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BEACH AND NEARSHORE MORPHOLOGY LYALL BAY, WELLINGTON

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Frontispiece : Vertical aerial photographs of Lyall Bay. The left hand photograph was taken in 1941 prior to the building of Rongotai Airport. The right hand photograph was taken in 1969 after reclamation for the Airport had been completed.

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R.A. Pickrill

INTRODUCTION

Lyall Bay is one of the few sand beaches on the south Wellington coast and is used mainly for recreation. Reclamations associated with airport extensions have reduced the area of the bay, while the position of the shoreline has been stabilised by urban development on the dunes, and the construction of a sea wall. This report outlines historical changes in the morphology of the bay, and processes affecting changes in the morphology and stability of the beach over a range of time periods.

GEOMORPHOLOGICAL SETTING

Lyall Bay beach formed at the southern edge of a tombolo connecting the N–S aligned hills of the Miramar Peninsula with similar hills to the west (Fig. 1) (Cotton 1912). The crescent-shaped beach, 1.2 km wide, is flanked by steeply inclined greywacke hills extending southward into Cook Strait, and as a result is sheltered from waves approaching from any direction other than due south.

The growth of the Lyall Bay tombolo connecting Miramar Peninsula with the mainland is a recent geological event (Lewis and Carter 1976). Maori history identifies the peninsula as being an island some 900 years ago (Cotton 1912; Best 1923). During earthquakes in the 15th century the area was uplifted about 3 m. The narrow neck of water between Hataitai and Miramar became shallow enough to wade, and soon after, this second entrance to Wellington Harbour was closed-off (Best 1923; Stevens 1974). The continental shelf and, to a lesser extent the flanking cliffs, have continued to supply sediment to the tombolo causing it to prograde southward and seaward until it attained its present width. The rate of coastline advance was accelerated in the 1850's when the 1855 earthquake raised the area a further 2 m. Because of the steep nearshore relief and low sediment input to the Evans Bay side of the barrier, progradation on the harbour shore has been negligible (Lewis and Carter 1976).

The bathymetry of the bay reflects the Pleistocene history. The former steep-sided valley has been infilled with sandy sediments and reworked by wave activity to form a flat surface sloping gently seaward (Fig. 1). At the sides, the flat surface abuts the steeper greywacke hills. Inshore of the airport breakwater the bay is asymmetrical, with a trough extending down the eastern shore and a wide shallow platform extending from the western shore.

POST EUROPEAN CHANGES TO THE SHORELINE

Since European settlement several important changes have been made to the beach system which have influenced and are still influencing, the stability of the shoreline.

The earliest development saw the growth of housing and industrial sites on both the secondary backshore dunes and the primary foredunes. The once extensive dune system has been completely destroyed and a road and protective sea wall now run around the bay in place of the foredune. The foredune previously acted as a buffer zone absorbing the erosional effects of storm events and replenishing the beach system during calmer periods, but this effect has now been lost, causing problems of sea wall erosion and wind-blown sand.

The construction of Rongotai airport (1952 to 1959) infilled 14 hectares of the eastern bay to connect with a natural rock breakwater extending from the eastern shore, and taking up nearly one-third of the original beach. The natural rock breakwater at the end of the runway was reinforced with a concrete structure. The runway was extended further in 1972 but this has not affected the beach system.

Prior to any reclamation, Lyall Bay had a crescentic equilibrium plan shape, hinged between rock outcrops at either end of the beach. Reclamation has narrowed the bay and shifted one of these hinge points. The changes taking place in the plan shape of the bay seem to be an attempt to regain equilibrium shape with this repositioned hinge point.

CHANGES IN BATHYMETRY 1903–1977

The 1903 survey of Lyall Bay by the *Penguin* shows a general form broadly similar to the present situation, with a shoal on the western side and a trough in the eastern centre (British Admiralty 1903). The contours of the bay paralleled the sweeping curve of the beach.

Lachlan resurveyed Lyall Bay in 1950 (N.Z. Hydrographic Office 1969). This survey shows few changes in the bathymetry between 1903 and 1950 (Fig. 2a). Regions that the *Penguin* survey recorded as 3–7 m deep had shoaled slightly with the addition of a 1–2 m thick sediment layer, which reached its maximum thickness in the head of the trough. The only area shown to have deepened was just inside the breakwater reef. This is a steep area where small errors in navigation or plotting could easily produce apparent changes in bathymetry.

The bay was resurveyed for the present study and the bathymetry compared with the pre-reclamation *Lachlan* survey (Fig. 2b). The trough has extended landward, removing material gained between 1903 and 1950. No measurable differences were found in the western bay, but east of the trough depths have been reduced. Shoaling is greatest in the water which was deepest prior to reclamation, with the area of fill taking the form of a wedge of sediment tapering away from the reclaimed area. The nett result of these changes has been to narrow and lengthen the trough without affecting the depths in the centre of it.

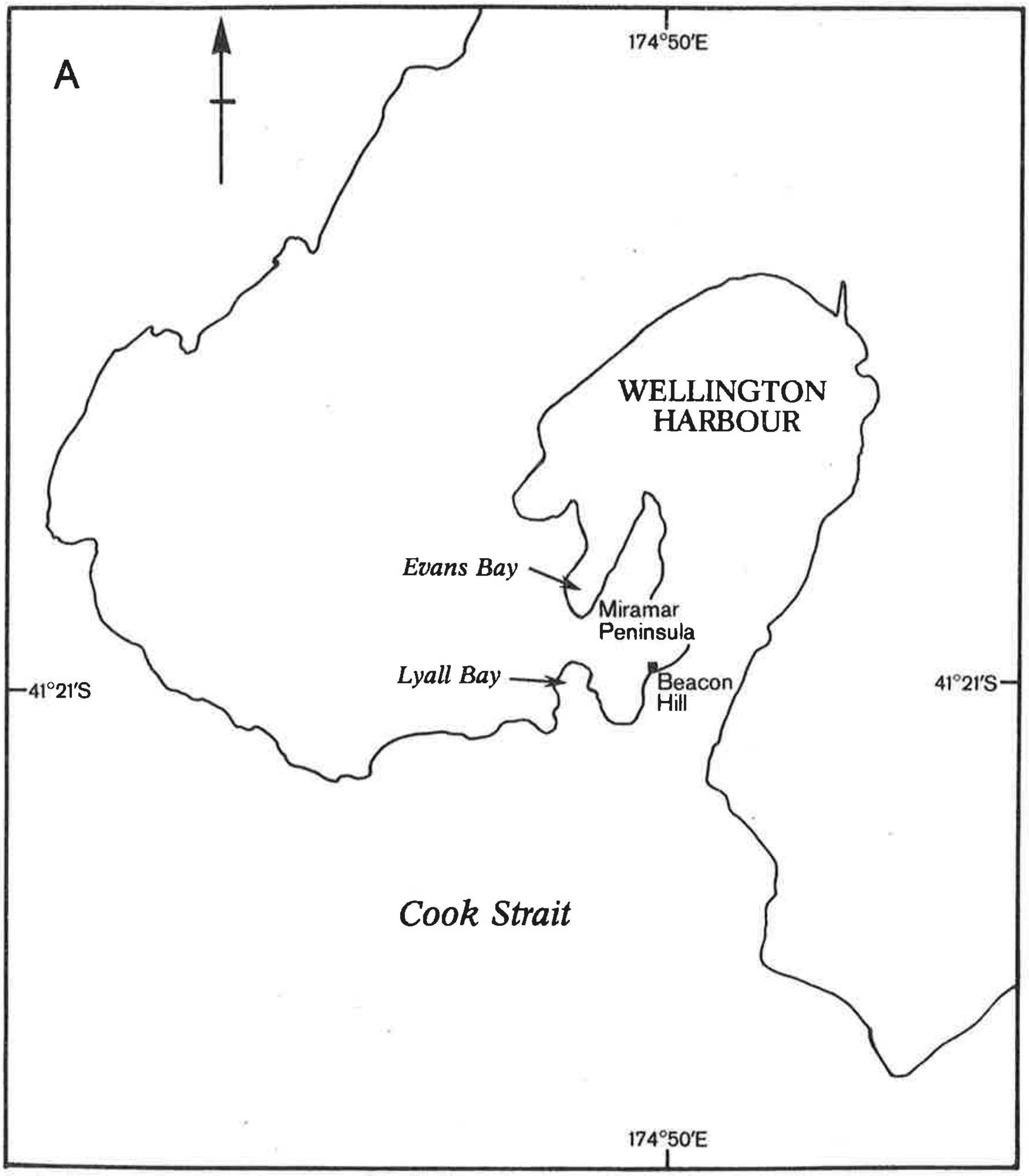

Fig. 1a. Location of Lyall Bay on the south Wellington coast.

SHORELINE STABILITY 1941–1975

In the 35 years from 1941 to 1975 six runs of vertical aerial photographs were taken over Lyall Bay; one before the airport reclamation in 1941, one in the early stages of construction in 1954, and four after, in 1962, 1969, 1970 and 1975. Nineteen photo control points were established on the photographs and shoreline positions for the six years plotted from these (Fig. 3).

Both before and after airport construction the greatest changes in shoreline position were at the ends of the beach. Maximum shifts in shoreline position were 50 m on the western end of the bay and 20 m in the centre. Foreshore slopes are lowest at the ends of the beach and steepest in the centre, so that relative changes in shoreline position are amplified at the ends of the beach compared with the centre. Therefore larger shoreline movements at the ends of the beach do not necessarily involve movements of larger volumes of sediment.

A comparison of the 1941 and 1954 shorelines with the four post-airport extension shorelines shows a consistent change in shoreline position and in the plan shape of the beach (Fig. 3). There has been a landward retreat of the shoreline in the eastern centre of the bay, between control points 11 and 14. This trend has continued into 1977/78 and has resulted in erosion of the sea wall and footpath. These shoreline movements have caused a change in the plan form of the beach and the curvature of the bay has been deepened. This landward retreat of the shoreline in the centre of the bay is paral-

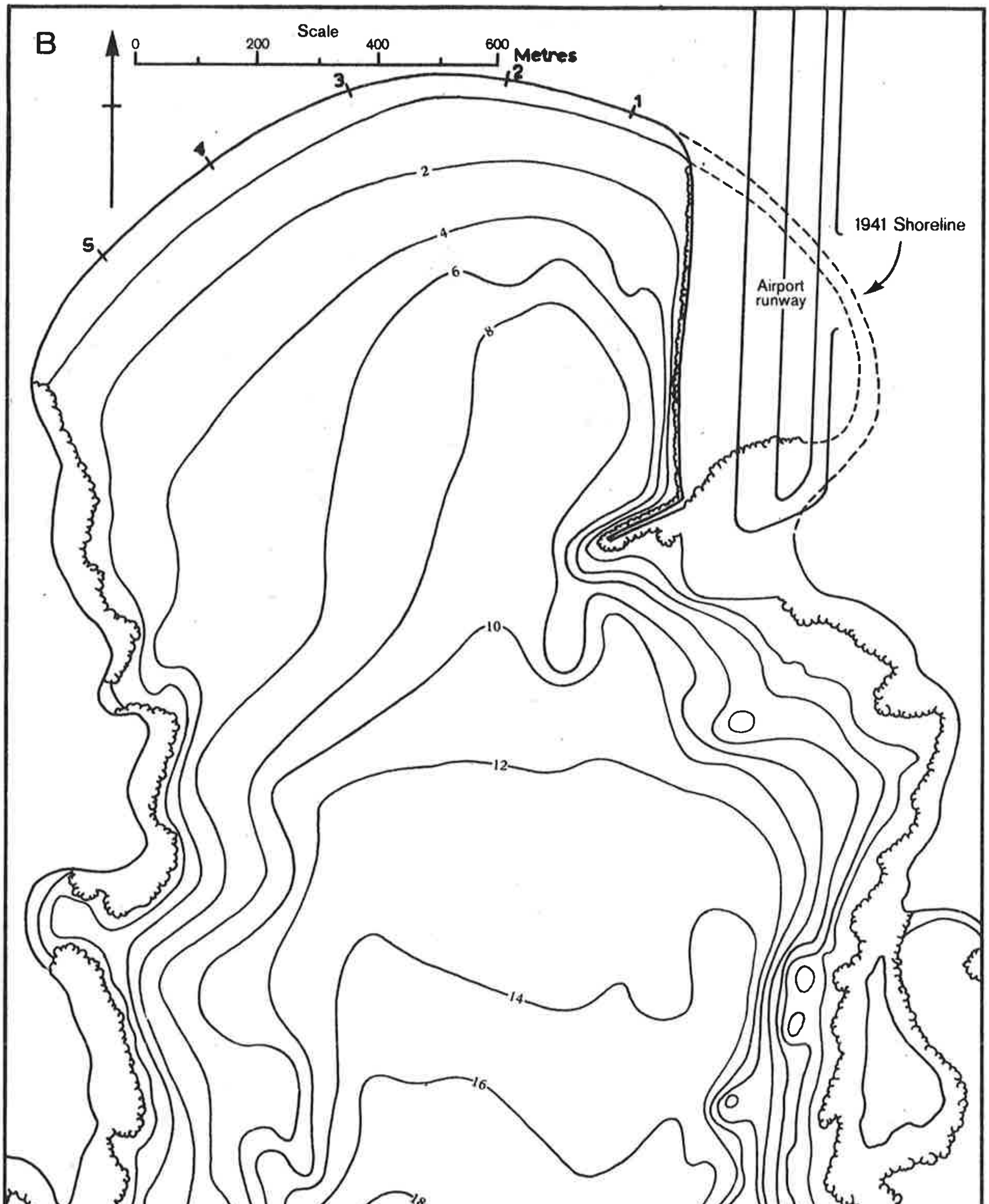

Fig. 1b: Bathymetric chart of Lyall Bay. Contours at 2 m intervals show depths below mean sea level (new city datum((*from* Carter and Lewis 1976).

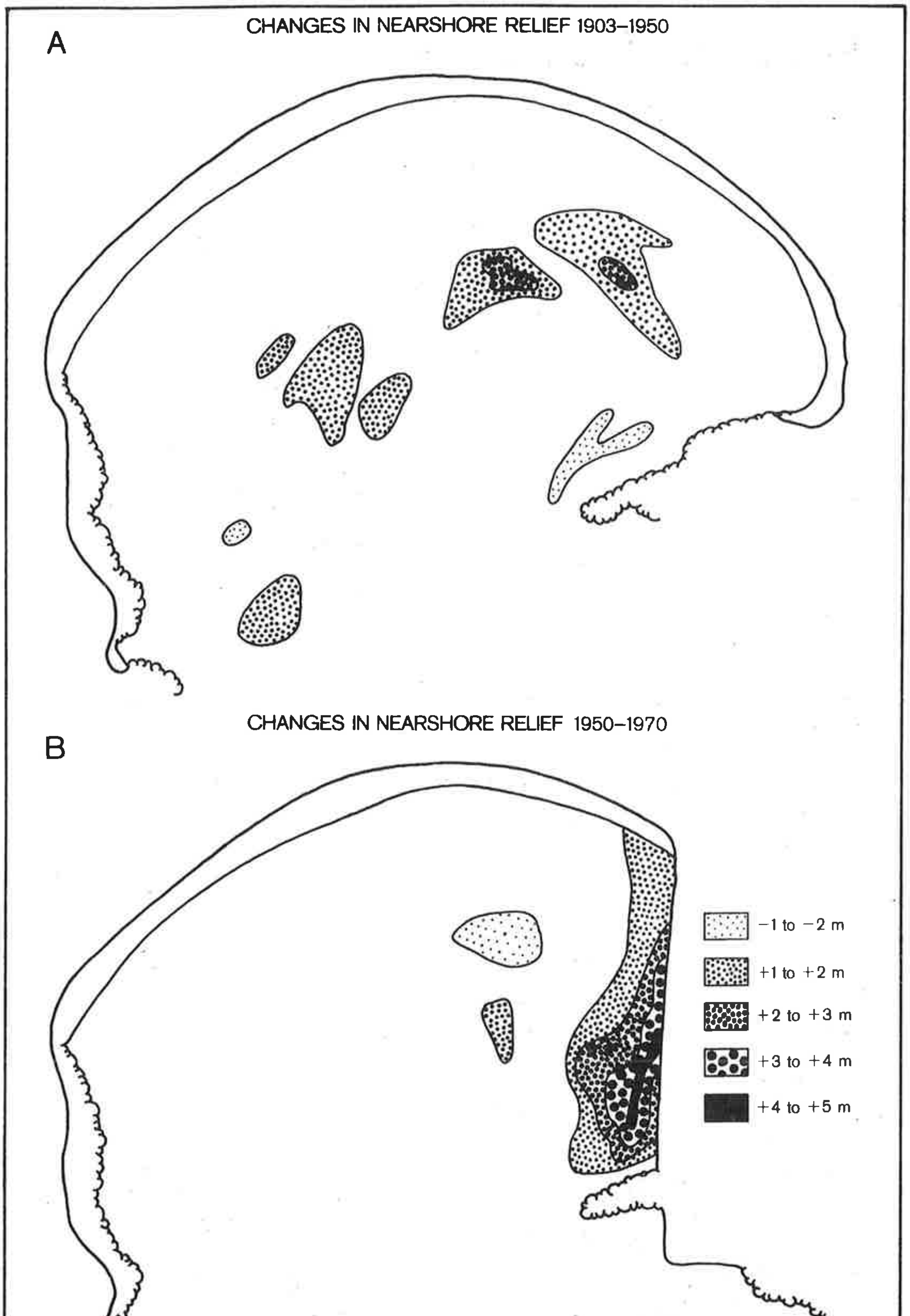

Fig. 2. Changes in bathymetry, Lyall Bay.

A. Changes between the 1903 *Penguin* survey and the 1950 *Lachlan* survey.
B. Changes between the 1950 *Lachlan* survey and an NZOI survey in 1977.

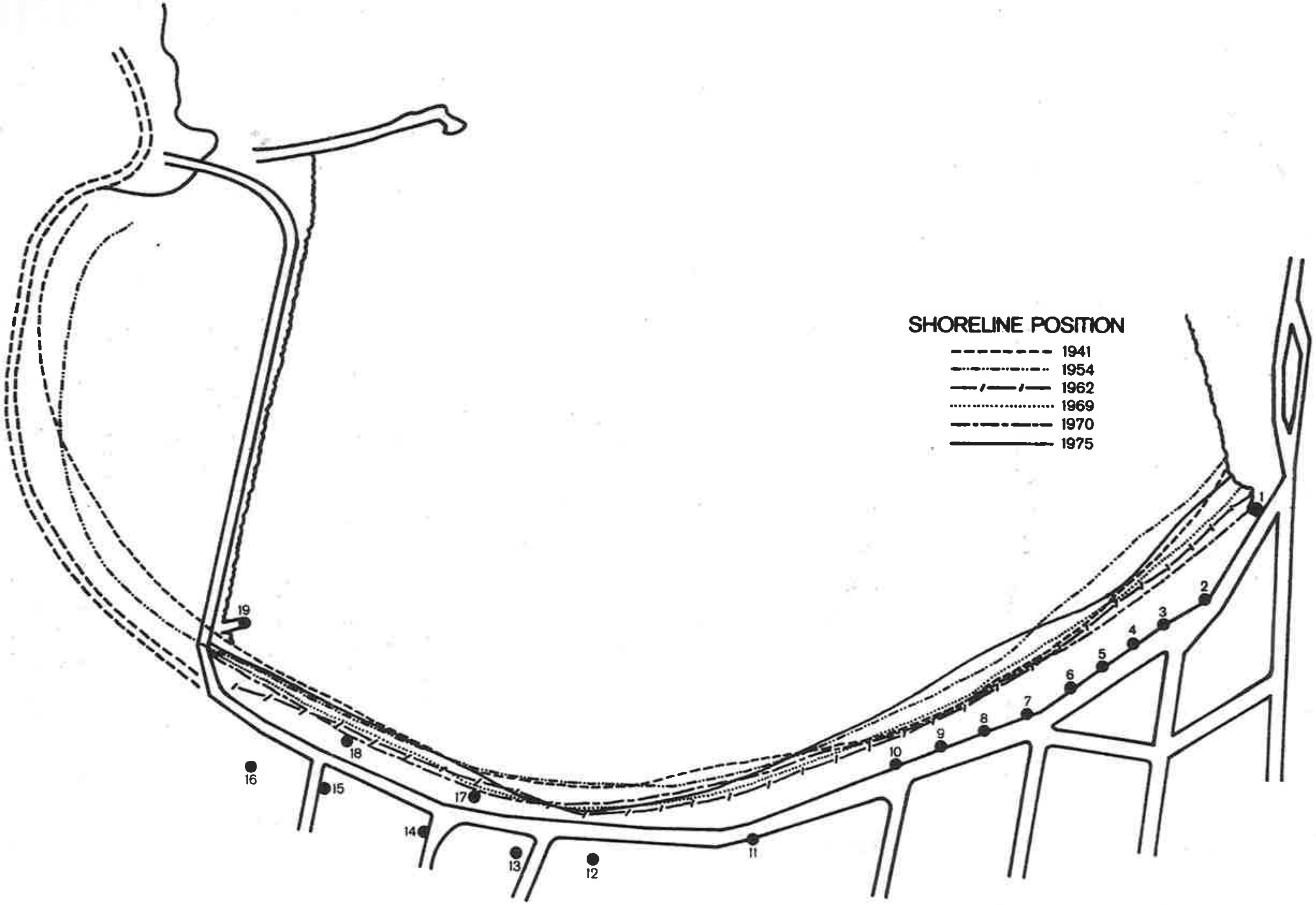

Fig. 3. Changes in shoreline position Lyall Bay 1941–1975 mapped from aerial photographs. Numbers show photograph control points.

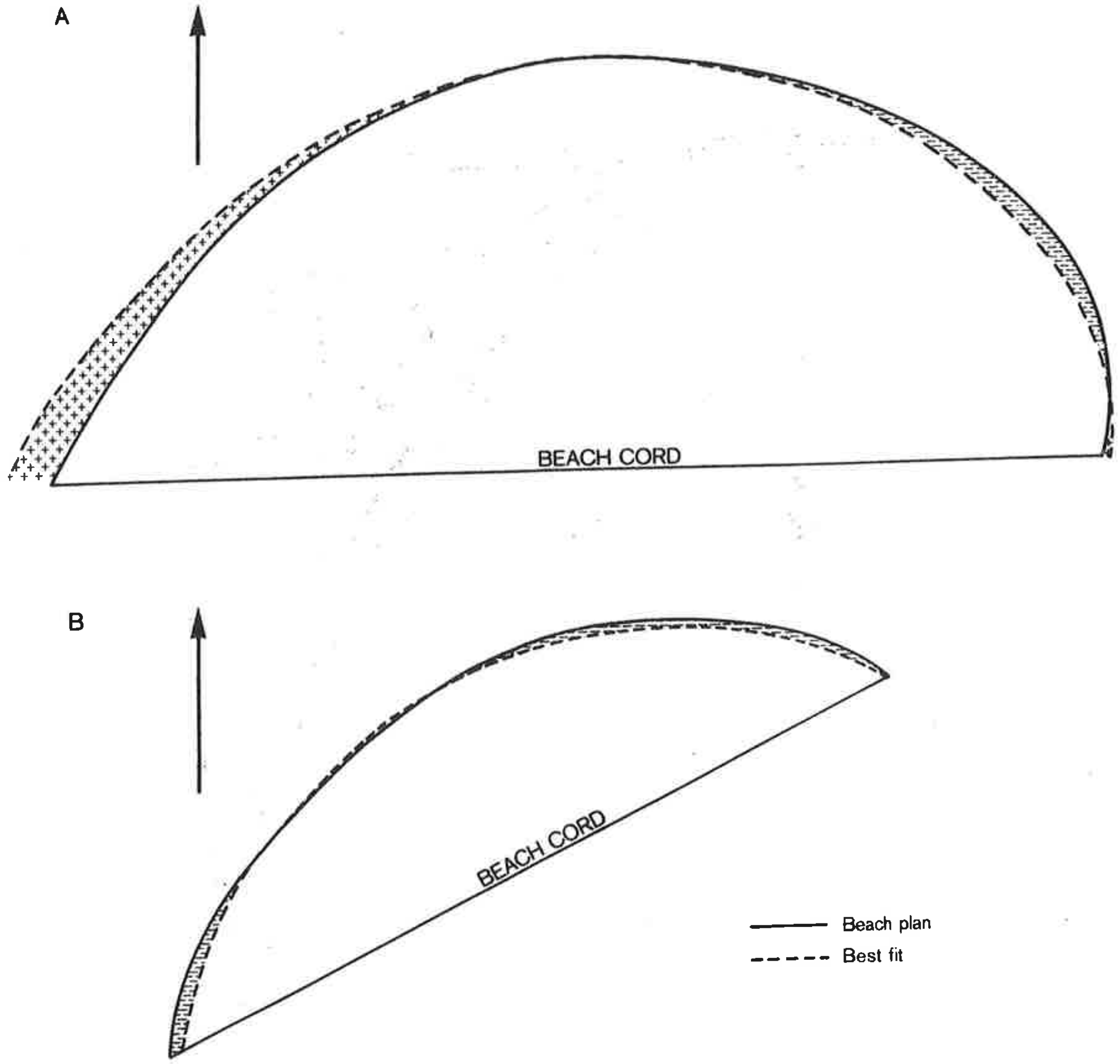

Fig 4. Best fit curves to the plan shape of Lyall Bay.

A. Best fit log spiral prior to airport reclamation based on the 1941 shoreline taken from aerial photographs.

B. Best fit circular arc after reclamation based on the 1969 shorelines taken from aerial photographs.

leled by changes in the immediate nearshore relief. The eroding section of beach is at the head of the trough which deepened over the period 1950 to 1977.

PLAN SHAPE OF LYALL BAY AND BEACH EQUILIBRIUM

Beaches limited by fixed headlands at either end and not swamped by excessive sediment supply develop equilibrium shapes in plan form. McLean (1967) demonstrated that many of the beaches on the east coast of the South Island develop a curvature which approximates a circular arc form, facing the main deep water swell direction. On beaches lying in the lee of headlands, sheltered from the dominant swell, the equilibrium shape takes the form of a logarithmic spiral (Yasso 1965; Silvester 1974), where the radius of curvature of the beach increases with distance from the headland. In this situation the geometric form is controlled by refraction, diffraction and reflection of waves into the wave shadow zone behind the headland.

Lyall Bay presents an interesting example with which to test equilibrium plan shape hypotheses as reclamation has altered the shape of the bay. Prior to reclamation the bay approached an equilibrium log spiral form developed from the natural rock breakwater on the eastern shore (Fig. 4). However the western end of the beach was slightly too curved and the central beach too flat for a perfect fit. The increased curvature at the western end of the beach probably resulted from shoaling transformations associated with the rock platforms

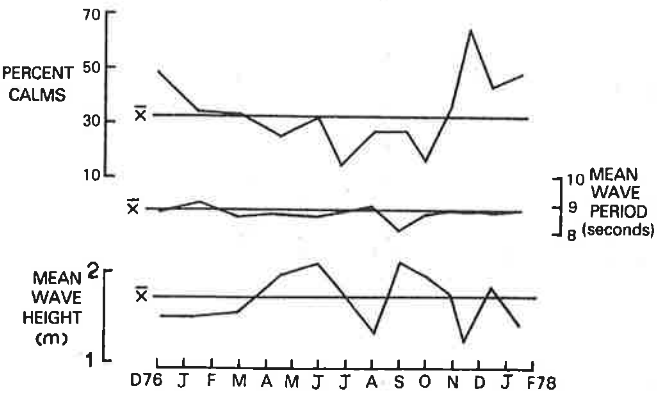

Fig. 5. The seasonal distribution of mean wave height, mean wave period and the frequency of calms for the intervals between beach surveys marked in Fig. 10.

on the western side of the bay entrance. Reclamation infilled the area most affected by refraction around the end of the breakwater (Fig. 4) causing the plan shape to approximate a circular arc form rather than a logarithmic spiral. However, the beach does not fit the circular arc plan perfectly, being too flat on the western end, and too deeply indented at the east. This increasing curvature along the beach from west to east suggests that the bay is trying to develop a new log spiral form similar to the pre-reclamation shape. The pattern of erosion on the beach and in the nearshore zone reflects these changes.

PROCESSES AFFECTING THE BEACH

Waves

Within Cook Strait the wave climate is strongly bimodal. Locally generated northerlies and northwesterlies are funnelled southward through the Strait and longer period southerly swell and storm waves move northward (Pickrill 1977). Lyall Bay on the southern coast of North Island is exposed only to the southerlies, being sheltered from the northerlies by the land mass of North Island and more specifically by the protective spurs of hills extending southward from both sides of the bay.

Visual observations of wave height and period from Beacon Hill Signal Station (Fig. 1) give some indication of wave conditions off Lyall Bay during the 12 months in which beach changes were monitored. Waves approach only from due south. During periods of northerly winds calm conditions prevail on Lyall Bay beach with a northerly 'slop' sometimes recorded in the outer bay. Calms were recorded 33% of the time, with the frequency showing a distinct seasonal pattern, decreasing to less than 20% of the time in winter, and increasing to more than 50% of the time in summer (Fig. 5).

The mean wave period was 8.8 s with most waves in the 7–11 s range. There is no apparent seasonal fluctuation in wave period (Fig. 6). The mean wave height was 1.7 m reaching a maximum of 4.3 m during storms. The seasonal distribution of wave heights parallels the cycle in the frequency of calms, with an increase in wave height from a summer mean of approximately 1.5 m to a winter mean of 2.0 m (Fig. 7). The increase in wave height in winter produces an increase in wave steepness. These periods and heights on the south Wellington coast are broadly similar to those recorded on other exposed beaches on the east coasts of both North and South Islands (Pickrill and Mitchell, in press).

Wave Refraction

When waves enter shallow water they are affected by friction at the water/seabed interface and their forward velocity is retarded. Depending on the bathymetry, the wave crest may also be refracted. The continental shelf off Lyall Bay is relatively narrow and steep, dropping away into the deep waters of the Cook Strait Canyon (Brodie 1966). The contours on the shelf parallel the east-west trend of the coastline so that the dominant southerly swell cuts them at right angles, and, as a result, southerly wave trains remain largely unaffected by refraction until they pass through the narrow entrance to Lyall Bay.

Within the bay refraction and the resultant distribution of wave energy around the foreshore are controlled by three features of the bathymetry :

1. In east-west cross section the outer bay floor is nearly flat. As a result waves entering the centre of the bay remain substantially unaffected by shoaling and retain most of their deep water energy. Therefore the centre of the beach is a high energy zone.

2. The bay is long and narrow with steep rocky sides, so that waves entering down the sides of the bay are refracted on to the rocks in the entrance, while those entering the bay and running up on to the beach undergo extensive refraction. Therefore the ends of the beach are low energy zones.

3. Landward of the breakwater the asymmetrical bathymetry, with a trough down the eastern side and a bank on the west, amplifies the transformations of the wave form described above. Close to shore refraction is greatest on the western side of the bay and smallest in the centre and east (Fig. 8).

The nett result of these transformations is that waves entering the centre and eastern end of the bay retain most of their deep water energy while there is a steady decrease in energy along the beach to the western end. The plan of the refracted wave crests shoaling on the beach is similar to the plan shape of the beach, indicating that alongshore currents are probably weak and that the beach is approaching an equilibrium plan shape in response to these waves.

Tides

While waves are the dominant process controlling sediment movement and beach morphology, the tidal range and tidal currents also influence the beach and nearshore system. The tidal range in Wellington is only

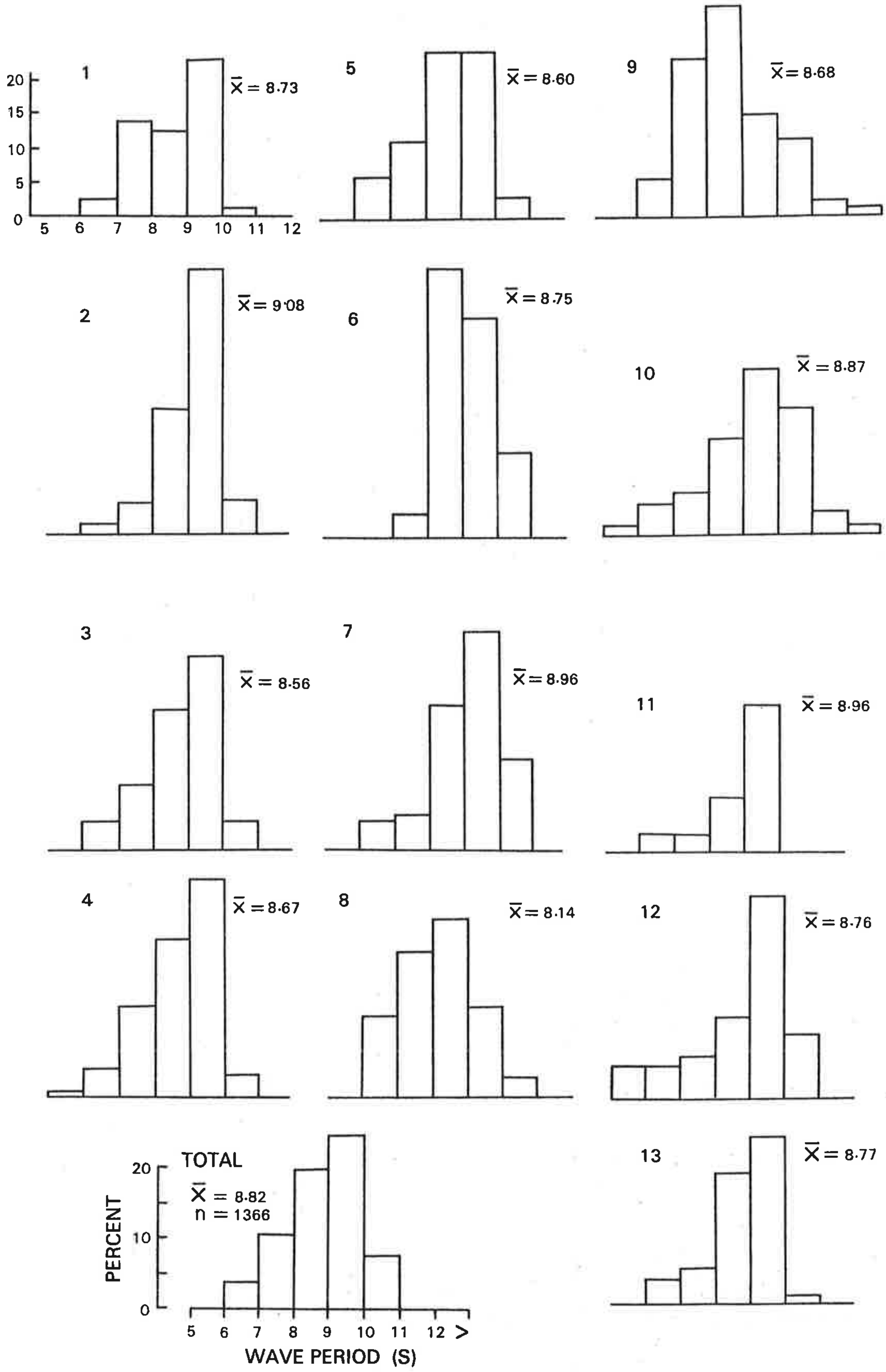

Fig. 6. The seasonal distribution of wave periods for the intervals between beach surveys marked in Fig. 10.

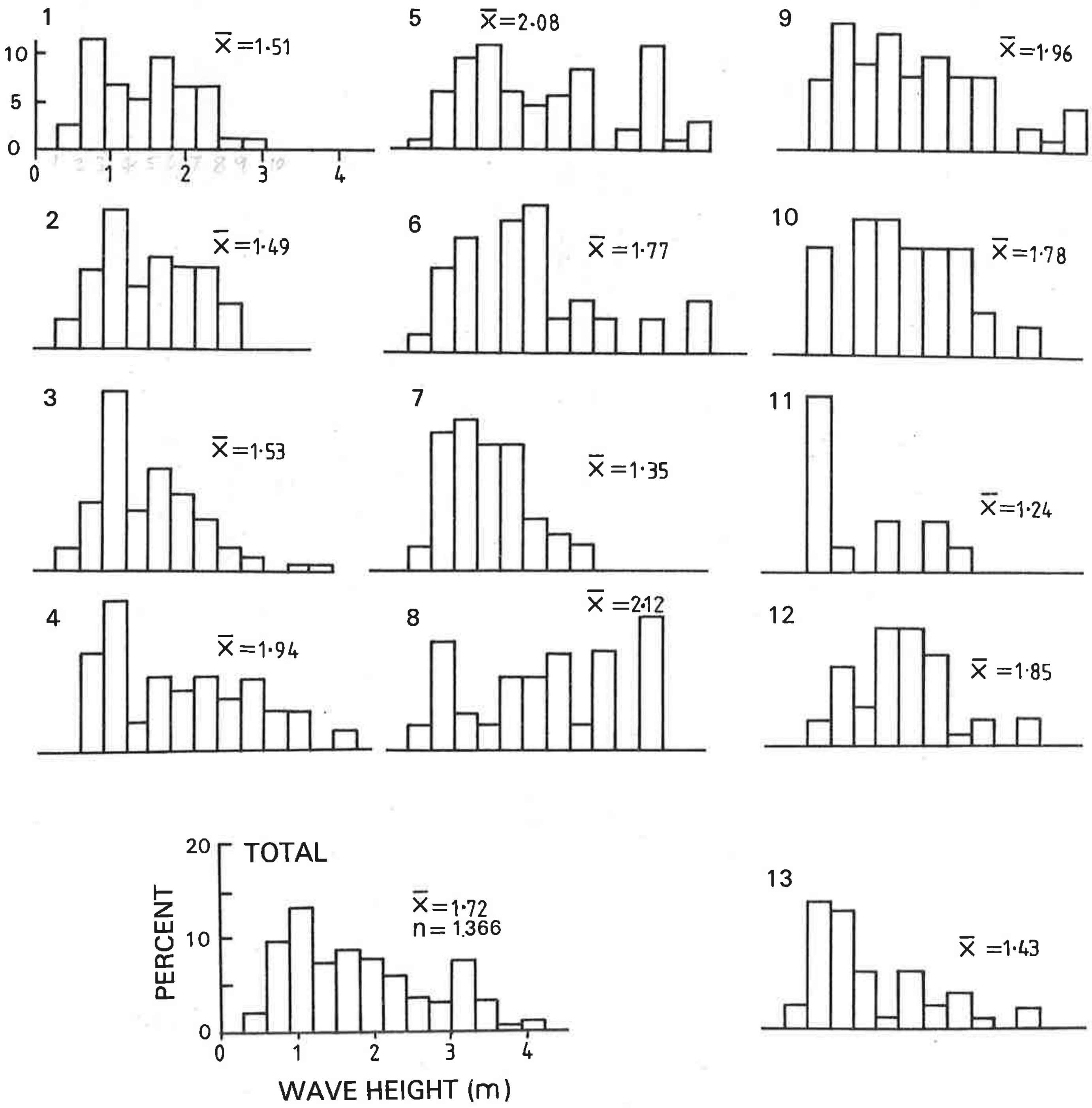

Fig. 7. The seasonal distribution of wave height for the intervals between beach surveys marked in Fig. 10.

1.0 m at mean spring tides (Marine Division, Ministry of Transport 1976), and so there is very little tidal translation of the surf and breaker zones across the beach, the wave energy being concentrated in a relatively narrow band down the foreshore.

In a confined inlet with long narrow sides, such as Lyall Bay, wave-set-up against the shoreface is magnified by the constricting morphology. During high energy wave conditions the mass transport of water shorewards leads to the formation of strong recirculating rip currents (Fig. 9). The trough down the eastern centre of the bay is probably maintained by these seaward-flowing recirculating currents.

During calm conditions both surface and sub-surface currents are weak. Surface flows follow the wind direction at 2 to 3% of the wind speed, and subsurface currents are slow and unpredictable (Gilmour and Ridgway 1975).

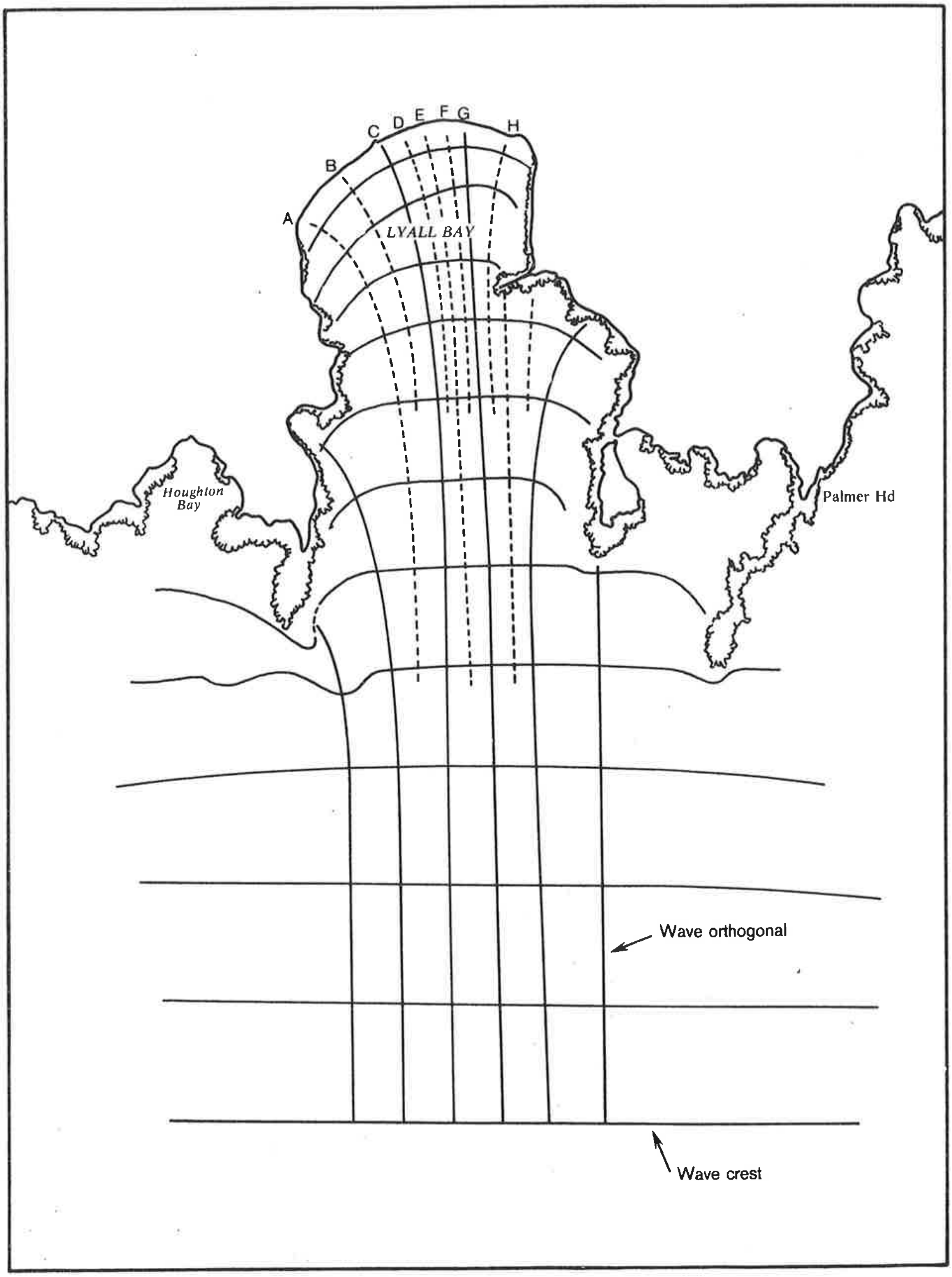

Fig. 8. Refraction diagram for a southerly swell of 10 sec. period showing every 3rd wave crest and wave orthogonals perpendicular to the crests. A 2.0 m high wave in deep water would result in refracted waves of 1.14 m at the beach in section A–B; 1.24 m in B–C; 1.72 m in C–D; 1.72 m in D–E; 1.72 m in E–F; 1.72 m in F–G, and 1.36 m in G–H.

Fig. 9. Vertical aerial photograph of Lyall Bay (1954) showing well developed rip currents transporting sediments far out into the bay. Infilling of the eastern end of the bay for airport extensions can be seen in the right hand side of the photograph. (Photograph by permission of the Department of Lands and Survey.)

BEACH MORPHOLOGY

Introduction

The beach at Lyall Bay is medium sand, coarsest at the high energy centre of the bay and fining slightly to the lower energy ends. For most of the year the beach assumes a concave profile steepest at the top of the beach and decreasing in slope offshore (Fig. 10). The foreshore slope is steepest in the centre of the bay (3 to 4.5°) and lowest at the ends (1 to 2°). Fine, wind-blown material sometimes accumulates at the top of the beach in a mobile dune against the sea wall, occasionally spreading across the road. In response to the alongshore distribution of wave energy, the beach is developed to the highest elevations in the centre of the bay, decreasing to the ends. Offshore the beach slope decreases and the morphology is either planar or barred depending on prevailing wave conditions.

Survey System

Five shore-normal profiles established around the bay (*see* Fig. 1) were resurveyed at monthly intervals for a 12-month period (Fig. 10). During two of these monthly surveys the profiles were extended offshore with a Raytheon Survey Echo Sounder. The boat position was fixed on the profile line with range poles. A tagged line, tethered on the beach and paid out from the boat, was used to fix horizontal distances every 10 m along the profile, these distance fixes being marked on the echo sounder trace. The last few positions of the beach survey overlapped positions on the sounding trace and enabled the beach and nearshore surveys to be tied together. Soundings were carried out during near calm conditions making a comparison of the two sounding surveys possible; maximum errors in the sounding system are of the order of 0.2 to 0.3 m.

Changes in Foreshore Morphology

Beach morphology changes in response to wave energy conditions. During periods of low energy, berms form midway down the profile extending to 1 to 1.5 m above mean water level. During periods of higher wave energy these berms are planed off and replaced by a broad concave profile extending the full width of the

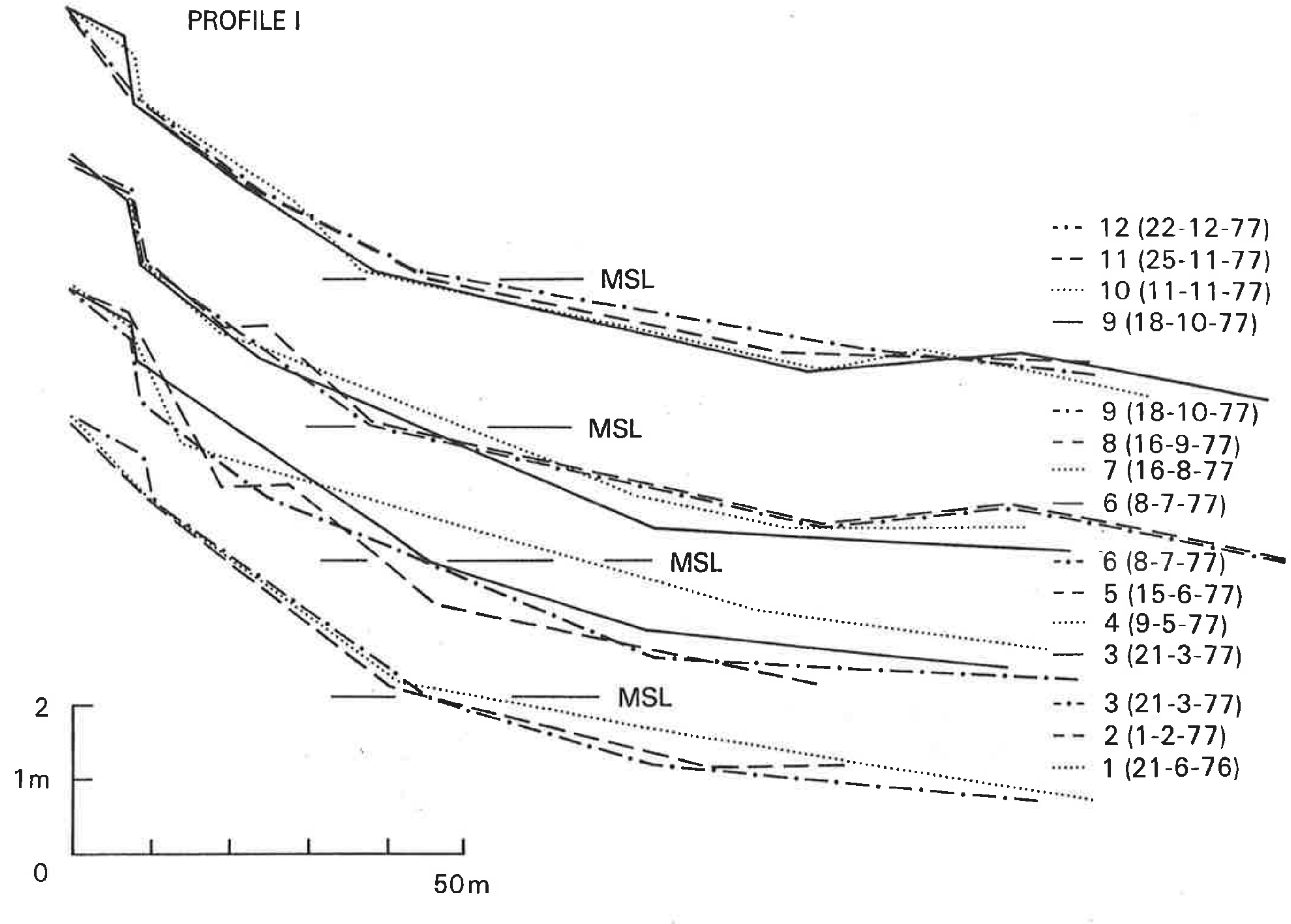

Fig. 10. Profiles of Lyall Bay beach showing monthly changes in beach morphology between 21.12.76 and 22.12.77. The positions of the five profiles around the bay are shown in Fig. 1.

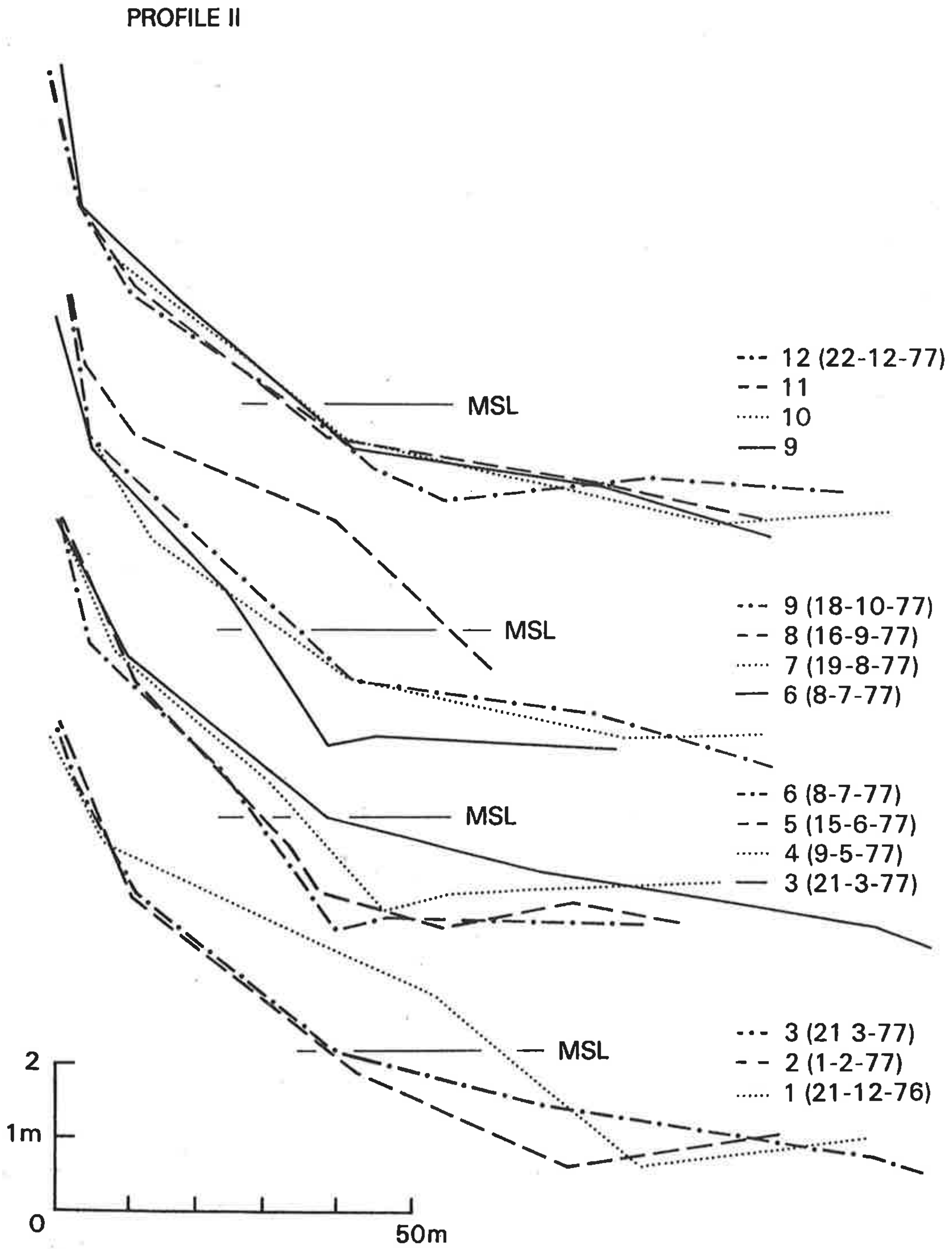

Fig. 10. *continued*

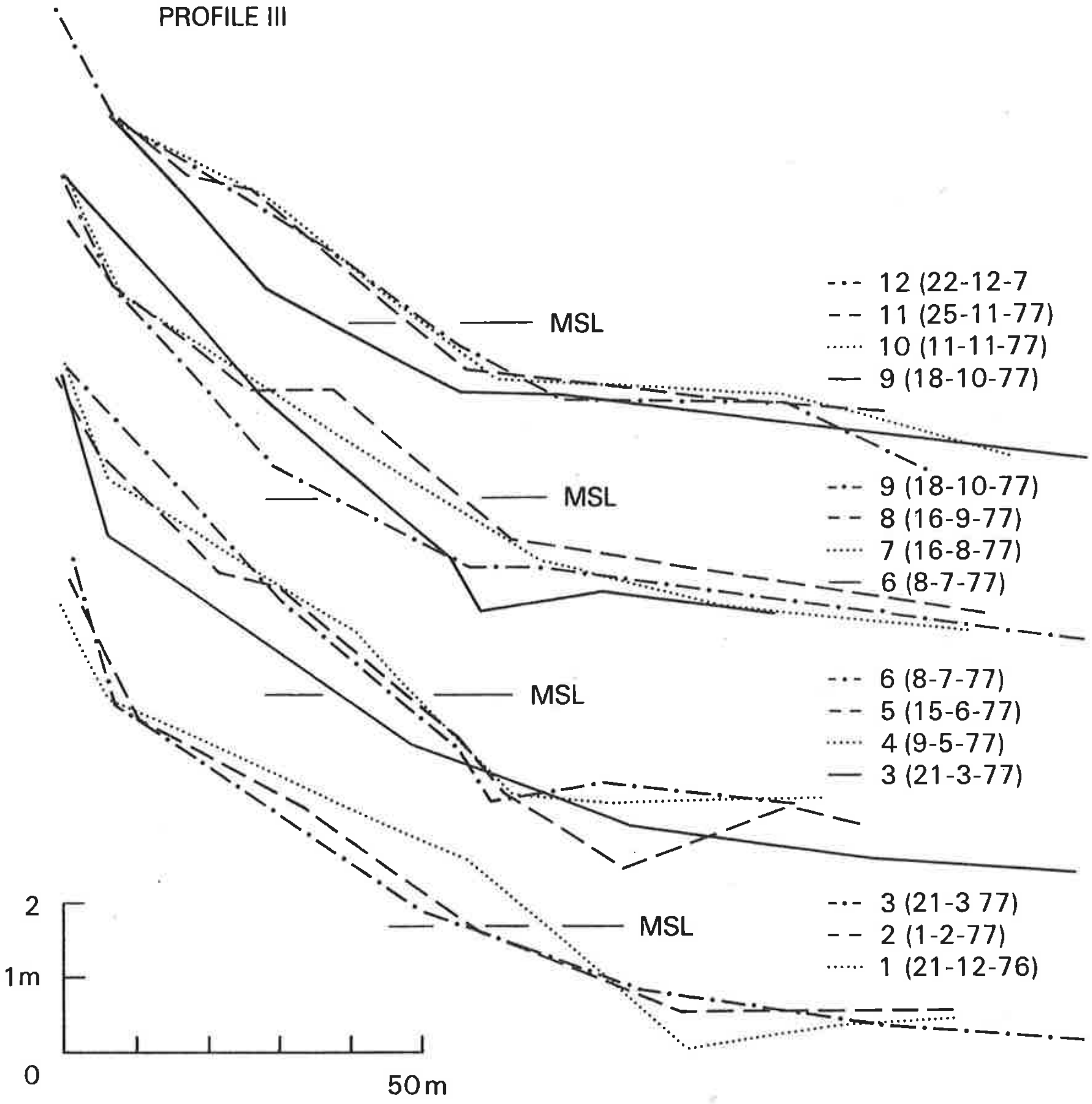

Fig. 10. *continued*

beach to elevations of 3-4 m above mean sea level. Beneath mean sea level nearshore bars were common.

Rather than comparing successive beach profiles, changes in morphology can be more clearly portrayed by plotting movements of selected contours across the beach through time. In Fig. 11 the positions of seven contours from each of the five profiles have been plotted for the 12 months of observations. All five profiles show similar patterns of change. Contour movements are smallest on the top of the foreshore and increase down the beach. All five profiles show a seasonal pattern of change with accretion and seaward movement of most contours from December through to March, followed by a period of erosion and landward contour movement from March through to July or August. From August through to December the beach was replenished and the contours moved seaward. While this pattern is not always clear on all contours on all profiles, the average contour movements for the entire bay show this movement quite strongly (Fig. 11). This cycle of accretion in summer and erosion in winter is maintained across the full width of the beach profile. There is no evidence of a simple re-adjustment in the beach budget with erosion on the top of the beach compensating for deposition on the lower foreshore, or vice versa. Rather there is a total shoreward migration of the beach face in winter and a seaward movement in summer with sediment being moved onshore and offshore from deeper water (beyond the -2 m contour). The average shore-normal shift in the beach contours from summer to winter and back to summer was 19 m.

While the beach profile migrates with the seasons this movement is not a simple parallel retreat and advance of the shoreface. The larger movements of the contours on the lower beach lead to a steepening of the foreshore

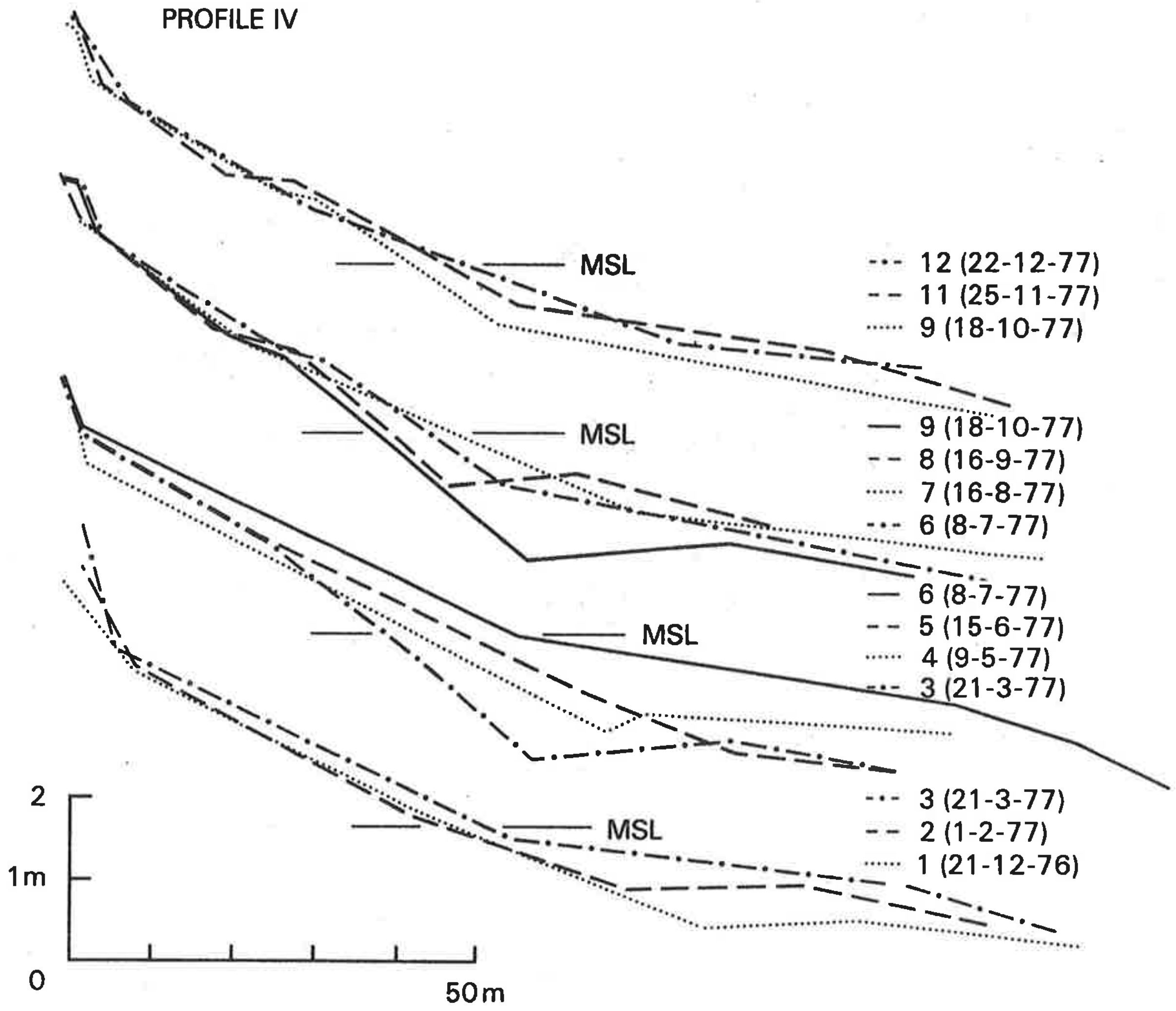

Fig. 10. *continued*

slope from summer to winter and a lessening from winter back to summer (Fig. 12).

Steepening of the beach face in winter and landward retreat of the total beach system is a direct response to seasonal patterns in wave energy. High-energy, steep waves in winter have an erosional down-combing effect on the profile, while lower-energy, less-steep summer waves enable the beach to recover. As such this pattern of winter cut and summer fill is similar to cycles of wave activity and beach changes found elsewhere (e.g., Shepard 1950), but, Lyall Bay is different in one important aspect; elsewhere beaches *decrease* in slope in winter, whereas in Lyall Bay they *increase* in winter.

Changes in Nearshore Morphology

The two echo sounding surveys show the nearshore relief to be an extension of the downward concave foreshore slope (Fig. 13). Two or three nearshore bars are superimposed on this slope. The one closest to the beach is 1.3 to 1.7 m beneath mean sea level and 0.3 to 0.8 m above the non-barred profile. The second, in 2.0 to 3.0 m of water is about 120 m further seaward. A third bar was found on profile 3 in winter (Table 1). The origins of multiple bar systems have been attributed to different levels of wave energy, the innermost bar forming under breaking waves during low energy conditions, the more seaward bars forming under higher energy conditions. With changes in energy the bars migrate, moving shore-ward in lower energy conditions and seaward during periods of higher energy. As a result of these movements, bars are best developed in the winter months.

The data from Lyall Bay are insufficient to draw firm conclusions about bar movements, but changes in the bar system from winter to spring are similar to those found elsewhere (e.g., King 1972) and agree with changes taking place on the foreshore. From winter to spring the bar system deteriorates, both the number and size of the bars being reduced. During winter the beach is in its most depleted condition, sediment being eroded from the foreshore and deposited in deeper water, and the shoreline moving landward. As a result, in winter the first bar forms close to the shore, and, as the beach progrades through spring this bar moves seaward with the beach face, always forming in the same depth of

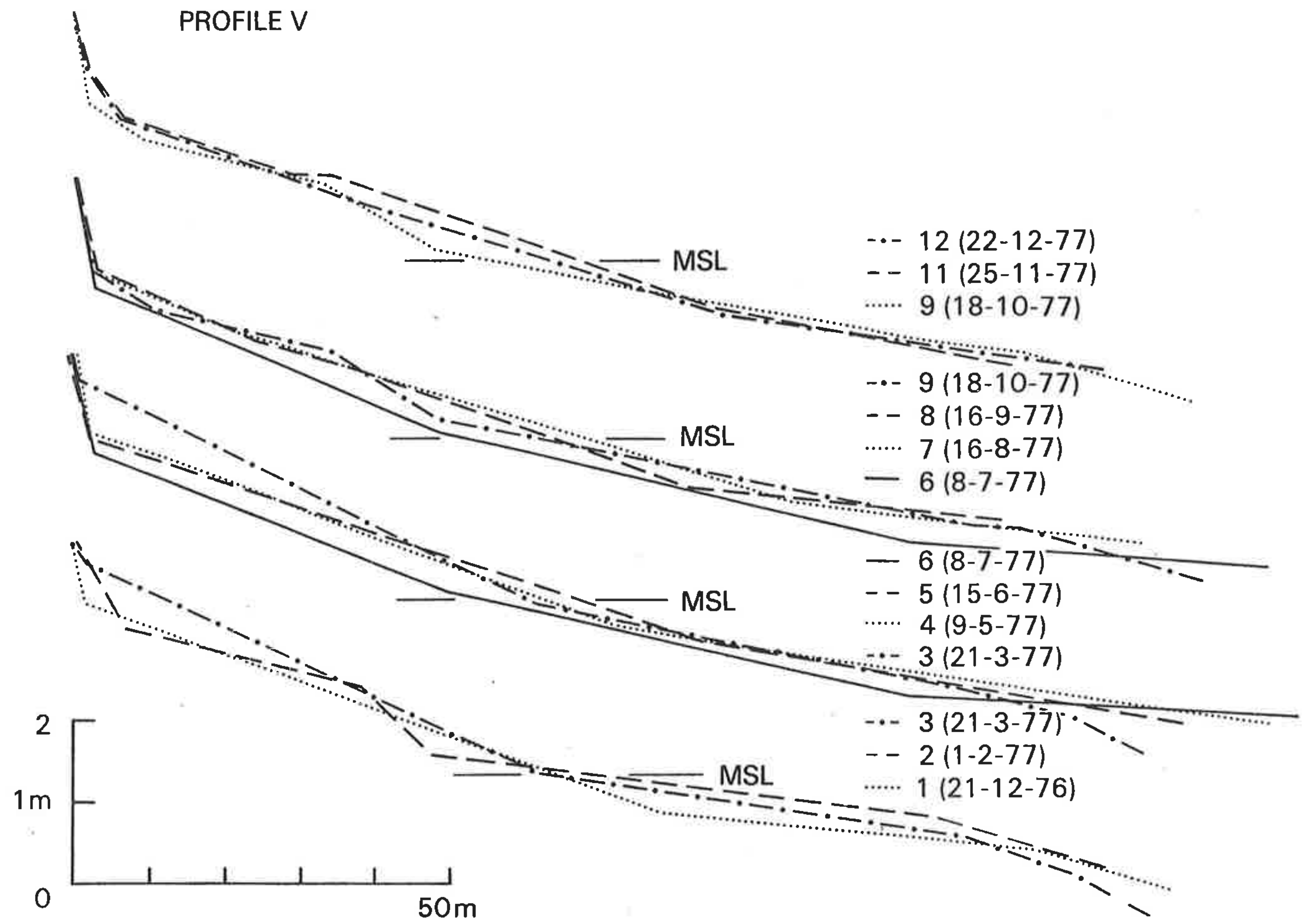

Fig. 10. *continued*

water (Figs 10, 13). The second, seaward bar moves in the opposite direction. In winter the bar forms in deep water, and with a return to lower energy spring conditions, it migrates shoreward (Table 1). The movement of these two bars away from one another in winter and towards each other in summer reduces the nearshore slope in winter, a reverse of the changes seen on the foreshore. In winter the offshore bar acts as a reservoir, storing material eroded from the foreshore. In summer the bar moves shoreward returning this sediment to the beach face. The migration of the bar systems in Lyall Bay is slightly different from that described for most beaches where both bars normally move in the same direction. Much of this discussion must remain speculative as only two echo-sounding surveys have been carried out, but such changes could be expected in view of both the beach dynamics demonstrated in earlier sections, and of accepted principles of bar movement and stability.

Seaward of the bar system, particularly in the high energy centre of the bay, sediment movement still produces changes in the morphology of the sea floor. At the limit of the echo-sounding profiles, in 8 m of water 500 m from the top of the beach, the sediment surface agraded 0.75 m between surveys (Fig. 13). Sea bed stability markers in outer Lyall Bay have been monitored by the Wellington City Corporation seven times between June 1977 and July 1978 (Campbell 1978). Results from these markers suggest that in 17.5 m of water vertical displacements of the sediment surface are of the order of 0.3 m. In 25 m of water vertical displacements are less than 0.2 m.

Sweep Zone Envelope Curves

Sweep zone envelopes, joining the highest points on all profiles and the lowest points on all profiles, show the height to which the beach rose in 1977, and the lowest level from which sand was removed (Fig. 14). The beach takes on a wide range of forms between these limits.

In Lyall Bay all the envelopes have a similar form, with the widest parts centred on, or just beneath, mean water level, tapering both seaward and landward. On some of the profiles the sweep zone broadens again at the top of the beach, where wind-blown sediment accumulates against the sea wall. The envelopes are thickest (3.2 m, profile 2) on the narrower, higher-energy, steeper profiles in the centre of the bay, decreasing in thickness to the lower energy ends (0.6 m, profile 5).

Wave conditions during the period of study were probably typical of those found on this coast. Changes

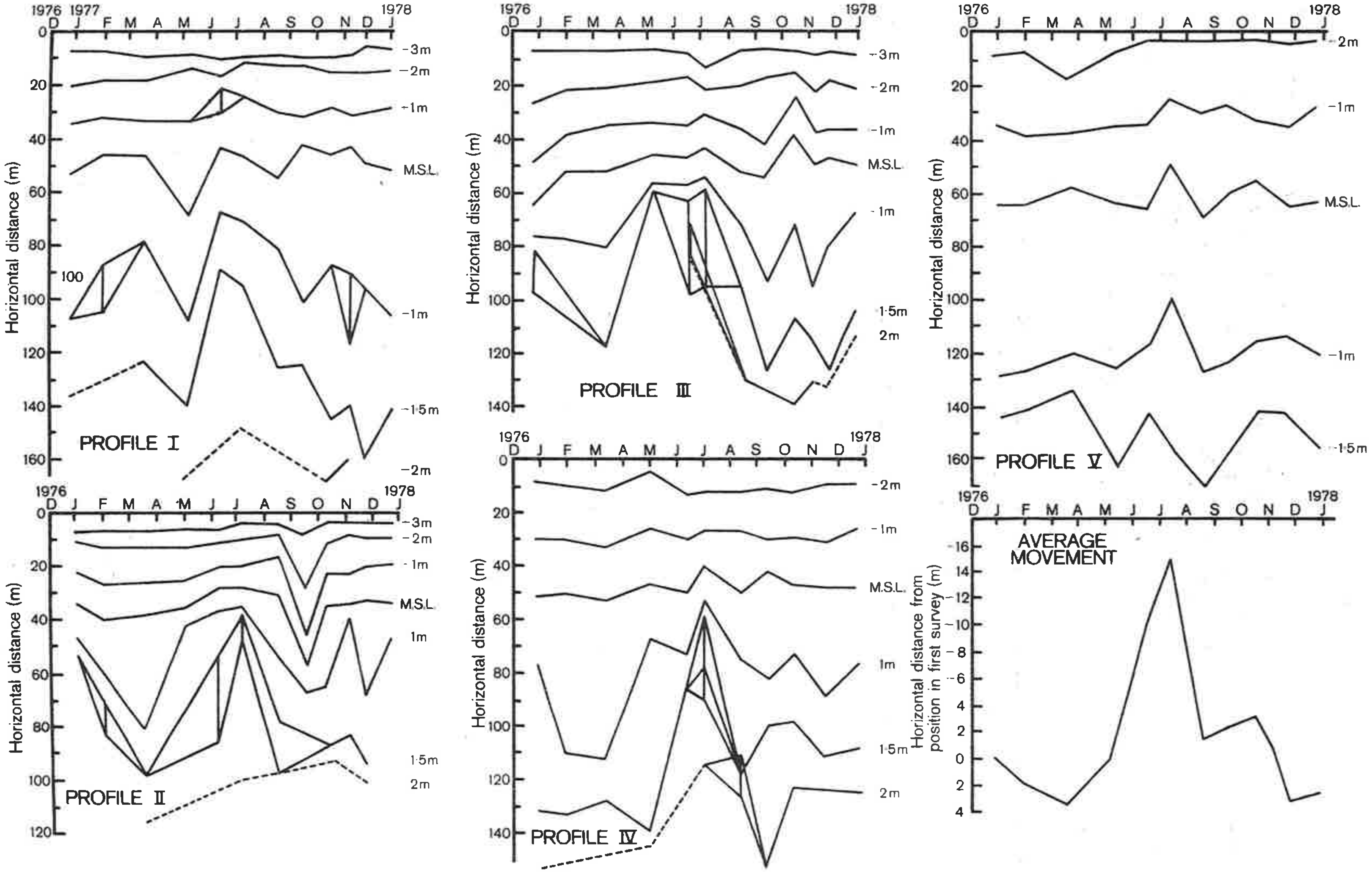

Fig. 11. Horizontal movements in beach contours in Lyall Bay between 21.12.76 and 22.12.77. The average movement in the beach face is also shown.

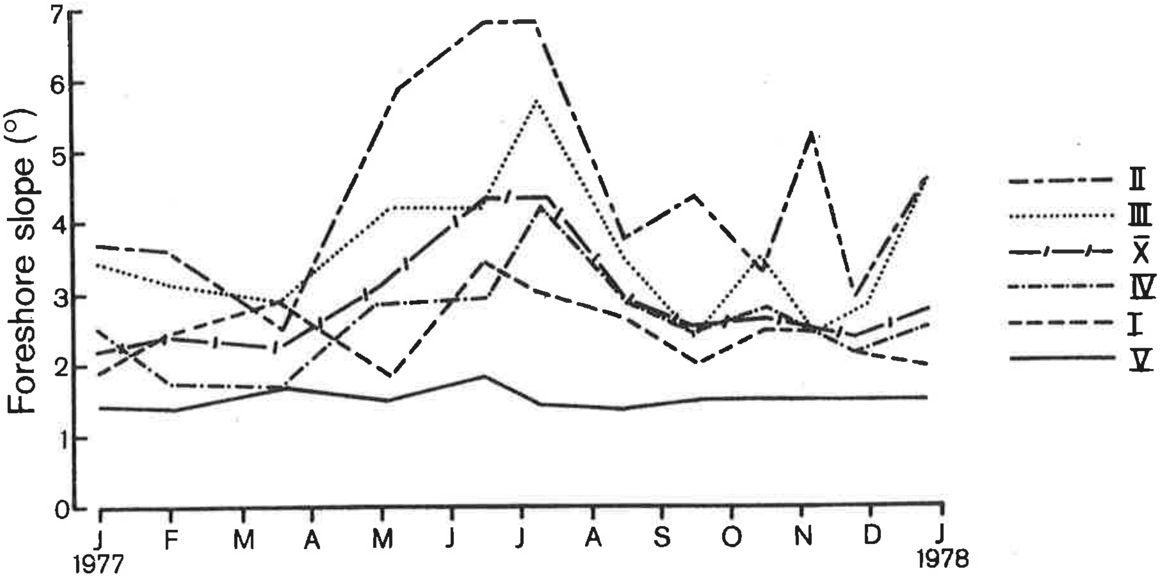

Fig. 12. Monthly changes in beach slope on the five beach profiles around Lyall Bay. The mean trend (X) is also shown.

Table 1. Summary of nearshore bar characteristics in Lyall Bay.

	INNER BAR			OUTER BAR		
Profile No.	Bar Position from shore (m)	Water Depth (beneath m.s.l.)	Elevation (above an extrapolated planar profile (m))	Bar Position from shore (m)	Water Depth (beneath m.s.l.)	Elevation (above an extrapolated planar profile (m))
1 Winter	150	1.4	0.6	240	2.3	0.9
Spring	130	1.2	0.4	195	1.7	0.5
2 Winter	75	1.3	0.6	250	3.0	1.5
Spring	120	1.7	0.3	220	3.0	0.9
3 Winter	100	1.6	0.9	270*	3.2	0.8
Spring	190	2.2	0.3	160	2.5	0.4
4 Winter	130	1.4	0.8	270	2.6	0.7
Spring	150	1.5	0.8	225	2.4	0.3
5 Winter	170	1.4	0.4	260	2.3	0.3
Spring	125	1.1	0.3	245	2.0	0.3
Winter $\bar{X}$	125	1.42	0.66	258	2.68	0.84
Spring $\bar{X}$	143	1.54	0.42	221	2.27	0.50

* A third bar formed in the winter on profile 3. This has been treated as an intermediate bar and not included in the averages.

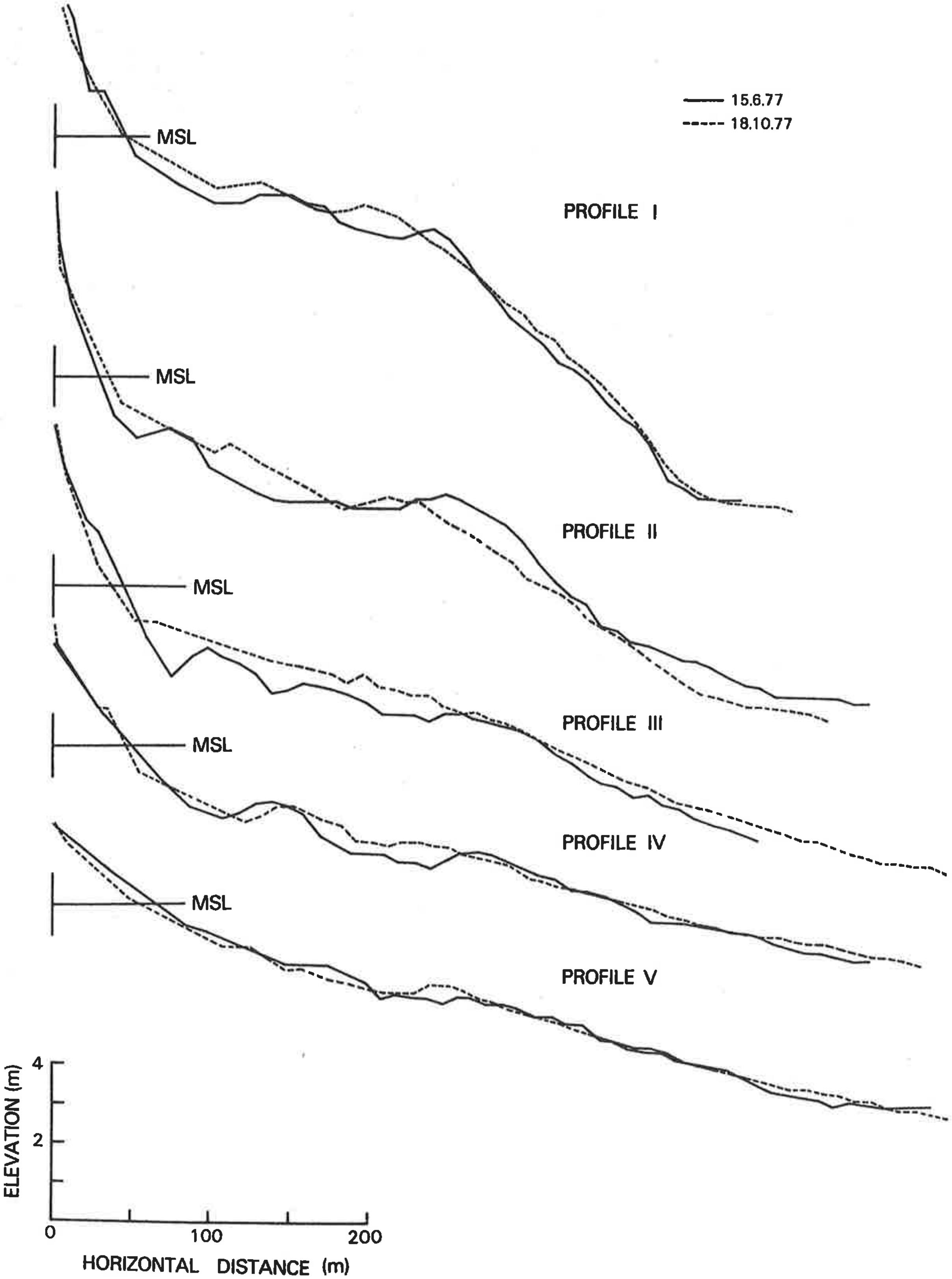

Fig. 13. Nearshore extensions of the five beach profiles around Lyall Bay.

Table 2. Volumes of sediment involved in beach changes between 21.12.76 and 22.12.77.

Profile No.	Total volumes in sweep-zone envelope curve (m^3/m).	Total volume of material in transit in beach (m^3).	Volumetric change summer to winter (22-12-76 to 8-7-77) (m^3/m).	Total volume in transit summer to winter (m^3).	Volumetric change winter to summer (8-7-77 to 22-12-77) (m^3/m).	Total volume in transit winter to summer (m^3).
1	90	21,600	- 62.5	- 15,000	+ 50.62	+ 12,150
2	80	19,200	- 28.1	- 6,740	+ 24.4	+ 5,850
3	112	26,880	- 53.1	- 12,740	+ 22.5	+ 5,400
4	95	22,800	- 41.9	- 10,050	+ 39.4	+ 9,450
5	65	15,600	- 40.6	- 9,740	+ 30.6	+ 7,350
TOTAL		106,000		- 54,270		+ 40,200

within the envelopes are therefore probably typical of what might be expected in any one year.

Volumetric Changes

Over the 12-month survey period volumes of material in the sweep zone envelopes ranged from 65 m^3/m of beach length at the low energy western end to 112 m^3/m at the higher energy centre of the bay (Table 2). Assuming the five beach profiles are representative of the beach, the total volume of material in transit on the beach is of the order of 106,000 m^3 per year (Table 2). Most of this is onshore/offshore transfers with the seasonal cycle of winter cut and summer fill accounting for at least half the total volume of material within the sweep zone (Table 2). During periods of erosion *all* profiles are eroded and likewise during periods of recovery *all* profiles are restored. There are no lateral shifts of large volumes of material around the bay.

CONCLUSIONS

Lyall Bay beach formed on the southern edge of a tombolo connecting the Miramar Peninsula with the mainland, blocking off a former shallow entrance to Wellington Harbour. The sandy beach has prograded seaward from sediment sources on the continental shelf and by uplift in recent earthquakes. Prior to European settlement the beach was backed by dunes and approached an equilibrium log spiral plan shape developed from the natural rock breakwater in the eastern approaches to the bay. In the last century the dunes have been taken over for housing, a sea wall built at the head of the beach, and the eastern third of the beach 'reclaimed' for airport runway extensions. As a result of the reclamation the plan shape of the bay has been altered causing sections of the sea wall to erode. Changes in the shape of the beach are reflected in changes in the nearshore bathymetry.

The beach and nearshore morphology, and changes in morphology are a direct response to the wave climate, the largest changes to the beach system taking place in the high-energy centre of the beach, with smaller

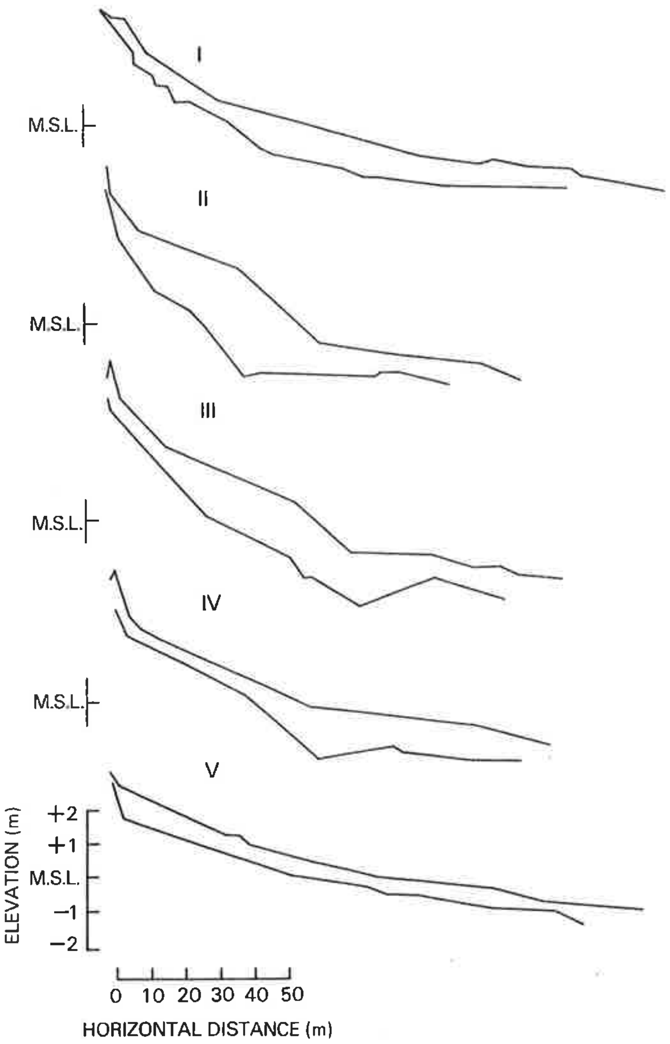

Fig. 14. Beach envelope curves for the five profiles around Lyall Bay. The curves are based on the monthly beach surveys between 21.12.76 and 22.12.77.

changes at the more sheltered ends. Lyall Bay is a high-energy beach exposed to southerly swell and storm waves. During periods of calm or low energy the beach has low berms, midway up the profiles. These are removed during storms and replaced by a wide concave planar profile. The wave climate on the south Wellington coast is seasonal, increasing in height and steepness in winter. As a result the beach exhibits similar seasonal changes in morphology with a downcombing, steepening, and landward retreat of the shoreline in winter and a reversal of this movement in summer. Sediment removed from the beach in winter is added to the nearshore bar system. The outer bar grows and moves seaward in winter. The inner bar moves in the reverse direction being tied to beach changes on the foreshore. The annual sand budget for Lyall Bay incorporates at least 106,000 m^3 of sediment, more than half of which can be accounted for in seasonal changes in morphology.

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REFERENCES

BEST, E. 1923: Miramar Island and its history : How Motu-kairangi was discovered and settled by Polynesians, and how, in times long past, it became Miramar Peninsula. *Trans. Proc. N.Z. Inst. 54* : 779–91.

BRITISH ADMIRALTY, 1903: Portion of Port Nicholson sounding collector 1:24,000. Hydrographic Department, London.

BRODIE, J.W. 1966: Cook Strait Bathymetry. *N.Z. oceanogr. Inst. Chart, Coastal Ser. 1:200,000.*

CAMPBELL, G.R. 1978: Moa Point outfall project. Sea bed sediment movement. Unpublished report, Wellington City Corporation, Wellington. 3 pp.

COTTON, C.A. 1912: Notes on Wellington Physiography. *Trans. Proc. N.Z. Inst. 44* : 245–65.

GILMOUR, A.E.; RIDGWAY, N.M. 1975: Currents in Lyall Bay, Wellington, New Zealand. *NZOI Rec. 2(9)* : 105–12.

KING, C.A.M. 1972: "Beaches and Coasts". Edward Arnold, London. 570 pp.

LEWIS, K.B.; CARTER, L. 1976: Depths, sediments and faulting on each side of the Rongotai Isthmus, Wellington. *NZOI oceanogr. Summ. 11* : 31 pp.

McLEAN, R.F. 1967: Plan shape and orientation of beaches along the east coast, South Island, New Zealand. *N.Z. Geogr. 23* : 16–22.

MARINE DIVISION, MINISTRY OF TRANSPORT, 1976: New Zealand tide tables for the year 1977.

N.Z. HYDROGRAPHIC OFFICE, 1969: Wellington Harbour, 1:25,000. *Chart N.Z. 4633.*

PICKRILL, R.A. 1977: Coastal processes, beach morphology and sediments along the north-east coast of the South Island, New Zealand. *N.Z. Jl Geol. Geophys. 20(1)* : 1–15.

PICKRILL, R.A.; MITCHELL, J.S. (in press): The wave climate of New Zealand. *N.Z. Jl mar. Freshwat. Res.*

SHEPARD, F.P. 1950: Beach cycles in Southern California. *Tech. Memo. Beach Erosion Bd 20.*

SILVESTER, R. 1974: "Coastal Engineering", Vol. 2. Elsevier, Amsterdam. 338 pp.

STEVENS, G.R. 1974: "Rugged Landscape. The geology of central New Zealand". Reed, Wellington. 286 pp.

YASSO, W.E. 1965: Plan geometry of headland-bay beaches. *J. Geol. 73* : 702–14.

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