

Technical Report No. 29
for PE/CCSP-1/VA6

BASELINE COASTAL STUDIES,
PORT VILA, VANUATU.

Geology and Stability

Visit 14th to 29th May, 1983

by
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INTRODUCTION and BACKGROUND:

This report follows a short consultancy visit to Port Vila during the period 14th to 29th May 1983, as part of the CCOP/SOPAC 1983 Work Programme under project element CCSP-1/VA6. The visit followed shortly after the coastal management workshop organised by the United States Geological Survey, run by Gary Greene and held in Port Vila during late April to early May. As a result of this workshop, it is expected that a very good summary of the present coastal zone environment will emerge. In June, Dr. Ralph Carter, a marine scientist from the Project Office, will return to Port Vila following a brief visit in February, to carry out studies particularly oriented towards water mass exchange and associated pollution in the coastal zone of Vila Harbour and Erakor Lagoon (see Trip Report No. 5 enclosed with letter NR/SOPAC/TECHSEC-168 dated 3 March).

Port Vila, on the island of Efate, is located approximately 17°44'S and 168°19'E and is the administrative and commercial centre of Vanuatu. The island experiences a humid tropical climate associated with prevailing southeasterly trade winds. The average annual rainfall is 2366mm (30 year average 1948-1977). The number of rain days per year averages 217, giving an average 11mm of rain per day. The area lies within the belt of tropical storms and hurricanes of the southwest Pacific. On average Efate experiences at least one tropical cyclone per year.

Efate is a Late Pliocene to Pleistocene volcanic island which rises to a height of 647m at Mt MacDonald. A series of elevated reef limestone terraces are widely preserved from sea level to heights of over 600m. Around Vila the topography is dominated by reef limestone terraces which have been uplifted, faulted and tilted. Underlying the limestone is the Efate Pumice Formation which comprises pumiceous breccias and tuffs of the original strato-volcano.

Where preserved, the heights of emerged Holocene reef vary up to 10m above sea level (Neef and Veeh, 1977; Ash *et al.*, 1978). This suggests that there is not simply one Holocene reef terrace produced in response to the eustatic sea level curve, but a series of uplifted Holocene reef terraces. Each has been produced in response to faulting and tilting which is likely to be co-seismic.

Efate, and the Port Vila area, is therefore geologically active and being deformed by faulting and tilting associated with earthquakes. The recurrence interval is not known, though evidence of such movements is widely preserved around the coastline.

Development of the coastal zone in the Port Vila-Mele Bay area is as yet limited. This development includes buildings along the coastline in Vila, and occasionally around the coastline elsewhere; a new wharf area on the south side of Vila harbour; a sheet pile seawall backed by fill has been constructed along the Vila foreshore between the Hotel Rossi and the old wharf area; some sand mining is taking place directly from the beach in the central Mele beach area.

There is historical evidence of movement of the coastline and the coastal zone, especially adjacent to the river mouths at the head of Mele Bay. Furthermore, these movements can be correlated with cyclone activity or periods of intense rainfall, and are a result of river flooding, or storm surges, or a combination of both.

OBJECTIVES:

- (i) To develop geological and related studies of the coastline in the Port Vila and adjacent areas; no studies were carried out related to tsunamis;
- (ii) investigate geological and historical evidence for any coastline changes;
- (iii) determine the causes of such changes; and
- (iv) suggest possible future work to be carried out, with the view of contributing to a broader-based coastal management study.

PERSONNEL PARTICIPATING:

- (i) Dr. Russell Howorth, Geologist, Principal Investigator, Geology Department, Victoria University of Wellington, New Zealand.
- (ii) Dr. A. Macfarlane, and Mr. R. Marks; Director and Principal Geologist, Department of Geology, Mines and Rural Water Supplies, Republic of Vanuatu.
- (iii) Mr. A. Tari and Mr. W. Harrison, Geological Technicians, Department of Geology, Mines and Rural Water Supplies, Republic of Vanuatu.
- (iv) The following personnel provided valuable help in many, varied ways. Without that help, it would have been impossible to carry out the field work and data research in Vanuatu:

Mr. Charlie Paine, Director of Lands and Surveys.
 Mr. Paul Emery, Director of Meteorology.
 Mr. Rees Discombe, Vanuatu Resident.
 Radiocarbon Dating Laboratory, Institute of Nuclear Sciences, DSIR, New Zealand.

EQUIPMENT and FACILITIES:

- (i) Three Vanuatu field assistants.
- (ii) Surveying equipment from Department of Lands and Surveys.
- (iii) Transportation by Department of Geology, Mines and Rural Water Supplies.

(iv) Lands and Surveys provided maps, air photos, and plan printing facilities.

(v) Lands and Surveys staff carried out on request three cross-profiles of the Tagabe River.

RESULTS:

The coastline in the Port Vila area (Figure 1) shows a bay-headland morphology, which has a distinct northeast-southwest pattern controlled by the faults and associated tilting of the blocks between the faults. The main bay, Mele Bay, is flanked by the two main headlands of Devil's Point in the west and Pango in the southeast. At the head of Mele Bay is an extensive coastal alluvial fan. The entrance to the almost enclosed Vila harbour is on the east side of Mele Bay. There are three islands in Mele Bay, one at the harbour entrance, one inside the harbour, and the third in the northwestern corner of Mele Bay. Two lagoons on the eastern side of Vila town are almost totally land-locked and linked to the sea via a narrow outlet about 5km east of Pango Point.

Low-lying uplifted Holocene reef, or a cliff undercutting higher, older uplifted reef, dominate the headlands and a large part of the coastline. Only Mele beach at the head of Mele Bay is a sandy beach environment. A fringing reef exists around the coastline but is absent along a large part of Mele beach.

(i) A Late Quaternary history of the Port Vila area.

The position of the Vanuatu group of islands astride the Australian/Pacific plate boundary between 10°S and 24°S is now well-established (Carney and Macfarlane, 1982). Ongoing tectonic deformation associated with the subduction of the Australian plate beneath the western margin of the Pacific plate and beneath the Vanuatu group of islands is also well-established (Neef and Veeh, 1977; Bloom *et al.*, 1978; Taylor *et al.*, 1980). Most of the islands in the group are flanked with reef limestone surfaces whose disposition (height and tilt) is related to age, tectonic uplift rate, and the eustatic sea level curve. Generally, in any given area the older surfaces are higher and more strongly tilted.

The most recent uplift occurred in August 1965 associated with a large magnitude ($M = 7.75$; depth = 12km) earthquake sequence in the Santo-Malekula area in the northern half of the group. Uplift of up to 1.36m of recent reef in the northern half of Malekula has been well-documented in relationship to this earthquake (Taylor *et al.*, 1980). In this part of the Vanuatu group Taylor *et al.* (1980) demonstrated that similar magnitude co-seismic events every 350 years would explain the disposition of the Holocene surfaces.

Port Vila is situated on Efate, one of the more southerly islands in the group. The island is also further to the east than Santo and Malekula, away from the Vanuatu (New Hebrides) Trench. The island is therefore less active and seismicity is generally much deeper (Figure 2). On Efate the best preserved sequence of uplifted raised reef limestones occurs to the northwest in the Port Havanah harbour area. This sequence has been dated and described by Kaplin *et al.* (1975), Neef and Veeh (1977), and Bloom *et al.* (1978).

Efate has grown as a volcano and emerged above sea level during the Pleistocene. The oldest volcanic rocks, Efate Pumice Formation, are dated $c. 1.58 \pm 0.05$ Myr ago; the Basalt Volcanoes Formation which outcrops only on the north side of the island is believed to be less than 0.7 Myr (Ash *et al.*, 1978). The reef limestones surround most of Efate; however in the southwest part of Efate in the Port Vila area anomalous structures occur:

(i) The large embayment of Mele Bay apparently breaches the reef limestones and it is headed by a large alluvial plain. (ii) To the east of Mele Bay in the Port Vila area the raised limestone surfaces are severely tilted and faulted, and correlation of the surfaces is difficult. In fact, correlation was not attempted by previous workers. (iii) Strong deformation, tilting and faulting of the raised limestones in the Port Vila area has resulted in a dramatic effect on the geomorphology. For example, two lagoons virtually at right angles to one another are almost totally enclosed by land and separated from each other and the sea by narrow areas. Similarly, a glance at the topographic map of the Vila area indicates the raised limestone surfaces to dip randomly with respect to one another. (iv) To the east lies the Teuma Graben (Ash *et al.*, 1978). This was mapped by them and Carney (1982) as a primary structural feature of Efate bounded by two facing faults, the nett throw of which exceeded 200m up on the western side (Carney, 1982).

Carney estimated that movement on the faults in the area of the Teuma Graben essentially ceased 100,000 years ago. He calculated this age based on the assumption of one millimetre per year uniform uplift. This uplift rate was that indicated by Neef and Veeh (1977) for the Port Havanah area. It is clear, however, from the data of Neef and Veeh (1977) and Bloom *et al.* (1978) that the uplift rate varies around Efate. In other words, the reef limestone surfaces are being deformed by relative uplift and tilting of the blocks between the major faults of Efate. Therefore Carney's interpretation is likely to be incorrect.

As can be seen from the seismic map of Efate (Figure 2) the Teuma Graben is at present an aseismic feature. Furthermore, offshore seismic profiling (Macfarlane, pers. comm.) indicates that the structure may not be a tectonic feature at all (Figure 3).

With the exception of the area between Mele Bay and the Teuma Graben, Efate appears to be being uplifted and deformed in a manner similar to elsewhere in Vanuatu. In the Port Vila area, however, small segments of uplifted limestone are randomly oriented with respect to one another, but generally speaking the raised surfaces decrease in altitude from the east at the Teuma Graben westwards towards Mele Bay.

It is suggested that a block comprising south Efate between west Mele Bay and the Teuma Graben is sliding in a southwesterly direction. As it slides, the reef limestone "carapace" is cracking and the pieces are being jostled with respect to one another. Faults in the Port Vila area are essentially shallow vertical features, the dip reduces to that comparable to the paleotopographic slope of the volcano at depths no greater than the thickness of the limestone. The Teuma Graben on the eastern boundary is simply the gap produced as the block slides away to the southwest.

Effectively therefore this part of south Efate is a large landslide (translational block slide) progressively moving down into the sea along the contact between the reef limestones and weathered older volcanic materials. It has broken up into a number of smaller block slides, each moving with respect to each other. If this is so, then the following are explained:

- the large depressed, embayment in the reef limestone of Mele Bay headed by an alluvial plain;
- the complex geomorphology of the Port Vila area, including the area of the two lagoons;
- the lack of a sequence of raised Holocene surfaces around the Port Vila shoreline;

- the lack of evidence for a tectonic graben structure offshore of the Teuma Graben.

It is reasonable that the boundaries of this large translational block slide are controlled by deep-seated fractures in the original volcano. It is not surprising, therefore, that where these two fractures intersect, at the head of the block slide, is an area where hot springs occur (Carney, 1982). If this model is correct, it has significance for the assessment at present being undertaken of Efate's geothermal prospects.

In an attempt to substantiate or otherwise this model the most reasonable suggestion for further work is to carry out a shallow, near-shore seismic survey in the Mele Bay-Port Vila harbour area to confirm whether or not a submerged reef limestone surface does exist, and dips westward from the Vila shoreline progressively across the Mele Bay area until it intersects the major break on the western margin of the bay. Overlying this surface should be a thin veneer of sediment which may increase in thickness towards the west and south.

(ii) Large earthquake recurrence period in the Port Vila area.

Vila is situated in an earthquake felt intensity 5-6 region (ORSTOM, pers. comm.). Strong earthquake activity has not occurred near Vila in recent times, but earlier this century three shocks of magnitude 8 or greater were recorded occurring within a 100km radius of Port Vila (Mallick, 1973).

If it is presumed that the uplift of a Holocene reef surface was co-seismic (compare with 1965 Malekula earthquake, Taylor *et al.*, 1980) then where a sequence of Holocene reef terraces is preserved a record of past earthquakes exists. Clearly the preservation of a complete record is dependent on an uplifted reef being preserved and not eroded by subsequent coastal processes.

An uplifted Holocene reef terrace sequence exists on the western side of Mele Bay near Pukura (168°13'E and 17°42.5'S). An east-west cross-section at right angles to the coast shows a sequence of uplifted Holocene coral reef terraces rising above present-day sea level to approximately 10m (Figure 4). A total of six surfaces were recognised. It is possible that additional less obvious surfaces do exist. From lowest to highest (youngest to oldest) the surfaces are numbered 1 to 6. Coral samples in growth position were collected for radiocarbon dating from Surface 1, Surface 3 and Surface 6. All samples showed some degree of recrystallisation; high magnesium calcite in addition to aragonite was recorded in each sample by either X-ray diffraction or staining. Nonetheless, it is hoped that the dates, at present being carried out by the New Zealand D.S.I.R. Radiocarbon Dating Laboratory, will be available for presentation at the 12th Annual Meeting of CCOP/SOPAC. It is unlikely that the highest surface is older than c. 6,500 years B.P. Therefore, with at least six surfaces already recognised, it is evident that a recurrence interval of no more than 1000 years is expected.

(iii) Historical evidence of coastline movement.

There are four main sources of information: an original cadastral survey 1929-1930, a French Government aerial survey in 1955, a French Government aerial survey in August 1971 and 2nd January 1972, a British R.A.F. aerial survey in August 1972. Other air surveys of Efate were carried out by the U.S. Armed Forces in 1943 and by the R.A.F.

in 1963; however, neither of these two surveys covered the Mele Bay-Port Vila area. A recent (1982) aerial re-survey by the Royal Australian Airforce had to be postponed because of bad weather; however, some large-scale photos of Vila and Mele Island were taken. All these records are held by the Lands and Surveys Department in Vila. It should be noted that the 1:50,000 and 1:25,000 maps of Efate are based on the 1955 photo survey.

The areas recording historical movement are as follows: Mele beach; Port Vila waterfront; Vila new wharf road; and the coastal headlands (see section on Cyclone Amanda).

Mele Beach: The alluvial fan behind Mele Beach is a constructional feature rising from the sandy beach to 40-50m at its highest point. The fan has been formed by the Tagabe, La Colle and Tepukoa rivers in response to changes of sea level and tilting of this part of Efate. The detailed morphology of the aggradation surface is uncertain, due to the widespread dense vegetation cover. However, a recent level survey in a small area immediately south of the airstrip indicates that a series of small channels and degradational terraces exist each with relief of approximately 1-2m. The present river bed occupies a relatively narrow channel only a few metres below the main aggradation surface (Appendix 1).

At the time of the visit, no part of Mele Beach was seen to be actively eroding; except for a few metres of beach on the northwest side of Mele Island, and approximately 500m of beach in the northwest of Mele Bay where the roots of trees adjacent to the road were well-exposed. Evidence of past erosion was seen only on the southeast side of Mele Beach where two storm beaches could be clearly seen. Also in this area some attempt at coastal protection had been carried out in the past; these attempts included the construction of a low coconut log wall, and a concrete wall built on elevated reef. Three beach profiles were levelled (Appendix 2) for comparison with any future changes in the position of the coastline. The best evidence of movement in the coastal zone is recorded by the changes in position of each of the three main river mouths. These are illustrated for the Tagabe River in Figure 5, the La Colle River in Figure 6 and the Tepukoa River-Swango Spit-Mele Island in Figures 7 and 8.

There are no progressive changes with time evident. For each river mouth it should be noted that two sketches are closely spaced in time, one for January 1972, and one for August 1972. The January 1972 sketches record the position of each river mouth approximately one month after Cyclone Ursula. The August 1972 sketches record further change after Cyclone Carlotta in mid-January 1972. It is almost certain that the changes following Cyclone Ursula were caused by peak flood discharge from the rivers associated with extreme rainfall intensity; and the changes following Cyclone Carlotta were caused by storm surge associated with prolonged periods of high wind.

Tagabe river mouth has changed its position along a coastline length of approximately 500m at least three times during the past 50 years. Similarly, the La Colle River appears to have changed its position approximately 500m at least three times during the past 50 years. The position of the Tepukoa river mouth is related to the development of the Swango sandspit towards Mele Island and the position of the river mouth appears to have changed up to 700m during the last 50 years.

After each change a sand bar develops across the mouth of each river. It is quite clear, however, that as a result of Cyclone Ursula significant volumes of material were added to the river mouth-beach system. This volume was substantially repositioned during Cyclone Carlotta and subsequent months at least until August 1972. Since there have been no nett long-term losses or gains in sediment to the river mouth-beach systems, it is

evident that any excess material added to the river mouth-beach system during peak flood conditions is relatively quickly transported offshore.

Port Vila Waterfront: The centre of Vila town, and the Vila waterfront area, is situated on the eastern side of Vila harbour, an almost totally enclosed small embayment on the eastern side of Mele Bay (Figure 1). The geology and topography is controlled by uplifted reef terraces which are tilted towards the west and rise to a maximum of 98m above sea level at Saralana. At least two terraces are preserved, a fault trending approximately east-west and downthrown 20-30m on the south side cuts the reef terraces. The displacement of the reef terraces by this fault is clearly seen on the 1:2,500 topographic sheet (Figure 9). The westward tilt of the uplifted reef terraces is less on the south side of the fault; the lower surface at Independence Park dips westwards at approximately 3°, whilst the higher surface rising behind the Telecommunications Centre dips westwards at approximately 6°. On the north side of the fault the lower surface in the Plateau area dips westwards at 6° whilst the higher surface in the area of the Judicial Courthouse dips westwards at approximately 11°. The age of these uplifted reef terraces is uncertain, however they are unlikely to be older than the Last Interglacial (approximately 100,000 years old). Compared with the soil development on the uplifted reef terraces at Klem Hill to the west of Mele Bay, the uplifted reef terraces in the Vila area have negligible soil development.

The waterfront area may be divided into three; a northern, a central, and a southern section. To the north and south, the uplifted reef terraces form a cliff with respect to the present-day coastline, this cliff rises steeply or near-vertically to heights of 10-20m. A very narrow toe separates the base of the cliff from the high water line. There is little evidence of uplifted Holocene reef. In the central waterfront area, the ground rises steadily to a height of 30m before rising over a 10m cliff of reef limestone. Whether this central part of town is tilted reef limestone, or a talus slope essentially developed on the underlying pumiceous deposits of the Efate Formation is uncertain.

Shown on the sketch maps of Figure 10 (A to E) is the development of the Vila waterfront area over an approximate 50 year period from 1930 to 1983. Shown on each sketch map are the main streets; and in addition Figure 10E (1983) shows the cliffs and the present buildings to the west, or seaward side, of Higginson Street. The original coastline is more or less as shown in Figure 10A (1930). This is the earliest data available from the first cadastral survey. First development and reclamation occurred in what is now the old wharf area on the south side of town. This wharf is now little used as it was replaced in 1972 by the new wharf on the south side of Vila harbour. Between 1955 and 1971 (Figure 10B and Figure 10C), the area in the central part of town was reclaimed up to 50m westwards from Higginson Street. In particular, on the north side of town around and to the south of the Hotel Rossi a seawall was constructed. Comparing the August 1971 and August 1972 sketches (Figure 10C and Figure 10D) will show most of this seawall to have been destroyed during Cyclone Carlotta in mid-January of 1972. Since 1972, a sheet pile seawall approximately 500m long has been constructed from the Hotel Rossi southwards to the northern end of the old wall. Approximately 50,000m² (5 hectares) of reclaimed land now exists behind this seawall and 16 buildings now exist westwards of Higginson Street, most of which are on reclaimed land.

There is little or no surface water in Vila town. Three natural drainage lines can be determined from the topography and are shown on Figures 9 and 10E. These drainage lines are believed to be positions where the aquifer developed on the contact between the reef limestone and underlying volcanic deposits drains to Vila harbour. On inspection of the waterfront area, these drainage lines were each seen to be flowing; one immediately

north of the Hotel Rossi, a second in the centre section of the sheet pile seawall, and the third in the area of the old wharf. Furthermore, the patch reef area immediately offshore was seen to be developed between these three aquifer drainage points, thus confirming that these have been, and still are, natural drainage lines. Evidently, the coral has found it difficult to get established close to these drainage lines where a high fresh-water input would be expected.

Vila Wharf Road: There are no records of landslides associated with the steep to near-vertical coastal cliffs of limestone around Port Vila. Nonetheless, plenty of evidence of rockfalls does exist, for example a large detached block in the vicinity of the Burns Philip Store.

In 1972 the development of the new road to the new Vila Wharf on the south side of Vila Harbour resulted in over-steepening of the natural slope. This generated an awareness of potential slope instability problems which was reported by Mallick (1973).

In March 1973 landslides (debris flows) were recorded in the area of the new wharf and were attributed to the 108.7mm of rainfall on March 5th which was associated with Cyclone Alison. Material involved in the debris flows was principally bedded pumiceous material, the origin of the flows appeared to be located just beneath the contact between the pumiceous tuffs and overlying reef limestone, and almost certainly was associated with the development of a spring at the tuff-limestone contact at this time (Carney, 1975). Further, a potential rockfall-slide situation was described immediately north of the new wharf and above the road (Carney, 1975).

It is evident that landslides (debris flows and rockfalls) have occurred and will continue to occur in the Port Vila coastal cliff areas, and may be generated either by seismic shaking or periods of intense rainfall.

(iv) Causes of historical movement.

Rainfall: Rainfall statistics available from the Port Vila Meteorological Office have been summarised for the 30 year period 1948-1977 (Appendix 3). On examination the highest daily rainfall statistics indicate the following. On only 8 days during this period was greater than 200mm of rainfall recorded, and on only 2 days were greater than 300mm of rainfall recorded. Maximum daily rainfall was 337.1mm on 23rd March 1950; there is no intensity data for periods less than 24 hours and there is no record of any cyclone at that time. On December 8th 1971 at the time of Cyclone Ursula, 322.3mm were recorded of which 235mm fell in a 6-hour period, 180.3mm fell in a 3-hour period and 101.6mm in 1 hour; the 15 and 30-minute intensities do not appear exceptional. Of the 8 periods where daily rainfall exceeded 200mm only 4 of these have been associated with cyclones. It is thus clear that high intensity rain storms may or may not be directly attributed to cyclone activity.

Tropical Cyclones: In the period 1948-1977, 38 tropical storms have been recorded in the vicinity of Efate. Of these 38 cyclones, 22 were associated with the highest daily rainfall figures for the month and 20 passed to the west and south of Efate and Port Vila suffered from onshore northwest to westerly winds blowing across Mele Bay. For this period, 3 cyclones are worthy of further consideration, each is summarised below, together with a complete documentation in Appendix 3.

Cyclone Amanda, "the Great Vila Cyclone", 29 December 1959. Cyclone Amanda produced north to northwest winds for 12 to 15 hours at gale force and 8 hours at hurricane

force, a lowest pressure of 975 millibars and a daily rainfall of 250.1mm. An extremely good record of the effects of Cyclone Amanda is colour and black and white movie films taken by Mr. Reese Discombe. These films clearly show the effects of up to 10m coastal erosion taking place in the southeast part of Mele Bay; inundation principally by waves of the Vila town waterfront at that time adjacent to Higginson Street; thirdly, the films show the effect on the two coastal headlands of Devil's Point and Pango of sand and coral rock debris washed/blown/thrown inland up to 150m.

Cyclone Ursula, 2-11th December 1971, produced southeasterly winds which blew for 12 hours at gale force, a lowest pressure of 997 millibars, and a daily rainfall of 322.3mm on December 8th. This is the second highest daily rainfall on Vila records and it produced considerable flooding in Vila and of the rivers on Efate, including the loss of bridge across the La Colle River (British Newsletter, 14 December 1971; Appendix 3).

Cyclone Carlotta, 13-20th January 1972, produced north to northwest winds which on the 18th and 19th blew for 34 hours at gale force and for 9 hours on the 18th at hurricane force, a lowest pressure of 982.5 millibars, and a rainfall of 103.1mm. In Vila, sections of the seawall near the Hotel Rossi were destroyed by the highest seas seen in Vila harbour for many years. Once the seawall was breached the reclaimed land behind was considerably eroded (British Newsletters, 25 January and 8 February 1972; Appendix 3).

Very fortunately, the French and R.A.F. aerial surveys of 1971-72 recorded the effects of these cyclones. Careful examination of the 2nd January 1972 and August 1972 air photographs for the Mele beach area clearly show the effects of Cyclone Ursula and Cyclone Carlotta on the coastal environment, particularly adjacent to the three river mouths (see above).

It is clear, therefore, that historical changes in the coastal zone have been caused by either periods of high intensity rainfall or storm surges during periods of strong sustained northwesterly winds associated with a cyclone or a combination of both. It can be concluded that these problems will continue to occur in the future and be associated with either the passage of cyclones to the west and south of Efate, which may or may not be associated with high rainfall, or simply a result of a high intensity rain storm.

(v) Present situation.

The data presented above shows that two severe storm surges and two periods of extreme rainfall intensity have occurred separately during the last 35 years. Hence it is likely that significant damage to the coastal environment of the Vila area due solely to climatic events occurs at least once every 10 years. In the past 10-11 years since Cyclone Carlotta, Efate has not experienced such an event. However, much development in the coastal zone has taken place or is now planned. This development includes: completion of the new wharf; completion of a fuel tank farm in the southeast corner of Vila harbour; initiation of sand mining in central Mele beach area; development in the Vila foreshore between the Hotel Rossi and the old wharf area, in particular this has included the construction of a sheet pile sea wall backed by 5 hectares of reclaimed fill; and light industrial and manufacturing development is proposed in the southeast part of the Mele alluvial plain in the Tagabe River catchment.

In the two sections which follow an attempt is made to predict the magnitude and possible effects of a storm surge and flood similar to those documented above.

Prediction of storm surge magnitude: Prediction of storm surge magnitude in Vila Harbour can be based on the data from Cyclone Carolotta using the method outlined by Frisby and Goldberg (1981). To predict the mean water level due to the storm surge effects associated with a storm similar to Carlotta, it is necessary to calculate the predicted astronomical tide level, the pressure set-up, the wind set-up, and the wave set-up. These effects have been calculated and the results are summarised below and in Figure 11. The datum for reference was high water mark at 1630 hours on 24 May 1983. The predicted astronomical tide is taken to be the highest spring tide level of 1983 which from the tide tables is 0.3m above datum. The pressure set-up based on a minimum pressure recorded during Cyclone Carlotta of 982.5 millibars is estimated at 0.31m. The wind set-up is calculated to be 0.1m. A wave set-up between 0.2 and 0.4m is calculated by estimating that the height of waves at break point was 2m during Cyclone Carlotta (refer illustration of Vila Waterfront in Appendix 3). The predicted storm surge water level is therefore 0.9 to 1.1m above the high water mark datum of 24 May 1983, or within half a metre of the top of the existing sheet pile seawall.

Any enclosed coastal body of water, like Vila Harbour, has a natural mode of oscillation. If a storm surge is superimposed with correct timing and frequency with respect to this natural oscillation a seiche may develop. During a seiche unusually large waves suddenly break at considerable height along the coast.

Likely effects of a storm surge similar to that predicted will be to cause overtopping of the seawall by breaking waves and subsequent scouring and erosion of the fill immediately behind. The storm water outlet pipes will be completely submerged which is likely to result in storm water emerging from the road drains in Higginson Street. If such a storm surge occurs during a period of high rainfall, extensive flooding and scouring of the fill area behind the seawall is likely to occur. Further, if the fill is compacted coral sand and gravel and the head of water in the aquifer rises rapidly, the fill may well liquefy. No data is available on the shear strength of the fill at 2.0m depth, but with zero pore water pressure the shear strength is unlikely to exceed 100kN/m². This strength will be reduced if the water table rises. Substantial damage to the properties in this area may result.

Prediction of flood magnitude: Predictable effects of rainfall with intensity similar to that experienced during Cyclone Ursula are calculated using the maximum rainfall intensity of 100mm in one hour. The antecedent rainfall conditions are very important in determining the effects of such a rainfall intensity. Since this rainfall fell during the rainy season and was associated with a 24-hour extreme intensity figure of 322.2mm, it is assumed that the 100mm which fell in the peak 1 hour period resulted in 100% run-off.

The approximate areas of the three catchments are as follows: Tagabe 29km², La Colle 57km² and Tepukoa 26km². Peak discharge of the three catchments during Cyclone Ursula is therefore estimated at: Tagabe 105.5m³/sec., La Colle 1583.3m³/sec. and Tepukoa 722.2m³/Sec. Plotted on Figure 12A this data is compared with approximate limits of the largest floods experienced in the United States at successive times. Whilst by no means exceptional, these data indicate that during periods of highest intensity rainfall yet recorded in the Vila area, the catchments draining into Mele Bay experience floods comparable to some of the largest experienced in the United States.

Using the cross-profiles in Appendix 1 for the lower Tagabe River, three channel cross-section areas are calculated at 50, 70 and 367m². For the smaller channel area, a discharge of 805.5m³/sec. would generate a flow of 16.1m/sec., at bank full conditions. This data is compared with similar data from the United States in Figure 12B. If the channel was unable to sustain this discharge, then substantial flooding of the adjacent low-lying areas would occur.

This data has implications for the manner in which development takes place for any light industrial or commercial areas in the Tegabe lower catchment area north of Vila and adjacent to the airport. The area should not be developed by initially levelling the terrace-channel topography. The lower areas should be retained and maintained as flood overspill channels. The buildings should be restricted to the higher surfaces.

CONCLUSIONS:

1. This report begins a geological and related studies investigation of the coastline in the Port Vila and Mele Beach areas.
2. Development of the coastal zone in the Port Vila-Mele Bay area is as yet limited but progressing steadily. An awareness of the potential movements in the coastal zone must be encouraged.
3. A large part of south Efate may be a large landslide progressively moving down into the sea. It is important that this model be tested further. *theory*
4. Vila is situated in an earthquake area. Strong earthquake activity has not occurred near Vila in recent times, but there is geological evidence to suggest large earthquakes affect the area with a recurrence interval of no more than 1000 years. Further work on this problem is desirable.
5. There is historical evidence of coastline movement. These movements have been caused by either periods of high intensity rainfall or storm surges during periods of strong sustained northwesterly winds associated with a cyclone.
6. Two severe storm surges associated with cyclones passing west and south of Vila have occurred during the last 35 years.
7. Two periods of extreme rainfall intensity have occurred during the past 35 years.
8. Likely significant damage to the coastal environment of the Vila area due solely to climatic causes occurs at least once every 10 years. This recurrence period is well within the design life of most structures likely to be constructed.
9. In the past 10 to 11 years, Efate has not experienced such an event.
10. Landslides have occurred and will continue to occur in the Port Vila coastal cliff areas, and may be generated either by seismic shaking or periods of intense rainfall.
11. Predictions of (1) storm surge magnitude and (2) flood magnitude have been made, and each indicates that substantial damage will result from a recurrence of these phenomena.

RECOMMENDATIONS:

- (i) CCOP/SOPAC through the Geological Survey of Vanuatu should actively encourage and develop an awareness of the situation as regards the physical changes likely to occur in the coastal zone. Initially, this might include organising a two- to three-day workshop ~~with~~ ^{for} appropriate Government officials as soon as possible. This could be done in conjunction with a similar seminar on likely biological changes associated with pollution.
- (ii) CCOP/SOPAC should assist if requested in appropriate planning and development studies. These might include: a shallow near-shore seismic survey in the Mele Bay-Port Vila harbour area to confirm, or otherwise, the suggestion that south Efate is a large landslide block; further work on large earthquake return periods, this will include sampling for radiocarbon dates and facilities for dating the samples must be arranged before field work commences (this item should be discussed at the 12th Annual Meeting if the dates requested as a result of this report are available); further work in the Vila waterfront area to determine the strength and stability parameters of the reclaimed fill area with respect to fluctuating ground moisture conditions; further work on establishing the reliability of the predicted effects of a storm surge and flooding event.
- (iii) The Vanuatu Government should consider requesting CCOP/SOPAC to be prepared to carry out a survey as soon as possible after the next cyclone similar to either Amanda, Ursula or Carlotta.
- (iv) The Vanuatu Government should consider requesting CCOP/SOPAC to be prepared to carry out a survey as soon as possible after the next earthquake.

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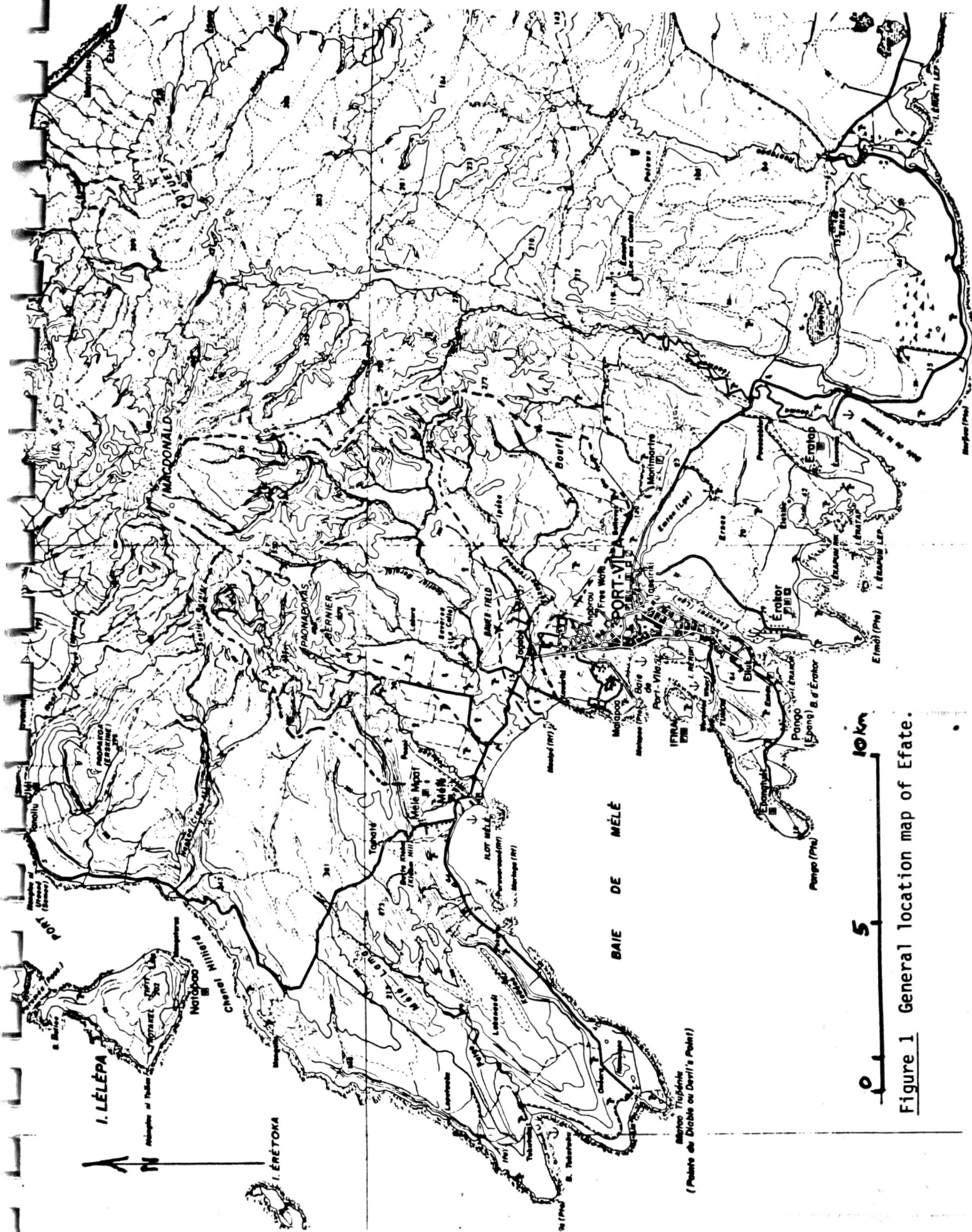


Figure 1 General location map of Efate.

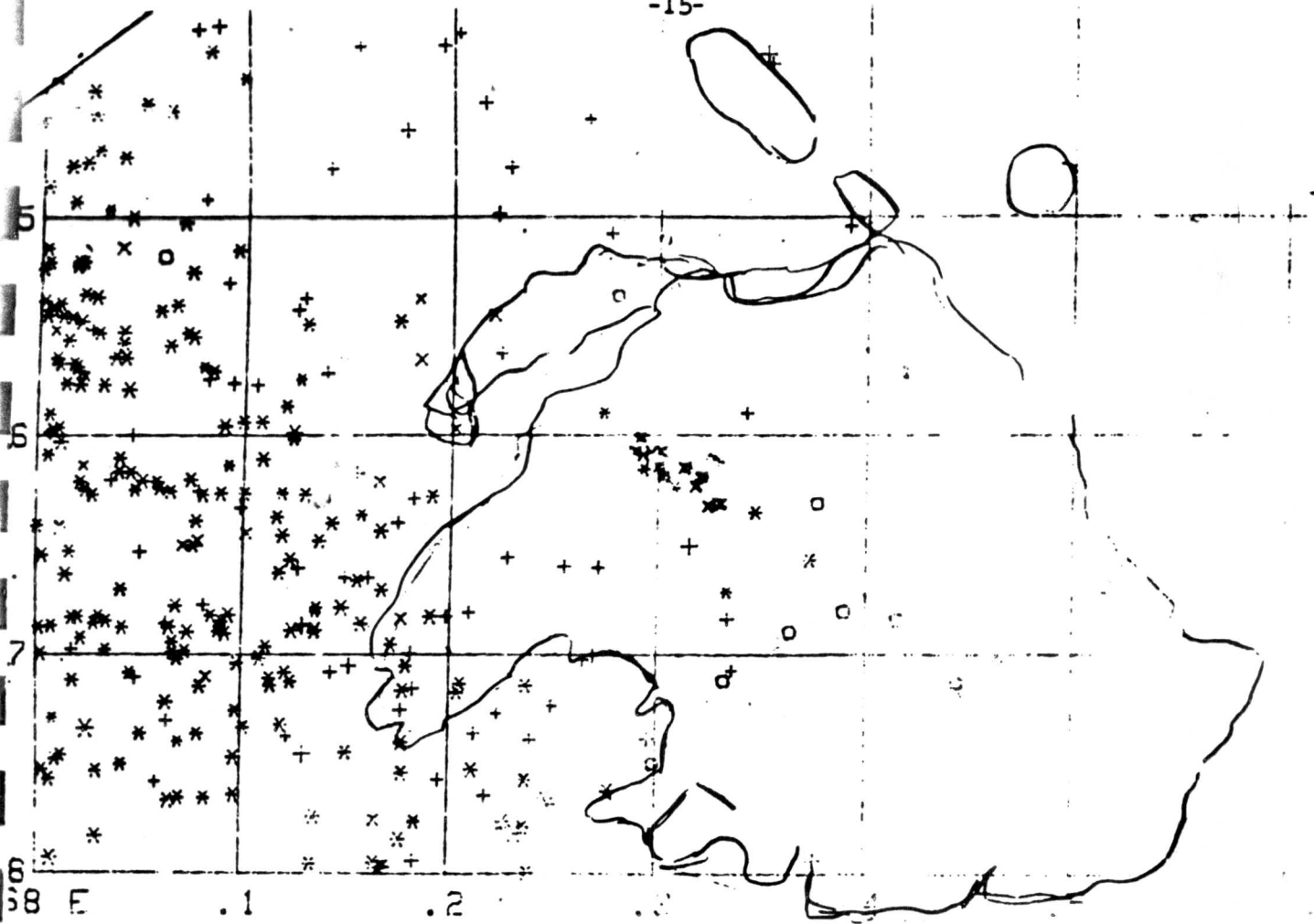


Figure 2 Seismic map of Efate (data since 1955). Focus 0-20km (x); 20-45km (*); 45-80km (+); 80-700km (o).

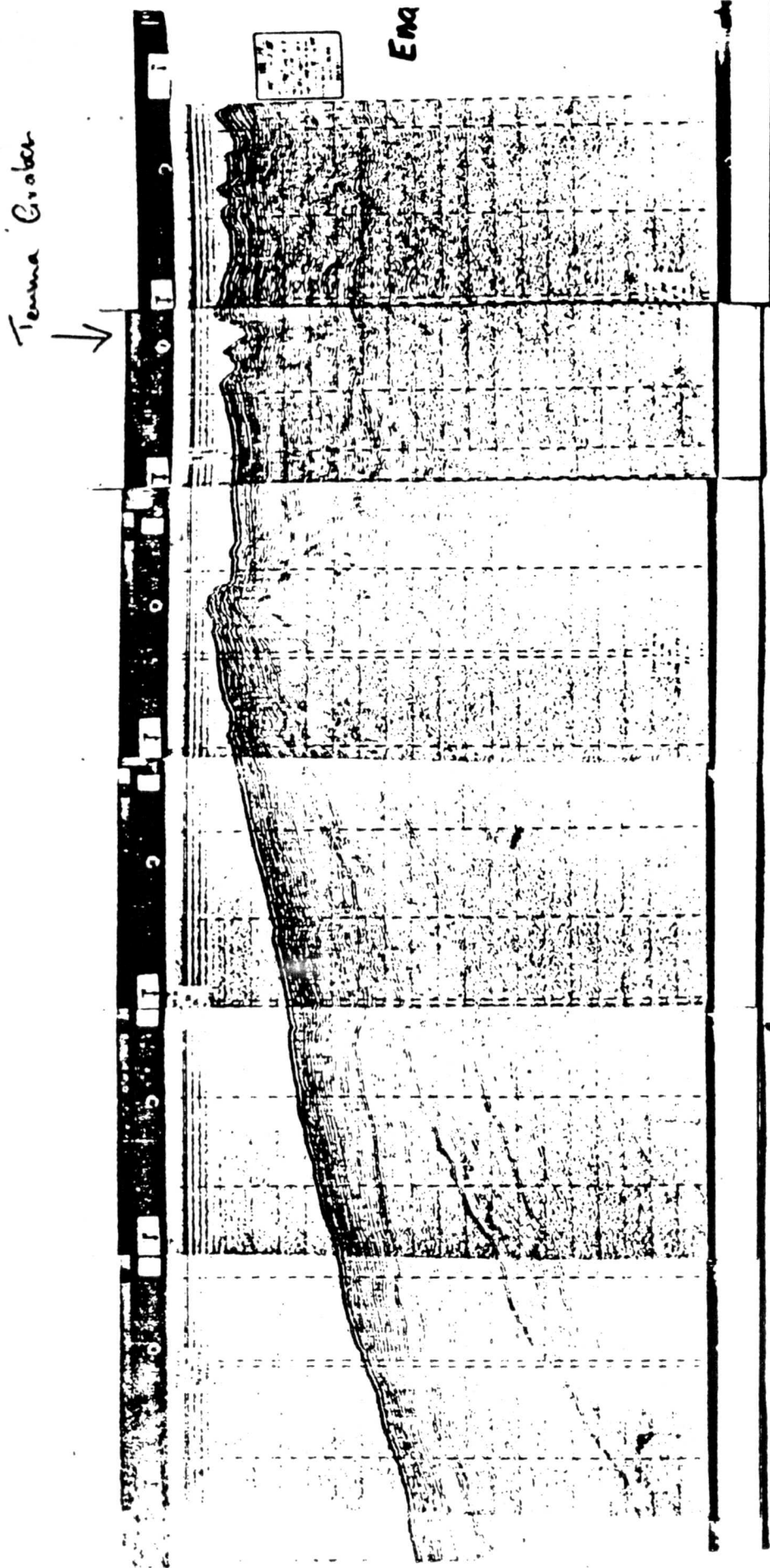
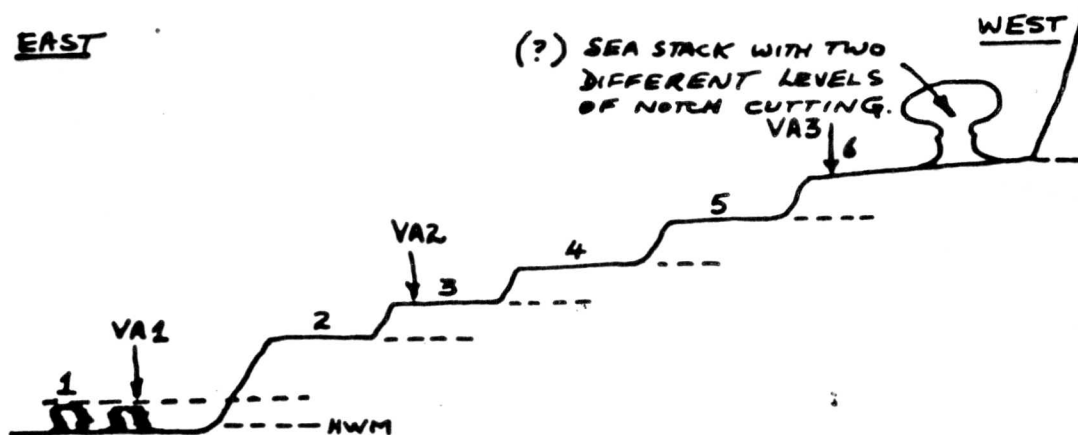


Figure 3 Seismic reflection profile offshore south Efate. Line 34, Leg 2: Suva to Vila, SP Lee Cruise 1982.



VA 1, 2 & 3 - RADIOCARBON SAMPLE POSITIONS

VERTICAL EXAGGERATION APPROX 25x.

SURFACE	HEIGHT ABOVE HWM	TOTAL* UPWFT
6	11.15	12.65
5	8.15	9.65
4	6.25	7.75
3	4.94	6.44
2	3.81	5.31
1	0.77	2.27

Figure 4 Sketch cross-section near Pukura, west Mele Bay, showing relative positions of six Holocene uplifted reef terraces. Note that other uplift events are almost certainly recorded, e.g. in wave notches cut in sea stack on Surface 6. Total uplift allows 1.5m for depth below HWM to living coral; no allowance has been made for changes in sea level during the Holocene; further work should enable a correction for the sea level curve to be made.

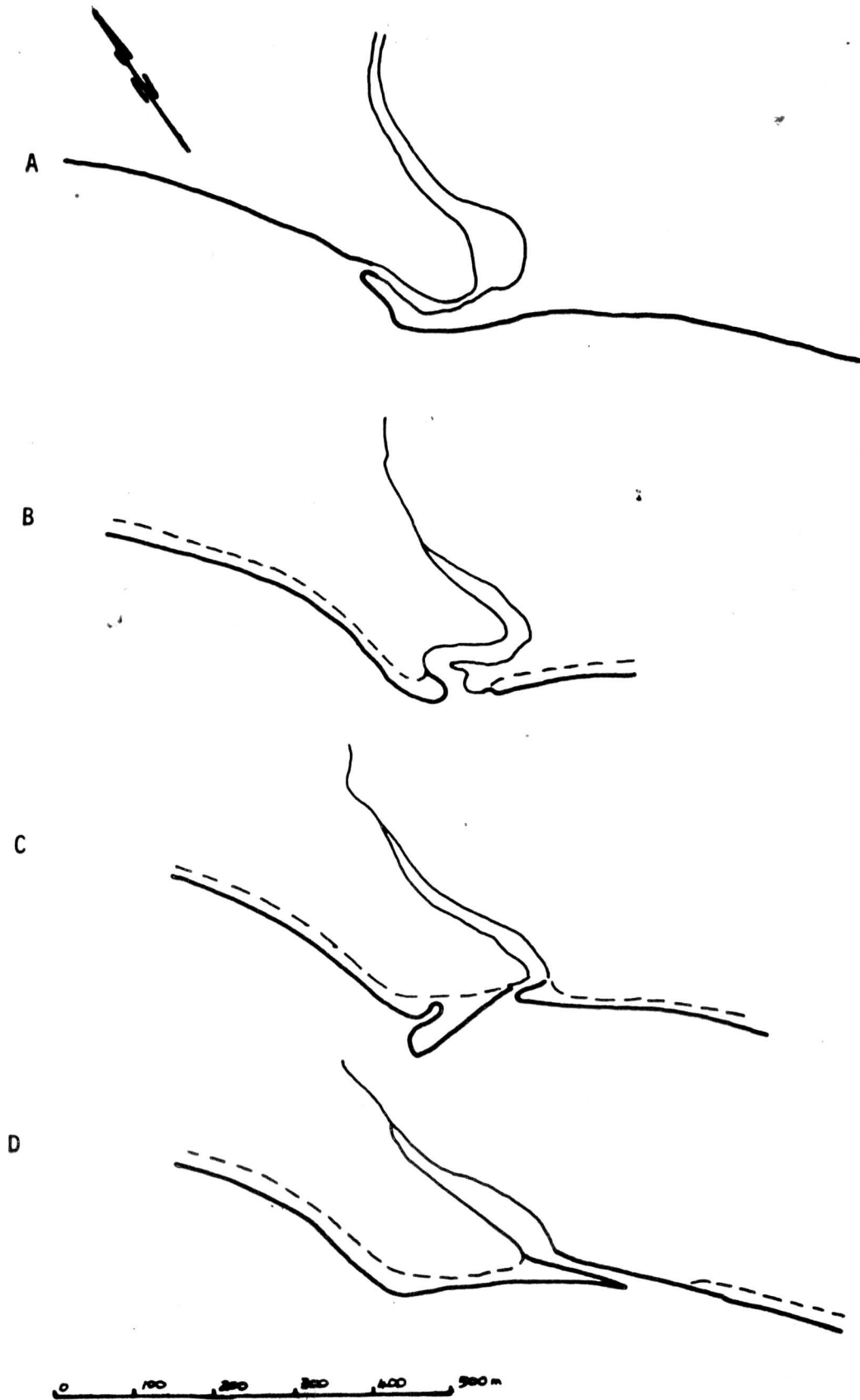


Figure 5 Tagabe River Mouth. A - 1929/1930; B - 1955; C - January 1972; D - August 1972. Where known, vegetation line shown by dashes.

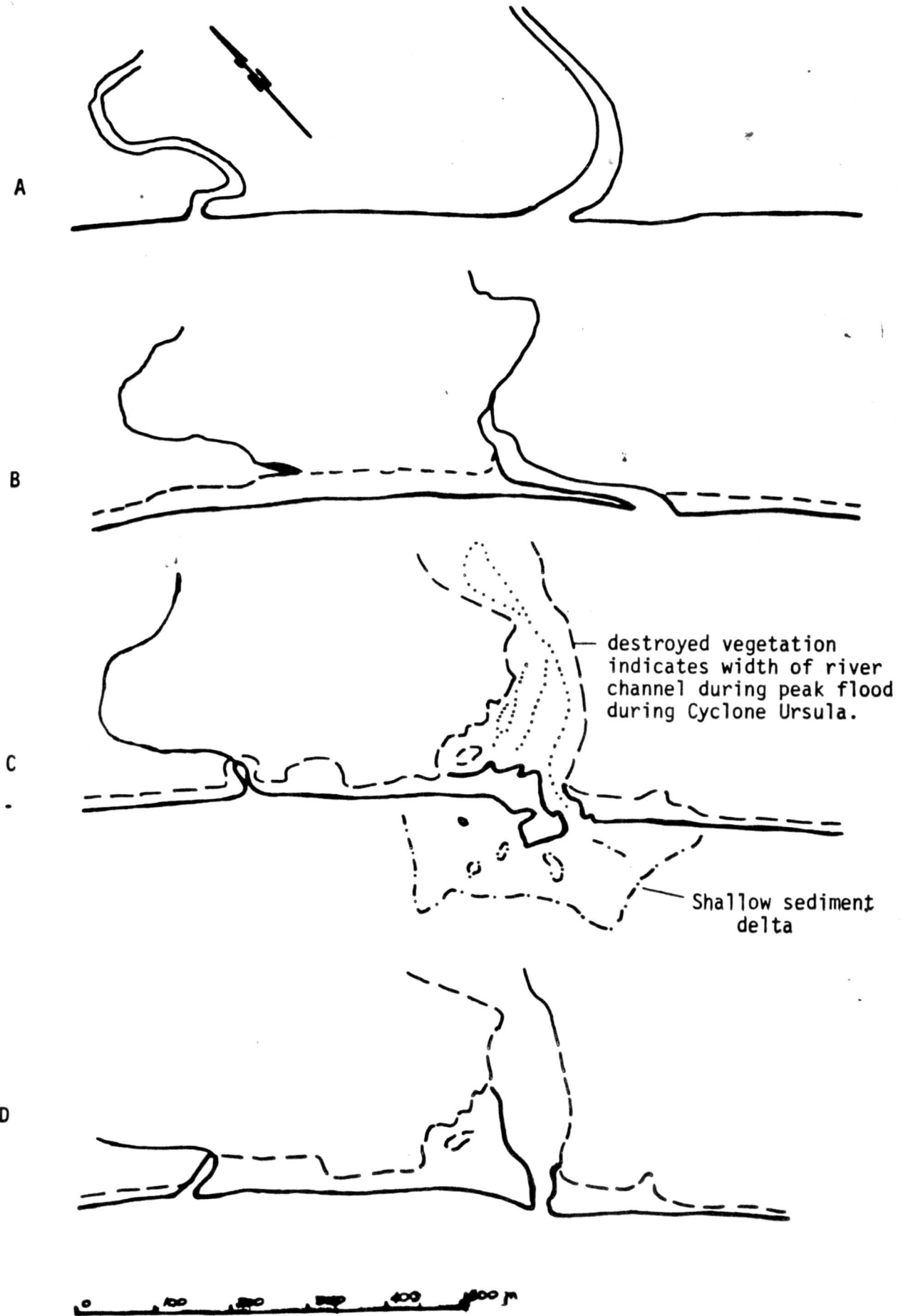


Figure 6 La Colle River Mouth. A - 1929/1930; B - 1955; C - January 1972; D - August 1972. Where known, vegetation line shown by dashes.

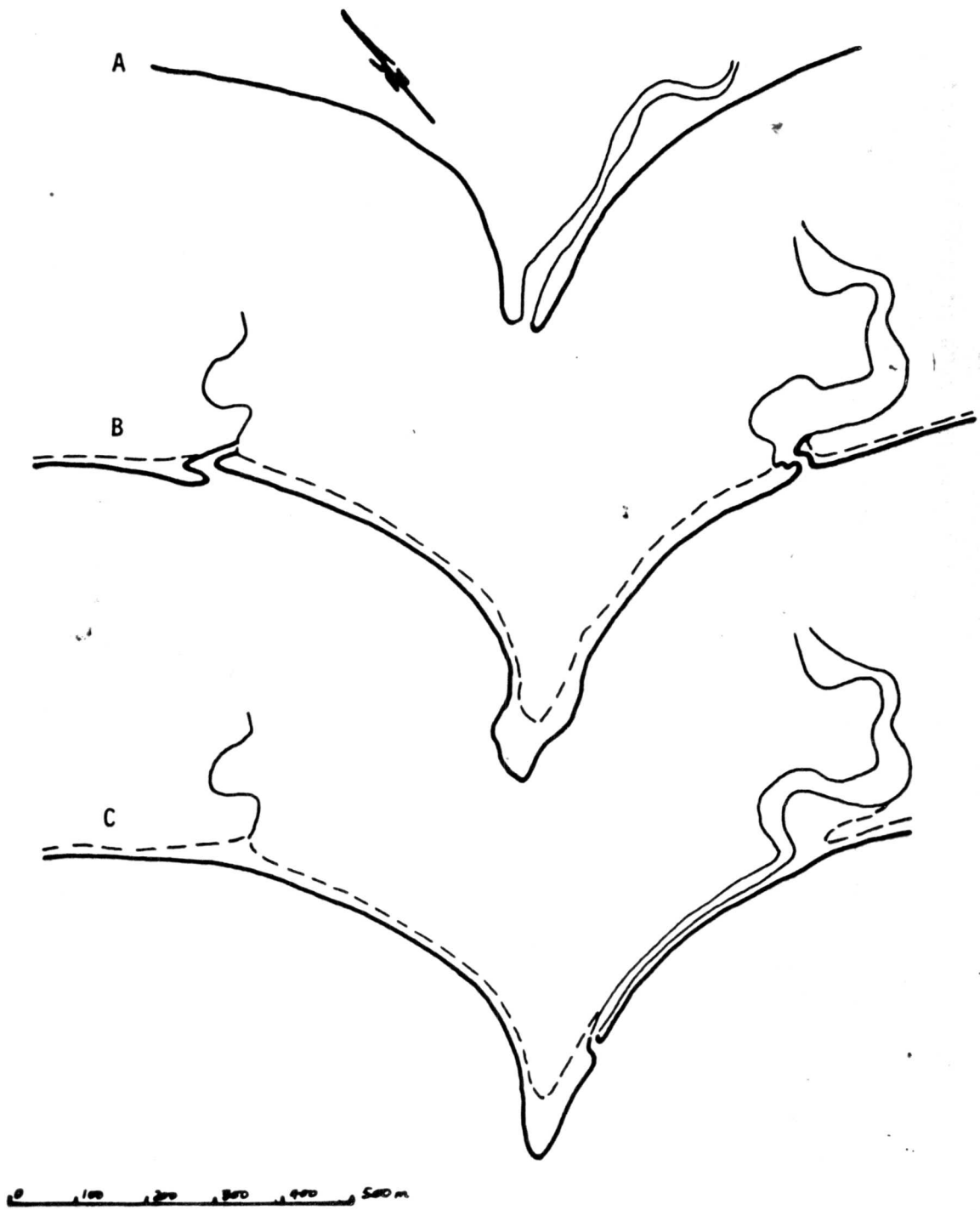


Figure 7 Tepukoa River Mouth and sand spit near Mele Island.
A - 1929/30; B - January 1972; C - August 1972.
Where known, vegetation line shown by dashes.

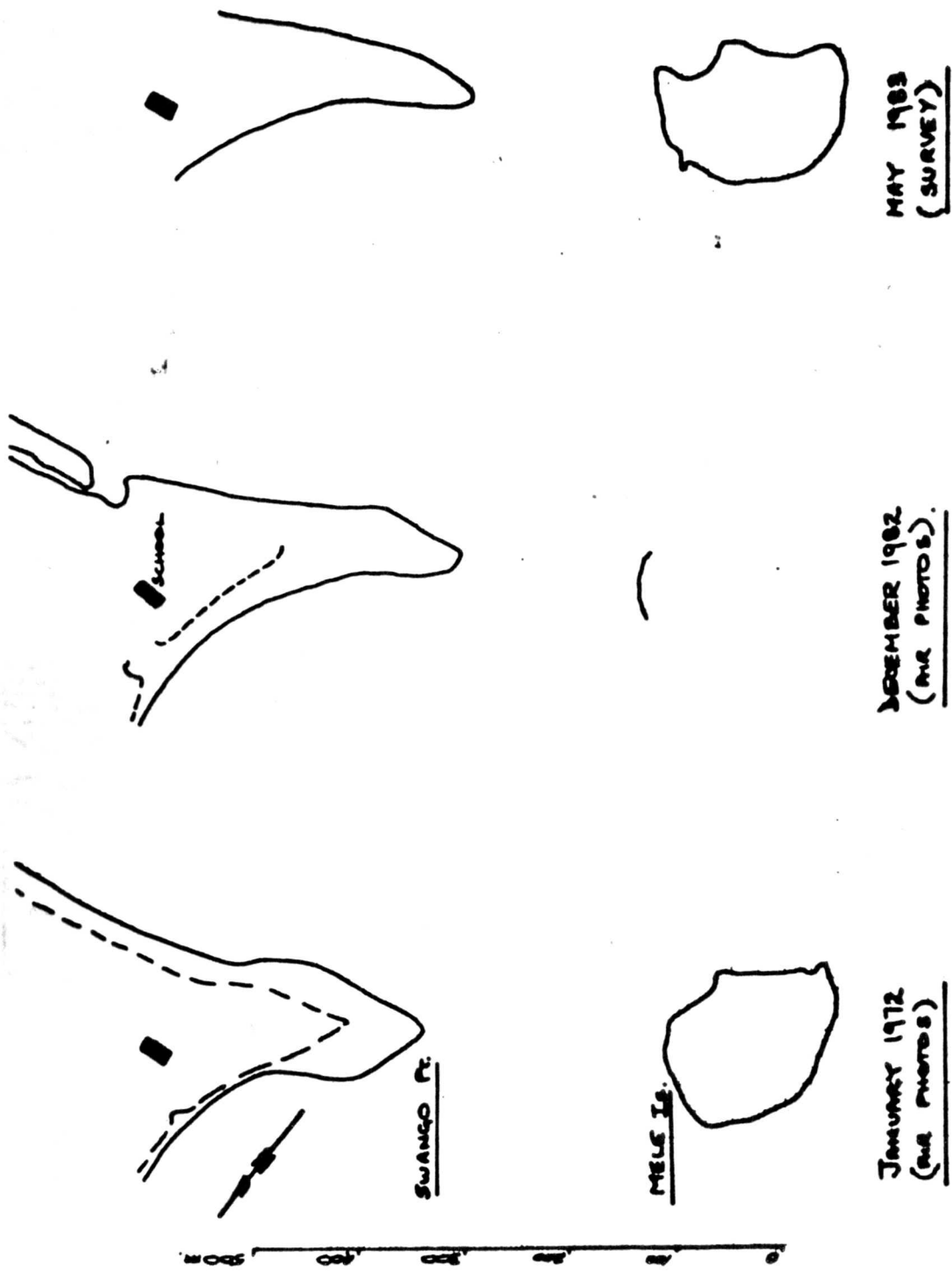


Figure 8 Swango Point and Mele Island, shows how Mele Island as a sand cay does not stay in fixed position; also Swango Point sand spit and the distance between it and Mele Island change.

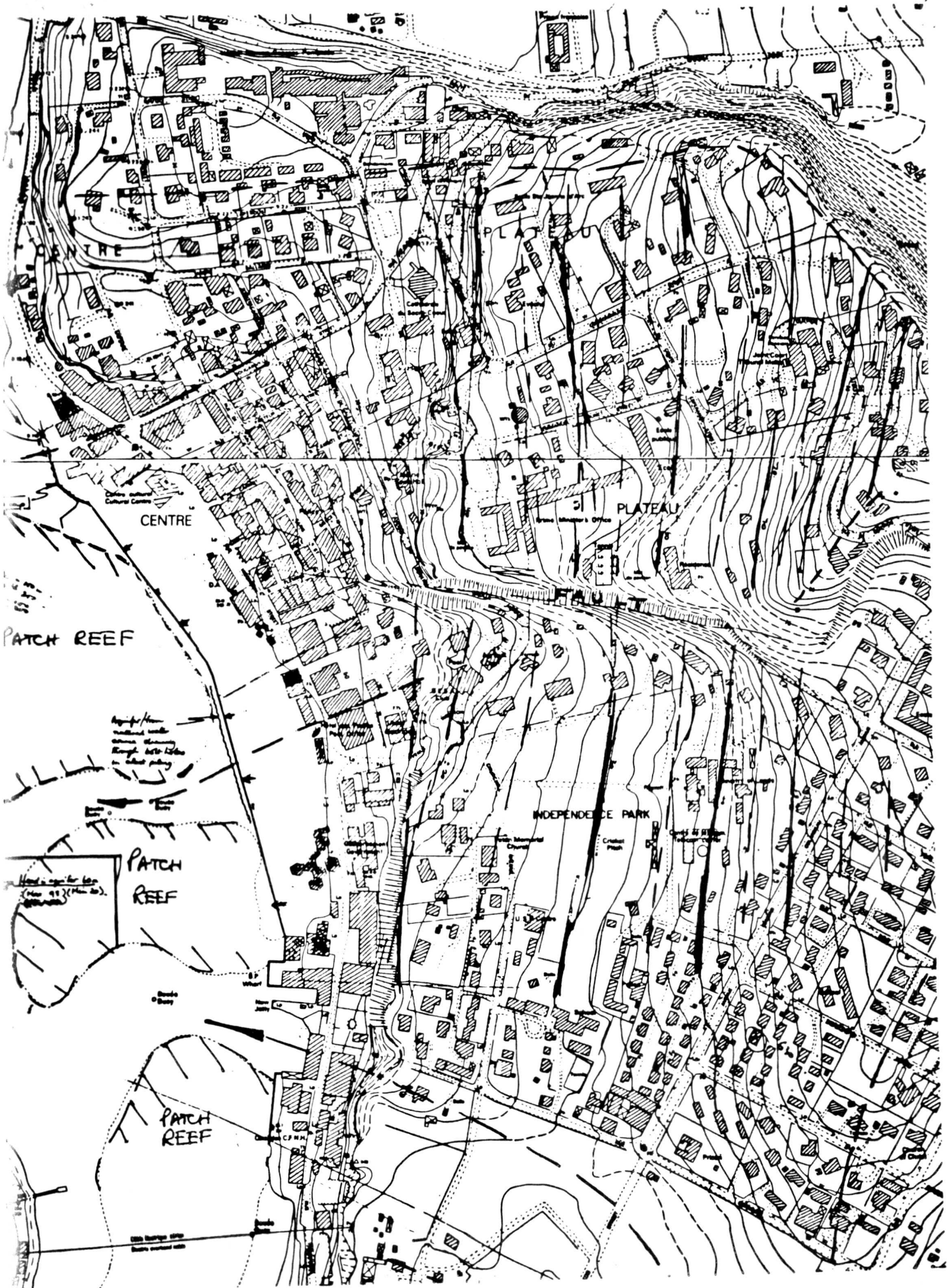


Figure 9 Vila town and foreshore.

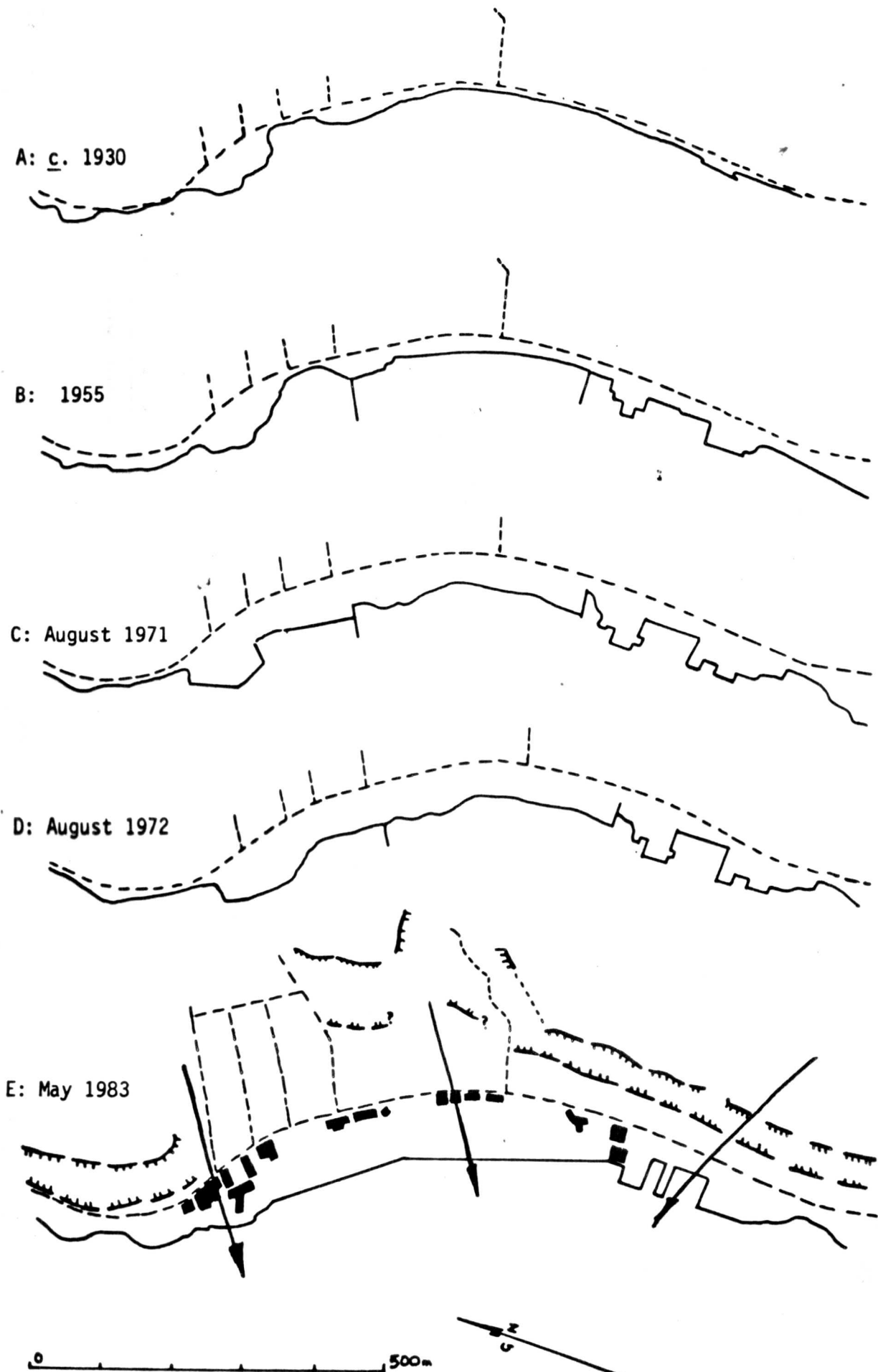
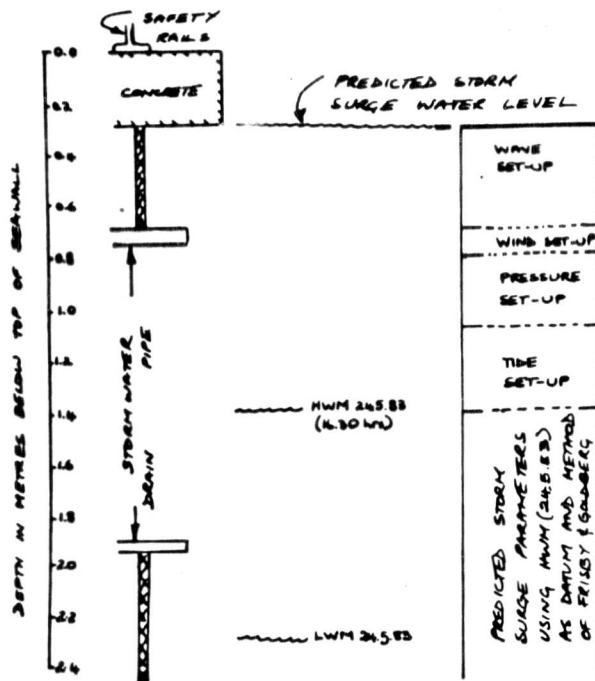


Figure 10 Vila waterfront development from c. 1930 to 1983.



- (i) Tide set-up: calculated from highest spring tide 1983 (see Vila tide tables).
- (ii) Pressure set-up: calculated assuming an average barometric pressure of 1014 millibars, a lowest pressure during Cyclone Carlotta of 982.5 millibars and allowing a 10mm rise in water level for each millibar difference.
- (iii) Wind set-up (h_w): where
$$\frac{h_w}{d_1} = \frac{K u^2 L}{g d_1^2 (1-d_1/d_2)} \log_e (d_1/d_2)$$

d_1 = depth at beginning of significant set-up fetch
 d_2 = depth at coast
 L = significant fetch for wind set-up
 K = a constant with value 3×10^{-6} for oceans
 u = wind speed

Using (i) $d_1 = 200m$, $d_2 = 1m$ and $L = 10km$ $h_w = 0.8 \times 10^{-4} u^2$

(ii) $d_2 = 100m$, $d_2 = 0.1m$ and $L = 3km$ $h_w = 0.6 \times 10^{-4} u^2$

Values approximate 0.1m for the wind set-up if a wind speed of 70 knots (36m/sec) is assumed. (Note winds blew for 8 hours in excess of 63 knots).

- (iv) Wave set-up: for a typical situation wave set-up (h_b) is given by $0.1 H_{br} \leq h_b \leq 0.2 H_{br}$ where H_{br} is the height of wave at break point. Given that H_{br} is estimated at 2.0m, h_b is between 0.2 and 0.4m.

Figure 11 Calculation of predicted storm surge water level at the Vila waterfront seawall.

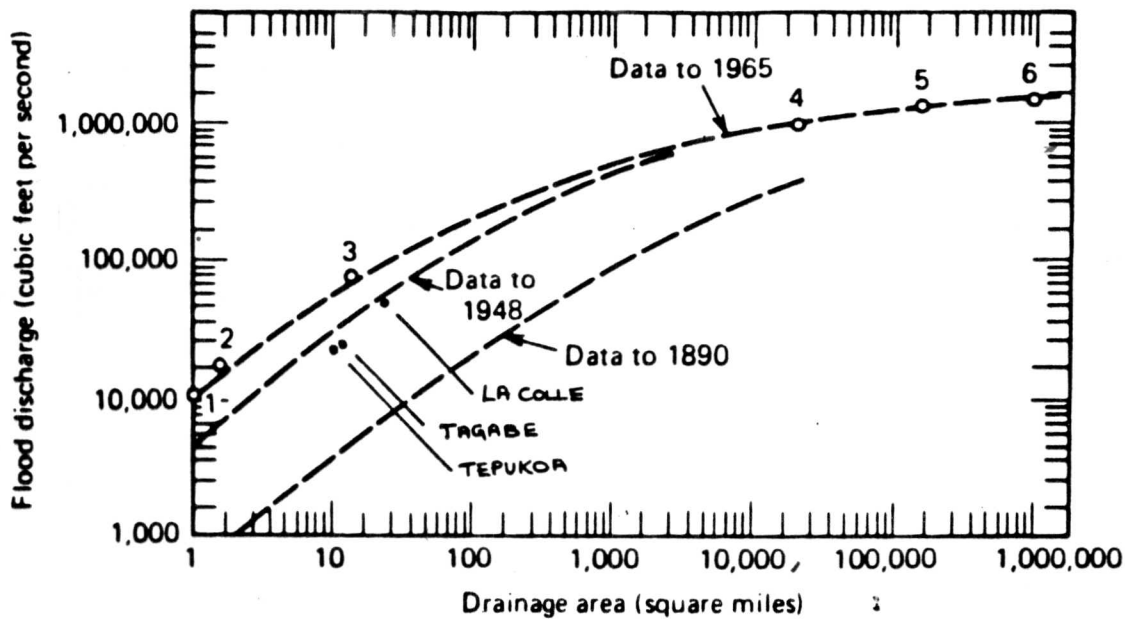


Figure 12A Curves showing the approximate limits of the largest floods experienced in the United States at successive times. The flattening of the curves at larger drainage areas indicates that the peak discharges per unit of drainage area are smaller as the size of the drainage basin increases. With the passage of time the limit or envelope curves have moved up as larger floods have occurred. Numbered points are selected peak discharges that have occurred since 1965. 1 = Humbolt River tributary near Rye Patch, Nevada, 1973. 2 = Big Thompson River tributary near Drake, Colorado, 1976. 3 = Bronco Creek, near Wikieup, Arizona, 1971. 4 = Susquehanna River, Conowingo, Maryland, 1972. 5 = Ohio River, Metropolis, Illinois, 1937. 6 = Mississippi River, New Madrid, Missouri, 1937. (modified from Fig. 12.3, Costa and Baker, 1982).

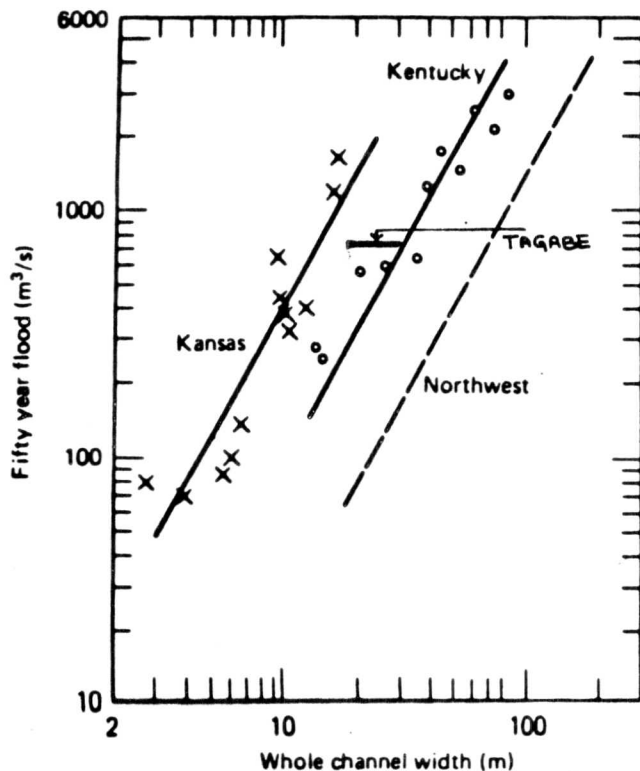
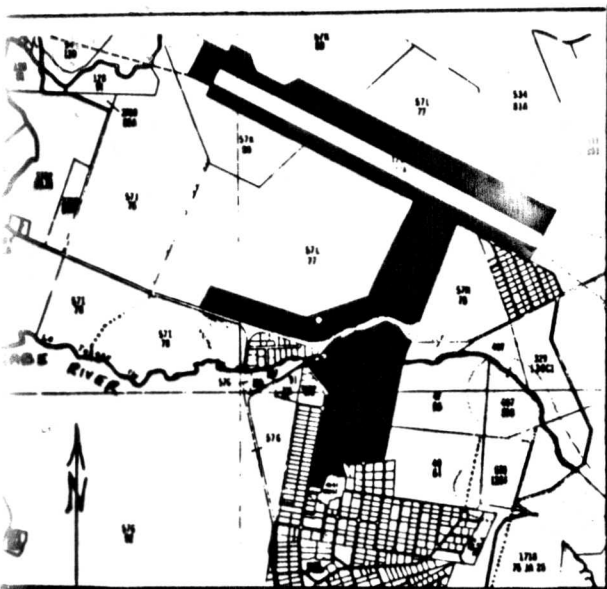


Figure 12B Curves showing 50-year flood discharge versus channel width for rivers in various parts of the United States (modified from Fig. 12.27, Costa and Baker, 1981).

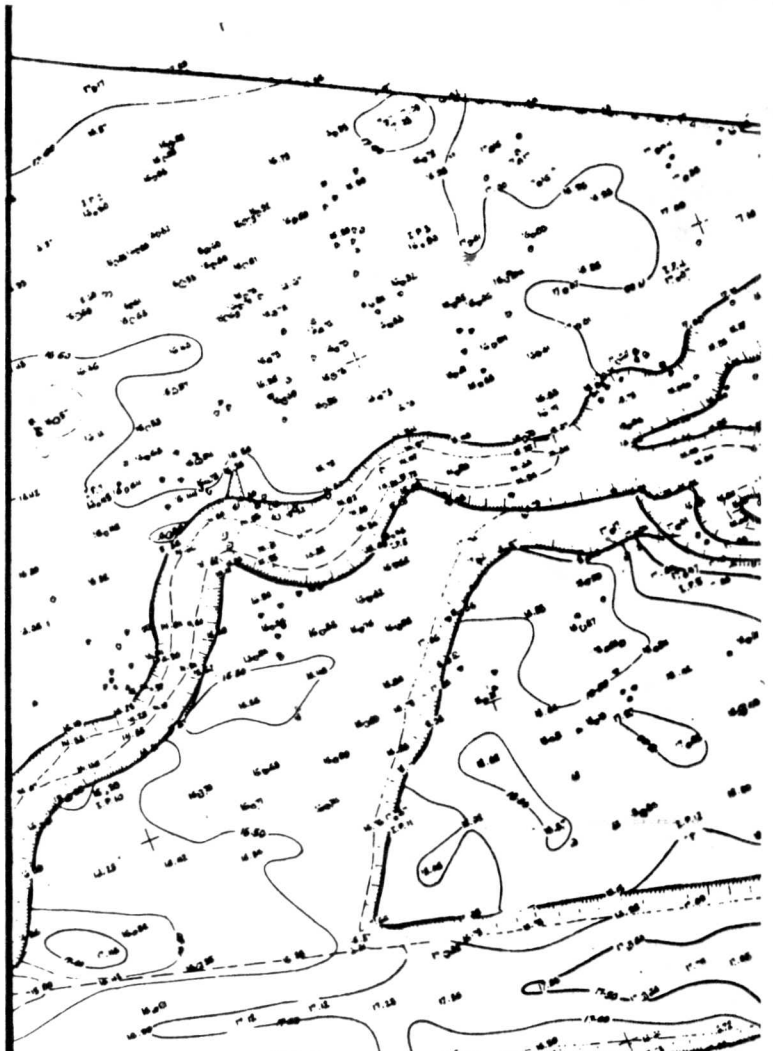
APPENDIX 1

- (i) Levelling plan of proposed site for industry on north bank of Tagabe River.
- (ii) 3 cross-sections of Tagabe river channel.

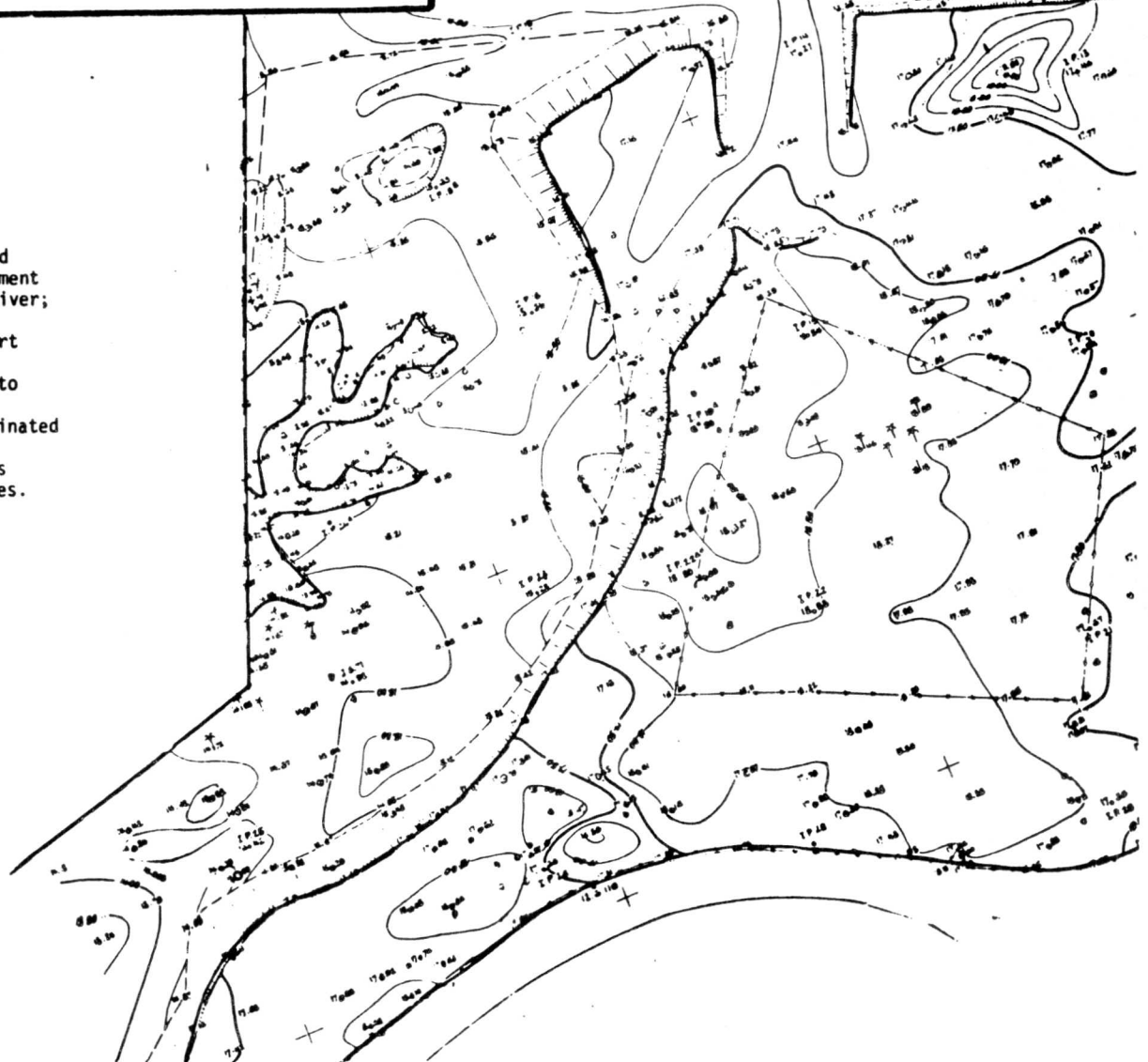


Inset:

Part of proposed land use zoning map of Vila; areas shown in black are for industry, and shaded areas are for housing.



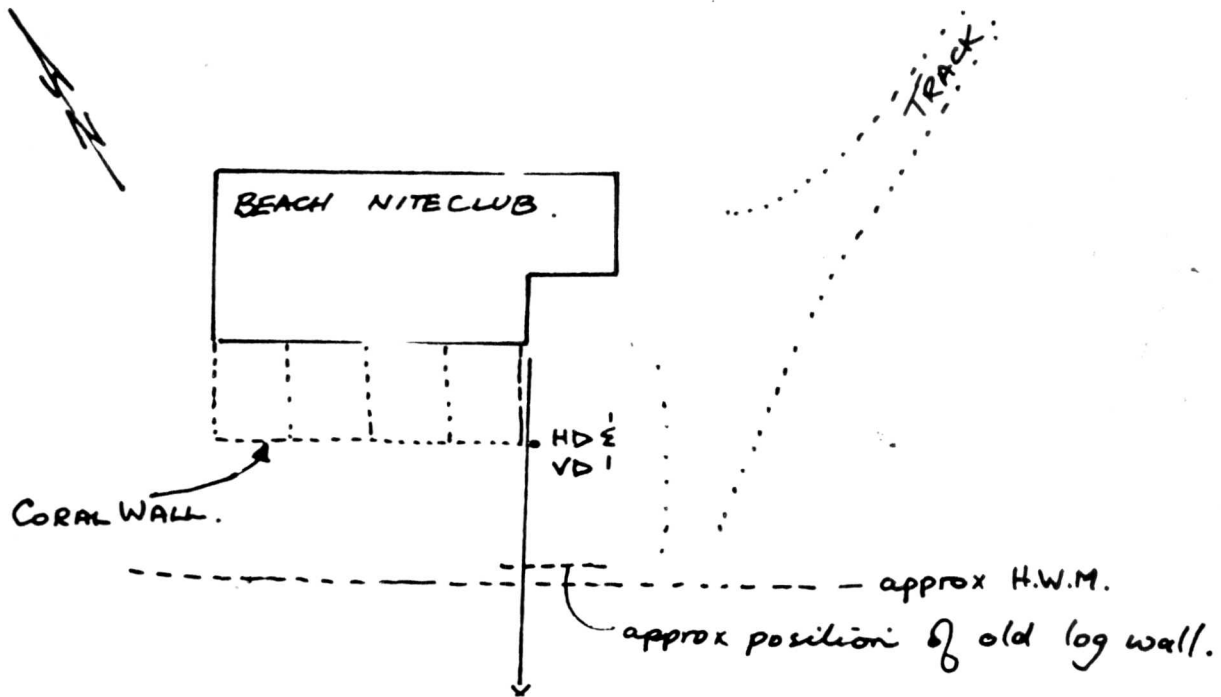
Leveling plan of proposed site for industry development on north bank of Tagabe River; south of airport and immediately west of airport road (see inset). The topography which appears to be very flat or gently undulating is in fact dominated by well-developed shallow channels and terrace edges with a relief of 2-3 metres.



APPENDIX 2

Beach profiles, Mele Beach.

MELE BEACH Beach Profile No. 1

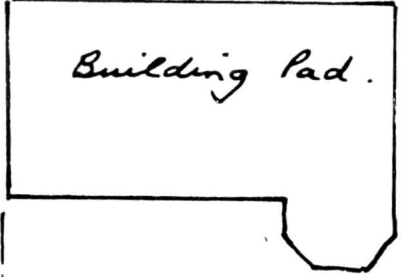


"BLACK SANDS BEACH." SE end MELE BEACH

Horizontal Datum: } At S. corner of coral rock wall; on ground
 Vertical Datum : }

Horiz. FE	Vert. M.	Horiz.	Vert.	Horiz.	Vert.
0	0.32	60	2.82		
5	0.36	65	3.09		
10	0.40	70	3.36		
15	0.44	75	3.44		
20	0.55	80	3.64		
25	0.70	85	3.86		
30	1.10	90	4.11		
35	2.00	95	4.24		
40	2.26	100	4.57		
45	2.40	105	4.65		
50	2.56	110	4.85		
55	2.64				

MELE BEACH Beach Profile No. 2



HD
VD

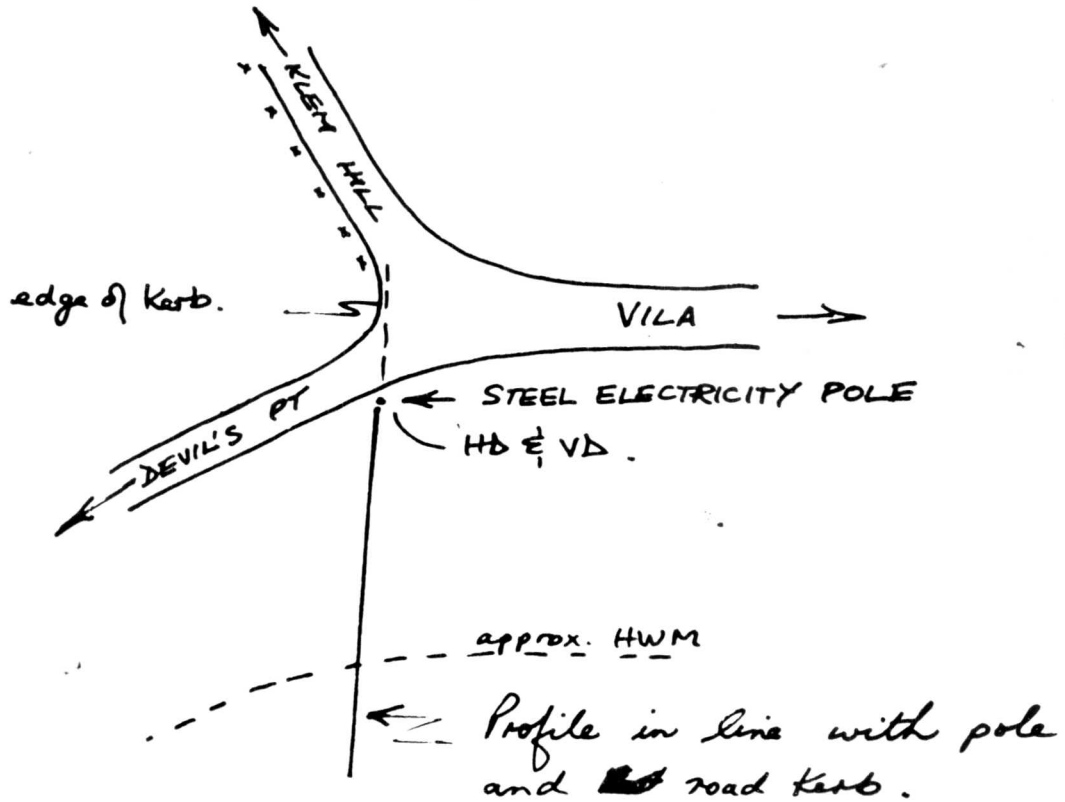
Barbed fence
approx HWM

CENTRE MELE BEACH \approx 100m E OF SAND MINING.

Horizontal Datum: } SW corner on ground of concrete pad
Vertical Datum : } to old building

Horiz. FT	Vert. M	Horiz.	Vert.	Horiz.	Vert.
0	1.31	60	1.30	120	2.77
5	1.25	65	1.29	125	2.72
10	1.25	70	1.35	130	2.68
15	1.20	75	1.40	135	2.80
20	1.16	80	1.50	140	3.00
25	1.02	85	1.60	145	3.24
30	0.94	90	1.66	150	3.41
35	0.90	95	1.75	155	3.69
40	0.98	100	1.84	160	3.95
45	1.12	105	2.07	165	4.24
50	1.23	110	2.36	170	4.50
55	1.26	115	2.56	175	4.77

MELE BEACH Beach Profile No. 3



Horizontal Datum: } In
 Vertical Datum : } At base of electricity pole

Horiz. FE	Vert. m.	Horiz.	Vert.	Horiz.	Vert.
0	2.35	60	1.70	120	2.98
5	2.43	65	1.48	125	3.15
10	2.45	70	1.36	130	3.27
15	2.48	75	1.50	135	3.43
20	2.40	80	1.72	140	3.80
25	2.08	85	2.11	145	4.16
30	2.10	90	2.32	150	4.44
35	2.08	95	2.34	155	4.75
40	2.10	100	2.30	160	4.95
45	1.92	105	2.32		
50	1.83	110	2.48		
55	1.77	115	2.70		

APPENDIX 3

Meteorological data and cyclone reports.

- (i) Monthly total rainfall.
- (ii) Highest daily (24 hour) rainfall.
- (iii) Cyclone Amanda.
- (iv) Cyclone Ursula.
- (v) Cyclone Carlotta.

BUREAU OF METEOROLOGY
 TABULATION OF MONTHLY DATA

F. 5
 (May 1978)

MENT MONTHLY TOTAL RAINFALL, STATION PORT VILA, (EFATE.)
 LAT: 17° 45'S LONG: 168° 18'E
 STATE OF _____ ALT: 20m

C.D.O. 9456

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1948	484.6	128.0	311.2	181.6	192.0	179.1	27.7	166.9	75.2	67.6	336.0	180.9	2330.7
1949	459.5	58.7	387.9	507.5	138.9	359.2	168.4	90.7	64.0	86.4	67.3	219.5	2608.0
1950	261.6	202.9	707.9	160.5	184.4	55.1	120.7	156.2	145.5	26.7	297.2	3307.3	2626.0
1951	109.0	542.5	293.6	152.9	132.1	111.3	40.6	57.2	51.8	36.8	419.1	597.9	2544.8
1952	179.6	132.6	219.7	212.3	161.6	260.4	369.8	52.8	56.9	107.4	28.7	225.6	2007.3
1953	215.1	201.2	498.9	292.9	171.2	175.3	228.6	116.8	105.7	71.1	24.9	95.5	2197.2
1954	209.3	296.9	88.1	228.3	262.4	273.6	128.8	55.6	190.8	57.9	122.7	294.6	2209.0
1955	75.2	211.1	465.6	111.3	111.5	183.4	246.4	42.9	193.5	45.0	303.5	273.8	2263.2
1956	401.3	232.7	558.5	236.0	137.2	73.7	179.1	63.5	290.6	123.4	148.8	157.2	2602.0
1957	290.3	236.2	368.3	79.5	163.1	98.6	26.2	110.2	83.8	139.4	18.5	83.8	1698.0
1958	318.0	250.7	214.6	285.0	95.0	35.3	32.3	8.9	58.9	49.3	102.6	4.8	1455.4
1959	168.7	235.7	233.2	405.6	95.8	117.6	149.1	225.3	74.7	74.7	240.8	403.9	2425.1
1960	275.8	213.4	523.7	145.5	149.9	149.1	57.7	55.1	146.3	144.8	32.5	51.1	1944.9
1961	632.0	214.4	493.8	173.5	274.6	103.6	98.3	220.5	336.6	129.5	511.8	156.2	3344.7
1962	393.2	359.9	440.7	471.2	125.2	127.0	176.8	92.7	57.9	79.8	120.7	277.9	2722.9
1963	587.0	218.4	248.2	365.5	186.2	84.8	142.2	190.0	43.4	57.2	57.7	58.2	2238.8
1964	54.4	133.4	550.9	230.9	167.1	210.8	5.6	108.0	104.9	131.8	272.5	138.2	2108.5
1965	399.3	238.8	273.3	126.7	168.4	89.4	100.6	110.7	74.2	224.3	102.1	392.4	2300.2
1966	445.5	269.2	363.0	139.2	100.6	72.9	28.2	35.3	12.4	49.3	115.3	192.8	1823.7
1967	332.7	263.1	281.5	133.6	167.1	283.7	184.9	163.6	129.0	187.7	185.7	171.5	2584.2
1968	256.0	798.3	343.7	150.6	49.3	258.3	127.3	31.8	21.1	19.8	81.3	267.0	2404.4
1969	305.3	166.4	321.1	113.3	63.0	20.3	198.4	204.0	30.5	20.8	123.7	35.6	1602.4
1970	151.9	418.6	114.8	164.6	77.0	152.4	37.8	72.1	49.0	263.1	341.4	175.3	2018.0
1971	266.2	232.4	387.1	381.5	63.2	423.8	517.4	192.0	169.9	164.3	175.3	566.4	3544.6
1972	373.9	486.4	272.0	365.8	189.7	198.6	10.0	29.8	213.7	43.3	185.4	325.0	2694.8
1973	66.5	172.9	307.1	121.4	286.6	63.4	224.1	102.9	106.1	162.7	137.6	133.3	1884.6
1974	359.5	312.0	394.4	59.6	188.5	265.7	99.1	76.8	104.6	565.8	226.1	214.3	2816.4
1975	221.3	245.7	541.3	340.9	460.5	190.1	52.2	112.6	169.8	129.9	307.8	251.8	3023.9
1976	561.7	263.8	233.4	493.8	92.5	213.7	152.0	155.0	126.6	146.3	64.9	71.1	2574.8
1977	483.1	257.4	771.4	114.6	53.8	83.9	56.4	262.4	27.4	15.5	186.4	86.9	2399.2
Average 48/77	311.3	307.9	376.9	231.5	155.3	161.0	132.9	112.1	110.5	114.5	177.9	213.7	2366.6
Best 48/77	632.0	798.3	771.4	507.5	460.5	428.8	517.4	262.4	336.6	565.8	511.8	597.9	3544.6
Year	1961	1968	1977	1949	1975	1971	1971	1977	1961	1974	1961	1951	1971
Best 48/77	54.4	58.7	88.1	59.6	49.3	20.3	5.6	8.9	12.4	15.5	18.5	4.8	1455.4
Year	1964	1949	1954	1974	1968	1960	1964	1959	1966	1977	1957	1959	1959

TABULATION OF MONTHLY DATA

EMENT HIGHEST DAILY RAINFALL FOR 24Hrs. (DATE.) STATION PORT VILA. (EFA TE.)
 LAT: 17° 45' N LONG: 168° 18' E
 STATE OF _____ ALT: 20. m

C.D.O. 9495

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1948	92.2 ²⁶	23.1 ¹⁸	79.2 ¹³	50.5 ²⁴	102.9 ²⁷	47.8 ⁶	10.9 ¹⁶	77.2 ²⁵	41.7 ²¹	21.1 ¹²	85.9 ¹³	40.1 ¹³	102.9 ^{27/5}
1949	100.1 ¹⁶	21.6 ²⁷	66.8 ⁷	85.3 ¹⁷	47.2 ¹⁵	171.7 ²⁴	35.8 ¹⁴	65.5 ⁴	18.3 ³	29.7 ¹⁵	29.0 ²⁷	102.1 ⁹	171.7 ^{24/6}
1950	46.5 ²⁵	43.7 ⁹	337.1 ²⁵	33.5 ¹⁴	52.1 ²	15.0 ²⁵	25.9 ³¹	32.8 ³¹	48.3 ¹³	5.6 ³⁰	108.9 ²⁶	59.4 ²⁶	337.1 ^{23/8}
1951	46.0 ¹⁴	134.1 ²⁶	64.0 ¹	34.5 ¹³	30.2 ⁶	52.3 ⁷	7.1 ¹	22.1 ¹²	27.9 ²⁸	17.5 ¹³	157.2 ²	250.1 ²⁵	259.1 ^{25/12}
1952	58.4 ¹	38.4 ¹⁸	54.9 ²¹	83.8 ¹⁹	35.0 ²⁸	120.7 ¹¹	100.0 ¹²	26.7 ⁸	20.6 ¹⁴	24.1 ¹⁵	6.9 ²¹	43.7 ²⁵	158.0 ^{12/7}
1953	51.8 ¹⁹	43.2 ⁴	142.0 ³⁰	148.1 ⁹	52.1 ²⁶	64.8 ³	128.3 ¹³	90.7 ¹⁸	41.9 ¹⁷	21.1 ¹³	12.4 ¹¹	44.5 ²⁷	148.1 ^{9/4}
1954	54.4 ²⁶	95.3 ¹⁶	28.9 ¹¹	100.3 ²⁵	132.8 ²⁸	74.9 ²¹	27.7 ²⁹	15.2 ¹⁹	75.9 ²⁴	28.2 ³¹	38.6 ¹³	137.4 ²⁹	137.4 ^{29/2}
1955	16.3 ²⁵	51.8 ¹⁶	62.7 ³	32.5 ²⁹	48.8 ²⁹	120.4 ¹⁴	204.2 ⁵	16.0 ⁶	40.1 ¹⁶	15.7 ²⁴	96.3 ²³	48.8 ⁶	204.2 ^{6/7}
1956	62.7 ²⁵	56.4 ⁴	118.9 ³⁰	40.4 ¹	35.8 ²²	15.0 ²²	89.7 ¹⁵	26.2 ⁵	176.5 ¹⁸	65.5 ²⁴	43.9 ¹⁰	54.6 ²⁶	176.5 ^{18/9}
1957	29.0 ⁷	45.2 ²⁸	44.5 ⁶	29.0 ²⁸	87.4 ⁵	33.5 ⁸	5.1 ¹⁹	51.5 ³⁰	25.4 ³	44.7 ³	5.3 ⁵	32.3 ¹⁴	87.4 ^{5/5}
1958	90.2 ²⁹	133.4 ²⁷	50.3 ⁹	50.0 ⁷	36.6 ¹⁰	13.5 ¹	18.8 ²	4.1 ²⁰	22.1 ¹⁰	17.8 ¹⁵	22.9 ²⁵	1.5 ¹⁹	133.4 ^{27/2}
1959	33.3 ¹⁸	76.2 ²⁵	57.2 ¹²	96.8 ¹⁵	24.1 ³⁰	33.5 ³	27.7 ¹³	58.7 ¹³	36.1 ¹⁰	11.7 ¹⁵	120.1 ⁴	147.8 ²⁹	147.8 ^{20/2}
1960	112.1	82.2	122.0	32.2	102.2	22.1	27.2	22.2	22.2	22.2	22.2	22.2	121.2
1960	170.9 ²	66.0 ¹	117.1 ⁶	42.7 ¹⁵	71.4 ²⁸	45.0 ⁷	12.4 ⁷	10.4 ⁹	40.1 ²²	49.5 ³	6.9 ⁸	20.3 ²⁷	170.9 ^{2/1}
1961	113.5 ¹⁰	62.2 ¹⁶	158.0 ¹⁵	36.6 ⁴	108.6 ¹⁵	36.1 ¹⁷	37.8 ¹⁴	53.6 ¹⁹	63.2 ²⁰	35.3 ³¹	191.3 ²⁴	58.4 ¹⁹	191.3 ^{24/11}
1962	68.1 ²⁷	66.8 ²	132.8 ¹	246.6 ¹⁶	58.2 ⁹⁰	36.6 ⁷	30.5 ¹³	26.9 ⁷	15.5 ¹¹	24.4 ⁷	63.8 ⁹	89.4 ¹¹	246.6 ^{16/4}
1963	90.9 ³¹	37.3 ²⁸	44.2 ⁹	71.4 ²⁵	39.6 ⁸	30.5 ²⁶	59.4 ¹¹	78.5 ²¹	15.0 ¹⁰	20.1 ⁵	19.8 ¹⁸	22.4 ¹	90.9 ^{31/1}
1964	14.0 ³¹	44.5 ¹⁸	156.5 ³¹	58.2 ¹	42.4 ¹⁹	60.2 ⁸	1.8 ⁷	53.6 ³⁰	49.8 ¹⁰	20.1 ⁵	87.6 ¹⁷	42.9 ²⁰	156.5 ^{31/3}
1965	102.1 ¹⁵	91.2 ¹⁸	69.1 ¹⁹	31.2 ¹⁷	69.3 ²⁸	55.1 ²⁷	47.2 ¹⁰	25.7 ²⁹	18.5 ²	63.5 ³⁰	36.6 ²⁷	95.0 ²⁰	102.1 ^{15/1}
1966	77.7 ¹⁹	138.7 ²⁷	78.2 ¹⁰	25.1 ⁵	64.3 ²	20.3 ¹²	8.4 ¹⁴	16.3 ²⁸	4.8 ²⁵	15.0 ¹⁴	42.4 ²⁹	35.6 ¹⁵	138.7 ^{27/2}
1967	62.2 ²⁶	38.1 ⁶	93.2 ²⁹	47.5 ²⁰	51.6 ¹⁰	99.3 ²⁸	129.5 ²⁸	49.3 ²¹	30.0 ¹⁶	46.7 ¹⁰	100.1 ²⁶	81.5 ²⁵	129.5 ^{28/7}
1968	69.8 ²³	246.9 ²⁰	61.5 ³⁰	79.0 ²³	15.7 ³⁰	173.0 ¹⁰	47.8 ²³	15.0 ⁸	8.4 ¹⁴	5.1 ⁶	43.2 ²	214.6 ¹³	246.9 ^{20/2}
1969	102.9 ³⁰	40.4 ¹²	68.6 ¹⁵	39.4 ²⁴	21.6 ¹	7.1 ²³	32.5 ²	124.7 ¹	13.0 ¹³	8.4 ³	31.8 ²⁴	19.1 ³⁷	124.7 ^{4/5}
1970	40.6 ²⁷	88.6 ⁹	40.9 ¹⁵	75.4 ²¹	16.0 ¹⁵	75.2 ²³	20.8 ⁹	25.1 ²⁰	8.6 ¹⁰	71.4 ¹²	121.9 ²⁷	50.3 ⁴	121.9 ^{27/11}
1971	45.2 ²	95.3 ⁸	91.4 ³⁰	112.5 ¹	30.0 ¹⁵	131.6 ¹⁶	180.1 ³	99.3 ⁵	35.6 ¹²	44.2 ⁶	60.5 ⁴	322.3 ¹³	322.3 ^{3/2}
1972	103.1 ¹⁸	175.5 ⁴	63.0 ¹¹	81.0 ¹⁶	32.0 ⁴	65.0 ²³	2.0 ³	9.7 ³⁰	101.3 ¹¹	14.5 ²⁵	42.7 ²⁷	68.6 ¹⁰	175.5 ^{4/2}
1973	23.4 ²¹	35.0 ²⁴	111.9 ⁷	51.5 ¹⁸	97.8 ²¹	21.6 ²³	84.6 ⁹	42.8 ²⁰	83.5 ²⁵	58.1 ⁸	35.6 ¹⁶	68.4 ³⁰	111.9 ^{3/3}
1974	68.2 ¹⁷	98.4 ²	79.8 ¹⁴	15.7 ²⁵	38.2 ⁸	72.4 ¹	38.0 ⁸	50.2 ¹⁹	27.2 ²⁰	171.7 ²⁸	60.2 ¹⁶	75.5 ⁷	171.7 ^{23/10}
1975	110.7 ¹⁶	45.8 ²²	168.7 ⁵	106.4 ¹⁶	158.3 ²⁸	82.7 ⁷	15.3 ⁶	44.3 ²⁵	46.0 ²¹	31.9 ⁶	92.0 ²³	52.6 ⁶	168.7 ^{5/3}
1976	86.8 ¹⁶	68.8 ⁷	56.7 ¹⁹	107.6 ²	17.2 ³	46.5 ⁵	33.7 ⁶	41.6 ¹⁵	55.4 ¹⁸	58.1 ²⁹	21.2 ¹²	26.7 ²³	107.6 ^{2/4}
1977	174.1 ²⁰	74.8 ¹¹	218.5 ¹³	47.2 ²	20.2 ¹	15.2 ⁷	11.0 ¹¹	112.5 ¹	15.7 ¹⁶	4.1 ²	101.1 ²⁵	27.4 ²⁷	174.1 ^{24/1}
													218.5
High 48/77	174.1	246.9	337.1	246.6	158.3	173.0	204.2	124.7	176.5	171.7	191.3	322.3	337.1
Date	20/77	20/68	23/50	16/62	28/75	10/68	6/55	1/69	18/56	28/74	24/61	8/71	23/3/50

Here are some facts and figures from the hurricane 28th-29th December.

Lowest pressure 975 mbs. M.S.L. 2.20am 29th.
Pressure fluctuated bet. 975.4 mbs ~~xxxxxxx~~ to 981 mbs from 1.30am
29th to 4.30am 29th.
Wind speed estimated during this period of 75 to 85 knots with gusts of
at least 100 knots.
Wind was above hurricane from about 10pm. 28th to about 6am. 29th.
And above gale force for approx 12-15 hours.
Of course considerable damage was suffered to buildings and along the
waterfront.
From the fact that the wind did not shift a great deal from the
North west to west quarter, I assume the track of the cyclone was North
east from the last position you gave me at 20 s. 165e., to a spot some 10
to 20 miles, maybe more maybe less, south of Vila, and then back on
its original course of southeast. From the reports of both Tanna and ~~and~~
Anietyum it passed to the south east of both those Islands.

At first I thought a secondary must have formed in the stream to the west
of Vila on the Monday afternoon, but I believe both yours and Noumea's
view was that the original centre was the one that hit us here. It must
have really moved at a pace if your last position report was correct.

By the way I would be also grateful if you could spare me about 12 forms
M.Z. Met 701, I use them to plot the ~~anal~~ on under a piece of plastic.
I lost all but one form during the big blow.

Yours faithfully,

J.F. Loughton.

New Hebrides - Anglo-French Condominium
Report for the years 1959-1960 Hmsc London 1961

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New Hebrides Condominium. 1959 and 1960

Recommendations of the conference included the establishment by the
British Administration, in partnership with the voluntary agencies,
of a Central Teachers' Training College and the appointment of a
British Education Advisory Committee. Land for the College was
purchased at Malapoa near Vila in 1960 and plans drawn up for
construction in 1961 and opening in 1962. The Advisory Committee
held its first meeting in November, 1960, when agreement was
made on a common educational syllabus for British education.

In 1959, 19 grants were made to 14 schools conducted by the
voluntary agencies. In 1960, 22 grants were approved. The grants
are for the construction of buildings, purchase of books and
materials, and publications.

Four scholarships were awarded in 1960 to New Hebridean boys
to attend King George VI Secondary School in the British Solomon
Islands Protectorate, and two scholarships were awarded to New
Hebridean students for Nasinu Training College, Suva, Fiji. Two
scholarships were also awarded to New Hebridean girls for Queen
Victoria Maori Girls' school in New Zealand. One New Hebridean
teacher continued to receive further training in Australia under the
Commonwealth Awards Scheme.

GENERAL

Two natural disasters occurred in 1959 and 1960. The more serious
was the hurricane that struck Vila and islands in the southern half
of the New Hebrides on the night of 28th-29th December, 1959.
The wind at times exceeded 100 knots in gusts and blew with great
force for several hours. The southern part of Efate suffered most,
especially Vila and nearby villages and plantations. Many buildings
were completely wrecked and many more seriously damaged. The
combined effect of wind and sea severely battered wharves in Vila
harbour and swept away houses in the native villages on the two
small islands of Makura and Mataso in the Shepherd Group, north
of Efate. Fortunately, and surprisingly, in view of the collapse of
so many buildings and the inundation of some villages by the sea,
there was no loss of life and only one or two minor injuries were
inflicted. No shipping was lost at sea and only one small vessel was
damaged beyond repair. The population rose to the occasion and
quickly set about the task of repairing damaged buildings, clearing
blocked roads and restoring public services with spirit and energy.
The Joint Administration organised emergency food supplies for
the worst-hit villages. Coconut groves were badly damaged by the
wind and, apart from trees up-rooted (which represented as much
as 10 per cent. of the total in some places), immature nuts and palm

General Review

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fronds were blown down, reducing 1960 copra production by at
least half in the affected areas. Production is not expected to recover
until the second half of 1961.

Six months after the hurricane, on 10th July, 1960, the volcano
on Lopevi, a small island rising steeply 4,000 feet out of the sea
a few miles north of Epi in the central New Hebrides, erupted with
a violent explosion of the plinian type after being dormant since
1939. A *nuee ardente* consisting of very hot gases and volcanic
fragments in suspension immediately surged out of the explosion
craters and down the north-western slope of the mountain, depositing
hot ash and scoria in its path. This phenomenon lasted until the
following day and was still visible when observers flew over the
volcano at 10 a.m. on the 11th. Once again there was fortunately
no loss of life or serious casualty amongst the island's 218 inhabi-
tants, although the *nuee ardente* passed between two small villages
on the western side of the island, missing one of them by a hundred
yards. Had the *nuee ardente* enveloped the village it is doubtful if
anyone in it would have survived, as it carbonised trees near the
craters and stripped all vegetation in the area it traversed. A further
hazard was constituted by lava bombs projected at short intervals
some distance from vents in several crater zones. The following day
several small vessels began to remove the population and the opera-
tion was practically completed on the 12th.

The eruption of Lopevi was of great scientific interest because of
the variety of types of activity: plinian initial explosion, *nuee ardente*,
strombolian emission of bombs, volcanian ash-showers, and silent
Hawaiian lava flow. A detailed study of these phenomena was made
by the Senior Geologist and a visiting French volcanologist. Lava
continued to flow from one vent for six weeks, and in all at least
ten vents or craters were formed, several of which emitted lava
during the first week. The volcano now seems to have become
dormant once more.

The British High Commissioner toured the New Hebrides twice
in each year, visiting islands in all parts of the group with the
exception of the Banks and Torres. In June, 1959, he was accom-
panied by the Secretary of State's Legal Adviser and in October,
1960, by the Parliamentary Under-Secretary of State and the head
of the Pacific and Indian Ocean Department of the Colonial Office.
The High Commissioner and the Resident Commissioner attended the
20th and 21st Sessions of the South Pacific Commission in
Noumea as members of the United Kingdom delegation, and took
advantage of the opportunity on each occasion to discuss New
Hebrides affairs with the French High Commissioner. Other visitors

Depression Tropicale " URSULA " - 2 au 11 Decembre 1971 -

Formation , le 2 , a environ 250 Miles au NNE de Vanikoro . Deplacement vers SW en direction de San Cristobal jusqu'au 6 , puis vers S et SE .

1) POINT DE TRAVERSEE DE L'ARCHIPEL : Sud MALEKULA le 9 vers 0230 loc.

Sud EPI le 9 vers 0500 loc .(8/ 1800 TU) . Pression au centre estimee a 985 mb.

2) PRESSIONS : Minimum enregistre a SOLA : 1002,0 mb le 9 a 0430
" " " SANTO : 998,4 mb le 9 a 0200
" " " LAMAP : 989,0 le 9 a 0230
" " " VILA : 997,0 le 9 a 0415
" " " TANNA : 1000,0 le 9 a 1630
" " " ANATOM : 1001,0 le le 9 a 1630

3) VENTS : Maximum observe a SOLA : 360/30 kt le 8 a 0800

" enregistre a SANTO : 030/36 kt le 8 a 1400
270/36 kt le 9 a 0200

Rafales > 33 kt de NE a N le 8 de 1300 a 1800
d'W le 9 de 0000 a 0400 .

Maximum observe a LAMAP : 090/45 kt le 8 a 1600
360/50 kt le 9 a 0200

Rafales > 33 kt , d'E a N , de 1400 le 8 a 0400 le 9 .

(rotation a N a 2000 le 8 , rotation a S vers 0300 le 9 .

Maximum enregistre a VILA : 130/50 kt le 9 a 0720

Vent de SE > 33 kt le 9 de 0045 a 1250 .

Maximum observe a TANNA : 150/18 kt le 9 a 1700 .

" " " ANATOM : 100/34 kt le 9 a 1100

Rafales > 30 kt de 0900 a 1700 le 9 .

4) PLUIES : Fortes a SOLA entre 2300 le 7 et 0800 le 8 : 83 mm

" a SANTO entre 0800 et 1700 le 8 : 162 mm

" 0800 et 1100 le 8 : 114 mm .

" A VILA de 1700 le 8 a 0615 le 9 : 311 mm

Maximum d'intensite de 2330 a 0130 : 154 mm en 2H .

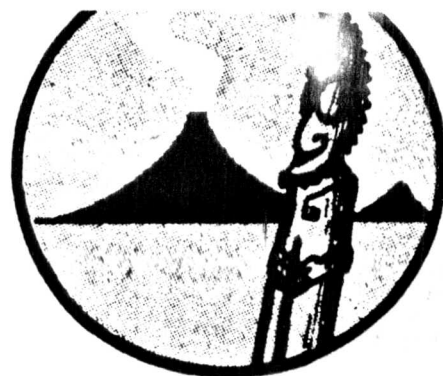
Pas de pluies importantes enregistrees dans les autres stations .

5) LEGATS : Crue violente des rivieres sur Efate : ponts emportes .
Cultures vivrieres devastees . Inondations a Santo .

Heures locales

A. Griesemann

BRITISH NEWSLETTER



ISSUED BY THE BRITISH RESIDENCY INFORMATION OFFICE - VILA, NEW HEBRIDES

14th December, 1971.

EARLY CYCLONE.

Marking in no uncertain fashion the start of the season (see Page 6), cyclone "Ursula" passed through the centre of the Group during the night 8th/9th December. The cyclone was of slight to moderate intensity and only light damage was caused by winds. However, it brought heavy rainfall which caused considerable flooding and some damage.

Vila recorded 12.7 inches and Santo 6.7 inches of rain in the 24 hours ending at 8.00 a.m. on the 9th, and both towns were affected by flooding. An important road bridge over the river Colle just outside Vila was washed away by storm waters, cutting the road to north Efate. A temporary bridge has been built using girders obtained from Dew & Co. and timber from Société Agathis. Near Santo the Renée River bridge, already badly damaged in the October earthquake, somehow stayed in place.

One injury has been reported as a result of the cyclone, a man on Tongoa having sustained a broken leg, but it is not known how the accident occurred.

Several households in Vila were washed out by floods while in Santo the Hotel Corsica earned the gratitude - and admiration - of guests by serving a hot meal within an hour of having its kitchens flooded knee deep.

The centre of the cyclone passed through the Shepherd Group, north of Efate, on an ESE path. Wind speeds within 50 miles of the centre were estimated at 70 knots. In Vila the maximum was 55 knots.

Vila's rainfall was the highest recorded for 21 years.

(The attention of readers is drawn to the information about cyclones prepared by the Meteorological Department and published on Page 6 of this issue.)
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BRITISH NEWSLETTER



ISSUED BY THE BRITISH RESIDENCY INFORMATION OFFICE - VILA, NEW HEBRIDES

25th January, 1972.

CYCLONE "CARLOTTA" - SOUTHERN ISLANDS BADLY HIT.

Cyclone "Carlotta" - "the mad cyclone" as it was called by Radio Noumea - caused serious damage to islands in the southern part of the Group when it made its assault on 18th/19th January. On Efate and its offshore islands many village houses were destroyed and village food gardens ruined while islands further south seem to have suffered even more severely. On Tanna the District Agents reported "devastation", with some villages almost entirely razed to the ground and gardens and forest destroyed, while many buildings in permanent materials, including the District Agents' houses and administrative buildings, were left roofless and seriously damaged. At the time this Newsletter is being prepared, little news has been received from Erromango, Aniwa or Futuna.

In Vila some buildings lost roofs and there was much minor damage but no large buildings were lost. Sections of sea wall near the District Agencies and the Rossi Hotel were smashed by the highest seas seen in Vila Bay for many years; electricity to many parts of the town was cut off and radio communications aeriels were brought down, leaving almost no communication with other islands or the outside world the following day. However, hard work by the Radio Department soon restored the latter.

Coconut plantations were badly damaged and, though the number of trees brought down was fairly small, it is estimated that some 60% of the young nuts were blown off trees.

It is expected that there will be a food problem in some areas for several months to come. Already some villages in north Efate have received essential food supplies and the Joint Administration is now considering the best way to help people during the hard times ahead. (More about "Carlotta" on Page 2).

CLONE "CARLOTTA"

This was the same cyclone that had caused serious damage in the central Solomon Islands, particularly Guadalcanal and the Russels, on 11th/12th January. After leaving the Solomons it hesitated for a day or two in the Coral Sea before moving south down a track about 100 kms west of the New Hebrides on 14th January. Half way down the archipelago it turned away west, having given no more than strong winds and some rain in northern parts of the Group, and left the population relieved but still suspicious.

The suspicions were more than justified when during 16th/17th January "Carlotta" reversed its track and approached on a latitude between Efate and Erromango travelling due east. On Efate really strong winds began to blow during the morning of 18th and intensified to hurricane force during the afternoon and night.

Having approached nearly to Erromango, the cyclone curved south until it was travelling almost exactly parallel with the line of the southern part of the Group but about 40 kms to the west. The result was to give sustained hurricane winds from the west lasting in southern islands until early the follow-

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ing morning.

"Carlotta" appears to have been the most intense cyclone to have affected the New Hebrides since 1959 when the "Great Cyclone" laid waste the town of Vila.

Mercy errand.

A dramatic voyage was made during the height of the cyclone by the British Marine vessel "Keo". A child on Fila island had had a leg broken by a falling door and there was no doctor available. With great courage Boatswain Ernest, Captain of the "Keo", volunteered to attempt to take a doctor from Paton Memorial Hospital on Iririki island to Fila island. The distance between the two small islands is only half a mile but in a hurricane with a raging sea it was no voyage for a 30-foot launch. In the event the trip was successful and Dr. Makau Kalsakau was successfully landed but it was a very considerable relief to onlookers when "Keo" reappeared out of the storm and successfully took up moorings once again.

The child was transferred to Paton Memorial Hospital the following day and is making a good recovery.

"Islander" damaged.

One of Air Melanesia's Britten-Norman "Islander" aircraft was seriously damaged when the hangar doors at Bauerfield blew in. Chief Pilot Captain Ted Shaw says it will be several weeks before the aircraft will be back in commission.

Making good the damage.

On Tanna all road communications were cut but the people are now working hard to make repairs in addition to trying to rescue some of the crops in their gardens. The District Agency houses and administrative buildings which were de-roofed are being repaired and it is hoped to have them habitable in a short time.

One of the problems in villages is that the palms which provide 'roofing leaf' have been badly damaged and it may be months before villagers will even have the raw materials with which to build new houses to replace those blown down.

But the biggest problem will still be the damage to crops and the shortage of food which is likely to continue for some time.

BRITISH NEWSLETTER



ISSUED BY THE BRITISH RESIDENCY INFORMATION OFFICE - VILA, NEW HEBRIDES

8th February, 1972.

SECOND CYCLONE IN TWO WEEKS.

It was the turn of the northern half of the Group to be battered when cyclone "Mendy" passed through the Banks Islands on 2nd/3rd/4th February. Early reports from the Banks indicate heavy damage with many houses destroyed and food gardens ruined. A message from Hota Lava said that one entire village, *Ava*, had been washed away by a tidal wave while hardly a tree on the island remained standing. Fortunately no-one was killed or injured. A report from Ureparapara says that nearly all buildings on the island have been destroyed while the touring vessel "Alize", on which the French District Agent was travelling, was beached by heavy seas funnelling into Crater Bay.

Another area where it is feared that damage will be extensive is north and west coast Espiritu Santo. The cyclone passed only thirty miles north of the Cumberland Peninsula and appeared to stop in the area for a time.

Further south, very serious damage was caused at the Palekula fishery. At one time the whole Palekula peninsula was covered by the sea and many of the S.P.F.C.'s buildings on the seaward side were destroyed by wind and waves. It was necessary to cut off all power supplies to the freezing chambers but fortunately a large shipment of frozen fish had been despatched only a week before so that losses are relatively small.

Along the waterfront of Santo town high seas caused damage to all wharves. On the main wharf, damaged in the October earthquake, some fill was washed away, causing a subsidence behind the retaining wall. The Burns Philp wharf, also affected in the earthquake, was totally destroyed while Simonsen's Wharf was damaged. In the town itself there was only minor damage to buildings but many trees fell, causing extensive damage to the telephone system
(Cont. P. 2)

and interrupting electricity supplies to some parts.

High winds were also experienced on islands further south and in Port Stanley, Palekula, the touring launch "Ida" had her anchor broken away by high seas. Fortunately she was able to make her way to shelter behind Uripiv islet where her second anchor was able to hold.

Winds near the centre of the cyclone were estimated to have been in excess of 30 knots, rather less than the winds speeds of "Carlotta", which affected southern islands on 18th/19th January. The latest report is that "Mendy" went on to hit northern New Caledonia.

Cyclone Carlotta

(Top) Vila waterfront during the height of the hurricane - waves at this point are usually about six inches high! In the background driving rain blots out most of the landscape. A few hours after the picture was taken this section of sea wall was breached and the retained land considerably eroded. (centre) A hangar door at Bauerfield was blown in and fell across one of Air Melanesia's 'Islanders'. One of the Lagon Hotel's recently completed new buildings shows the kind of minor damage that some Vila buildings incurred due to the cyclone. (left) Fallen trees and the entire roof of an incomplete block of flats litter a field near Vila.

