SPREP Reports and Studies Series no. 62



South Pacific Regional Environment Programme

# Existing and Proposed Extension to **Gabion Seawall Protection in Tokelau:**

## Environmental Impact Assessment

by
Roger McLean

Original Text: English

Published and printed
in June 1993 by:
South Pacific Regional
Environment Programme
P.O. Box 240
**Apia**
Western Samoa

Financial assistance from the
**United Nations Development Programme** (UNDP)

**Cataloguing-in-Publication Data**

McLean, Roger
Existing and proposed extension to gabion seawall protection in Tokelau: environmental impact assessment / by Roger McLean. - Apia, Western Samoa : South Pacific Regional Environment Programme [SPREP], 1993.

iv, 40p. : ill. ; 29 cm.
Includes bibliographical references.

ISBN: 982-04-0047-3

Funded by the United Nations Development Programme (UNDP), in support of the Office of Tokelau Affairs.

1. Climate changes - Tokelau I. Title

# SOUTH PACIFIC REGIONAL ENVIRONMENT PROGRAMME

## EXISTING AND PROPOSED EXTENSION TO GABION SEAWALL PROTECTION IN TOKELAU: ENVIRONMENTAL IMPACT ASSESSMENT

Roger McLean
Department of Geography & Oceanography
University of New South Wales
Australian Defence Force Academy
Canberra, Australia

A report prepared for the South Pacific Regional Environment Programme and the Office for Tokelau Affairs and financed by the United Nations Development Programme

January 1993

ISBN: 982-04-0047-3

CONTENTS

## 1. INTRODUCTION

### 1.1 Background

Following Cyclone Ofa, which caused extensive damage to Tokelau in February 1990, a programme of seawall construction was undertaken by the New Zealand Defence Force (NZDF) and Tokelau in the last quarter of 1990. The position and design of the seawalls was based on a report by Maccaferri Gabions New Zealand Ltd prepared in June 1990 by Mr C.C. Brockliss. The initial design concept was to construct seawalls that would provide adequate protection but at the same time have minimal effect on the natural environment. Construction of the seawalls was not completed before the NZDF departed and the Tokelau people continued with the work.

To complete the project the United Nations Development Programme (UNDP) and the Office for Tokelau Affairs (OTA) agreed to continue and complete construction of the required seawalls. An On-site Design Consultancy was commissioned on behalf of UNDP and OTA in November 1991 and a report prepared by Mr Brockliss in March 1992. In the interim Cyclone Val struck Tokelau in December 1991 at a time when the seawalls were in various stages of completion. Cyclone Val therefore enabled Mr Brockliss to make a critical analysis of the performance and effectiveness of the gabion seawalls during his visit, as well as to assess the overall quality of the construction work, suggest modifications to the original design and to list priorities and material requirements for proposed extensions.

Some concerns about possible adverse environmental effects of the seawall construction programme had been recognised by OTA following comments in the Tokelau Country Report for the United Nations Conference on Environment and Development (Humphries and Collins,1991). As a result UNDP/OTA commlssloned Mr G J Shuma to undertake a brief desk study on the possible environmental impact of the shore protection works. His report discusses the general requirements for shore protection in atoll environments, available solutions and specific requirements in Tokelau in terms of ongoing works. He also noted "that to be able to determine to the fullest extent likely long term impacts, both positive and detrimental, it is necessary to carry out a detailed environmental impact assessment (ElA) of the works." Such a study would involve the collection of some field data.

### 1.2 Present mission

On 2 December I was engaged by the South Pacific Regional Environment Programme (SPREP) and OTA to visit Tokelau and undertake an EIA of the existing and proposed extensions to the gabion seawall protection on the three atolls. The EIA is part of the Tokelau Environmental Management Strategy (TEMS) Project. Briefings with SPREP, OTA and UNDP were held prior to departure and copies of the Brockliss(1992) and Shuma (1992) reports were provided as background to the project.

The M V *Wairua* departed Apia at 2300 hr Saturday 5 December and returned at 1530 hr Friday 11 December. In all a total of 23 hours was spent on the three atolls, approximately 8 hours on Fakaofo, 5 hours on Nukunonu and 10 hours on Atafu. Informal discussions were held with village officials and staff engaged in seawall construction (where possible), shore protection works were inspected and levelling surveys across the four village motu were carried out. Except on Fenuafala, where there are no seawalls, the surveys included transects over the seawalls. Only on Atafu was a formal meeting held with elders and island officials to discuss the project.

A detailed itinerary and list of activities is given in Annex I.

Following the field visit a meeting was held at UNDP headquarters in Apia with representatives from UNDP (Ms Sarwar Sultana, Resident Representative) OTA (Mr Casimilo Perez, Official Secretary) SPREP (Ms Neva Wendt, National Environment Management Strategy Project) and the writer. At that meeting the major conclusions and recommendations contained in the present report were outlined and discussed.

### 1.3 Structure of report

This report comprises several parts. Section 2 presents a brief description of the atolls and village motu and of the major factors involved in their formation. The role of storms in island building and erosion under natural conditions is highlighted. This gives a perspective against which modifications to natural processes resulting from seawall construction can be assessed. Section 3 summarizes the main materials and methods used in gabion seawall construction as well as the original design concepts. This section relies heavily on the reports of Brockliss (1990, 1992). Section 4 considers the environmental impact of seawall construction activities. Two groups of physical impacts are reviewed, the effects of the seawalls themselves and the effects of stone removal from motu, beaches and reefs. The social impact of seawall construction is also addressed. The following three sections (5, 6 7) assess the impacts on each of the three atolls (Atafu, Nukunonu and Fakaofo) and island-specific future priorities and recommendations relating to seawall extensions and stone source areas are made. Section 8 draws together some general conclusions from the preceding analysis and presents a series of general recommendations about the future of the gabion seawall project.

## 2. GEOGRAPHICAL FACTORS

### 2.1 The atolls

The three atolls of Tokelau are typical coral atolls with an encircling reef surrounding a lagoon (Fig. 1). Importantly the reef rim is continuous and there are no natural passages through it that permit ship access to the lagoon. The reef rim is exposed at low water thus isolating the lagoon as a 'lake' at such times. During the low sea level phase of the 1982-83 El Nino event in the Pacific, lagoon water levels in Tokelau were reported to be 20-30cm below the level of the reef rim for a period of several weeks and this had a devastating effect on corals, fish and other life in the lagoon.

The total land area of Tokelau is about 12 sq km which is made up of 127 separate motu or small islets. The motu vary in size from about 90m to 6km in length and a few metres to over 200m in width. The largest atoll is Nukunonu with 4.7 sq km on 24 motu followed by Fakaofo with 4 sq km on 61 motu and Atafu with 3.5 sq km on 42 motu. All of the motu are located on the reef rim and all are made up of wave deposited coralline sand and gravel from the adjacent reef and lagoon. The motu all posses features typical of such environments - small size, low elevation, poor soils and a limited terrestrial biota.

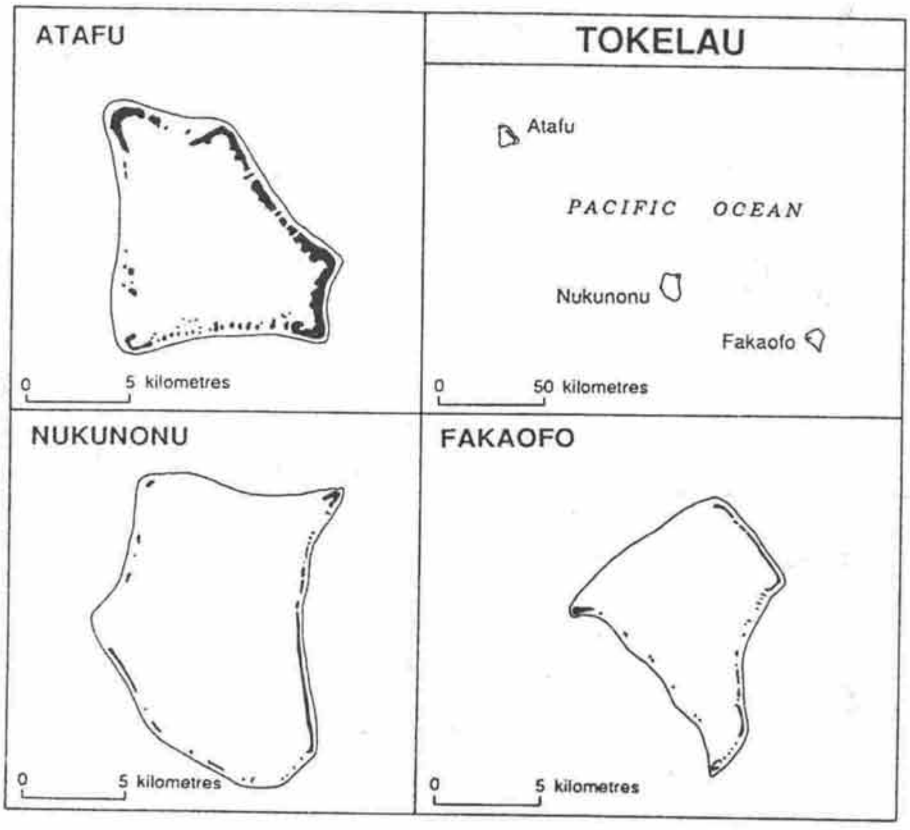



Figure 1: The three atolls of Tokelau

## 2.2 Village motu

Settlement is concentrated on four motu, one on Atafu and Nukunonu and two (Fale and Fenuafala) on Fakaofo. The village motu are all located on the western side. They are therefore sheltered from the predominant south easterly trades, but are exposed to strong winds and seas from northerly to westerly directions which occur at intervals during the 'summer' months.

Fale, the smallest motu is most intensively developed and its shore perimeter comprises a number of seawalls and rubble defences and has no natural beach profile. The other three village motu are larger. They have areas of vao and a significant proportion of the shoreline away from the immediate village areas have natural profiles. Without ship access to the lagoon, boat channels have been excavated across the oceanside reef towards the villages of Fale, Nukunonu and Atafu. The presence of these deep shore-normal gutters has an effect on water flow and sediment movement on the nearby reefs and island shorelines.

## 2.3 Tropical cyclones

Although Tokelau is located to the north and east of the core region of the southwest Pacific's hurricane belt, tropical cyclones sometimes form in close proximity to the islands (Thompson, 1986). Because the islands are so low storm surges and seas generated by gales or tropical cyclones several hundreds of kilometers away have swept over the islands. Notable storm events occurred in January 1914, December 1925, January 1936, February 1941, November 1941, December 1957, January 1966, November 1972 and January 1978.

More recent events include the storm surges in February 1987 which struck Tokelau during a period of high spring tides and were associated with cyclones several hundred kilometers away to the southeast and southwest. On the atolls this event is known as the Cyclone Tusi storm. Cyclone Ofa and Cyclone Val developed in the vicinity of Tokelau in late January-early February 1990 and December 1991 respectively. Damage reports were prepared on these cyclones and are available at OTA.

## 2.4 Island evolution and development

Field surveys and observations made during the present visit confirmed the important role of storms in the development of Tokelau's motu and also confirmed that models developed elsewhere for the formation of atoll islands in the region (for Tuvalu, Kiribati and the northern Cook Islands) are generally applicable to Tokelau.

First, all of the motu are very young. Second, they have developed on a conglomerate platform (or coral hard-pan or te papa) which probably formed just 2-4000 years ago with a sea level higher (by 0.5 - 1.0m) than present. In places, particularly along the western rim of the atolls and on the ocean side of the motu, this conglomerate platform is exposed and forms a distinct step up from the modern reef. The motu are partly anchored on to this platform, at least on their seaward sides (and so are some of the gabion seawalls). Third, accumulation of the motu is likely to have been partly contemporaneous with the platform's formation and partly results from the subsequent fall in sea level in the last 1-2000 years.

## 2.5 Role of storms in island building and erosion

While the destructive effects of cyclones Val, Ofa and earlier Tusi were uppermost in residents minds on all three atolls during my visit, most recognized that in addition to the erosion of shorelines and undermining of house foundations, slab seawalls, etc, the storms had also washed sands and stones on to parts of the motus. Some of this material had come from the erosion sites and some fresh from the adjacent oceanside reef flats. Not only were sediments deposited on the surfaces of motu, but in places new banks of storm rubble appeared on reef flats (such as the 40m wide boulder tract in front of the village at Atafu) or new ridges of stones accumulated near to or against the oceanside beaches (such as the extensive natural 'reclamation' along the northern half of Atafu).

These examples serve to illustrate the fact that storms are both erosional and depositional events. Generally, under natural conditions, the net effect of storms is to enlarge islands and increase their elevation, rather than reduce their area and height. (This, however, is not always the case particularly in areas where there has been human modification to reef flats through the excavation of boat channels and quarrying of stones, or through the building of solid shore protection structures, all of which interfere with natural processes).

Also these recent examples serve to illustrate how the islands initially formed and grew. Evidence for earlier episodes of accumulation are apparent in the stratigraphy of the motu which show successive layers of coral gravel (kilikili) and sand (oneone) built up during storms and longer periods of normal wave activity. Periods of land stability and the presence of vegetation are also evident in the subsurface stratigraphy as dark humus rich soil layers with charcoal indicating human activity. Such layers indicate that the motu were much lower than at present and when, as Best (1986) found during his archeological survey, conditions for settlement were "far more difficult than those of today." He concludes that:

> "The islands on which the present-day villages of Atafu and Fakaofo are situated were between one and two metres lower and thus more vulnerable to storm waves"

This comment is equally applicable to Nukunonu where stratigraphic sections excavated for the placement of the gabion seawall indicate an occupation layer at least lm beneath the present surface. Clearly, in all cases there has been substantial build up of the motus since the earlier days of occupation.

Finally, surveys across the four villages carried out during the present visit show that these motu all have an asymetrical profile with the highest elevation at the oceanside ridge and the surface dipping down towards the lagoon. Such profile indicate that the motu have extended lagoonward as a result of westerly storm wave erosion, deposition and washover, the lagoonside beach initially migrating across the conglomerate platform and then onto the shallow sandier parts of the lagoon shore. On Fenuafala, Atafu and to the north of the Akau Loa on Nukunonu, sandy sediments derived from the lagoon have also aided this process. But on Fale (Fakaofo) and south of Akau Loa at Nukunonu further lagoonward extension of the motu is limited because the shoreline drops off steeply into deep water.

## 3. GABION SEAWALL CONSTRUCTION: MATERIALS AND METHODS

### 3.1 Introduction

In simplest terms seawall construction is carried out using imported Maccaferri gabion baskets which are filled with local coral rocks. However, this simple statement does not do justice to the range of materials and the range of designs that are used in gabion seawall construction to achieve their primary purpose. During the field reconnaissance it became apparent that some of the construction materials were being used for purposes other than what they were intended for and not all seawall builders appreciated the importance of optimal placement and design, or, if they did, it was not always practiced. This was particularly true on Fakaofo and Nukunonu where there are a number of 'private' segments of seawall on the lagoonside of those islands that were not constructed as per design.

Thus, it is important for both officials and residents to understand what the materials used in seawall construction are and what the primary purpose of the programme is. From an environmental point of view it is also important, given the fact that the material requirements for Stages 2, 3 and 4 of the seawall project include a total of:

- 5 km of 4m wide Bidim A64 (grey 'carpet')
- 22.22 km length of gabion units
- 20,975 kg of PVC tie wire coils; and
- 20,000 cubic metres of coral rock for basket fill

[Figures calculated from Brockliss, 1992, Appendix 2]

These quantities are in addition to those already used in the construction of stage 1.

### 3.2 Materials

Four main materials are supplied for construction:

**Gabion baskets.** These consist of a heavy zinc coated mild steel wire sheathed in PVC and woven into a hexagonal mesh. Mesh size is 8cm and wire thickness 3.8mm. Baskets come in various sizes, typically 4m x lm x lm and 2m x lm x 0.5m. The gabions are assembled into 'boxes' divided into cells by diaphragms at lm centres. To accommodate stone movement the baskets can be stretched: design stretch is at least 12%.

**Terramesh panels.** These are single panels, like one side of a gabion and are made of similar materials. Panels or typically 6m or 4m long x 2m wide.

**PVC tie wires.** For strength and stability the baskets and panels are tied together at top, bottom and sides by PVC tie wires which are cut from coils of wire supplied at 10 per cent of the gabions weight.

**Geotextile (Bidim A64 or equivalent).** This grey carpet-like material is made up of 100 per cent polyester fibres. It comes in rolls 4m wide x 100m long, and has a mass of 500g per square m. The mat is 4.8mm thick and has a fine pore space

(0.14mm max) which does not permit sand sized material or gravel to pass through, though water can at a minimum flow rate of 118 litres/$m^2$/second.

Local materials involved in seawall construction include:

**Stones for gabion basket fill**. With a mesh diameter of 8cm stones need to be larger than this; stones of 10-25 cm diameter are the ideal size. Flat edge rounded stones pack best and are most stable; angular stones with sharp edges may cut into the PVC mesh.

**Backfill**. Material for backfill comprises a number of different sediments ranging from large mass boulders and blocks to sands depending on location and dimensions of the wall.

Large quantities of fill are required in seawall construction and the sourcing of this material has important environmental implications (see later).

### 3.3 Original design concepts

It is also important to reiterate the primary purpose of the construction activities. These have been stated by Brockliss (1992) from which the following comments are extracted. The gabion seawalls are intended only to be operative during severe storm events (cyclones). But because of differences in shore and reef characteristics, particularly between Fakaofo (Fale) compared with Nukunonu and Atafu, there are design differences (Fig. 2).

On Nukunonu and Atafu the gabions were designed for placement just inland and above the top of the existing beach to complement and extend the existing beach profile and enable higher energy events to be dissipated whilst ensuring that wave energy reflection would not compromise the existing beach regime. In other words a 'natural' beach was to be maintained against and seaward of the seawalls.

On Fakaofo (Fale) the seawalls were designed essentially as a retention system or physical barrier and retaining structure. This because the natural beach system had already been lost over the years due mainly to wave reflection from stacked coral rubble walls and other shore structures.

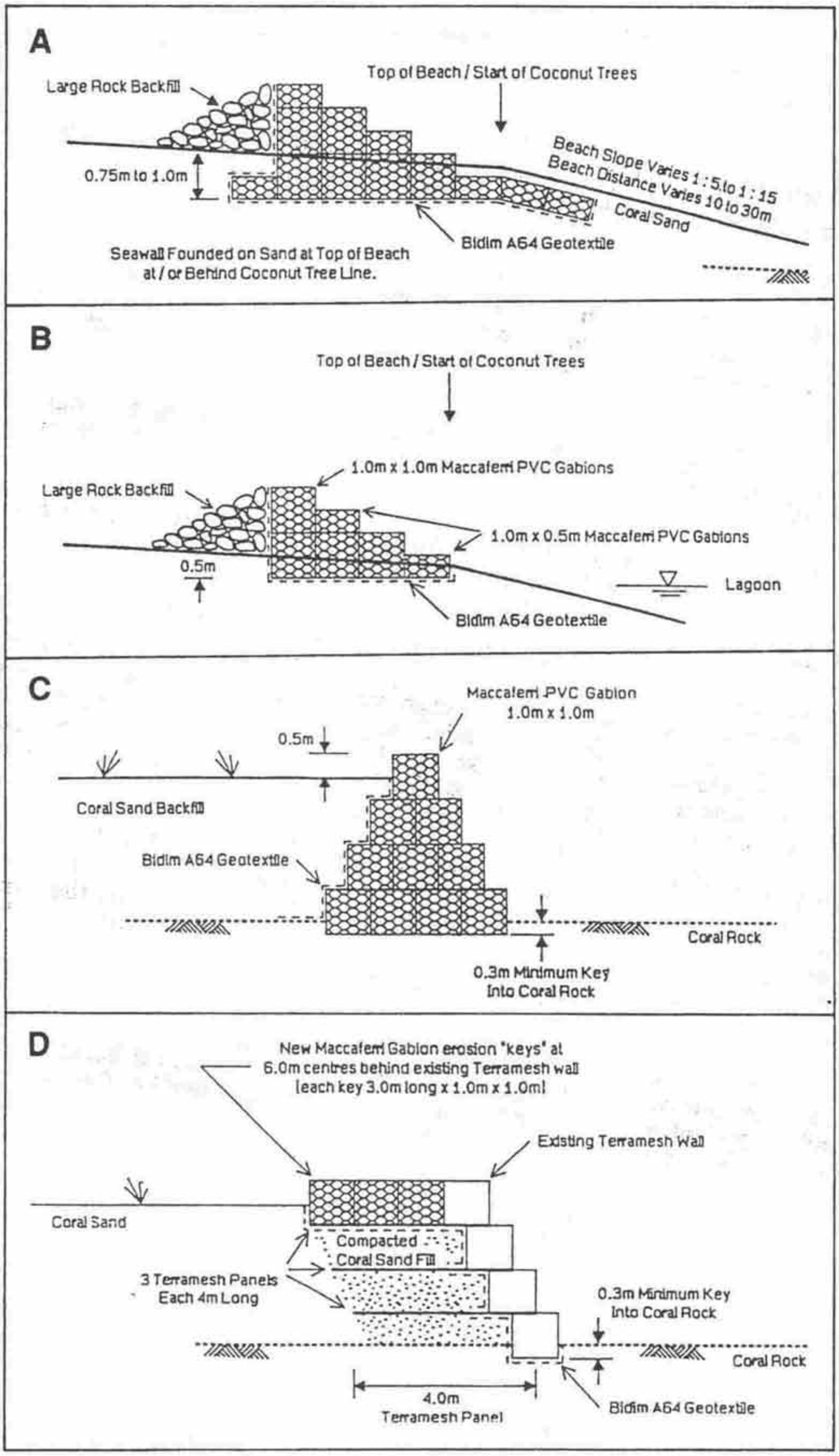



Figure 2: Gabion seawall designs for Tokelau.. A. Configuration for foundation on beach sand for oceanside of Atafu and Nukunonu. B. Modified configuration for lagoonside of Atafu and Nukunonu. C. Mass gravity wall for all new construction on Fale (Fakaofo). D. Terramesh configuration for foundation on hard coral where no beach exists at Fale showing extra gabion keys .
(After Brockliss, 1992).

## 4. ENVIRONMENTAL IMPACT OF SEAWALL CONSTRUCTION

### 4.1 Introduction

There are two main issues to be considered here. First, the physical impacts of the gabion seawall construction project on the natural environment and on natural processes. And, second the social and amenity aspects of the project. These impacts are considered both in the short and long term, and where negative effects are identified suggestions are made on how these can be mitigated.

### 4.2 Effects of Seawalls

#### 4.2.1 Cyclone Val and subsequent modifications

It is worth recalling that the primary purpose of the seawalls is to protect the land during severe storm events (cyclones). The effectiveness of the seawalls constructed prior to December 1991 was tested during Cyclone Val, and Brockliss (1992) concluded that

- the gabion seawalls were successful in providing cyclone protection to structures at Tokelau during Cyclone Val; and,
- the gabion seawalls suffered very little damage during Val.

Nevertheless, he identified some failings in design and construction, and as a result of overtopping and scour of backfill at Fakaofo, recommended that additional protection against scour should be constructed (using 3m long 'keys' spaced at 6m centres) behind the gabion wall along the official jetty area (Fig. 20). These 'keys' (or loka) have since been constructed.

Comments by officials during my visit also expressed general satisfaction with the performance of the seawalls during Val, though they were quite concerned about the fact that the walls were overtopped by seas and with scour behind, at the ends and through access points in the wall. As a result of this experience and soon after the storm the northern 40m of the seawall at Atafu was raised in height by adding 1.5m of exta gabions, access gaps were blocked off and boulders placed at one end of the wall. Heights have been increased at a number of other segments of seawall elsewhere, a practice that Brockliss (1992) says should be stopped and should not be necessary if the walls are sited in their design position.

#### 4.2.2 Effect of seawalls on reef-beach-island system

Earlier sediment movements between the reef, beach, and island systems were discussed and the linkages examined in terms of island building. Anything that inhibits free exchanges, such as construction of a barrier between any of the three components of the system, will reduce the rate of natural island building. Clearly the gabion seawalls do this, though their stepped surfaces are also designed to reduce wave reflection and the potential to remove beach sediments on the seaward side.

Field observations show that some accumulation of sand and gravel is taking place against the walls and that incipient beaches are developing in places. While it is too early to evaluate the effect of seawall construction on the development of substantial frontal beaches (which will be dependent on the long-term balance between the rate of delivery and the rate of removal of sediment) there are some locations where current speeds and directions are such that sedimentation is unlikely. These occur in the water catchment area surrounding the boat channels, where, on the receeding tide, water flows are fast and directed away from the shore (that is towards the boat channels), and also at the southern end of the walls where tidal flows in natural channels inhibit sediment settlement.

The foregoing comments are applicable to the oceanside seawalls on Atafu and Nukunonu. On the lagoonside no beach building in front of the walls can be expected because of the proximity to deepwater and the lack of suitable supplies of sediment.

#### 4.2.3 End wall effects

The ends of seawalls that run parallel with the shore are frequently problem areas. Scour and erosion is focussed in such locations and this happened in all cases during Cyclone Val. It is also a problem in tidal channel locations, unless there is a constant import of sediment to compensate. End wall scour will be a constant problem without some remedial action.

### 4.3 Effects of stone removal

#### 4.3.1 General considerations

Materials used for filling the gabions and for backfill need to be of the appropriate size, shape, roundness and quality. On atolls adequate supplies of the desired materials are generally abundant and may be sourced from motu lands, beaches or reefs and reef flats.

(1) Removal from vegetated motu lands is usually limited because of questions of land ownership, multiple handling and the visually obvious effects of quarrying. Nevertheless, in some cases (outside of Tokelau) whole islets have been set aside for quarrying purposes in order to concentrate the environmental effects of removal. In other cases opportunist quarrying takes place. For instance, where excavations are required for other purposes e.g., water tank, septic tank, pulaka pit, the excavated products can be stockpiled or used in other projects e.g., seawalls.

(2) Removal of material from beaches. Island beaches are frequently attractive sources of construction materials because the sediments are usually clean, well rounded and relatively easy to collect from either land or water. Removal from beaches will normally (i) accelerate local erosion, particularly during storms; and (ii) reduce the supply of sediment downdrift and hence expand the area of erosion. Beaches are the primary natural form of defence against land erosion and the consequences of extracting materials from such dynamic sites are usually serious. Exceptions occur where beaches are continually accreting or where they are located downdrift of sites that need protection.

(3) Removal from reefs and reef flats. The natural source of all sediment for building islands and their beaches in atoll situations are the reefs and reef flats which provide the first line of defence against island erosion - by substantially reducing wave energy. Actively growing plants and animals of the reefs are the primary producers of sediment. Reef flats usually store large quantities of sand,

gravel and boulders which are moved to the shore under storm conditions to replenish beaches and ultimately islands. Additionally, the very presence of both live hard skeletoned animals such as corals as well as their dead and broken counterparts, serves to baffle and reduce wave action reaching island shores. Removal of such materials therefore increases wave action, and hence erosional potential with possible serious consequences. It is unwise to remove reef and reef flat material around sites that require protection.

### 4.3.2 Sources of fill

When Brockliss visited Tokelau in March 1992 over 700 m of gabion seawall had been completed or was under construction. I estimate this would have required about 5000 cubic metres of fill (9 $m^3$/m gabion, 4 $m^3$/m terramesh). Brockliss also noted that initially fill was secured close to the construction sites using coral gravel found on the tidal reef. As construction progressed stones were brought from further afield such that by the time of his visit they were being carted by boat from other motus (the NZDF left 3 aluminium boats on each atoll for this purpose).

My observations and enquiries in December confirmed that fill was again being primarily taken from reef flats close to the village islets: at Atafu from a boulder tract south of the boat channel and within 150 m of the seawall; at Fakafo from the reef flats to the south and particularly to the northwest of Fale adjacent to the Te Papa (piggery area) some 200 - 500 m from the seawall; and, at Nukunonu from deposits on the reef flat and conglomerate platform in the Na Papa area, 500 m to 1 km southeast of the village. Stones are gathered by hand at low tide and either stockpiled locally in cairns or carted away by boat at high tide. Further afield sites at Nukunonu are rubble mounds on the reef flat and conglomerate platforms between Te Kamu and Te Puka about 5 km across the lagoon to the north of the village, and at Fakaofo stone is taken from the Ahaga Loa area a site which involves lagoon boat travel (4 to 6 return trips per day). At Atafu, the second main site of stone removal is from the accretionary beach on the north side of the village islet. Cartage is by truck.

At all sites stones were being collected from storm rubble deposits emplaced during the recent cyclones either as veneers or discrete mounds on reef flats and at Atafu initially from a rampart that has since accreted against the beach and is locally known as the reclamation. Live coral are not abundant at any of the extraction sites though occasionally a massive coral (Porites) is collected with the surrounding stones. They are also not abundant on the reef flats (which get exposed at low tide) but are on the outer reef slope; areas well beyond easy access.

Recommendations relating to preferred sources for rock fill on each atoll are given later in this report.

### 4.5 Social impact of seawall construction.

The Tokelau people have a long tradition in stone wall construction not only for land protection but for other purposes as well. Although on a larger scale, and utilizing new materials and methods, the gabion seawall project is seen as a continuation of that tradition. No doubt in the absence of the present post-cyclone community seawall project, and the provision of funds and materials to carry it out, private seawalls would have been constructed, particularly on the lagoon and channel sides of the village islands. Already several traditional coral slab walls have been constructed, and in both Fakaofa (Fale) and Nukunonu, gabion walls have been privately built for a range of purposes including boat ramps, small boat harbours and reclamations, as well as for shore protection. Purpose, placement, design and use of the gabions has severely compromised the original specifications and decreased effectiveness against storm wave incursion and damage. On the other hand greater amenity has resulted; shore protection being seen as just one use, but not the only one, for gabion walls. Ad hoc construction is likely to continue particularly along lagoon frontages where easy boat access is an important requirement.

On the oceanside, however, the situation is quite different. Here the seawalls are seen very much as community developments and defences. Placement, design and construction quality more closely matches specifications and the prime purpose of the seawalls is accepted. Community confidence in these seawalls appears high following the experience of Cyclone Val. That experience has also resulted in modifications to the original design by increasing wall height (adding another layer of gabions), blocking off access gaps and by constructing gabion 'keys' (or loka) on the inside of the wall (at Fakaofa).

Such modifications can be viewed as local adjustments to the storm hazard; adjustments that are favoured over siting or moving buildings further back from the seawalls. In many coastal locations elsewhere in the world a range of community adjustments are adopted to protect property and structures. These include land use zoning, buffer zones and building codes which are designed to complement and reinforce storm protection works. Such a range of adjustments have not been adopted in Tokelau, perhaps for two reasons. First, there may be complete faith in the gabion seawalls to provide defence against storm wave incursion, or, second, because cyclones are of such short duration other matters of amenity are perceived as being of more importance. Values of traditional land ownership or land occupation may also be important.

Given the foregoing analysis it is my view that the single purpose of the seawall project is not completely congruent with community perceptions of the importance of the cyclone hazard. And that there are other values including amenity values, which, for long periods of time are of greater significance. It is for these reasons I later recommend that the seawall construction project be expanded from its single purpose to incorporate other construction activities using gabion materials and technology.

## 5. ATAFU ENVIRONMENTAL ASSESSMENT

### 5.1 Island geography

The village island is located at the extreme northwestern corner of the atoll and is particularly exposed to weather and seas emanating from that quarter. The island is an open U-shape with its axis directed towards the WNW and with arms approximately 1 km long and 200 m wide increasing to about twice that width towards the apex. The northern arm of Atafu comprises two islets separated by a 200 m wide corridor of coral rubble and *Pemphis* (gagie) vegetation with a tidal channel on the southern side. The main village is located on the western arm towards the southern end. Here the island reaches 3-5 m above reef flat level on the oceanside and it slopes gradually towards the lagoon. (Fig. 3). North of the school the land surface topography is more complex and comprises two or three separate ridges and swales, the ridges being higher than those to the south.

### 5.2 Coastal dynamics

The lagoon is quite shallow towards the apex of the island and there are a number of sheltered embayments on the lagoonside. The school is located behind one of these embayments. Sedimentation is taking place in the Pauluku area between the two arms of the island (Fig. 4). Further south lagoon depths increase alongside the main village permitting boat access at all stages of the tide. Small boat access between the lagoon and ocean is possible at high tide using a natural channel between the southern end of Atafu and Ulugagie. The excavated boat channel is located to the north of this natural passage and coral blocks from the excavation have been placed close to shore towards the northern end of the seawall.

The position, shape and morphology of the island indicates that lateral (longshore) movement of beach and reefal materials takes place along the ocean shore. Field observations suggest there are two predominant drift directions: (i) from west to east along the northern arm of the island (the northern drift cell); and (ii) from north to south along the western arm (the western drift cell). Drift-parting occurs between Te Utua O Muli and Teluto O Te Vai and this area separates the two drift cells (Fig. 4). The village is located at the downdrift end of the western cell. The southern end of the island accreted after the 1914 hurricane and the village later expanded on to this new land (Best, 1986).

During cyclones Ofa and Val the seaward edge and slope of the reef was damaged and eroded and large quantities of coral rubble deposited on the reef flat. A small boulder tract was formed south of the boat channel and a much larger storm rampart developed along the northwestern side of the Atafu. This rampart has subsequently migrated and welded up against the oceanside of the island forming a natural reclamation. Both deposits are used as sources of fill for the gabion seawall.

### 5.3 Gabion seawall construction.

In March 1992 Brockliss (1992) reported that 190 m of gabion seawall had been completed along the oceanside of Atafu both to the north and south of the boat channel. He also noted (i) that the seawall was constructed too far down the beach by some 5-15 m; (ii) that following cyclone Val access gaps in the seawall had been

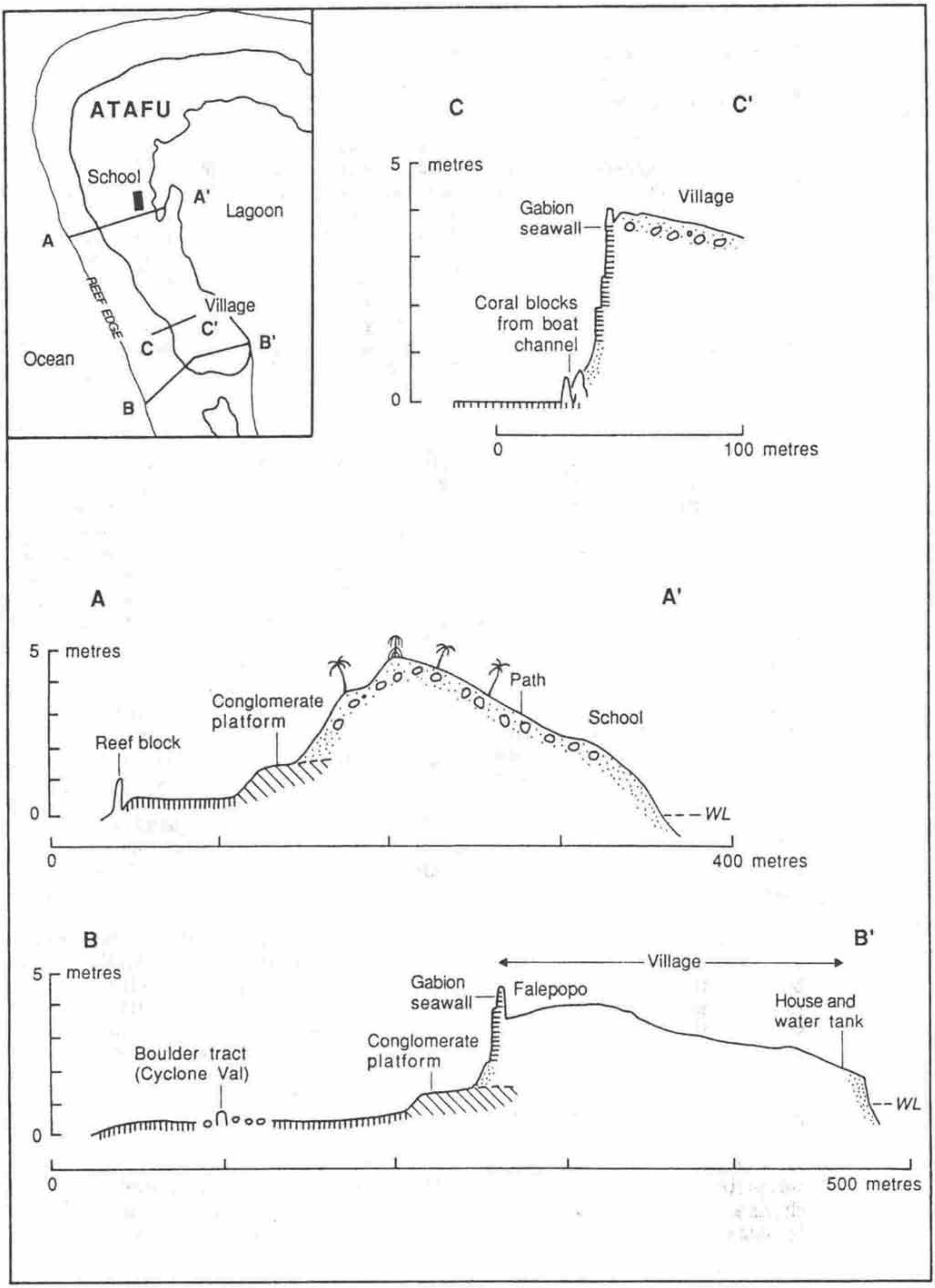



Figure 3: Atafu surveyed cross-sections.

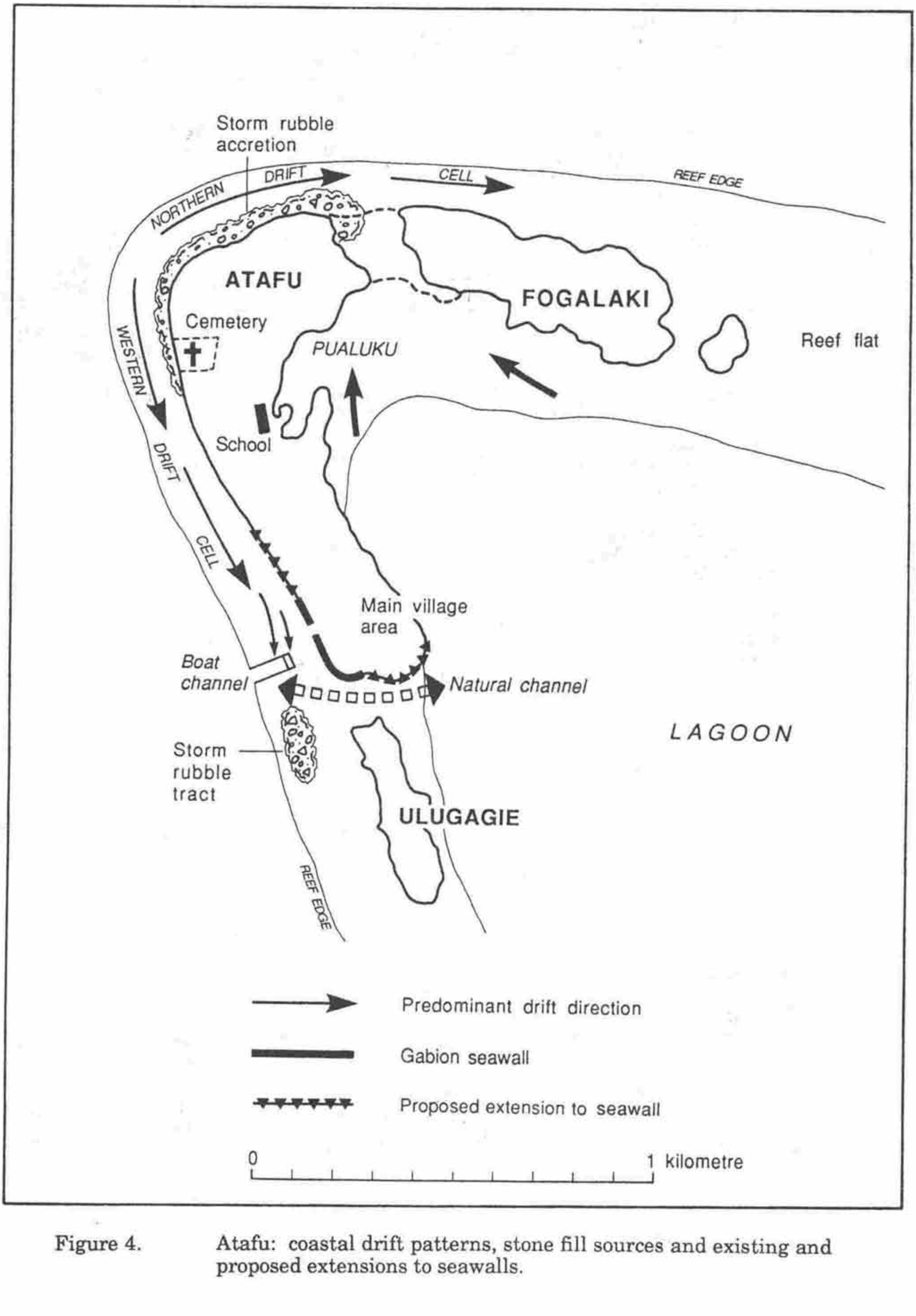



Figure 4. Atafu: coastal drift patterns, stone fill sources and existing and proposed extensions to seawalls.

closed off (except for the access ramp leading to the boat channel); and (iii) that the northern 40 m of the wall had been raised higher by adding 1.5 m of extra gabions. This was done because of the concern at the amount of overtopping and scour behind the wall that occurred during Val. Brockliss (1992) goes on to say that this practice should be stopped as increasing the height of the seawall on the top gabion has the detrimental effect of steepening up the front wall slope which is likely to cause more wave energy reflection during cyclone events and have undesirable effects on the beach system.

Photographs of the southern part of the seawall taken during my visit on 8 December are shown in Fig. 5. At that time the seawall was being extended northwards and just landward of the first row of coconut palms. Backfilling of the seawall had not kept pace with wall construction and some roll-back of the top gabions had occurred. (Fig. 5B). In order to remedy this situation the following recommendations were discussed with the Faipule and Executive Officer:

(1) that backfilling of the seawall completed so far should be carried out immediately, and thereafter concurrently with seawall construction;

(2) that technical advice should be sought as to whether or not gabion 'keys' (or loka) should be constructed behind the wall to add strength and reduce backfill scour; and,

(3) that sands and gravels excavated from the seawall site be not used for backfill, but rather it should be placed on the seaward side of the wall to assist in beach formation.

Severe erosion and scour was also evident around the southern end of the seawall and this had undermined a house necessitating the emplacement of large coral blocks for protection (Fig. 5A, 5C). On the other hand beach material had accumulated on the conglomerate platform and against the central section of the seawall (Fig. 3C, 5).

### 5.4 Sources of material for fill

Material from two primary sources is being used for gabion fill, from the boulder tract south of the boat channel and from the area of natural reclamation along the northern end of the island (Fig. 4, 6). As mentioned earlier both deposits accumulated during the recent cyclones (particularly Val). Both afford a measure of natural protection against future storm wave incursion. Both sites are readily accessible. The southern site is just 150 m seaward of the seawall. The northern site is 1.2 km by path from the main village and cartage is by road transport.

### 5.5 Future priorities and recommendations

Brockliss (1992) identified a total of 800 m of further seawall construction for stages 2, 3, and 4 of the project. In reviewing these priorities I recommend that:

(1) only stage 2 should be proceeded with. This work involves extension of the existing seawall (a) to the southeast by some 150 m around the southern end of the island towards the lagoon (Fig. 5A); and (b) a further 180 m northwards along the oceanside (Fig. 4).

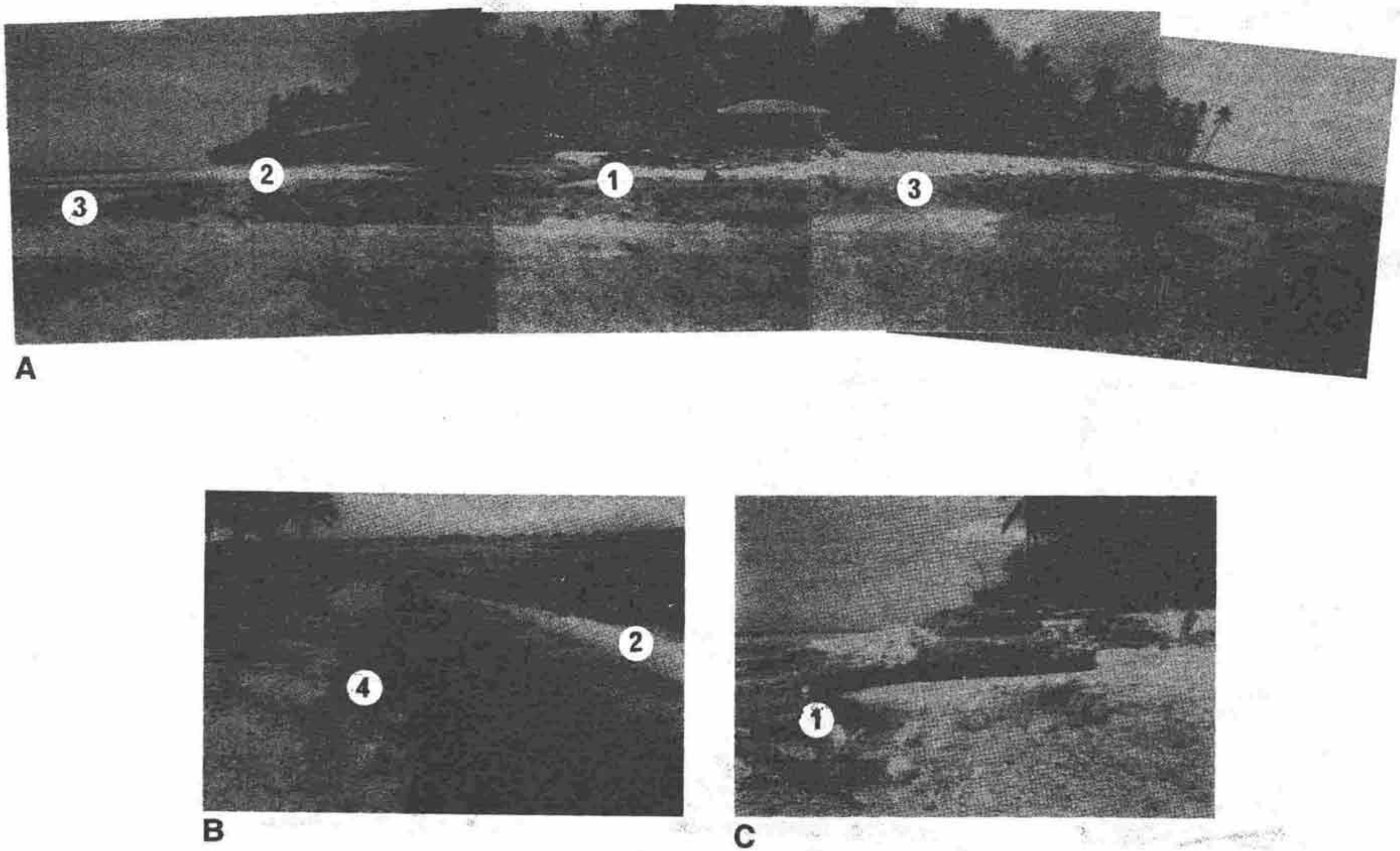
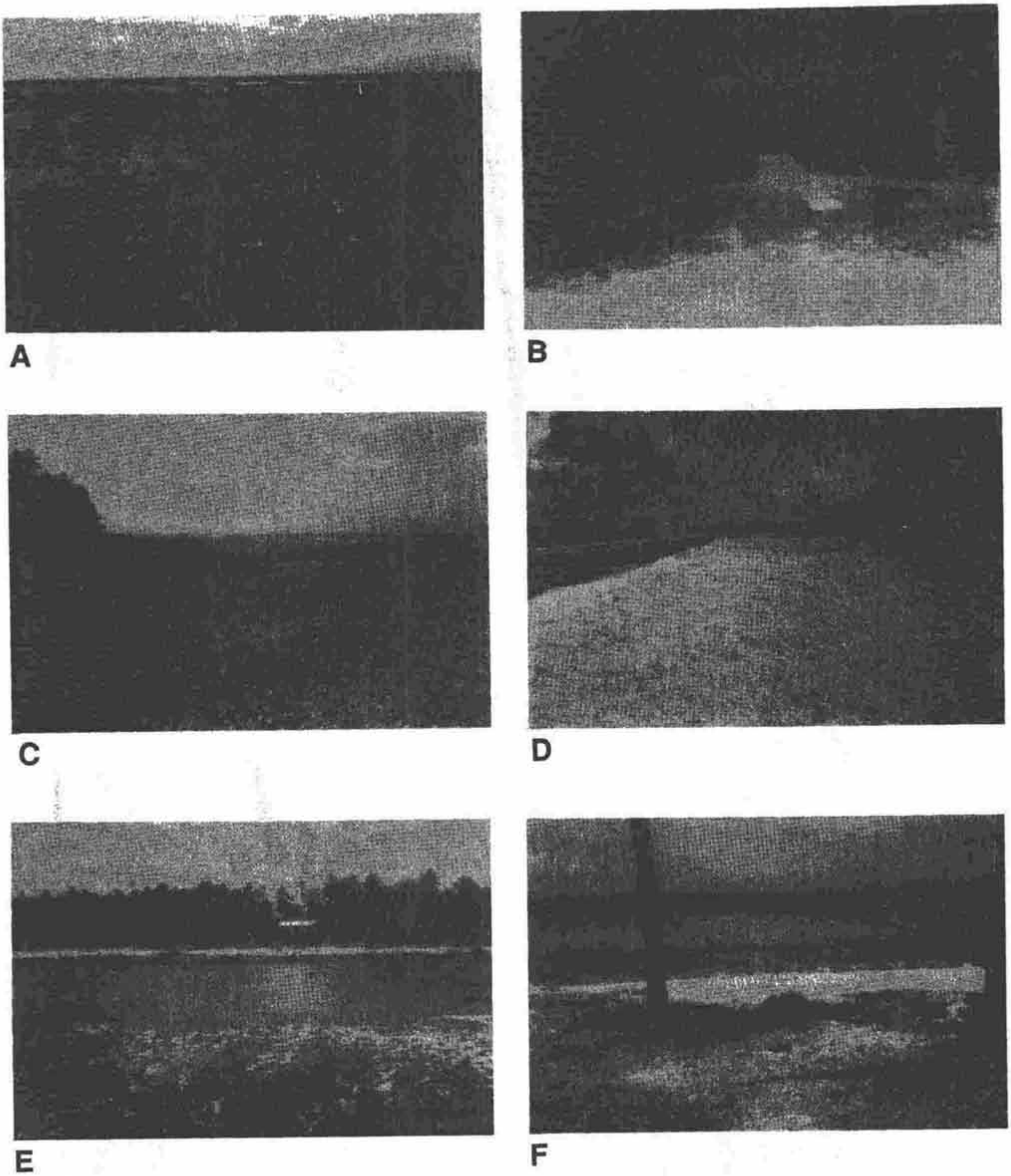



Figure 5: Atafu southern section of gabion seawall. A. Panorama from south end of Atafu looking north along oceanside to left and lagoonside to right. B. Seawall from top looking south. C. End of southern seawall. 1. Scour around end of wall. 2. Beach accumulation in front of wall. 3. Natural channel. 4. Incomplete backfill.



A B C D E F

Figure 6: Atafu: A. Rubble tract formed by Cyclone Val looking west. B. boat channel and access path. Note to left centre pile of white stones (1) removed from rubble tract beyond and stored for gabion fill. C. Storm rubble deposit at north end of island looking west (see Fig. 4 for location). D. Storm rubble accretion against north end of island looking east. E. Oceanside reef flat, conglomerate platform, beach and island along line of transect A (Fig. 3). F. Similar to E but looking west from island.

(2) stages 3 and 4 (which involve further extension to the north by 170 m on the oceanside and 400 m on the lagoonside) should not go ahead until the stage 2 works are completed (including backfill) and their effectiveness is reviewed.

The proposed extensions of stage 2 will require about 3000 cubic metres of stone for gabion basket fill. To complete present and future requirements for backfill a further 2000 cubic metres is necessary. While it is not normally advisable to take material from reef flats or beaches that are already providing islands with natural protection, in this case it is recommended that:

(3) material for fill can be taken from the natural reclamation site at the northern end of the island. (Fig. 6C, D).

This site is located at the downdrift end of the northern drift cell; the size of the resource is in the order of 10,000 cubic metres; and, there is abundant loose material on the adjacent reef flat to replenish the site during future storms.

No further material for seawall (or other) construction should be taken from the southern storm rubble site (Fig. 6A, B) which affords immediate protection for the village, and there is no evidence to suggest that this site would be replenished.

Further seawall extensions proposed in stages 3 and 4 is not supported. Nor is the local proposal to build a gabion wall in front of the graveyard towards the northwestern corner of the island supported at this stage. This for two reasons. First a short segment of seawall is likely to magnify end wall erosion, and, there is abundant fresh sand and gravel derived during Cyclone Val to naturally extend the beaches seaward and to provide material to drift in a southerly direction along the ocean shore. In time this 'slug' of fresh material will move downdrift towards the village and should be available to renourish incipient beaches in front of the gabion seawalls there.

A final local proposal is to remove the row of large coral blocks from in front of the present northern end of the seawall and to use these for backfill (Fig. 3C). Such removal is not recommended for two reasons. First, they provide a natural baffle that reduces wave action against the seawall, and second they provide a potential locus for inducing further sedimentation particularly of coarser gravel and rubble. However, because of the concentration of flow in a southern direction towards the boat channel during the ebbing tide sands are unlikely to accumulate in this area in the short term. It is one area that needs further investigation.

## 6. NUKUNONU ENVIRONMENTAL ASSESSMENT

### 6.1 Island geography

The village is located on two motu (Nukunonu and Motuhaga) separated by a narrow tidal channel and linked by a bridge. The motu are situated on the southwestern rim of the atoll and are aligned northwest to southeast. The ocean shore faces directly southwest and the lagoon shore faces northeast with a maximum fetch distance of 10 km across the lagoon to the atoll's northeastern corner. Both motu are elongate in plan with lagoonward recurving ends. Nukunonu is about 2 km long and Motuhaga 0.5 km long. Both are narrow with a maximum width of about 250 m. The main village is located towards the southern end of Nukunonu and there are a few houses and the hospital on Motuhaga (Fig. 7)

The motu reach the maximum elevation of 3-4 m above reef flat level along the oceanside and the surface dips gradually to the lagoon (Fig. 8). Outcropping along the oceanside is a 10-50 m wide solid conglomerate platform which separates the active reef flat from the beach. The islands have been built on this platform which is not exposed on the lagoonside. Large exposures of conglomerate platform occur on the reef both to the north and south of the village motu.

### 6.2 Coastal dynamics

There is some evidence in the surface topography and pattern of cuspate recurves on the lagoonside to suggest that Nukunonu previously comprised three or four separate islets that have subsequently been linked by barriers along the ocean shore. Oceanside drift is both to the northwest and southeast. (Fig. 7A). Seas from the west and north tend to move sediment in a southerly direction while seas from the southeast to southwest quadrant move sediment northwards. There is no evidence to suggest a preferential net drift direction along the oceanside of the motu. Net drift along the lagoon shore from northwest to southeast is clearer. The presence of Akau Loa reef acts as a natural groyne and blocks the movement of sediment to the southeast. As a result the lagoon shore along the main village area is starved of sediment and drops off quickly into deep water, while to the north of Akau Loa beaches are wide and the lagoon shallow (Fig. 8).

There is also some evidence to suggest that previously net sediment movement through the narrow interisland channel was from the oceanside towards the lagoon because of the presence of lagoonward recurves on both sides of the channel and the presence of a small flood-tide delta extending into the lagoon. However, little field evidence was found to support this view perhaps because of modifications to water flow and sediment drift patterns associated with the excavation of the boat channel, and construction of the bridge and seawall. Certainly the presence of the boat channel appears to enhance lagoon to oceanside flows and southerly ebb tide flows along the ocean shore to the north of the channel.

### 6.3 Gabion seawall construction.

In March 1992 Brockliss (1992) reported that a total of 275 lineal metres of gabion seawall protection had been completed or was currently under construction at four locations on Nukunonu (at the southern end of the island on the oceanside

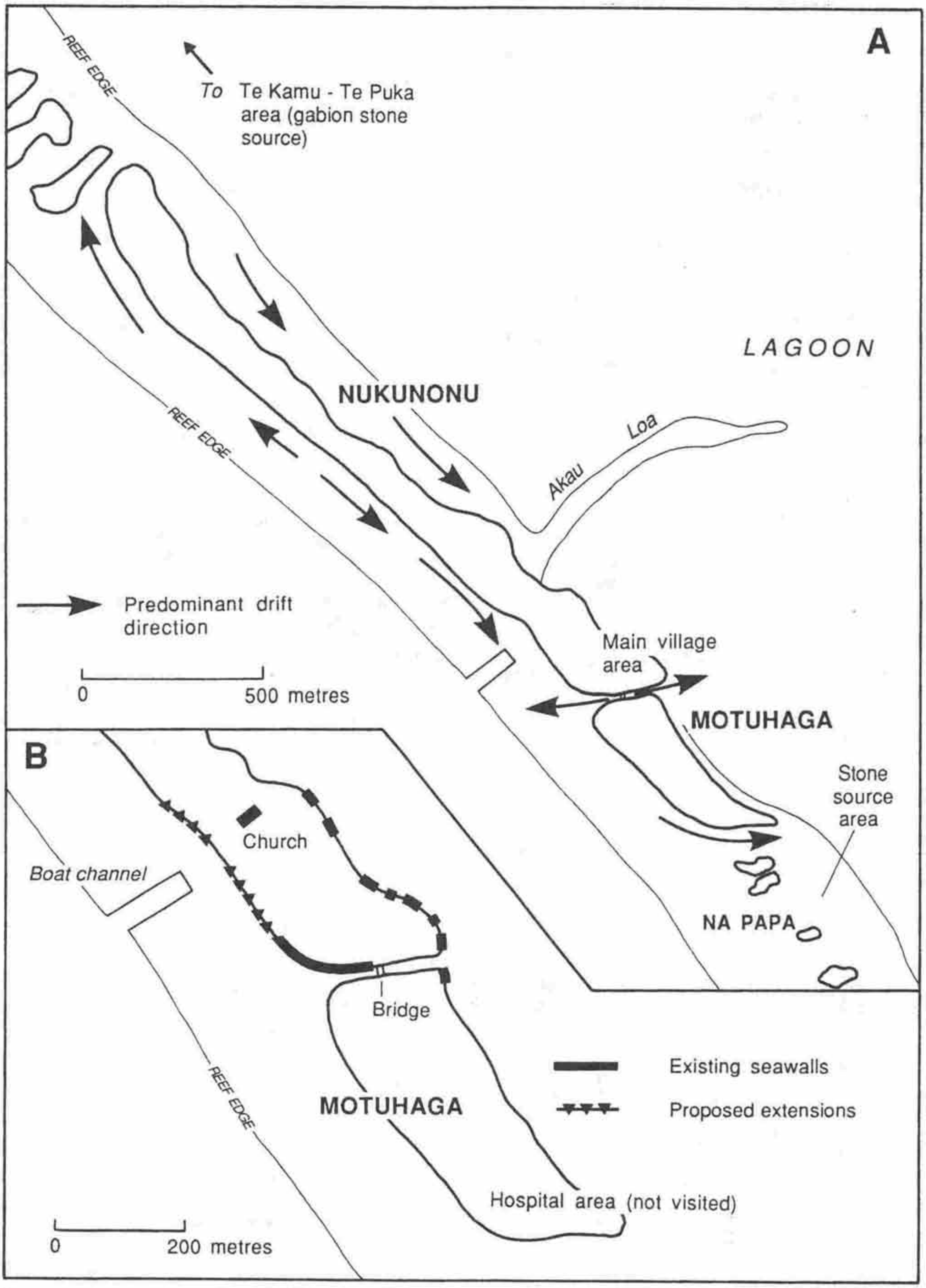



Figure 7: Nukunonu and Motuhaga: A. Drift patterns and location of stone fill source areas. B. existing seawalls and proposed extensions.

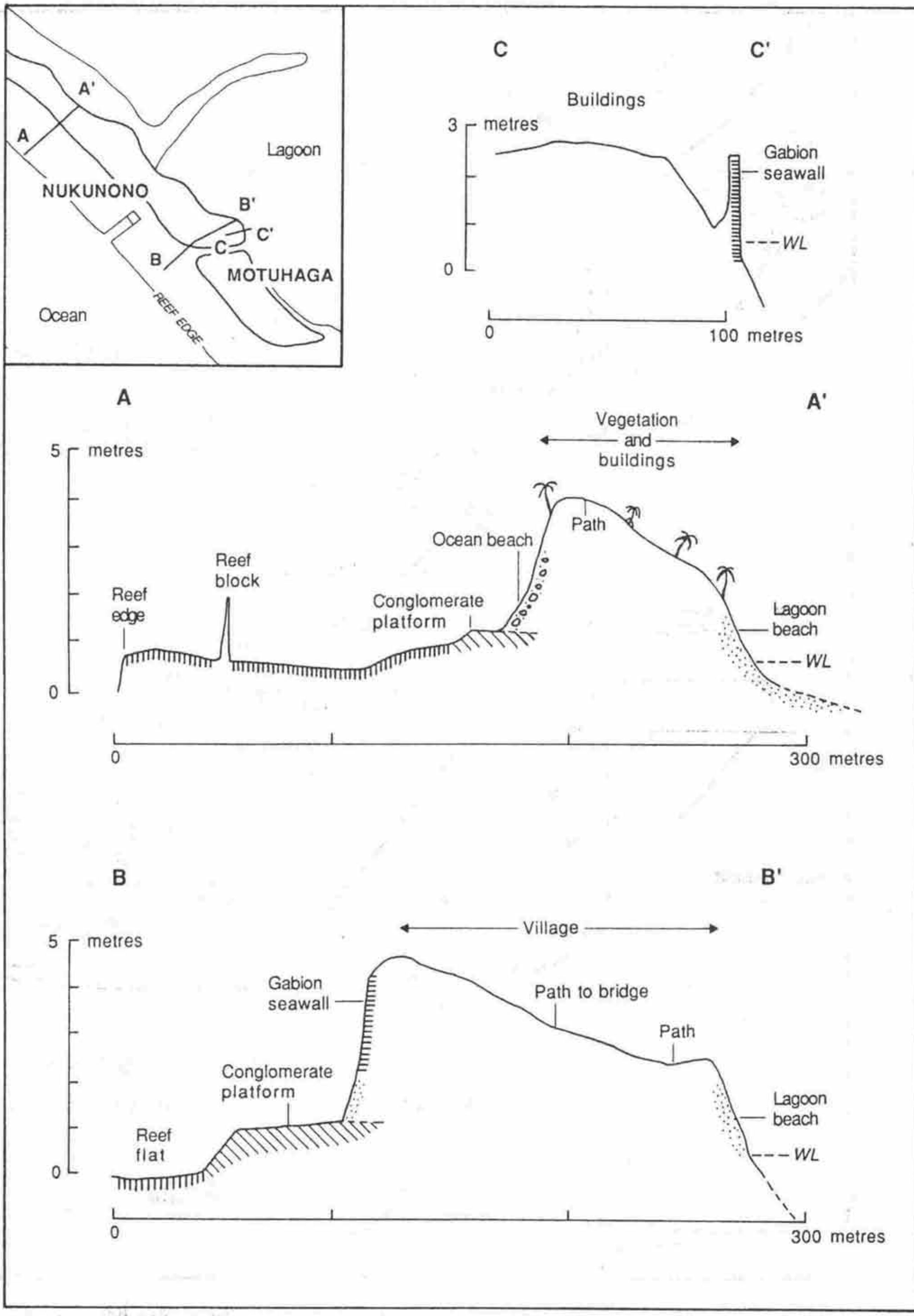



Figure 8: Nokunonu surveyed cross-sections. Transect B passes over the section of seawall shown in Fig. 9C and transect C includes the seawall shown in Fig. 9F.

extending along the channel towards the bridge, and at three separate sites on the lagoonside in front of the administration building and two private dwellings) and at one location on Motuhaga (in front of the hospital). Brockliss also found that at all locations the seawalls had been constructed further down the beach than was intended, by some 4 to 7 m for the community seawalls and 12 m for the private seawalls giving the impression that the private builders had endeavoured to reclaim land using the gabions.

At the time of my visit on 7 and 9 December the ocean seawall had been extended along the channel to the bridge and further northward towards the boat channel where construction was still underway (fig. 9A, D). Of particular note on the oceanside was the accumulation of gravel and sand at the base of the wall with a natural beach profile reaching half way up the gabions (Fig. 9C). The source of this sediment appeared to be a combination of that obtained from excavating the site prior to wall construction and from oceanside southerly drift. No sediment had accumulated against the channel segment of the seawall up to the bridge (Fig. 9A).

On the lagoonside several more private seawalls had been completed since March 1992 or were under construction in December. The alignment, position, design and quality of these seawalls is quite variable (Fig. 9E, F). Gabion baskets have been provided to local residents who have used family labour and boats to obtain and cart fill materials and build the seawalls. As a result of these private initiatives there has been little attempt to maintain the integrity of the original lagoonside design and in places the primary defensive purpose of the seawalls has been compromised.

There was insufficient time to inspect the hospital seawall site on Motuhaga though the Executive Officer informed me that there had been no further construction since the Brockliss visit in March.

### 6.4 Sources of material for fill

I was informed that no fill materials have been taken from the local beaches or reef flats around Nukunonu or Motuhaga. The main source of stones is from the Te Kamu - Te Puka area 4 to 5 km northwest of Nukunonu where there is a large quantity of good quality stones. Access to this area is by boat and one boat load of material is only sufficient to fill two gabion baskets. A larger and stronger boat is required to improve the efficiency of the cartage operation. On occasions material is also collected from the reef flat conglomerate platform centred on Nahau 1 to 2 km south of Motuhaga (Fig. 9A). The foregoing areas are apparently the preferred sources of fill both for community and private seawall construction.

### 6.5 Future priorities and recommendations.

Brockliss (1992) identified a total of 1060 m of further seawall construction for stages 2, 3 and 4 of the project. In reviewing these priorities I recommend:

(1) that the first two priorities of stage 2 be proceeded with, that is to extend the existing end of the oceanside seawall northward by 140 m to the boat channel and a further 120 m from the boat channel to just north of the petrol store, leaving an access ramp between these two segments: and

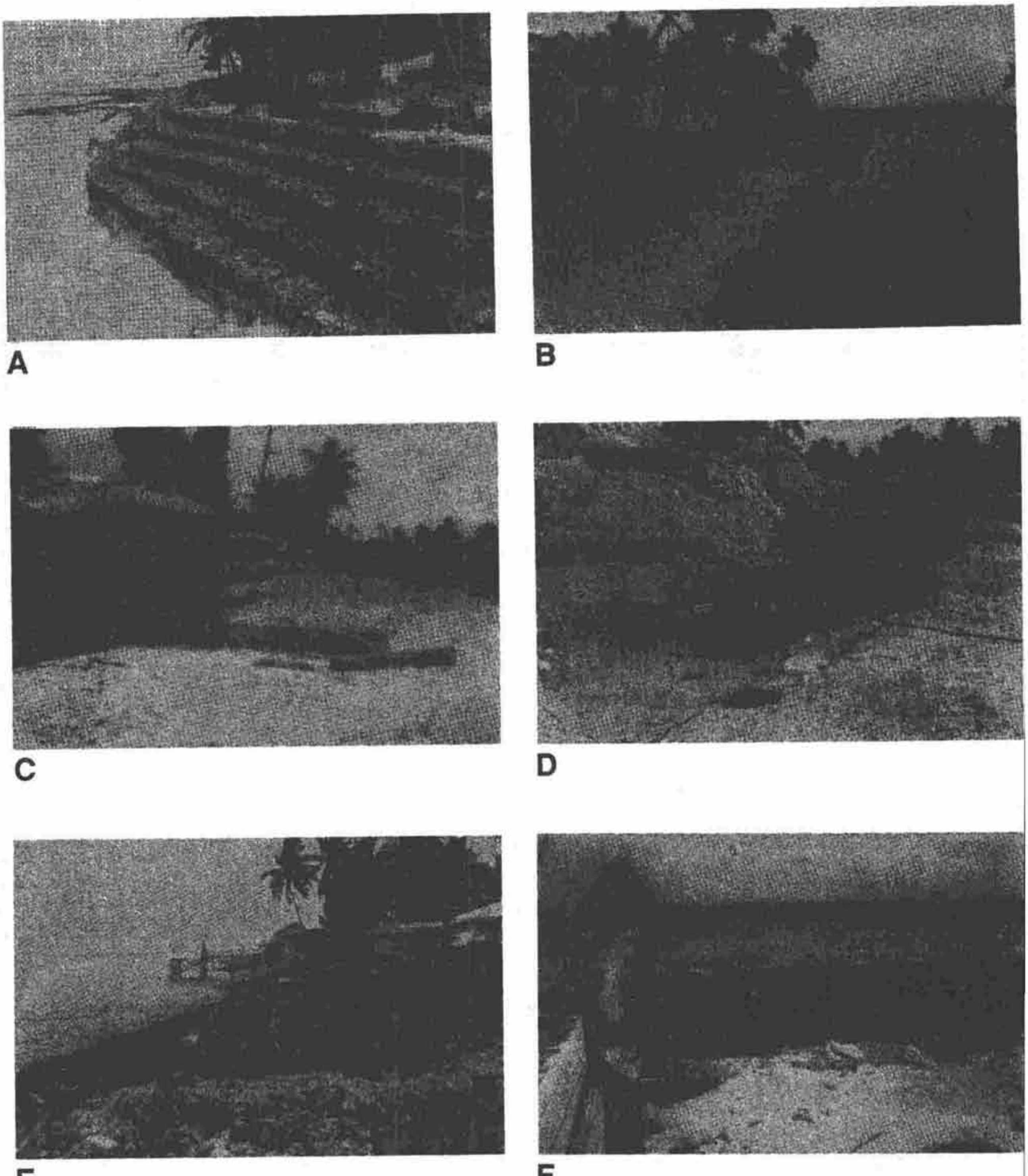



Figure 9: Nukunonu: A. Completed seawall along northern side of inter-island channel from bridge looking west. B. Erosion and undermining on northern side of inter-island channel from bridge looking east into the lagoon. C. Incomplete oceanside seawall looking south. Note accumulation of beach material against lower half of wall. D. Seawall construction in progress northern end oceanside wall. E. Lagoonside segment of seawall in front of administration building. F. Lagoonside wall segment at southern end of island and site of transect C (Fig. 8).

(2) that further northward extension of the oceanside seawall to the powerhouse and beginning of the school compound should be delayed until the above work is completed including backfilling of the existing seawall.

I estimate that (1) will require about 2500 cubic metres for gabion fill and an additional 1500 cubic metres to complete present and future backfill requirements along the oceanside-channel wall.

Placement and design of the extensions to the oceanside seawall should follow the original Maccaferri recommendations and the boat channel access ramp and walls should be constructed using the modified drawings contained in Brockliss (1992).

For the hospital site on Motuhaga Brockliss identified two priorities, for stage 2 a 50 m long wall on the oceanside and for stage 3 a 150 m long wall on the lagoonside. Having not visited this area I cannot comment on whether or not construction should proceed. This is a matter on which a further technical opinion should be sought.

Similarly with the Brockliss proposal for the lagoonside which would involve a further 500 m length of seawall. There are three points that should be considered before any further construction is carried out. First, Brockliss gives lagoonside extension the lowest priority and includes it in stage 4. Second, it is not clear from the original Maccaferri (1990) report exactly what was proposed for the lagoonside of Nukunonu except that north of the bridge "protection over some 70 m to 80 m should be considered". Third, the ad hoc development of private seawalls in this area, which have not been placed optimally or built according to the modified design proposed by Brockliss, together with the fact that the present seawalls are discontinuous along the shore, poses severe constraints on further placement and design if the objective is to achieve one continuous defensive structure along the lagoonside of the village.

Collectively the foregoing comments suggest that additional advice is required. It is therefore recommended:

(3) that further technical assistance should be obtained to specifically review the requirements for seawall protection at

- the hospital site on Motuhaga;
- the lagoon shore of Nukunonu; and
- the proposed extension of the oceanside seawall north of the petrol store.

In the interim there should be a moratorium on further construction in these areas. Extensions of the channel seawall from the bridge to the lagoon needs considering. This is not explicitly commented upon by Brockliss (1992) though it is an area undergoing erosion (Fig. 9B).

The review should also consider whether or not natural protection, afforded by the beaches and high seaward ridge on land, at the hospital site and along the oceanside, is inadequate recognising (i) that these areas are situated in downdrift locations and can be naturally supplied with sediment; and (ii) that further gabion seawall construction can result in some detrimental environmental effects, for example end wall erosion and enhanced wave reflection.

One further topic should also be addressed. This is the possible environmental consequences of cutting a NW to SE channel through the Akau Loa reef on the lagoonside of Nukunonu. This reef, which runs perpendicular to the shore impedes southward drifting sand from the north of the island reaching the main village area (Fig. 7A). As a consequence deep water occurs immediately off the lagoonside of the main village such that wave action is not attenuated before reaching the shore. Moreover seawall construction in this area inhibits the development of a natural beach profile and reinforces the problem. In the long term increasing sediment supply from the north would reduce depths and encourage the development of a natural beach profile. The combined effect would be to reduce at-shore wave action and increase protection. The question of cutting an artificial channel through Akau Loa was discussed with staff at OTA and appears to warrant further investigation.

## 7. FAKAOFO ENVIRONMENTAL ASSESSMENT

### 7.1 Island geography

The atoll of Fakaofo is roughly diamond-shaped with a long north-south axis. Settlement is divided between two motu. Fale is the administrative and service centre and has the majority of the population though it is the smaller of the two motu with a land area of about 6 ha. The school and hospital are situated on Fenuafala (35 ha) along with several families. Fenuafala is located at the extreme western corner of the atoll where the reef rim changes direction from facing northwest to facing southwest (Fig. 10). The island has a distinct gravel ridge around its southern and western sides which reaches 3-4 m above the adjacent reef flat level. The centre of the island forms a low dome with slopes towards the ridge and lagoon. There has been little modification to the natural shoreline which has a steep gravel beach on the oceanside and gentle sandy beach on the lagoonside (Fig. 10A).

Fale, located 2 km to the southeast of Fenuafala is quite different. It is a small circular island whose shoreline has been severely modified through reclamations and seawall construction, such that there is no natural beach profile anywhere around the island. The land surface has also been modified, though the natural topography is bowl shaped with the highest elevations reaching 4-5 m above the reef flat, on the oceanside facing southwest (Fig. 10B). Conglomerate platform is exposed to the northwest and west of the island and its presence suggests that Fale has been much larger in the past. The conglomerate platform reaches slightly above normal high water level and passes beneath the island on its western side.

### 7.2 Coastal dynamics

The lagoon shoals towards Fenuafala and there is evidence to indicate that sedimentation is continuing to the west of Tuimanuka reef and along the island's lagoon shore. Southeast from Tuimanuka the lagoon deepens such that on Fale there is an abrupt drop off from the island into the lagoon. Along the southern shore of Fenuafala drift is directed eastwards and the island is continuing to build out in that direction. Between Fenuafala and Fale net drift also appears to be predominantly from west to east, that is from the oceanside into the lagoon.

Around Fale drift patterns are more complicated being influenced by the presence of the conglomerate platform, boat channel and seawall structures around the island. (Fig. 11A). On the ebb tide there is a strong lagoon to ocean current along the southern edge of the island with water exiting through a shallow natural channel and the boat channel which also captures southerly directed flows along the edge of the conglomerate platform. Natural sediment production around Fale is limited. The abrupt slope into the lagoon on the eastern side inhibits lagoonal sediments from reaching the island. Similarly, with the extensive conglomerate platform to the northwest. This means that sediment can only be supplied from the active reef, which around Fale is generally depauperate and has only a thin veneer of primarily storm deposited rubble on it. Thus, unlike the other village motu in Tokelau, the natural supply of sediment to Fale is restricted and it is unlikely that this situation will change in the future.

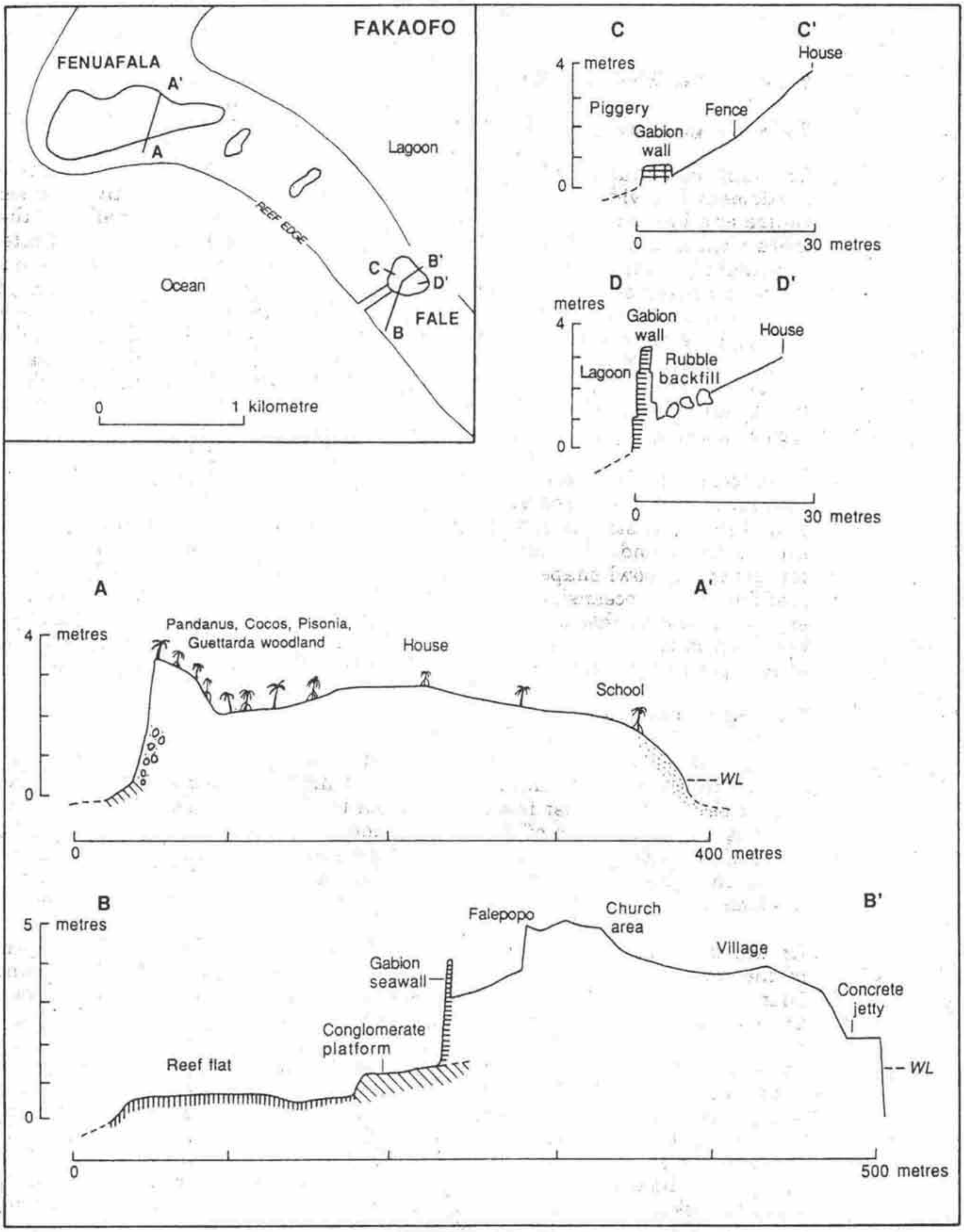



Figure 10: Fakaofo: Surveyed cross sections on Fenuafala and Fale.

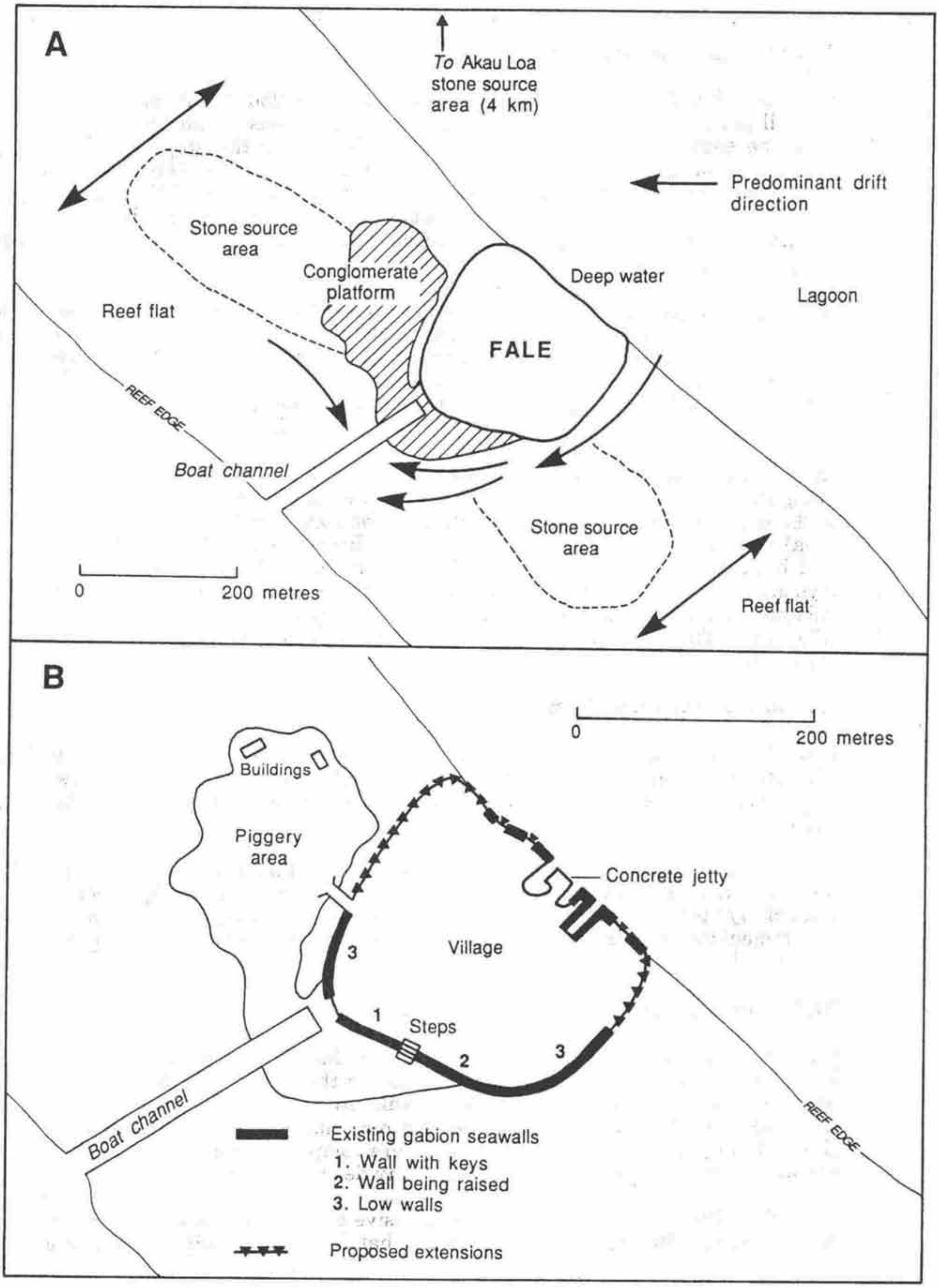



Figure 11: Fale (Fakaofo): A. Drift patterns and stone fill source areas. B. Existing seawalls and proposed extensions.

### 7.3 Gabion seawall construction

In March Brockliss (1992) reported that a total of 250 lineal metres of gabion seawall protection had been completed or was under construction on Fale. At that time the seawall extending from the boat channel to the steps had been 80% completed using the Terramesh tied back gabion wall system (Fig. 2D). Beyond that a mass gravity wall (Fig. 2C) was being constructed around the southern end of the island and another from the boat channel towards the bridge in the northwest (the piggery area). On the lagoonside one segment of seawall had been completed and others were under construction.

Brockliss also pointed out that during Cyclone Val forces on the front face of the Terramesh wall, which was unsupported by backfill, resulted in the top baskets being rolled back. Waves overtopped the structure and caused some damage to the new Falepopo. He recommended that two layers of gabion should be added on top of the rolled units and that as an additional protection against scour a series of 3 m long 'keys' should be constructed at 6 m centres at the back of the wall.

At the time of my visit on 7 and 9 December the above repairs had been completed along the boat channel - steps section of the wall and construction was underway to the southeast of the steps (Fig. 11B, 12). The boat channel - bridge wall (piggery area) was basically in the same condition as Brockliss found, except that a start had been made at the southern end to add a second layer of gabions. On the lagoonside several different segments of private wall were being constructed and gabions were also being used to build boat shelters and for reclamation purposes. (Fig. 13). There appeared to be no systemmatic placement or design for the lagoonside walls.

### 7.4 Sources of material for fill

I was informed that there were three primary sources of stones for fill on Fakaofo. All were from reef flat areas; two close to the island and one on the northwestern side of the atoll along the Ahaga Loa some 4 km across the lagoon from Fale (Fig. 11A).

In all three areas fresh reef flat rubble was deposited during cyclones Ofa and Val and some live massive corals are included in the rubble mass (Fig. 13E). At the time of my visit stone was being taken from only one of these areas, from the reef flat immediately to the northwest of Fale at low tide and carted by boat to the island at high tide.

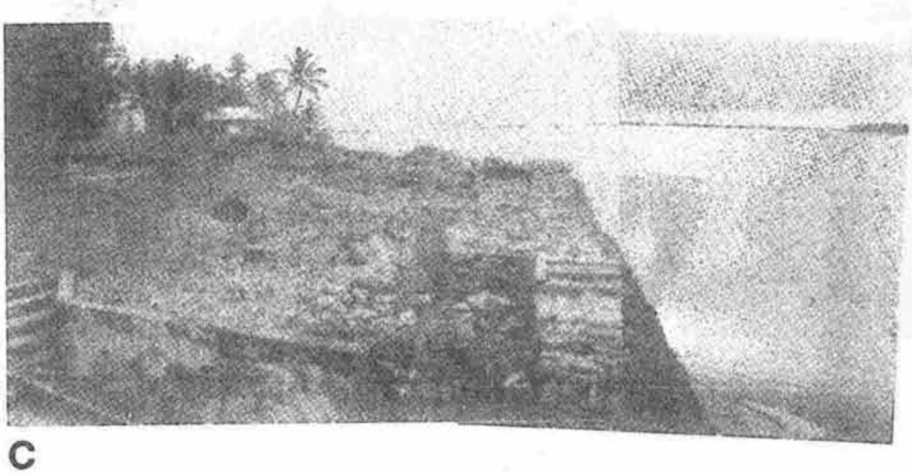
### 7.5 Future Priorities and recommendations

Brockliss (1992) identified a total of 500 m of further seawall construction for stages 2, 3 and 4 of the project, which when added to the existing walls and those still under construction in stage 1 (250 m) will provide full protection around the circumference of Fale (Fig. 11B). He also recommended that no additional work should take place until the current walls are completed and that all future walls should be constructed using the mass gravity design (Fig. 2C).

To achieve full protection around Fale massive amounts of stone fill are required, both for gabion fill and backfill. I estimate that the total quantity needed for gabion

A

B



C

Figure 12: Fale (Fakaofo): A. Seawall 1 (Fig. 11B) behind boat channel looking north across conglomerate platform to Fenuafala in left distance. B. looking south from same position as in (A). Seawall has been raised and 'keys' added on landward side as per configuration in Fig 2D. C. Seawall 2 (Fig. 11B) additional gabions being added to top, looking southeast into lagoon.

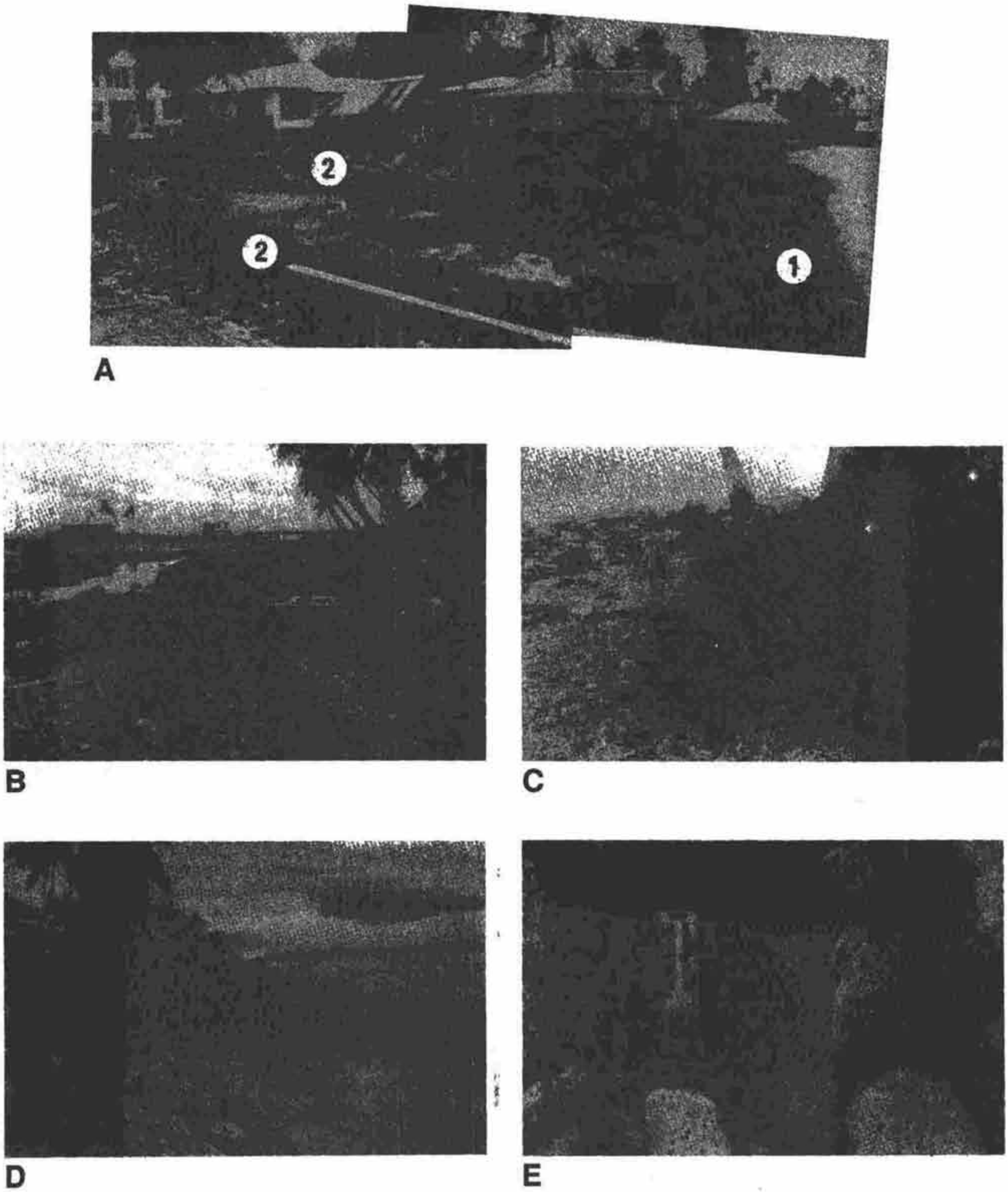



Figure 13: Fale (Fakaofo): A. Lagoonside gabions looking northwest toward concrete jetty (Fig. 11B). Note seawall on right (1) and gabions along sides of small boat harbour (2). B. Low seawall (Fig. 11C) separating island from conglomerate platform looking north towards bridge to piggery area. C. Erosion and undermining of coconut palms on northwestern side of island to north of bridge to piggery area. D. Eastern side of island looking towards lagoon along shore of proposed extension. E. Close-up of stones used for gabion fill including live Porites coral to right of 10 cm scale bar.

fill is about 5500 cubic metres and for backfill 12,000 cubic metres made up as follows:

| Stage | Location | Gabion fill ($m^3$) | Backfill ($m^3$) | Total ($m^3$) |
|---|---|---|---|---|
| 1 | Existing walls and under construction | 500 | 2500 | 3000 |
| 2a | Send oceanside to lagoon | 1600 | 1600 | 3200 |
| 2b | Boat channel to piggery bridge | 900 | 2700 | 3600 |
| 3 | Lagoon to piggery bridge | 1200 | 3600 | 4800 |
| | Total | 5,500 | 12,000 | 17,500 |

Estimates of fill requirements for gabions are based on the number of gabion units given by Brockliss (1992, Table 4.1) with the figure for 2a being 800 units rather than the 80 units mentioned by Brockliss. Backfill estimates are based on field observations and surveyed sections (Fig. 10) to achieve the design profile (Fig. 2C).

Of the three present sites where fill is taken from, there should be no further exploitation of the two reef flat areas near Fale (Fig. 11A) which afford a measure of natural protection to the oceanside of the island. Sediments in both areas, which presently veneer the surface, have the potential to be built into rubble tracts under storm conditions, such as that at Atafu (Fig. 6A, B) which result in even greater protection in the long term. Moreover, the quantities involved in these areas would not be sufficient to satisfy requirements.

Thus, at Fakaofo fill will have to be sourced from sites some distance away from the island such as the Ahaga Loa area along the northwestern rim of the atoll. Other sites need investigating. Based on map interpretation the reef flat between Nukumatu and Kauahua O Kupaga to the south of Fale appears to have potential. Given the large quantities of stone that need to be shifted a substantially larger cartage vessel (e.g. barge) than the boats presently used is required.

Once the existing seawalls have been completed, including backfilling, extensions can be proceeded with as proposed by Brockliss. Completion of protection along the lagoonside (stage 3) will be a problem because of the ad hoc development of private seawalls, other gabion structures and the concrete jetty which place severe constraints on further seawall placement and design. As with Nukunonu, further technical advice will have to be sought as to how future protection can be best achieved along the lagoonside of Fale where amenity values will also have to be considered.

Two further comments are appropriate. First, as recognized by Brockliss (1992) on Fale the natural beach system had already been lost over the years due mainly to the construction of stacked coral rubble walls and reclamations using local stone sources. Thus, the gabion seawalls were designed essentially as a retention system or physical barrier and retaining structure as the immediate priority. The question of how a natural beach system could be established on Fale once the seawalls have been completed remains. Brockliss suggests that a significant amount of extra technical data pertaining to the hydraulic dynamics and sediment transport regime would need to be collected. I concur with this statement, though the present brief reconnaissance of the area around Fale suggests there is a deficit of sediment available for transport and that there are topographic impediments (conglomerate platform, steep drop off to lagoon) from potential sediment source areas to the island.

Second, during my visit the matter of seawall protection along the lagoonside of the second village motu, Fenuafala, was raised. In my view it would be unwise to proceed with any construction in this area. The natural beach profile should not be interfered with given the accretionary trend along Fenuafala's lagoon shore (see 7.1 and 7.2 above). Rather controls on future.land use, such that buildings are sited further back from the shore than the present hospital and school could be instituted thereby reducing damage potential from the cyclone hazard. Similar controls may also be necessary on Fale which, inspite of the seawall protection, will still be vulnerable to storm wave activity in the future.

## 8. CONCLUSIONS AND RECOMMENDATIONS

### 8.1 Conclusions

Four groups of conclusions arise from the present assessment. These relate (i) to seawall protection and other adjustments to the storm hazard (Conclusions 1 to 4) (ii) to the importance of understanding atoll geomorphology and the natural processes (including storms) that have formed the islands and how seawalls modify those processes (Conclusions 5 and 6) (iii) to the question of the use of gabions not just for protection but for other purposes as well (Conclusions 7 and 8) and (iv) to the direct and indirect environmental impacts of seawall construction activities in Tokelau (Conclusions 9 to 16).

1. The primary purpose of the project is to provide protection to Tokelau's village islands from the incursion of storm seas, thereby reducing the magnitude of damage, loss of life etc that would otherwise be sustained on the islands.

2. The seawalls are intended only to be operative during severe storm events (cyclones). The seawalls are land protection structures rather than shore protection structures. The seawalls (if completed to design standards) should provide the desired protection. But those standards have been already compromised in the existing seawalls (in terms of placement and height) and are unlikely to be met in the extensions without substantial changes.

3. Even with complete seawall protection (to design standard) gale force winds, heavy rainfall, washover and wave overtopping of the seawalls will occur and substantial cyclone damage to villages can still be expected. That is there will still be a requirement for post-cyclone relief and rehabilitation.

4. Seawall protection is just one adjustment to the cyclone hazard. Other adjustments to reduce hazard effects include land use controls, building codes, and the establishment of buffer zones. Such adjustments do not appear to have been used in Tokelau and should be considered to complement seawall protection. These are clearly matters for the village councils and OTA to address.

5. In atoll environments storms are the primary mechanism for island building. Morphologic and stratigraphic evidence collected during the field reconnaissance confirms this in Tokelau. The net effect of storms is to increase island elevation by sweeping reef derived coral and other materials on to the islands. When initially occupied the islands were 1 - 2 m lower than present. Episodic storms have provided the sediment for island building since then and this process continued during the recent cyclones. Anything that inhibits free exchange between reef flat and island will reduce the natural rate of island building. The gabion seawalls will have this effect.

6. Natural beach systems normally provide a measure of protection against storms and they temporarily adjust to storm wave activity through erosion. Rarely is recovery not completed later during fair weather periods. In places substantial accretion results from storm supplied sediment. At the time of my visit natural beaches at Atafu, Nukunonu and Fenuafala

(Fakaofo) were all in the recovery phase and some had expanded beyond their pre-cyclone positions. The introduction or extension of seawalls into such systems can be questioned as they may inhibit the recovery phase.

7. Devastating as they may be storm events are of short duration. In this regard the single purpose gabion seawalls, which may affect amenity and other values for long periods of time between storms, needs to be reviewed.

8. The utility of gabions, not just for seawall construction, but also for other development purposes such as the construction of small boat harbours (as has happened at Fakaofo and Nukunonu), small jetties, groynes to direct or impede water and sediment flows merits some investigation. The increasing expertise of Tokelauans in gabion construction would be an advantage. Design and placement of additional structures would require some technical assistance, with village councils and OTA being responsible for developing an overall plan for each island.

9. Gabion seawall construction has a number of impacts on the physical environment by affecting beach systems and water and sediment circulation patterns and through the mining of materials for baskets and backfill.

10. The gabion seawalls (on Nukunonu and Atafu) were designed to complement the existing beach profile and not compromise the existing beach regime. It is too early to judge whether or not natural beaches will develop in front of the gabions, though some small accumulations have already taken place. In the long-term I believe there will be natural buildup in front of the oceanside seawalls particularly at Atafu and to a lesser extent at Nukunonu, both towards the northern end.

11. Where the ends of the gabion walls adjoin the natural shore accelerated erosion has taken place at most locations in Tokelau. Given the discontinuous distribution of seawalls on the lagoonsides of Nukunonu and Fale (Fakaofo) and termini on ocean and channel sides of all islands, the problem of end-wall erosion is likely to become even more serious especially during storms. Technical assistance in designing appropriate end-wall configurations for a range of seawall situations is necessary to provide a solution to what will be an ongoing problem.

12. The combined effect of seawalls and boat channels has resulted in strong ebb-tide flows being directed towards the boat channels. Sediment is carried which may otherwise serve to form a beach. There are two consequences: (i) accretion against the seawall is inhibited; and (ii) sedimentation occurs in the boat channels. Gabions lining one side of natural inter-island channels have a similar effect. Technical assistance would be required to provide advice on how to overcome these problems.

13. Materials used for filling gabions and backfill must be of the appropriate size, shape and quality. Generally removal from beaches, reefs and reef flats reduces natural protection, increases at-island wave action and accelerates erosion. In Tokelau materials are sourced from inter-tidal reef flats and beaches (including sediments deposited by Cyclone Val) and primarily from locations adjacent to or near the village motu. This practice, and the collection of live corals, should be discouraged.

Recommendations regarding appropriate sites for stone supplies on each atoll are given in this report, together with recommendations on the provision of cartage boats and vehicles.

14. The Tokelau people have a long tradition in stone wall construction and the gabion seawall project is seen as a continuation of that tradition. It is also seen as a community project for the oceanside walls. On the lagoon side private gabion construction prevails using baskets from the project and stones collected by families. The possibility of more formally authorising private construction could be encouraged if it is carried out to design standards, recognizing that several of the present ad hoc structures are likely to magnify not reduce storm impacts.

15. For the foregoing reason social impacts of the seawall project appear mainly positive although there is some loss of amenity. Private use of gabions for a whole range of purposes may compensate for amenity loss.

16. Construction projects (port developments, causeways, boat channels, seawalls) in atoll environments have invariably created long term problems that have proven difficult or impossible to rectify. Initiating major seawall construction in a natural area that has not been previously modified should only be done with the utmost caution and justification. In this regard I question the rationale for some of the proposed extensions and new work and make recommendations accordingly.

### 8.2 Recommendations

Specific recommendations were made for each island in the appropriate section of the report. There are, however, some general recommendations which complement or supplement those comments and relate to the future of the overall project as follows:

1. That the gabion seawall project be continued, but in modified form.

2. That the project's purpose be expanded from primary storm protection to include other projects that utilize gabion materials and technology.

3. That the oceanside and channel seawalls in stage 2 be proceeded with for storm protection as per the original placement and design.

4. That because the original placement and design of the lagoonside walls has already been compromised (as a result of negative effects on amenity) a more flexible approach to placement, purpose and design be permitted in this area.

5. For the lagoon areas a comprehensive plan, integrating storm protection and other purposes be drawn up in consultation with village councils. The construction of further ad hoc structures in these areas should not be permitted until such a plan has been prepared.

6. That private construction of seawalls and other gabion structures be encouraged, but that oceanside and channel seawall construction should still remain a village council (community) responsibility.

7. That collection of stones and materials for seawall, backfill and other construction purposes from village motu and adjacent islands and reef flats be generally not permitted, and that the preferred sites for stone collection identified in individual island assessments be followed. Live coral should not be collected.

8. The present boats and vehicles used for excavation and cartage are too small and not robust enough for the quantities of material required to be shifted. Moreover, in the future substantial amounts of backfill will be required in addition to gabion fill. Appropriate cartage units for each atoll should be provided (eg. motor barge with ramp, front end loader, digger).

9. That technical assistance is required to advise on such matters as end-wall scour, water flows and sediment movement in seawall - boat channel areas and natural passes and other problems identified in this report, as well as to advise on village proposals for integrating lagoonside seawall and other construction. It is also envisaged that the technical adviser, in consultation with village councils and OTA, would develop a work programme for each island and monitor progress at regular intervals.

10. That other island-specific recommendations made elsewhere in this report be adopted.

Finally there are two other issues that should be raised based on the experience of this mission. First, resource materials available at OTA and in Tokelau are completely inadequate for environmental assessment purposes. Maps of the atolls are not readily available and OTA does not hold copies of the vertical aerial photography taken by the Royal New Zealand Air Force. This photography was flown in 1973 and consideration should be given to obtaining funding or support for an updated coverage. For mapping lagoonal environments and resources satellite imagery could be obtained but such imagery has lesser value for land and reef mapping where higher resolution data is required. Difficulties with transport to and from Tokelau highlight the importance of having good resource materials available at OTA that can be used in part as a surrogate for field observations, though the latter will always be necessary.

Second, at present settlement is concentrated on four motu on the three atolls of Tokelau. There is, however, accumulating evidence to suggest that environmental problems, including those associated with seawall construction, are increasing on these motu (and particularly Fale) and it may be that they will not be able to support present levels of population and environmental quality in the future. Environmental conditions of the present village motu and their adjacent reefs and waters should be investigated in order to determine the long term sustainability and population carrying capacity of the motu in relation to possible future environmental changes. At the same time a number of other motu on each atoll should be evaluated as potential sites for future settlement in the event the present village motu become uninhabitable. Clearly, village councils and OTA would need to be involved in these studies which could be undertaken as part of the Tokelau Environmental Management Strategy Project.

## 9. REFERENCES

Best, S. 1986: *Tokelau Archaeology Initial Survey and Excavations* , Mimeographed 16pp [Copy in OTA Library].

Brockliss, C.C. 1990: *Report on Seawall Protection Tokelau Islands,* Maccaferri Gabions New Zealand Ltd, Auckland, June 1990, 10pp & drawings.

Brockliss, C.C. 1992: *Report Existing and Proposed Extensions to Gabion Seawall Protection Tokelau Islands,* March 1992, 17pp & appendices and drawings.

Humphries, S. and D. Collins 1991: *Tokelau Country Report for the United Nation's Conference on Environment and Development.*, 57pp.

Shuma, G. 1992: *Tokelau Environmental Impact of Shore Protection Works,* 8 pp.

Thompson, C.S. 1986: *The Climate and Weather of Tokelau*, New Zealand Meteorological Service Miscellaneous Publication 188/4, 34 pp.

**Annex I**

## Itinerary of Visit to Tokelau 5-11 December 1992 (R F McLean)

**Saturday 5 December**

2300 Departed Apia, M V Wairua

**Sunday 6 December**

Enroute Apia-Tokelau

**Monday 7 December**

0645 Arrive Fakaofo. Met with Peni Semisi (Faipule) and George Tinielu (OTA). Inspected gabions and tour around Fale. Met with Keli (seawall construction foreman)

0945 Level survey, transect 1 ocean reef edge, gabion wall to Falepopo (copra shed) assisted by Apeti

1030 Return to boat

1100 Depart Fakaofo for Nukunonu

1530 Arrive Nukunonu

1545 Met with Pio Tuia (Executive Officer) Inspected seawalls, channel to bridge, private gabions on lagoonside. Met with Steve Brown (UNV)

1815 Return to boat

2000 Depart Nukunonu for Atafu

**Tuesday 8 December**

0700 Ashore at Atafu. Met with Kuresa Nasau (Faipule) and Maka Toloa (Executive Officer).

0830 Levelling survey of three transects. Inspected gabion seawall.

1130 Inspected gabions southern area

1200 Lunch put on by Womens Committee

1300 Welcome by Paulo Kitiona (Pulenuku) and meeting with Elders to discuss purpose of visit. Chair and translator Dr Iosefa. Steve Brown in attendance.

1430 Walk with Faipule and Steve Brown to north of island. Inspected pig pen wall, rubble bank on oceanside formed during storms.

1700 Left for ship

1800 Departed Atafu for Nukunonu

**Wednesday 9 December**

0900 Ashore at Nukunonu

0900 Levelling surveys, three transects from ocean to lagoon across island

1150 Return to ship

1245 MV Wairua departs for Fakaofo

1715 Arrive Fakaofo

1715 Levelling surveys across Fale, continuation of transect 1 plus transects over private gabion walls and pig pen wall

1900 Return to ship

**Thursday 10 December**

0815 Ashore at Fale and transported to Fenuafala

0830 Levelling survey across Fenuafala, ocean to lagoonside

1000 M V Wairu departs for Apia

**Friday 11 December**

1530 Arrive Apia