corresponding to background activity levels. We therefore only considered the 9 to 42 cm layer to be a stratified layer in which dating was possible.

When plotting the log of excess 210Pb versus depth (Fig. 2) it was possible to obtain a linear function. The linear fit calculated on the log of excess 210Pb activity versus depth for the only 9 to 42 cm depth data set (n=18) yielded a coefficient of determination (r2) of 0.90 and gave an average sediment deposition rate of 0.82 cm yr-1.

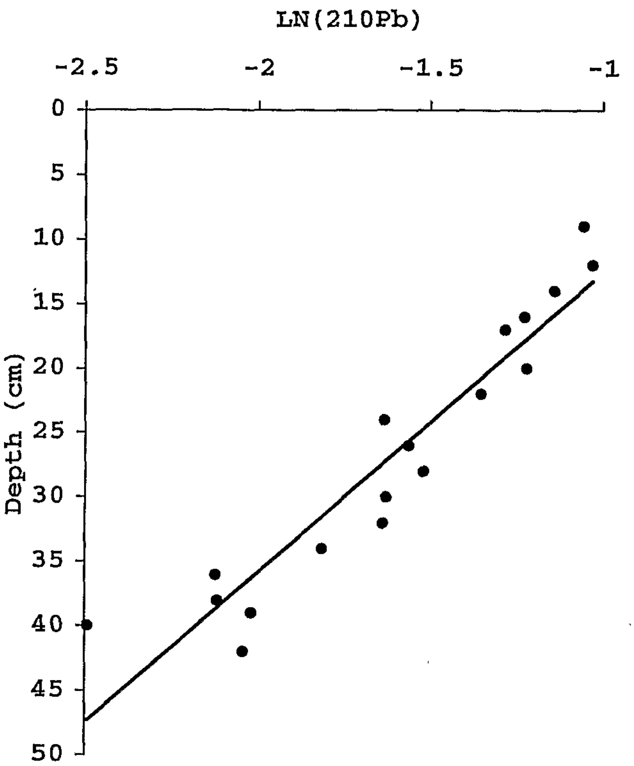

Fig. 2: Vertical profile of the log of excess 210Pb activity (mBq/g) in the PPV core as measured from indirect alpha counting of 210Po activity.

It was possible to use this average deposition rate of 0.82 cm yr-1 in the top sediment layer to calculate the age of two sediment levels that proved to be of special interest when interpreting the results from complementary sediment analyses. At 42 cm depth we calculated sediments to be dated year 1962. At 36 cm depth the sediment was deposited in the year 1967. That result closely corresponded with the period of intense building activities in Papeete and more precisely in Papeete harbor (1963-1966). Our results therefore demonstrate that human induced modification in the geomorphology of the reef-lagoon system resulted in environmental changes that have lasted for the past 40 years.

Sediment complementary analyses

The boundary between sediments dated from prior to 1962 and younger ones also corresponded to clear differences in colors and granulometry as well as in the measured sediment parameters

Description of the core showed a visible separation in two different layers. The top 40 cm was formed of a brown mud very similar to the island basaltic soils locally known as « Mamu » The bottom of the core was composed of a compact gray mud. The two layers were approximately separated by a 10 cm transition zone.

The profile for sediment water content (Fig. 3) showed 4 well identified sediment layers. The top 8 cm layer was composed of a very fluid mud with a high water content that sharply decreased from 65 % at the sediment surface to 55 % at 8 cm depth. This high water content is related to recent sediment deposition plus ongoing sediment bioturbation as evidenced by radioisotope dating techniques. Between 8 and 36 cm the water content was rather homogeneous only showing a slow decrease with depth from 53 to 47 %. Deeper in the core, the sediment water content sharply decreased from 45 % at 36 cm to 35 %. at 42 cm Below 43 cm depth we observed a layer with a relatively homogeneous water content of 32-39 %. The strong decrease in water content below 36 cm cannot be only attributed to sediment compacting alone. It further evidence a change in the structure of the sediment.

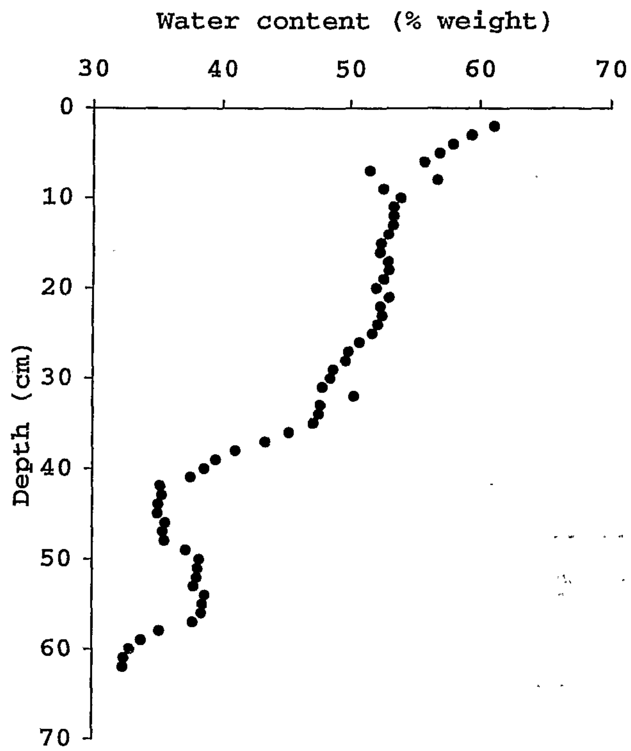

Fig. 3: Vertical profile of the water content expressed as per cent of wet weight in the PPV sediment core. Two sediment layers with different water content are clearly identified

Analysis of sediment carbonate composition (Table 1) matched the shift observed for water content. Between the surface and 32 cm depth the dark mud deposited after 1960 was composed of less than 50 % of acid-soluble fraction that can be considered as carbonates. Below 48 cm depth the gray sandy-mud deposited before 1960 with more than 80 % of acid-soluble sediment was mainly composed of carbonates.

Table 1: Percentage of acid-soluble fraction in sediment core Papeava expressed in percent of sediment dry weight.

Sediment depth (cm)	soluble fraction (%)	insoluble fraction (%)
9	43.3	56.7
17	36.9	63.1
24	38.3	61.6
32	45.1	54.9
39	68.1	31.9
48	86.3	13.7
54	84.4	15.6
62	89.4	10.6

Similarly, measurement of organic matter content by loss on ignition technique (Fig. 4) showed a clear interface between 32 and 40 cm depth. The top layer had a high organic matter content ranging between 16 and 20 % of the sediment dry weight. Below 40 cm depth the organic matter content was no more than 6 % of sediment dry weight.

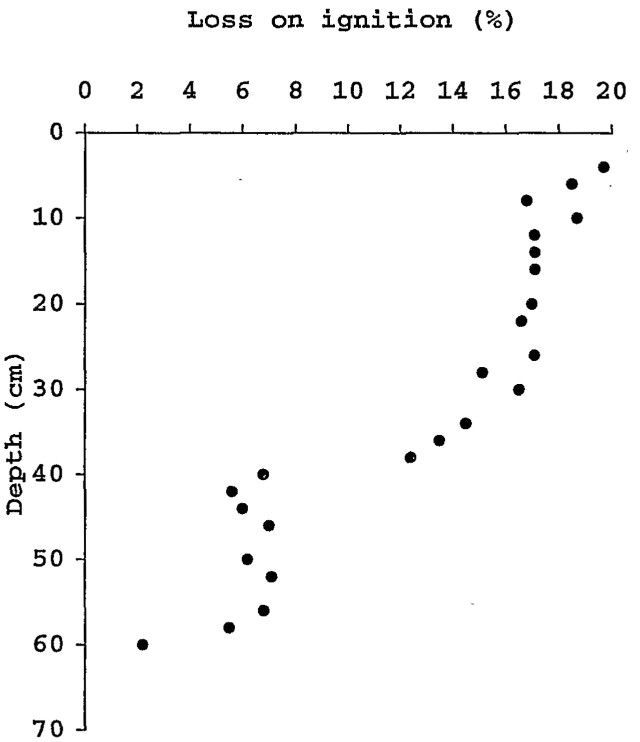

Fig. 4: Vertical profile of sediment loss on ignition as expressed in percent of sediment dry weight in the Papeava core.

The shift in sediment deposition rate corresponded with a shift in sediment structure that has to be related to a shift in sediment input. Again, modifications in sedimentology are easily explained by developments during the building of Papeete harbor. The sea wall built on the barrier reef totally blocked water exchange over the reef and subsequent discharge currents in the lagoon. The general decrease in water circulation strongly favored deposition of terrigeneous particles especially as terrigeneous inputs were concurrently enhanced by erosion due to increased land use.

DISCUSSION

From our results it is possible to demonstrate that the building of the harbor protective structures combined with the anthropogenic enhancement of terrigeneous inputs strongly modified the sediment deposition regimes in the lagoon of Papeete. It is possible to make a synthetic description of the core structure which will enable the evolution from the bottom of the core to the top, hence from past to present to be followed.

Below 42 cm sediments could be dated as prior to year 1962. Those sediments have high carbonate content that demonstrate a major marine origin, are strongly compacted and have low organic matter content. Prior to the building of Papeete harbor water exchange between the ocean and the lagoon ensured a proper water renewal in the lagoon and the discharged terrigeneous products were washed away. Such conditions led to the deposit of carbonate mud corresponding with what we know of unprotected deep coastal lagoon channels from the area.

Above 36 cm sediments were dated from before 1967. Those sediments have a low carbonate content, have been deposited with a high sedimentation rate and have high water content and high organic levels, the latter being certainly due to both high organic content of deposited sediments and incomplete diagenesis in anoxic conditions. The 1963-1966 period corresponds with the building of Papeete harbor sea wall along the reef and the diversion of the Papeava river estuary from Papeete harbor to its present location. The combination of the decrease in the circulation rate with increased terrigeneous inputs resulted in a major change in the composition and rate of sediment deposition. The shift in sediment composition clearly identify a major alteration in environmental conditions.

The shift from a slowly accumulating carbonate dominated mud with low organic matter content to a rapidly accumulating non-carbonate mud with high organic matter content has strongly modified the habitat conditions for benthic organisms. As an obvious example underwater probing through the sediment with a rod showed that the fringing reef slope located at the mouth of the Papaava is now covered by more than 1 m of estuarine mud. Concurrently, particle-bounded organic material of terrigeneous and anthropogenic origin has accumulated in the sediment. It is very likely that the main consequence of this is to increase the organic mineralization of the sediment and associated release of nutrients. Local nutrient enrichment is obvious in Papeete harbor water and it clearly translates into phytoplankton biomass (chlorophyll-a) and production (Fichez & Pagès unpublished results). In addition to these chronic effects it must be noted that in its present state the lagoon environment is likely to be heavily influenced by exceptional events such as cyclones. There is an serious added risk that the occasional release of material partially trapped in the sediment sink will trigger the development of an environmental crisis in the form of an hypoxic event. The impact of coastal human activities has resulted in the indirect enhancement of sediment deposition rates that now represents a major environmental problem for the Papeete lagoon. Taking such adverse effects into account is an obvious challenge for the future and unavoidable economic development of the Pacific island states (Maragos, 1993).

In conclusion we may observe that the structural changes imposed on the coastal zone resulted in a significant shift in lagoon environmental conditions. Sedimentary records proved a satisfactory approach for reconstructing past environmental changes in coral reef lagoons. Complementary analysis of the present core and of other cores covering additional tracers such as metals and organic biomarkers (sterols, hydrocarbons) are currently in progress They will give further information regarding the extent of human induced environmental alterations in the lagoon of Tahiti.

ACKNOWLEDGMENTS

We would like to thank J. Orempuller, N. Mahiota, J. Paoaafaite and J. Teuri for their assistance in the field and in the laboratory. This work was supported by ORSTOM, CORDET, the Ministry of Research and the Ministry of Environment of French Polynesia.

REFERENCES

Chanton JP, Martens CS, Kipphut GW, 1983. Lead-210 sediment geochronology in a changing coastal environment. Geochim cosmochim Acta 47:1791-1804.

Faure G., 1986. Isotope geology. Wiley & Sons, New York, p. 363-385.

Gabrié C, Licari ML, Mertens D, 1995. L'état de l'environnement dans les territoires français du Pacifique sud, La Polynésie Française et l'Ile de Clipperton. Rapport Ifen - Ministère de l'Environnement, Paris, 121 p.

Gabrié C, Payri C, Hutchings P, 1995. The current status of coral reef management in French Polynesia. Mar Poll Bull 29:26-33.

Maragos JE, 1993. Impact of coastal construction on coral reefs in the U.S.-affiliated Pacific islands Coastal Management 21: 235-269.

Nittrouer C, Sternber R, Carpenter R, Benett J, 1979. The use of Pb-210 geochronology as a sedimentological tool: Application to the Washington continental shelf. Mar Geol 31:297-316.

Valette-Silver N, 1993. The use of sediment cores to reconstruct historical trends in contamination of estuarine and coastal sediments. Estuaries 16:577 588.

Zuo Z, Eisma D, Berger GW, 1991. Determination of sediment accumulation and mixing rates in the Gulf of Lions, Mediterranean Sea. Oceanologica Acta 14:253-262.