THE EFFECTS OF THE CYCLONES OF 1983 ON THE ATOLLS OF THE TUAMOTU ARCHIPELAGO (FRENCH POLYNESIA)

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Abstract. In the TUAMOTU Archipelago, tropical cyclones may contribute to the destruction as well as to some building up of the atolls. The initial occupation by the Polynesians has not increased the vulnerability of these islands as much as have various recent alterations caused by European influence and the low frequency of the cyclone hazard itself. An unusual series of five cyclones, probably related to the general thermic imbalance of the Pacific Ocean between the tropics struck the group in 1983 and demonstrated this vulnerability through the damage that they caused to the environment and to the plantations and settlements. However, the natural rehabilitation has been faster than expected and the cyclones had a beneficial result in making obvious the need to reinforce prevention measures and the protection of human settlements. An appraisal of how the lack of prevention measures worsened the damage is first attempted, then the rehabilitation and the various steps taken to forestall such damage are described.

1. About Atolls and Cyclones: Some General Information

Among the islands of the intertropical area of the Pacific Ocean, most of the low-lying lands are atolls. The greatest number of them are found in this part of the world.

Most atolls are characterized by a circular string of narrow islets rising only 3 to 10 m above the average ocean level. This ring surrounds a shallow area (lagoon) whose communication with the open sea is occasionally interrupted.

The matter constituting these islets is made up mainly of water-born deposits, especially coral and sand accumulated by the waves, which may submerge them during strong storms, particularly during summer tropical cyclones (Tracey *et al.*, 1961). These deposits settle upon or beside the emerged remainders of ancient coral structures. (Service Mixte de Contrôle Biologique, 1972). Natural disasters such as cyclones, droughts, tsunamis, periodically jeopardize and interrupt the continuity of the setting process of terrestrial plants and animals in this precarious environment.

The colonization of these atolls can be explained by such factors as the proximity of high islands or continental areas, the regularity of the climate, the position of the atoll and its direction in relation to the currents and to the winds that make transports possible, and the size and the absolute altitude of the islets forming the atoll.

Conversely, such factors as isolation, irregular precipitation, higher frequency of tropical cyclones, geographical situation away from the major currents or continental areas and high islands, small size can weaken such an homogeneous system, hinder its colonization and permit us to define limits.

Tropical cyclones work on the low islands through mechanical constraint, the drought they engender, the sea spray and the waves they generate. Their winds begin to affect the vegetation of the low islands when they reach speeds of 75 to 80 km h^{-1}. With the average rise of the ocean level that follows the drop in atmospheric pressure accompanying a cyclone, the waves build up the storm surge that may flood the low-lying coastal land generally up to 4 to 6 m above the average sea level. Only wind and salt

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resistant species can survive if the frequency of cyclones exceeds 1 every 5 years, this being the minimal span of time needed for the reconstitution of vegetation under optimum rainfall conditions (Alkire, 1978).

2. The Tuamotu Archipelago and the Cyclone Hazard

The case of the TUAMOTU ARCHIPELAGO shall be studied in the light of the response of the above-specified natural environment, but also of the people who live there exposed to the cyclone hazard. The 75 atolls of the group are scattered over nearly 1500 km between 14 and 23° South, 135 to 148° West (Figure 1). The closest high islands of the SOCIETY ARCHIPELAGO are situated at a distance of about 300 km. Less scattered to the West than to the East, where their chances of being hit by passing cyclones are lessened, these atolls experience only moderate precipitation (1000 to 1900 mm annual rainfall). These rates increase from North-East to South-West. Their seasonal variations may exceed 50%. This percentage is reached in their inter-annual variations. Often, most of the annual rainfall is experienced within 30 days.

The archipelago is not included in an area of high cyclone frequency (Dupon, 1985). Observations recorded since the first quarter of the last century allow to differentiate between the area stretching from the COOK ISLANDS to the AUSTRAL ISLANDS, where the risk is of 1 cyclone every 2 to 3 years, and the area embracing the TUAMOTU ARCHIPELAGO, where the risk drops to one every 10 to 25 years, beyond a transitional zone that includes the SOCIETY ARCHIPELAGO and the North-Eastern atolls of the group, South of the MARQUESAS ISLANDS. Before 1983, the most serious cyclones that struck the Tuamotu group were in 1878, 1903, 1905, 1906.

Soils bear only a specific, limited vegetation. The scouring of their upper layers by the storm surge during cyclones may therefore result in important losses.

The fruit of the coconut palm and the direct collection of rainwater from tree trunks at first, then from tin roofs, enabled man to solve the fundamental problem of fresh water. Man also seems to have always used underground water on which plants survive. The balance of the fresh water lens is all the more frail as it is thin, since its theoretical depth depends on the altitude of the island in relation to the average sea level. This balance is influenced by tides, precipitation, evaporation, water extraction by plants and of course by man. It may be highly endangered by seawater incursions during cyclones. Man's cautious extraction of water that was almost always briny was formerly the fruit of an empirical experience in the use of the underground fresh water layer: permanent wells were always dug far apart from one another, at a greater distance from the ocean than from the lagoon, and were listed under individual names (Emory, 1975).

Today the possibilities and the limits of underground water resources are better known.

3. Utilization of the Atolls, its Evolution

Their climate and their remote situation, in the Indo-Pacific area, enabled the TUAMOTU ARCHIPELAGO to bear naturally only a few dozen species of plants and trees. The emerged parts of the atolls are only a few thousand years old. Additions to the natural local flora, through introduction by man, were brought about over two

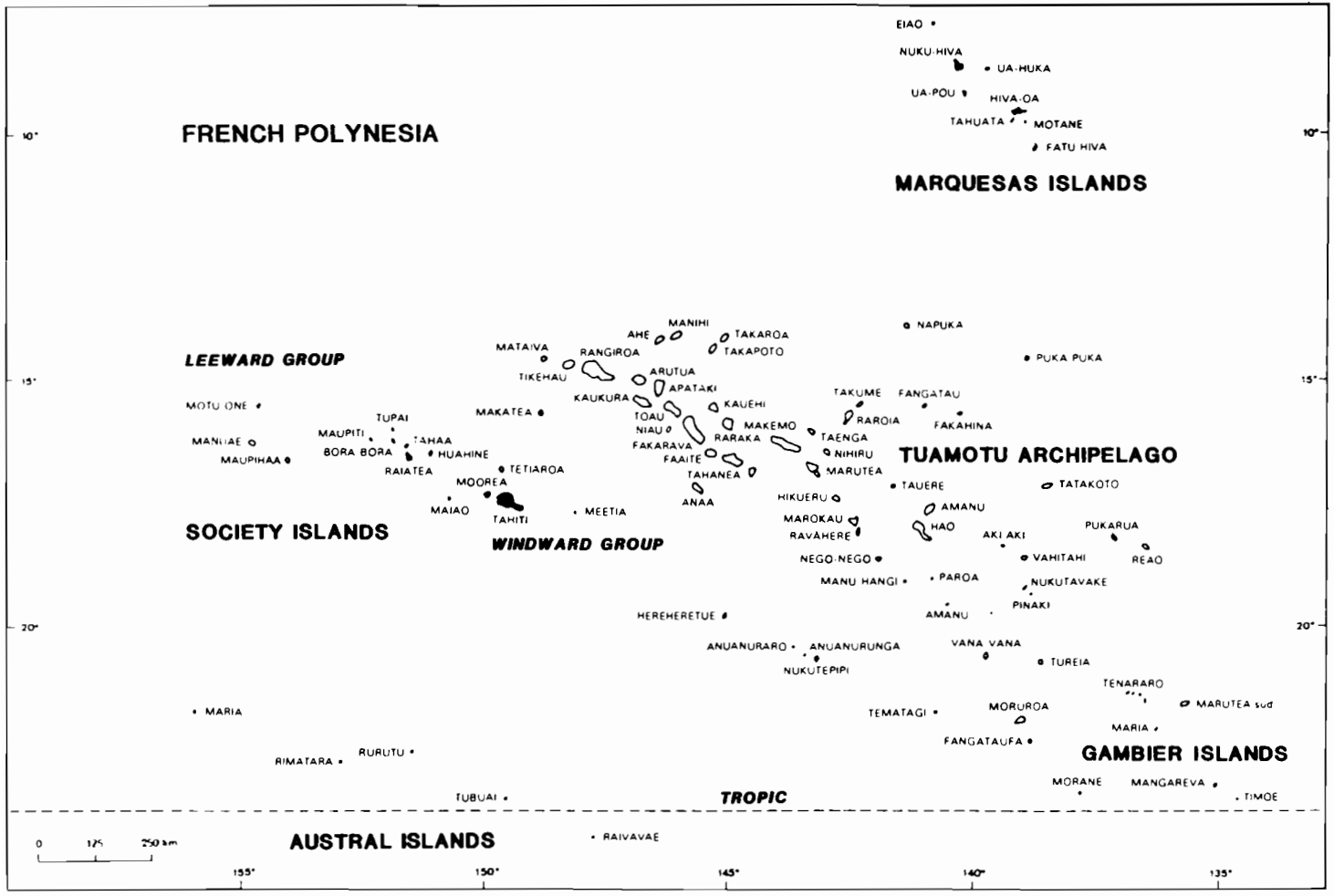

Fig. 1. French Polynesia and the TUAMOTU Archipelago.

separate periods. Before any contacts with Europeans and up to the first quarter of the last century, the food-plants that were introduced were those of Polynesian culture: pandanus, taro, breadfruit tree and of course coconut palm. Trees and shrubs for medicinal, ornamental and arts and crafts use, widened this range only under the most favourable conditions (Regional technical meeting — South Pacific Commission, 1982).

Insecurity, the localization of taro pits, the social system, all may explain the scattered settlements which characterized each atoll in those days. Food-shortages, resulting from cyclones, droughts, or demographic excess, compelled people to resort to violence in order to survive. The habit of storing food by means of several conservation methods (pandanus fruit-pulp cake, drying or preserving of breadfruit) testifies to the acuteness of the food problem. After the cyclones, losses of life due to famine were sometimes greater than those directly resulting from the natural hazard.

Since as far back as the end of the 18th century, relations between the islands have led people to gather on the motus (islets) that were highest, where fresh water was more abundant, or that were more readily accessible by sea.

The spreading of Christianity, the establishment of trade and of European administration during the second half of the 19th century, drastically changed the life on the atolls. The settlement of permanent villages around the Mission and the Church, near a pass or an anchorage, mostly on the leeward side, was generalized, spurred by the new needs related to trade. In large areas, coconut plantations supplanted natural vegetation, the needs of commercial production and the introduction of a monetary economy, progressively led people to abandon taro pits; this process was probably also hastened by the devastation suffered during the strong cyclones that hit the atolls at the beginning of this century (1903—1905—1906). Some of the useful plants introduced to the SOCIETY ISLANDS in those days spread to the TUAMOTU ARCHIPELAGO. But for a few exceptions however, these species play only a minor role today in a diet that has for a long time been based on imported products in which carbohydrates, sugar, vegetable fats and tinned food predominate.

Since the seventies, an effort has been made in educating the population and encouraging vegetable and fruit growing as well as animal husbandry, while a settlement and resettlement policy was simultaneously implemented in order to stop the flow of the inhabitants toward TAHITI and the urban center of PAPEETE. Excluding the personnel employed at the Nuclear Experimentation Center, the census carried out in 1983 counted over 8100 inhabitants of the archipelago. Some conditions must be met on the atolls if people are to settle there for good, and if those who have left are to return: regular transport services, convenient connections with TAHITI and within the archipelago, facilities equivalent to those theoretically existing in the city, new resources. That's why fishing, pearl farming, mother-of-pearl collection, aquaculture and various forms of tourism have been developed, greatly changing the economy of the archipelago over the last 20 years. These projects are intended to take over from the copra industry which, in the early eighties and in spite of heavy territorial Government aids to the producers, produced insufficient quantities (8000 to 10000 t per year) in view of the surface planted (30 to 40000 ha). The neglected plantations were in urgent need of regeneration. Half of them consisted of trees of more than 75 years of age, 80% of the trees were over 50 years old. Poorly kept, infested by rats and parasites, they were not harvested regularly.

4. The Cyclones of 1983 in the Archipelago

In such a context the TUAMOTU ARCHIPELAGO was struck by 5 cyclones between January and April 1983. They caused 22% of the total damage estimated for all the archipelagos of French Polynesia (Table I). Over 3/4 of the 40 inhabited atolls were affected (Dupon, 1984). This apparently exceptional series of cyclones seems to have been directly linked to the general temperature imbalance in the Tropical Pacific area.

TABLE I
Tuamotu's share of the total damage for each cyclone in 1983

cyclone NANO	cyclone ORAMA	cyclone REVA	cyclone VEENA	cyclone WILLIAM
57	83	15	7	100%

(Source: Civil Defense).

4.1. Effect upon the environment

In the most badly struck inhabited atolls, the winds and the sea affected the terrestrial and marine environment in the same way as was previously described about other areas of the Pacific (Blumenstock, 1958, 1961). With the first three cyclones, the maximum wind speeds were between 150 and 180 km h^{-1} in gusts. They reached 200 km h^{-1} with the fourth cyclone but they seem to have remained below 120 km h^{-1} with the fifth.

The storm surge and the waves that occurred with it, caused deposition and erosion, especially on the north-west side of the atolls and on the leeward zone which are usually the first and the most severely affected parts in the TUAMOTU ARCHIPELAGO. Although the altitude of most atolls does not exceed 5 to 6 m above sea level at high water, villages are rarely built on the highest points. They are more often to be found on the leeward side, by the passes, and on the gentle slopes of the islets facing the lagoon. In most cases, the total or partial submersion of inhabited areas exceeded 1 m. It often reached 1,5 m; which amounts to say that the amplitude of the storm surge was around 3 to 4 m at least.

Much material was transported by the sea in its invasion: chunks over one meter large were torn off the outer reef to be dumped onto the reef flats, ridges and beds of coarse rubble, dozens of cm thick, were piled up or spread, thinning out toward the lagoon on the islets that were crossed from side to side by the waves. The most noticeable forms of erosion are the widening and deepening of passes that already existed between the islets, because of the turbulence of the water laden with all sorts of material. These forms of erosion grow scarce in the direction of the lagoons.

Where erosion prevailed, soils were not buried under the coral rubble, but washed away, sometimes thoroughly.

On most atolls, the natural vegetation, the introduced species and the coconut plantations were badly damaged. On over half of the atolls, coconut plantations lost more than 50% of the trees. In some places, fruit trees have been totally wiped out as

were the few vegetable gardens. Coconut palms have mostly been uprooted by the combined action of the waves and the winds rather than having their trunks broken or their tops snapped off. The unequal resistance of the most common species has been verified.

Finally the action of the cyclones did not just modify the emerged part of the atolls. The breakers also damaged the upper coral structures of the outer reef slope as is evidenced by the presence of chunks dragged onto the reef flat, and the preponderance of coral in the deposits of debris from the outer reef on the ocean side.

Within the lagoons, the coral pinnacles have also locally been broken or damaged by the waves. In the passes, madrepores appear to have died because of the increased turbidity that occurred when lagoons spilled out owing to the cyclones (Laboute, 1985).

P. Laboute sees a direct link between the low hazard frequency and the high impact of cyclones on the reefs of the TUAMOTU ARCHIPELAGO. The severe impact of cyclones on human activities can be accounted for with the same explanation.

4.2. Effect upon people and activities

In 1983, the cyclones caused the death of ten people in the atolls, while at least 117 perished in February 1878, 515 in January 1903 and over 120 in February 1906. The progress made in weather forecast, the existence of a rapid and adequate warning system, no doubt account for the good results obtained with the few protective and preventive measures that were taken. But we may also ask ourselves about the relation existing between the changes brought about by the new activities, the new population concentrations, and the high death toll caused in 1878 and 1903 by the cyclones. In those days, when the means of communication were slower, the new commercial speculations would cause people to abandon relatively safe dwelling sites, which were generally provided with a building that could be used as a community shelter (Church), in order to move to more exposed islets (motus) for the seasonal production of copra (thus, the majority of the population of KAUKURA was caught by the cyclone in 1878), or for mother-of-pearl collection (377 perished on HIKUERU in 1903 in the same conditions). Moreover, people gather near passes — found in over 30 atolls —, where schooners can easily enter the lagoon, or cast anchor, but which, on the other hand, are situated on the leeward side, the area most exposed to cyclones; and this fact revealed the same ambivalence: relief and assistance can certainly be brought faster by sea, but some villages, like TUUHORA on ANAA, were destroyed several times because of their location. The Church or the Protestant Temple has yet often been used as collective shelters in 1983 in these villages. But, as was the case in other islands of the Pacific, though often stronger than individual dwellings, they sometimes collapsed on the refugees (as in MAROKAU atoll, 1903), increasing the number of victims (Franco *et al.*, 1982).

Because of the commercial orientation of the archipelago's activities, the population of the TUAMOTUS have long been made dependent on imported food, but also now on a whole range of materials, technical equipment and services, which the cyclone experience revealed as inappropriate and expensive.

The traditional housing, like the traditional cultivation, has totally disappeared to give way to a transitional type of construction, often light, in which wood and boards are predominant. In the total absence of Government regulations regarding building standards, the low frequency of the cyclone hazard made people less vigilant. The same

can be said about seasonal and general prevention. There was no tested collective shelter, adapted to cyclone and tsunami hazard in 1983.

Thus, many villages, particularly on KAUKURA, ARUTUA, MANIHI, NUKUTAVAKE, but above all on ANAA were practically wiped out by the combined action of the wind and the waves laden with debris (Figure 2 and 3). Out of a little less than 1800 individual dwellings, over 1500 were to be repaired or totally rebuilt; of these, 3/4 were situated on the western and central islands. It may be estimated that about half of the dwellings were completely destroyed by the cyclones. (Figure 4). The sea invading the villages has often caused the pollution by salt water of domestic watertanks. At best, fresh water was polluted by sea spray once the tanks tops were blown off.

If housing turned out to be poorly adapted to the risk and was therefore badly damaged, the same can be said about Government and Church buildings. Even though the latter have often been effectively used as collective shelter in extreme situations (the Church on ANAA, the school building on KAUKURA, the town-hall on AHE), their permanent structure, often of recent construction, did not keep them from being damaged and in some cases totally destroyed. Thus, shortcomings in design, almost as serious as those concerning housing, were brought to light on about half of the atolls concerned.

The cost of the damage sustained by the main facilities, mostly harbours and airports, was all the higher as these facilities have been multiplied over the last 20 years to improve communications with isolated islands.

Lastly, on the worst hit atolls, the proportion of lost or wrecked boats may have reached a total of 80%. These were mostly modern often light boats, equipped with outboard engines, which contributed to the loss increase, many engines having been damaged by salt water. For the whole of the TUAMOTU ARCHIPELAGO, 400 over nearly 700 boats had to be replaced following the cyclones of 1983.

To this we must add the loss sustained by the pearl farms installations, i.e. the rafts and spat collectors, and the destruction of the fish traps.

In spite of the successive trials they had to undergo, the psychological resistance of the inhabitants of the atolls was remarkable. Observers have attributed it, as on JALUIT in 1958 and on ULITHI in 1960 (Lessa, 1964), either to a fatalistic acceptance of an act of God explicitly nourished, in some cases, by religious convictions, or to their being accustomed to living under hard conditions. Mutual help and voluntary reconstruction generally got the better of individualistic behaviour.

Most of the few families that were evacuated to TAHITI or had decided to go there on their own initiative, very soon returned to their native islands. The dispatching of aid and assistance, the evacuation of the wounded and the evaluation of the damage were rapidly carried out, relying mostly on the Army's air and sea equipment in TAHITI. In this way, local shortages of drugs, fresh water or staple foods were successfully dealt with.

5. Consequences of the Cyclones, and Lessons to be Learned

Among the aid brought to the stricken population of French Polynesia, a distinction has to be made: first the *assistance* in the form of money or goods forwarded by the State.

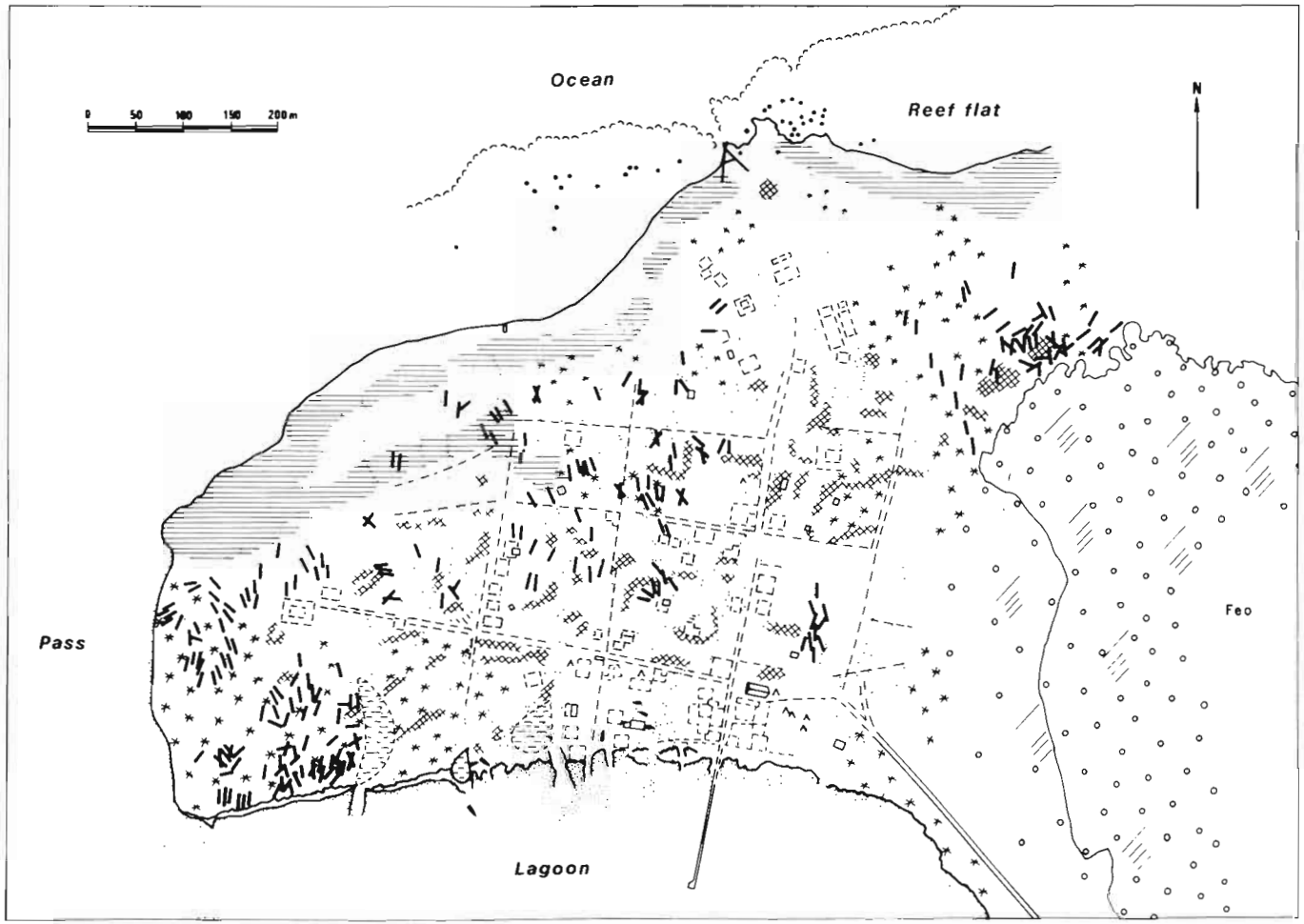

Fig. 2a. The effects of cyclone ORAMA (Feb. 1983) on the village of TUUHORA. ANAA Atoll. (TUAMOTU). From aerial photographs by F.P. Town and Country Planning Office.

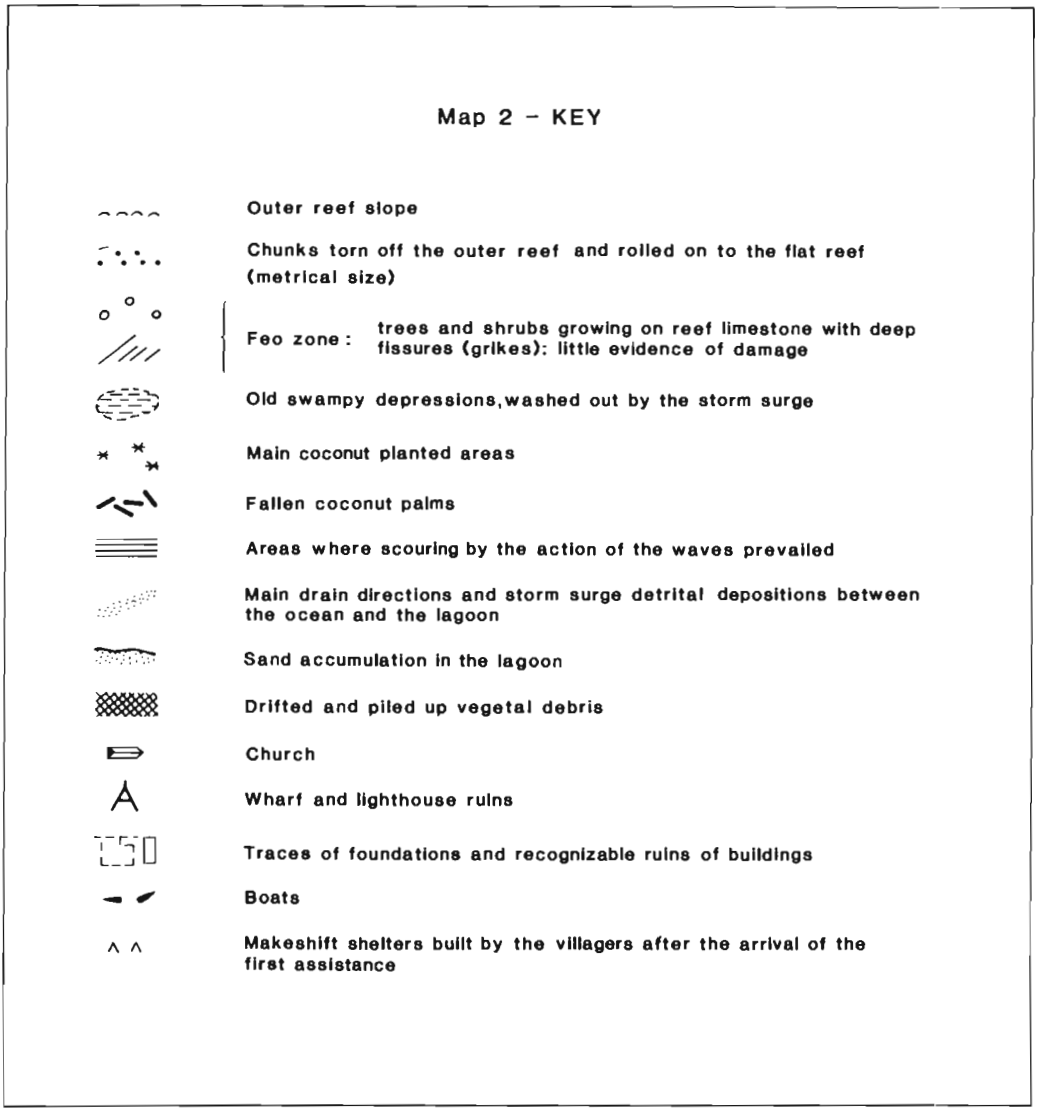

Fig. 2b. Key to Figure 2a.

About 2/3 of the families of the TUAMOTU ARCHIPELAGO (which counts a total of 1655) were assisted in this way. As a rule, this type of aid concerns only movables.

Then the actual reconstruction, basically financed by the Government by means of exceptional taxes, bank loans and sums taken from its own budget; it was directed by an organisation that was especially created for the occasion: the Territorial Agency for Reconstruction (ATR), (Dupon, 1984).

The destruction on the coconut plantations had a beneficial selective effect. It hastened and generalized the regeneration programme that had already been started before the cyclones. Over half of the 5000 ha that were scheduled to be replanted were

Fig. 3. The central part of the village of TUUHORA. ANAA atoll, after cyclone ORAMA. View taken from the lagoon. The storm surge came from the upper part of the photograph.

Fig. 4. The action of the sea on the buildings of TUUHORA. (Cyclone ORAMA). The storm surge came from the right.

done within 18 months after the cyclones, and this work provided the producers with ready cash resources. The drop in copra production, quite severe at first (more than 60% compared with 1982), began to recover by the end of 1984, a recovery that was to be confirmed in 1985. This quick recovery suggests that the potential was not employed to its full extent before the cyclones.

The rehabilitation of fruit plantations has been undertaken in more than half of the atolls that were struck.

Natural regeneration of the living environment has taken place in the same time span as was observed elsewhere. Pioneer plants species began to colonize coral rubble deposits within a year after the cyclones. Laboute (1985) observed the recolonization by madrepores down to a depth of 15 m within the same time span, together with the return of the fish.

The rehabilitation of the tools of production justified a significant effort in the field of fishing and pearl farming. Like the regeneration of coconut plantations, this cannot be dissociated from putting transportation facilities back into good working conditions. The cost of repairs on ports and airports in the TUAMOTU ARCHIPELAGO was estimated at 5.5 millions FF (US$ 800 000) in the wake of the cyclones of 1983. In most cases, works were almost completed 18 months later.

Rehabilitation of individual housing was undertaken in two different ways: either repairs carried out quite easily by the families concerned (over half of them) with the help of material supplied to them; or total reconstruction. The Territorial Agency for Reconstruction endeavoured to propose a modular type of dwelling, consisting of a wooden structure, covered with plywood boards and a tin roof, slightly raised from the ground or short stilts. Only one village, the site of which was deemed particularly exposed, was relocated (TUUHORA on ANAA, 89 lodgings) (Figure 5). The new village has been built to the East of the former one near the lagoon, and away from the pass. This relocation does not totally solve the problem of protection against storm surge, and the same may be said about many other villages.

It may however be considered that establishing housing on the lagoon side, when as on ANAA the central part of the islet is elevated, constitutes in itself a partial protection, even though it is not exceptional for storm waves to cross the whole width of the islet.

The great number of inhabited atolls and the fact that on some of them the population is rather numerous, rules out generalized preventive evacuation in the TUAMOTU ARCHIPELAGO, in spite of a rather dense network of public and private airfields.

After the cyclones of 1983, which revealed the insufficiency of protective measures for the population, the Authorities decided to opt for a combination of preventive measures as regards construction. The type of individual dwelling proposed by the Territorial Agency for Reconstruction includes the conventional provisions to improve resistance to wind: ground braces, wind-proof bracing, bolted-down frame, reinforced roof fastening, short stilts, adapted openings. (Figure 6)

In the second place, the State decided to apply new regulations to the construction of public buildings, thus enabling them to resist winds of speeds over 200 km h^{-1}. The resulting extra cost of construction is in the range of 3 to 10% as the case may be.

Finally, as early as before the end of the 1982/83 cyclone season, the decision was taken to launch a programme for the construction of community shelters, on the 13

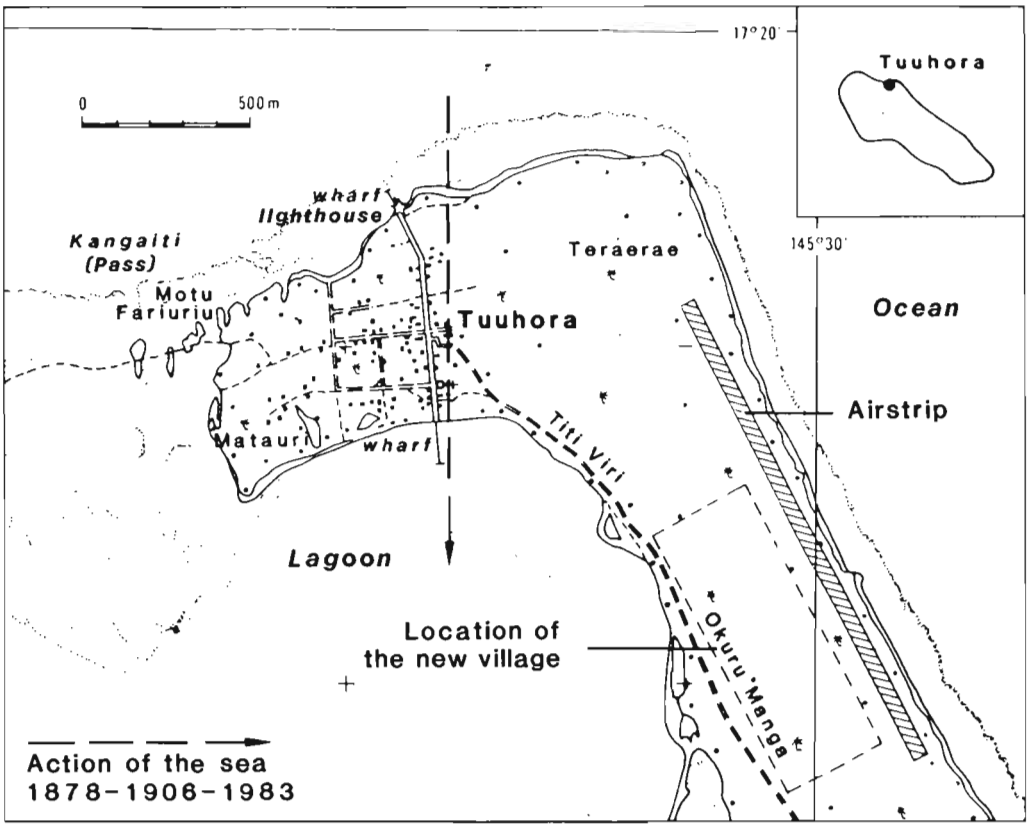

Fig. 5. Relocation of TUUHORA. ANAA Atoll.

atolls deemed to be the most exposed, for a total cost of 16.5 million FF (US$ 2.4 millions). Full implementation of this programme should affect 30 to 40% of the archipelago's population.

The accepted common regulations for the construction of these shelters should enable them to withstand winds up to 300 km h^{-1}, water pressure of 4 tons per sq. m up to 3 m above the ground, and shocks equivalent to a push of 5 tons of power. In most cases, the shelter will normally be used as either town hall or dispensary, sometimes both. Such is the case with the ANAA shelter, built on the new village site. (Figure 7)

In this shelter, the costliest (4.45 million FF), (US$ 640 000), protected areas are raised from the ground by means of deeply sunk 3 m stilts. The floor and the ceiling are made of concrete slabs. The building is equipped with a watertank and a solar cell system for producing electricity. It is also planned that in most cases the radio transmitting station could be set up in the shelter.

The construction programme was delayed for reasons pertaining to the atolls' characteristics. It turned out to be difficult to find contractors ready to set up large construction sites under difficult logistic conditions as are mostly to be found on the atolls. Also, the land problem has often hindered or even stopped the opening of

Fig. 6. ATR dwellings in the relocated village of ANAA atoll.

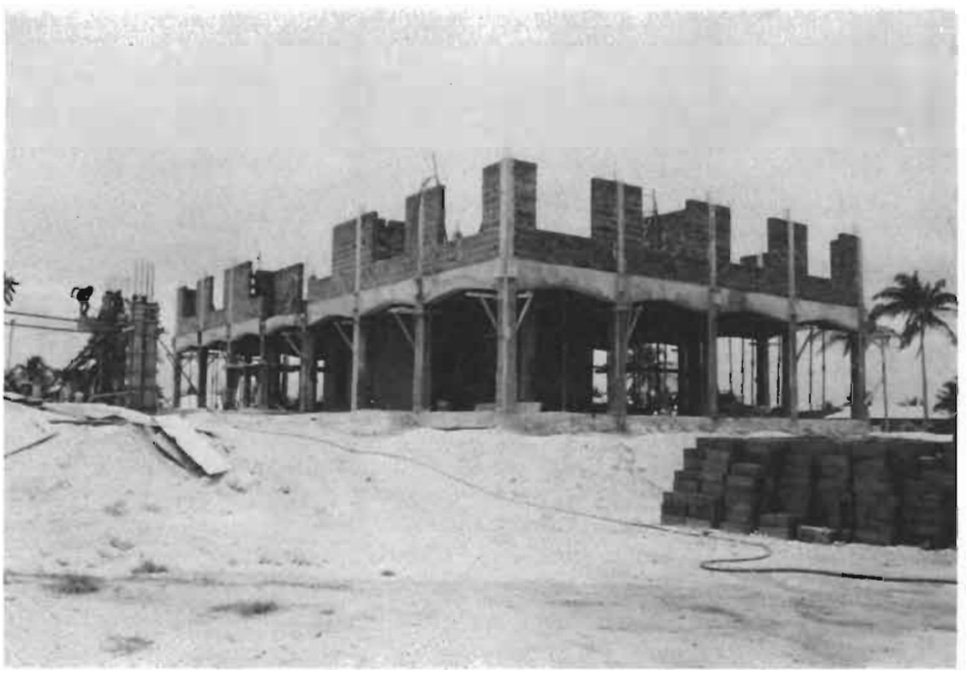

Fig. 7. Construction of the community shelter of ANAA atoll (Oct. 1984).

construction sites, obliging the authorities to initiate long and intricate expropriation procedures.

Luckily, since 1983 cyclonic depressions have spared the TUAMOTU ARCHIPELAGO. Having for ages contributed to the construction of the atolls as well as to their destruction, they remain however an element of their environment that has to be taken into account. Prevention and the protection of human settlements in these islands cannot be neglected even though short-term weather forecasting is increasingly accurate and though reliable medium-term forecasting can be hoped for thanks to a better understanding of ocean and atmosphere interaction in tropical areas.

Unlike in the situation on ULITHI (CAROLINE ISLANDS) twenty years ago, as described by Lessa (1964), the cyclones of 1983, in spite of the shock they caused, do not seem to have accelerated the acculturation, already well under way, of the PAUMOTU people (inhabitants of the TUAMOTU group). But they have yet increased the PAUMOTU's dependence upon the outside world.

6. Conclusion

The atolls of the TUAMOTU ARCHIPELAGO are seldom visited by serious tropical cyclones. That is why the devastating series that struck the group in 1983 showed the effects of a low frequency hazard upon a fragile natural environment and human settlement of low lying islands that had greatly evolved over the last century. The impact of the cyclones there was globally more severe than in places where frequent hazards cause regular adjustments. As costly as was the 'unpreparedness' of the natural environment, it could not be prevented. But damage to human settlements and activities can be significantly reduced thanks to appropriate prevention measures, be they implemented through official regulations and Civil Defence policy or through the education of individuals.

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