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Coastal Erosion in South Tarawa, Kiribati

As part of the work program for the Government of Kiribati, SOPAC has for over a decade been carrying out coastal studies particularly related to coastal erosion in Kiribati. This report is on the latest of these studies.

In recent years, Japanese assistance to the Government of Kiribati has included two major infrastructure projects in South Tarawa. One, the Nippon Causeway, was completed in 1987: significant accretion has since occurred against parts of the causeway, raising concerns about starvation of beaches nearby, and erosion has been a problem at one point on the causeway. The other, the Tungaru Central Hospital, was completed in 1991: within only two years of completion, coastal erosion was recognised as a potentially serious threat. Most recently, it became apparent that plans for a new grant aid project to upgrade the King George V - Elaine Bernacchi Schools would benefit from an understanding of coastal processes in Bikenibeu. In view of these concerns, the Japan International Cooperation Agency (JICA) requested SOPAC assistance in March 1995.

The field mission, 21 June to 7 July 1995, involved a general reconnaissance of the South Tarawa coast and detailed shoreline reconnaissance of the hospital, schools and causeway sites. An aerial reconnaissance provided an opportunity to take low-level oblique photographs and video. The shoreline survey was carried out using a Sokkia Set 2C™ electronic total station. Data analysis employed the public-domain Geographic Resource Analysis System (GRASS) software of the US Army Corps of Engineers, running under UNIX on a Sun SPARC work station at the SOPAC Secretariat. Historical air photographs (1943, 1969, 1992) and the 1972 topographic map were digitally scanned and rectified to Tarawa Local Grid (approximated by UTM zone 59) to remove tilt, rotation, and lens distortion. However, the 1943 data could not be used for quantitative analysis.

The GIS capabilities of GRASS enabled measurement of beach width, shoreline position, and shoreline recession. Rectification of the 1969 and 1992 air photographs and the 1972 topographic maps was judged to be adequate, with maximum errors of about ± 2 m and generally much less, and measurements of shoreline change were obtained to better than ± 0.3 m. Estimates of mean recession rate (in metres per year: m/a) had approximate errors of ± 0.09 m/a (1969-1995), ± 0.10 m/a (1969-1992), and ±0.77 m/a (1992-1995). In fact the 1992-1995 recession estimates were closer to ±0.1 m/a in most cases because direct measurements could be made in the field from structures and other features seen on the 1:3000 scale air photographs.

The report contains summary of previous work carried out by SOPAC and others, together with an account of the current state of knowledge and practices regarding the physical environment of South Tarawa including: geology and coastal geomorphology, climate, weather, coastal oceanography, physical infrastructure, coastal protection and reclamation planning policy.

Oblique airphoto of Tungaru Central Hospital (24 June 1995) showing details of shore morphology and structures.

Tungaru Central Hospital

This facility, completed in 1991, is situated along the ocean shore to the east of Bikenibeu close to the southeast corner of the atoll. This section of the coast faces slightly west of south. Although reasonably straight, it is marked by a succession of embayments on the west sides of conglomerate outcrops and platform headlands projecting onto the reef flat. In retrospect, it is most unfortunate that this important facility was constructed so close to the coast. The distance from the backshore scarp to the emergency access now ranges from 0 to 8 m, except at the east end of the property, where the road turns away from the shore. Damage to the road foundation has already begun at the west end, where partial loss is imminent.

Airphoto showing Tungaru Central Hospital.

The report concludes that:

- The medium-term rate of coastal recession at Tungaru Central Hospital (1969-1992) was approximately 0.2 to 0.4 m/a.
- The rate of erosion at the backshore scarp increased to an average of about 1.2 m/a over the past 3 years (1992-1995), and at one site up to 2.5 m/a, but most of this erosion may have occurred during an extreme event between May 1992 and April 1993.
- The eroding backshore scarp is now 0-8 m from the emergency access road at the hospital and ≤9 m from the nearest ward.
- An artificial berm may be assisting to retard erosion in the eastern and central section of the hospital shorefront.
- Coastal erosion could facilitate flooding of the low-lying hospital site if it breaches the low backshore ridge or the artificial berm along the present shore.
- It is uncertain whether the recent high rates of erosion are a short-term aberration related to unusual and persistent ENSO conditions in 1991-1995, or to an individual storm event (perhaps in December 1992), or whether they represent the beginning of a trend to more rapid erosion. This could be related in part to disruption of the natural shore system by the intake and outfall structures at the hospital, the seawall at the eastern boundary, removal of backshore trees during construction, other construction damage, excess pedestrian traffic, and/or small-scale sand removal.
- There is evidence to suggest cyclic variations in the sand volume on the beach, associated with ENSO-driven changes in prevailing winds. The beach at the west end of the site has recovered some volume since 1992.
- The erosion threat at the hospital demands close monitoring and urgent attention.

King George V - Elaine Bernacchi Schools

This site lies along the ocean shore of a broad embayment and long sandy beach extending more than 1200 m from the east end of Bikenibeu to the west end of the campus. Prominent outcrops of coral conglomerate standing above the reef-flat pavement, similar to the conglomerate platform at the west end of the hospital site, form a natural barrier to longshore sediment transport at the west end of the KGV beach, although some beach sand has moved into a small pocket beach between the two conglomerate tongues. Attempts at protection initially by constructing a grouted sandbag seawall about 96 m long and up to 1.75 m high in front of the two-storey classroom block at the west end of the beach began in July 1992.

The report concludes that:

- The medium-term rate of coastal erosion ranged up to 0.3 m/a at the west end of the site (1969-1992), erosion reaching within 3-4 m of the

classroom block in May 1992.

- The grouted sandbag seawall constructed along the front of this building in July 1992 was severely damaged in December 1992, rebuilt early in 1993, damaged again in November 1994 and repaired in early 1995.
- The recession rate of the backshore scarp in the 150 m immediately east of the seawall accelerated from an average of 0.11±0.14 m/a (1969-1992) to 0.93±0.20 m/a (1992-1995), with a maximum of 1.2-1.3 m/a near the Public Utilities Board pumphouse, which now projects out onto the beach.
- Farther east along this shore, the back-shore scarp disappears and the shore has been stable in recent years, although the beach shows evidence of long-term recession (exposure of beachrock and conglomerate) and localised washover suggests the potential for erosion in severe storms.
- The erosion threat at this site demands urgent attention to preserve the saltwater supply to the Bikenibeu sewerage system. The most appropriate response in this area may be retreat.

Nippon Causeway

The Betio-Bairiki road link (Nippon Causeway), completed in 1987, is the largest Japanese-funded infrastructure project in Kiribati. It is 3.4 km long, of solid fill construction, with a single gap in the middle to allow small boats to cross under the causeway and travel across the reef between the ocean and lagoon. This channel, 800 m long and 10 m wide, is known as the "fisheries access channel" and was an integral part of the causeway project.

Surveys conducted during this mission will provide an estimate of the present accreted volume. This analysis will be undertaken over the coming months in connection with a comprehensive review of the SOPAC beach monitoring program on Bairiki and Betio. Preliminary conclusions include the following:

- There has been substantial accretion along the Nippon Causeway since construction was finished in 1987. As of February 1988 (18 months after the start of construction and 7 months after completion), a total sediment volume >108 000 m^3 had accumulated along the causeway.
- The major areas of accumulation against the causeway are along the lagoon shore at the east (Bairiki) end and the ocean shore at the west (Betio) end. There has also been significant accretion on the east side of the fisheries channel (ocean and lagoon sides of causeway) and along the lagoon shore west of the channel. This accreted area, which is extensively vegetated, has been declared a part of a new National Park.
- Limited damage to the matted berm and toe protection was experienced directly onshore from the borrow pit at the west end lagoon side of the causeway in December 1994.
- The ocean shore of southeast Betio may be experiencing minor sediment starvation caused by accretion along the causeway to the east. Otherwise, there is no clear evidence that the causeway has affected coastal stability on adjacent shores of Bairiki or Betio.
- Sand transport along the causeway and reef flat on the ocean side causes shoaling in the fisheries access channel, which Public Works Department dredges on a quarterly basis. The channel was effectively filled along part of its length prior to dredging in June 1995.
- Tidal exchange of water between the ocean and lagoon has been reduced by 95% to 97% or more (and is effectively eliminated when the fisheries channel is full of sediment). The implications for lagoon flushing, water quality, and reef productivity (relevant to beach sand supply) are unknown.

In addition the report includes twelve general conclusions related to planning and coastal management issues and sixteen recommendations for future work.

Forbes, D., Hosoi, Y. 1995: Coastal erosion in South Tarawa. Report of mission to determine shoreline recession rates at Tungaru Central Hospital & King George V/Elaine Bernacchi School, erosion and sedimentation along the Nippon Causeway, and coastal protection strategies in Kiribati, June-July 1995. SOPAC Technical Report 225: *91 pages. The work was funded by JICA and the government of Canada.*

Coastal Sedimentation and Coastal Management of Fongafale, Funafuti Atoll, Tuvalu

Fongafale is the main island (islet or motu) of Funafuti Atoll in Tuvalu. It is only 1.42 km^2 in area, long and narrow with a broad "V" shaped outline and can be divided into three geographical areas: (i) the south arm, extending southwestward 2.3 km, from 150 m southwest of the south end of the runway or the point of the lost beach profile base station BS16; (ii) the central area, from BS16 north approximately 2 km to Teuaea Road; (iii) the north arm, extending northeastward 4.5 km from Teuaea Road. The central area is relatively wide and the north and south arms are narrow. The maxium elevation on Fongafale is less than 3 m, and coastal erosion occurs primarily on the lagoon (western) side.

From 6 April to 15 May 1995, field work was carried

out on the lagoon side coast of Fongafale in order to produce a coastal geological map (scale 1:2500), to study coastal processes with an emphasis on coastal erosion, sediment transport and deposition, and to determine the evolution of Fongafale Island. Transects were surveyed at 200 m intervals across the reef flat at low tide and observations on the beach were made along most of the shoreline. From 800 m north of Funafuti Wharf to the north end of Fongafale, the transects were spaced at 500 m. The 1:2500 topographic map, published in 1979 by the British Government's Overseas Development Administration (Directorate of Overseas Surveys) was used for a base map.

The shoreline of the reclaimed land in World War II is shown by the cemented coral stone cylinders, which were put in gasoline drums. The remains of a gabion basket seawall lie between the eroded coast and the cylinders.

The report includes good accounts of the changes in the lagoon coastline during the Second World War, the present day morphology of the lagoon reef flat, and of the formation and evolution of Fongafale.

Change in the Lagoon Coastline during the Second World War

Senior residents remember that there was a long, low-gradient, sandy beach prior to the Second World War. The Royal Society Expedition in 1904 recorded that there was an extensive sandy beach at the turn of the century. Aerial photographs taken on 26 June 1941 show most parts of this beach, which extended from the position of BS16 at least as far north as the present Primary School. The state of the coastline to the south and north of this beach at that time is unknown. Aerial photographs taken on 9 July 1943 show that most of the beach had been covered by reclaimed land, with sandy beach remaining only to the north of the present Teuaea Road. The sandy beach extending from BS16 to Teuaea Road before 1942, along the central part of Fongafale, was about 30 m wide and 2 km long.

When the US forces arrived in Funafuti in October 1942, there was a lake with surrounding mangroves in the north part of the central area of Fongafale. In order to build a longer runway, a large volume of gravel had to be dug from the land area to fill in the lake and mangroves. Sand dug from the lagoon was used for paving the runway, and an area 2 km long and 25-40 m wide was reclaimed along the lagoon shore to provide an access road. This extended from 90 m northeast of Catalina Ramp to 370 m southwest of the present runway. A long borrow pit was dredged, more than 10 m wide, forming a channel parallel to the shore. Another access road connected the shore and the runway. The Catalina Ramp was the seaplane base and there was a borrow pit beside and in front of the ramp. A shore-normal channel 35 m wide was dredged 450 m southwest of the south end of the present runway for a petrol torpedo boat base. A road was built from here to the south end of the shore access road, using stone and sand dredged from a borrow pit at the toe of the beach. The result was 2.3 km of reclaimed land with a coral stone seawall and a long borrow pit (often called a channel) immediately beside it in the reef flat. In the north area, two other channels normal to the shore and one 125 m long channel parallel to the shore near the present Tuvalu Co-operative Wholesale Society were also dug.

These developments completely changed the shoreline and sediment transport patterns along the lagoon side of Fongafale. The seawall was placed at about the former low-tide line and suffered erosion soon after it was built. The borrow pits or channels have been filled with sand transported by waves and longshore currents and with sand and gravel eroded from the reclaimed land. However, land in Fongafale is very limited and valuable, so people have been making efforts to keep the reclaimed land. This leads to a conflict between the natural

processes and the desires of the people. After destruction of the coral stone seawall built in the Second World War, gabion basket seawalls were built. Only small parts of these have survived. In recent years, seawalls of concrete cubes have been built from Teuaea Road south to the disused Vaiaku Wharf, along with a vertical stone-cemented seawall and concrete seawall in the front of the new Vaiaku Lagi Hotel.

Along the shoreline to the north and south of the central Vaiaku area, few man-made changes have taken place. Erosion has occurred but the scale is much smaller than that in the central area of artificial shore.

Lagoon Reef Flat

The lagoon reef flat is 55-350 m wide, including a 15-25 m wide beach. It consists of three provinces: (i) the south province, south of the disused Vaiaku Wharf; (ii) the central province, from the disused Vaiaku Wharf to the Catalina Ramp; and (iii) the north province, north of the Catalina Ramp.

The reef flat is classified into two types and divided into three provinces. The south province and north province belong to Type I and the central province belongs to Type II, showing good symmetry. The beach is also classified into two types and can be divided into three regions which coincide exactly with the geographical and reef flat division of the island. The good symmetries of division of reef flat provinces and beach regions are controlled by longshore currents, which in turn are closely related to the outline of Fongafale.

The concrete seawall and boulders on the beach on front of Vaiaku Lagi Hotel.

The longshore currents transport sand from the northwest and southwest towards the central area, producing a good sand beach before World War II. Because of human activity initiated during the war, the beach in the central area is now mostly covered by boulders and concrete cubes. However this area has good potential for sand beach recovery.

The report describes coastal sedimentation patterns (including the effects of erosion and progradation) and the effects of human activity on sedimentation patterns.

Formation and Evolution of Fongafale

There was a lake with surrounding mangrove swamp in the widest part of Fongafale before 1942. Most of the lake was shown by the aerial photographs taken in June 1941. The northwest part was filled up during the Second World War for building the runway, but the rest still exists.

In the past, Fongafale may have been six small islands, three of which were arranged along the northwest and three along the southwest. Among them, the two central islands had two opposing headlands respectively, which gradually grew together, leaving the lake. At about the same time, the remaining islands also became connected to form the broad V-shaped narrow island of Fongafale. The bends of the present island and the areas of sand accumulation may be the connecting points between former islands. After formation of the two long northwest and southwest extending arms, more sand was transported to the central area of Fongafale and accumulated there, forming a long sand beach. The progradation on the lagoon side of the central area of Fongafale was relatively fast. The lagoon coasts of the two arms have been relatively stable. On the ocean side, coastal progradation occurred after a very strong tropical storm, Cyclone Bebe, in 1972.

The natural central depressions of Fongafale are about in the middle of each arm, between the ridge complex on the ocean side and the ridge complex on the lagoon side. Both ridge complexes are composed primarily of gravel

(much coarser on the ocean side). In the central area of Fongafale, the distance between the mangrove (the margin of the lake) and the ocean side vegetation line is only 6-18 m. But the distance between the mangrove surrounding the lake and the vegetation line on the lagoon side was more than 240 m in 1941.

Coastal Management and Sand Beach Recovery

Since the island formed gravel has accumulated on the beach along the two arms, with only limited sand, whereas sand has accumulated preferentially in the central area. The seawall constructed during the War has helped to protect the coast, but it is aesthetically unpleasing and prevents the sandy beach from recovering. Coastal management and coastal protection efforts should therefore aim to recover the natural state if possible.

A sand beach was present in the central area of Fongafale from the time of its formation until the Second World War. This beach disappeared because of the land reclamation in the War and now most places are covered by relict boulders and seawall. The central area has potential for sand beach recovery. This is the area of convergence between the southwest and northwest arms, receiving sand from both directions. Moreover, sand is easily transported to the beach by shoreward currents because there is a relatively wide zone of thick sand on the reef flat.

There is a severe shortage of sand in Funafuti Atoll. Moreover, if sand is directly replenished, the recovered sand would be removed by waves, because the sea-bed slope is too steep to keep sand. It is therefore necessary to seek another way. In order to speed up the sand beach recovery, gravel can be placed on the sea bed at a slope close to the natural gradient of the sandy beach, and on which sand can naturally accumulate. A beach nourishment area is proposed around the new Vaiaku Lagi Hotel.

In recent years gravel has accumulated at the south end of Fongafale and at both ends of the islands south of Fongafale, such as Futato, Funangongo and Funamanu. Removing the gravel would not produce a significant environmental impact, except at the southwest end of Funamanu, although taking this gravel would be more expensive than taking gravel from the southwest end of Fongafale.

Construction of seawalls should be avoided, as they promote beach erosion. The jetty close to the Vaiaku Lagi Hotel should be demolished or changed to a pier-type wharf. Otherwise erosion will continue on the downdrift side of the jetty, just in front of the hotel.

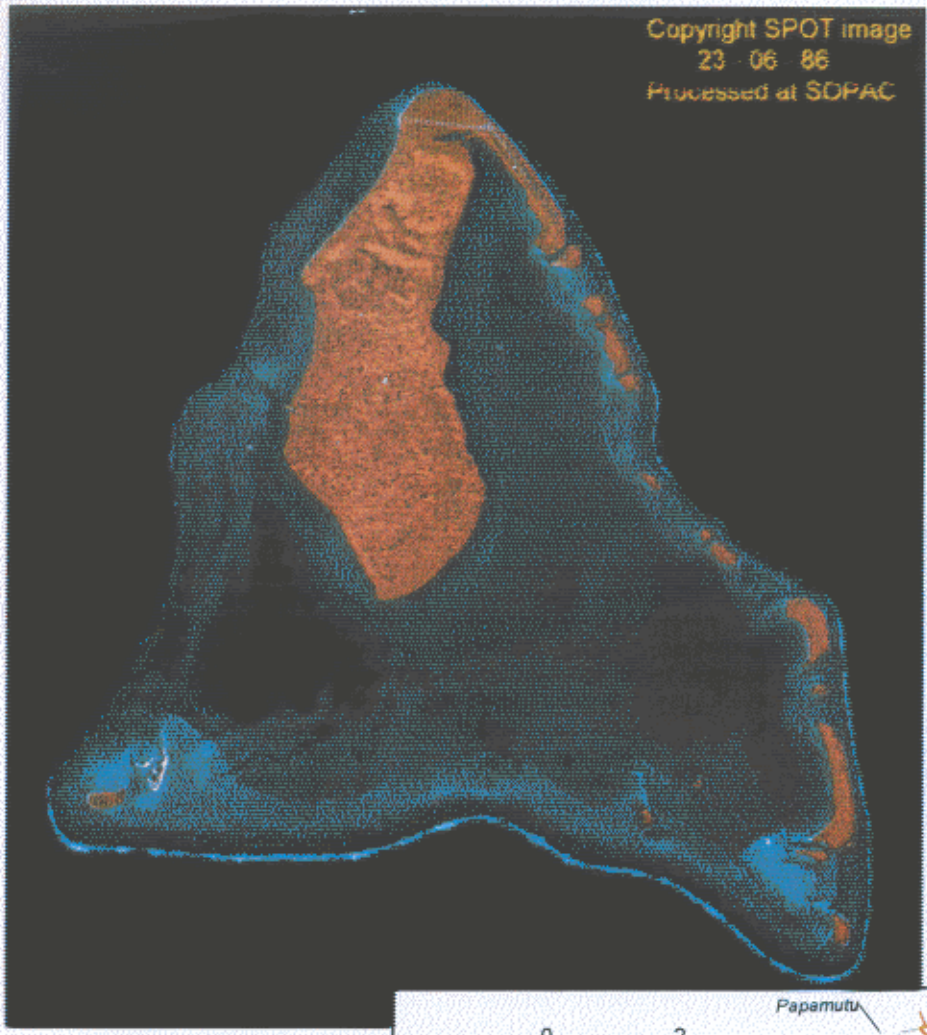
Xu, C., Malologa, F. 1995: Coastal sedimentation and coastal management of Fongafale, Funafuti, Tuvalu. SOPAC Technical Report 221: *54 pages + map in pocket. Funding for this project was provided by the Government of the People's Republic of China.*

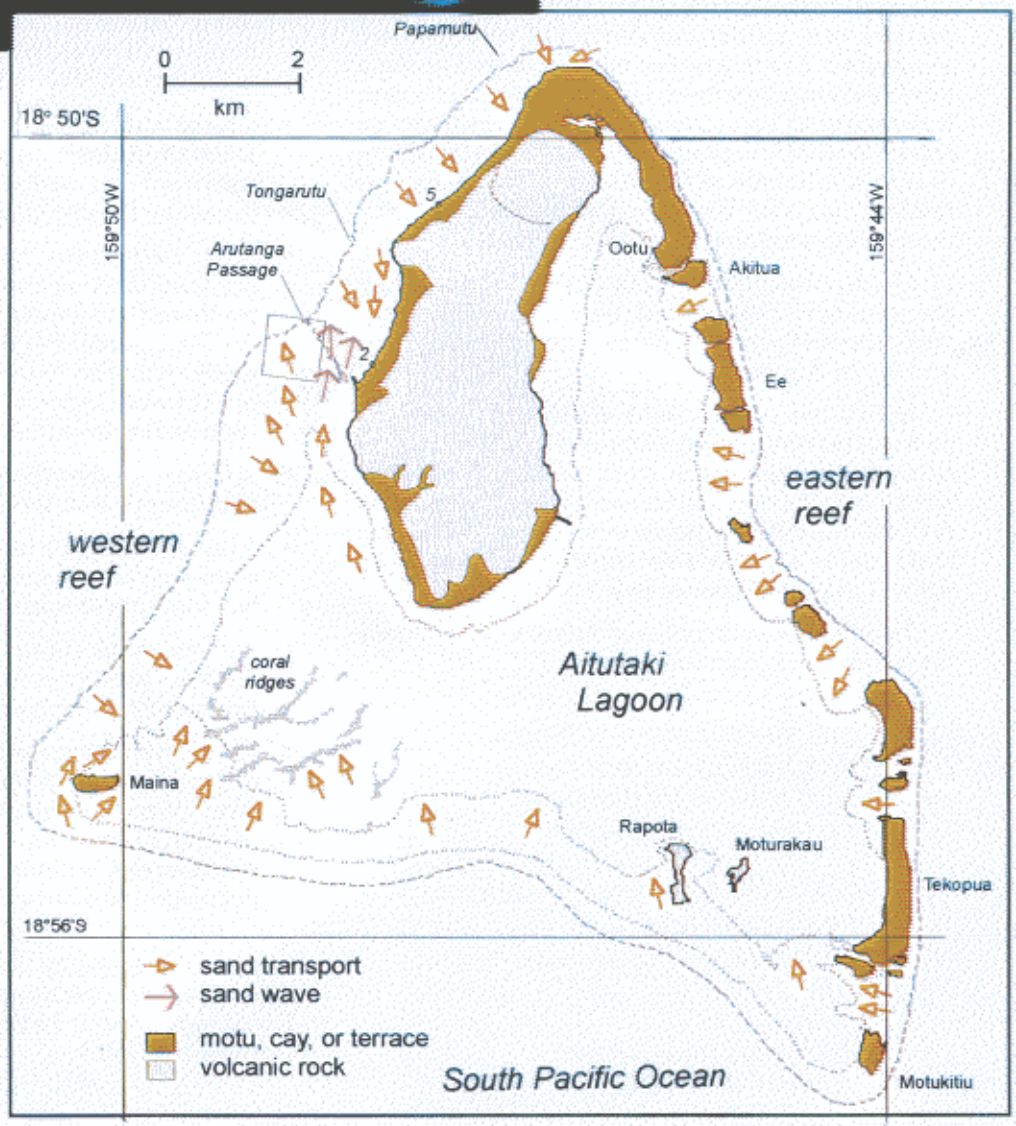
Coastal Stability and Sand Transport Aitutaki, Southern Cook Islands

Aitutaki lies 225 km north of Rarotonga in the southern Cook Islands. It is an "almost-atoll", retaining a volcanic island of 17 km^2 within the atoll reef perimeter, along with a shallow lagoon. The exposed volcanic rocks distinguish Aitutaki from fully-developed atolls in which the volcanic foundation is completely buried by a limestone cap and submerged below present sea level.

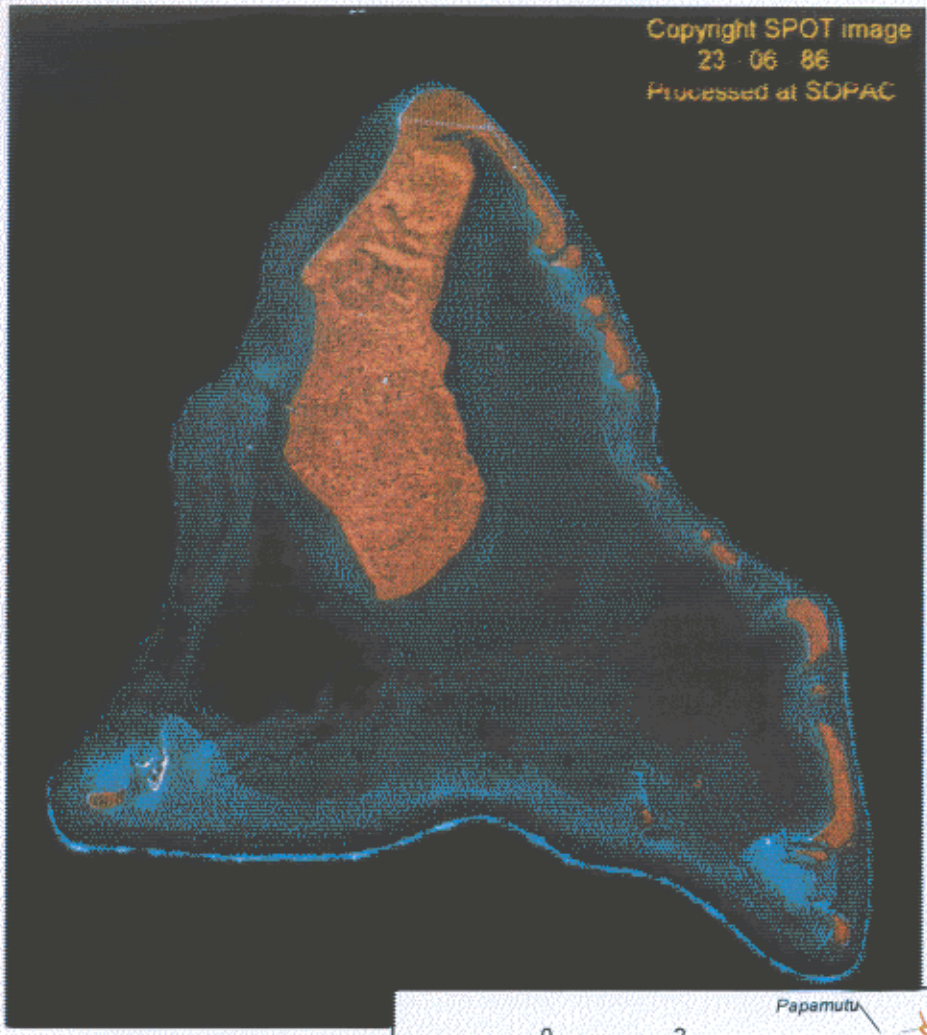
Although much of the population formerly occupied higher ground of the island interior, many people now reside near the coast on a low marine terrace along the western shore. The harbour facilities at Arutanga are also located in this area. Other infrastructure facilities, such as the clam hatchery and airport, are located on a motu terrace along the north and northeast coast. Tourist facilities, important to the future economic growth of Aitutaki, have recently been developed on the northernmost motu islet on the eastern reef, Akitua, and on low ground along the southern shore of the main island. All of these structures are potentially vulnerable to coastal instability and other hazards associated with cyclones, sea-level fluctuations, reef degradation, or changes in sediment supply. The latter may result from sand extraction, harbour dredging, or other artificial manipulation of the reef flat, lagoon, and shore zone.

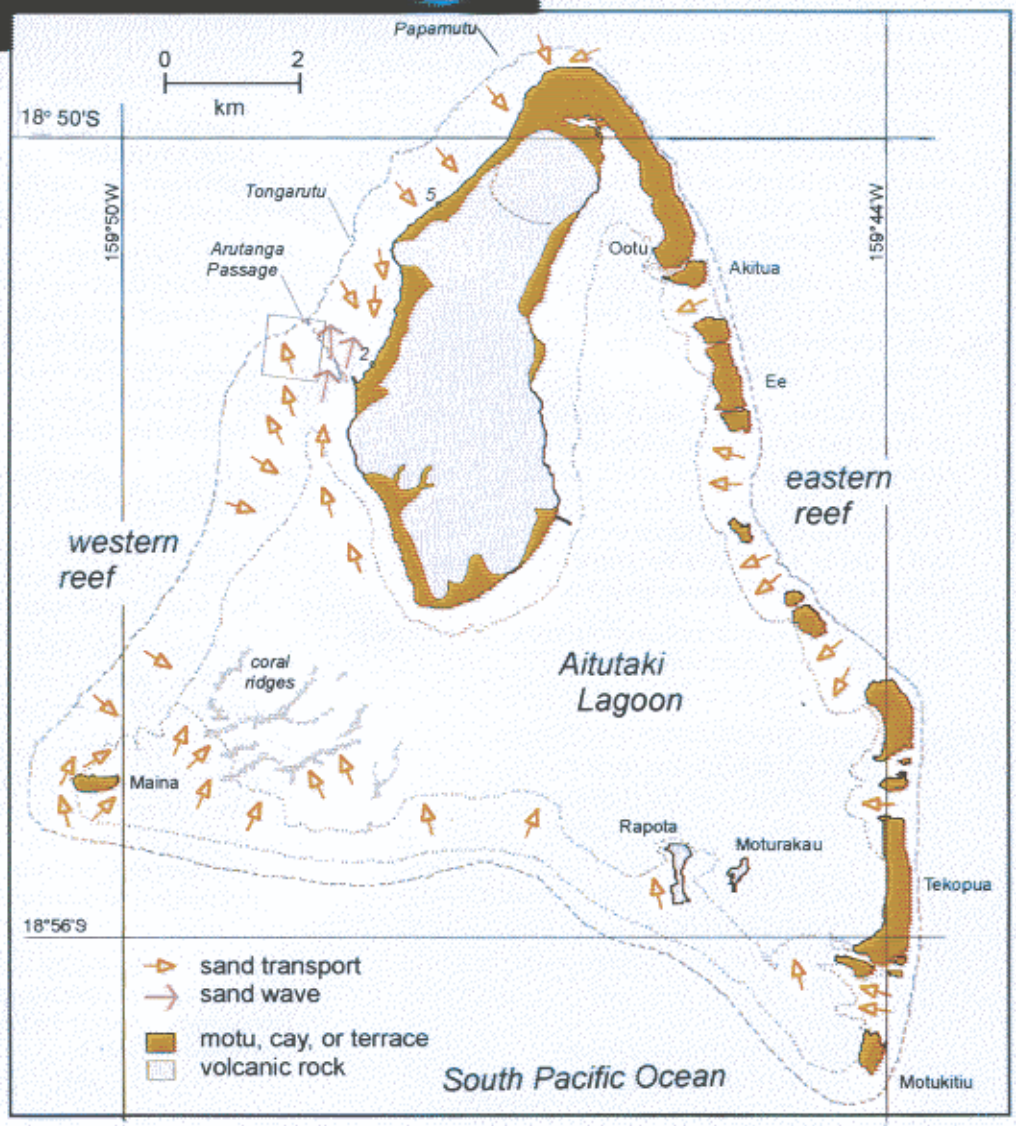
This report gives a preliminary summary of work carried out during a 3-day brief reconnaissance field program in late March 1995. The objectives of this work were to gain a general overview of the coastal system at Aitutaki, to establish beach profiles along the western shore of the main island as a basis for future evaluation and monitoring of shoreline





This 1986 SPOT image and the accompanying map show the high central island, the motu terrace and islets along the eastern reef, and the sandy cay in the southwest. Sand moves into the lagoon across the eastern, southern, and part of the western reef margins, but moves seaward and possibly also onshore in the area of Arutanga Passage.





This 1986 SPOT image and the accompanying map show the high central island, the motu terrace and islets along the eastern reef, and the sandy cay in the southwest. Sand moves into the lagoon across the eastern, southern, and part of the western reef margins, but moves seaward and possibly also onshore in the area of Arutanga Passage.

Looking south along the western shore of the main island toward Arutanga. Seaward-leaning coconuts attest to an earlier erosion event, while the cuspate gravel swash bar points to more recent accretion of material from the reef flat.

stability in that area, and to investigate sand transport patterns on the reef flat and in the northwest lagoon. The work was motivated by proposals for harbour expansion and enlargement of the boat channel at Arutanga and questions about the effects such changes might have on sand movement, stability of nearby shorelines, and the potential for sand extraction in the area.

Grain-size analyses of the sand samples were carried out using conventional dry sieving techniques. Beach profiles were surveyed using a modified Emery method, which is fast and efficient. It is subject to cumulative errors, but these can be shown to be very limited and partially self-cancelling over profile lengths of the order of about 100 m. This method has also been used in SOPAC's coastal monitoring program in South Tarawa, Kiribati.

The report reviews the physical setting including the geology, coastal and reef geomorphology, Holocene reef growth, climate, oceanography, and ecology of Aitutaki.

Indicators of net sand transport, including obstacle marks (leeside drifts and hollows) around storm blocks and patch reefs, sand ribbons, sand waves with sharp slipfaces, and features comparable to flood-tide deltas between motus along the eastern reef, enable a reasonably complete picture to be formed of sand dispersal processes.

The report, which contains four recommendations for future work, concludes that:

- Prevailing easterly winds and waves move sand into the lagoon across the eastern and southern reefs.
- Westward wind-driven circulation and tidal transport in the main lagoon move sand northward and seaward across the northwestern reef flat and harbour channel in the vicinity of Arutanga.
- Storm waves approaching from the west and northwest move sand onshore across the western reef flat north and south of the Arutanga region.
- Coarse sand and gravel derived from the reef and shore erosion along the northeast coast move westward and onshore under refracting waves driven by the prevailing easterly winds.
- Fine carbonate sand (0.15 mm mode) predominates in beach sediments along the southwest and western shores of the main island. A coarser, coral-fragment, beach sand (0.6 mm mode) was also found in the tidal sheets of the northwest lagoon, implying a possible contribution from this source to the western shore.
- A former southern boat channel, present in 1892, had disappeared (presumably filled) by 1961.
- Although a minor beach cut was noted on the southwest and western shores, most of these beaches appear reasonably stable at present.
- Cyclone wave runup can approach or overtop the 3-4 m terrace north of Arutanga and along the north coast of the island.
- Rates of sand transport, losses to deep water, and degree of exchange with beaches on the western island shore remain uncertain, making it difficult to predict the impact of proposed channel enlargement without more detailed study of circulation and sediment transport.

Forbes, D.L. 1995: Coastal stability and sand transport, Aitutaki, southern Cook Islands. SOPAC Technical Report *226: 47 pages. Funding for this project was provided by the Government of Canada.*

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