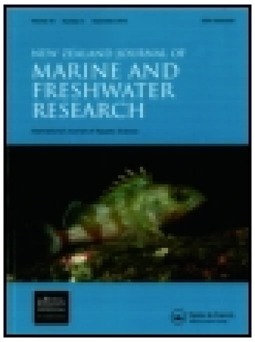

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R. A. Pickrill

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A micro-morphological study of intertidal estuarine surfaces in Pauatahanui Inlet, Porirua Harbour

R. A. PICKRILL

New Zealand Oceanographic Institute, Department of Scientific and Industrial Research,
P.O. Box 12-346, Wellington North, New Zealand

Monthly changes in the elevation of the intertidal flats in Pauatahanui Inlet over a 15-month period were measured to the nearest 0.5 mm. Changes were small, mostly less than ±10 mm, and erosional events were as frequent as depositional ones. Net deposition of 2.9 mm was recorded over a 12-month period. The mid-tidal area, high tidal sand beaches, and the deltas of the inflowing streams are the least stable zones.

INTRODUCTION

On a geological time scale, rates of estuarine sedimentation have been derived using a variety of dating techniques on material preserved in the geological record. On shorter time scales, sediment transport by tidal currents and wind waves has been studied over tidal cycles, annually, and over longer periods. These techniques involve different approaches, one emphasising paleoenvironmental reconstruction, the other concentrating on the physical processes of sediment transport. Between these two extremes very little is known about the short-term stability of estuarine sediment surfaces.

In this paper monthly changes in the micro-morphology of Pauatahanui Inlet are described and related in a general way to environmental conditions. Monthly and annual changes in the sediment surface are outlined, the influence of storm events on micromorphology is described, and local variations in the stability of the intertidal sediment surface are discussed.

PAUATAHANUI INLET

Pauatahanui Inlet is an eastern extension of Porirua Harbour (Fig. 1). During the late Pleistocene it was a shallow embayment of the sea, but has subsequently been cut off from the open coast by a southward-growing Holocene spit. The inlet comprises two bathymetric units: the eastern section is a gently sloping basin with maximum water depths of 2.4 m (Irwin 1978); the western, seaward section has intertidal banks dissected by distributory channels draining southward into the main channel on the northern side of the greywacke outcrop of the Golden Gate Peninsula.

Six streams discharge into the inlet, with a combined freshwater inflow of $75.3 \times 10^6\ m^3.y^{-1}$ and an estimated annual suspended sediment input of 13 360 t (Healy 1977). Nothing is known of stream bed load contributions or the inflow of sediment from the open coast. The three largest streams—the Pauatahanui, Horokiwi, and Kahao—have well developed, progradational deltas, and though rather small are probably a major source of sediment. The Mana and Central banks, just inside the inlet entrance, probably represent a flood tide delta formed from sediment sources outside the inlet, on the open coast.

As in most estuaries the surface sediment distribution reflects the energy available to transport, deposit, and redeposit sediment (e.g., Allen 1971). The eastern basin sediments are silty, coarsening to silty sands on the shallower margins and intertidal flats (McDougall 1976). Tidal currents are probably weak on these flats and margins, where locally generated wind waves are probably the most important agent of sediment transport. Tidal currents are strongest ($1\ m.s^{-1}$) in the channels and on the bank margins at the western end of the inlet (Healy, in press). These high-energy areas are mantled with sand, shell, and gravel.

INTERTIDAL MORPHOLOGY

The largest intertidal areas are associated with the major sources of sediment – the deltas of the inflowing streams, and the flood tide delta of the Mana and Central banks. Although much of the area exposed at low tide can be attributed directly to deltaic sedimentation, this area was probably increased by the 1855 earthquake, which raised the area by about 1 m (Adkin 1921, Stevens 1974, pp. 186 & 239). Representative cross-sections show that most intertidal areas have gradients ranging from 1 in 100 to 1 in 200 (Fig. 2). The sediments veneering most of these flats are poorly sorted muddy (0.80–4.80ϕ) sands incorporating particles in a wide range of sizes from sands to clays. At the top of the flats, where wave activity is concentrated at high tide, the sediments may be

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well sorted, with the mud washed out and redistributed over the rest of the profile and the sand concentrated in a narrow, steep beach (gradients 1 in 10 to 1 in 20). Similarly, at low tide wave action may separate the sand and mud fractions to form a sandy, low tide bar. On the flats sheltered from wave action, such as the upper delta of Ration Point Stream, salt marsh vegetation colonises the area around high water mark. The seaward edge of the vegetation is commonly marked by a small step, which originates either from cliffing of the marsh edge by wave action, or from the presence of the community itself, which accelerates deposition; probably both processes combine to produce the step. Large sand waves or mega-ripples with wavelengths of 15–20 m and amplitudes up to 0.1 m form on the more exposed flats where wave and tidal currents are stronger and there is less mud in the sediments ($<10\%$).

All the streams flowing across the deltas enter the estuary through single, well defined channels. Levées are well developed on the upper deltas of some of these streams (e.g., Fig. 2, Profiles 2 & 7), but during flood flows these are overtopped, and a complex system of shallow, braided flood channels are brought into use. The Horokiwi and Kahao streams have well developed bird's-foot deltas.

Morphologically the intertidal banks (Fig. 2, Profiles 8 & 9) are similar to the fringing flats. Slopes are low except close to high water, where strong tidal currents and wave action concentrate coarser material into steeper banks and beaches. Unlike the fringing flats, the banks are crossed and bounded by comparatively steep-sided channels lined with coarse sand and shell. These channels are maintained by strong tidal flows draining the waters of the upper inlet.

Although Pauatahanui Inlet was raised by the 1855 earthquake it has been very stable morphologically over the past 31 years (Irwin 1976). Vertical aerial photographs show only a few small changes in the position of stream channels across the deltas and in the form of the banks.

METHODS

In dynamic studies of coastal geomorphology various methods of surveying have been used to measure changes in morphology. On high-energy beaches, where measured changes are large, a great deal of information has been collected on long-term, short-term, and cyclical trends in beach behaviour. However, in low-energy environments such as estuaries, errors in the surveying systems may approach the measured changes in magnitude, and the results

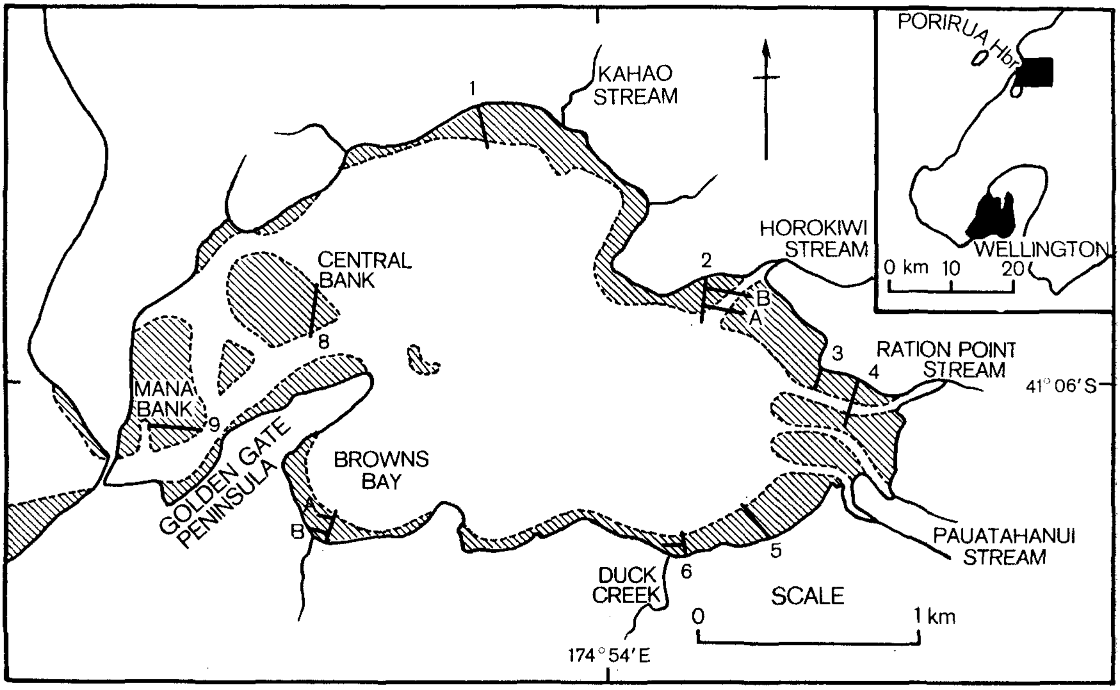

Fig. 1. Pauatahanui Inlet, showing intertidal area and location of representative cross-sections illustrated in Fig. 2.

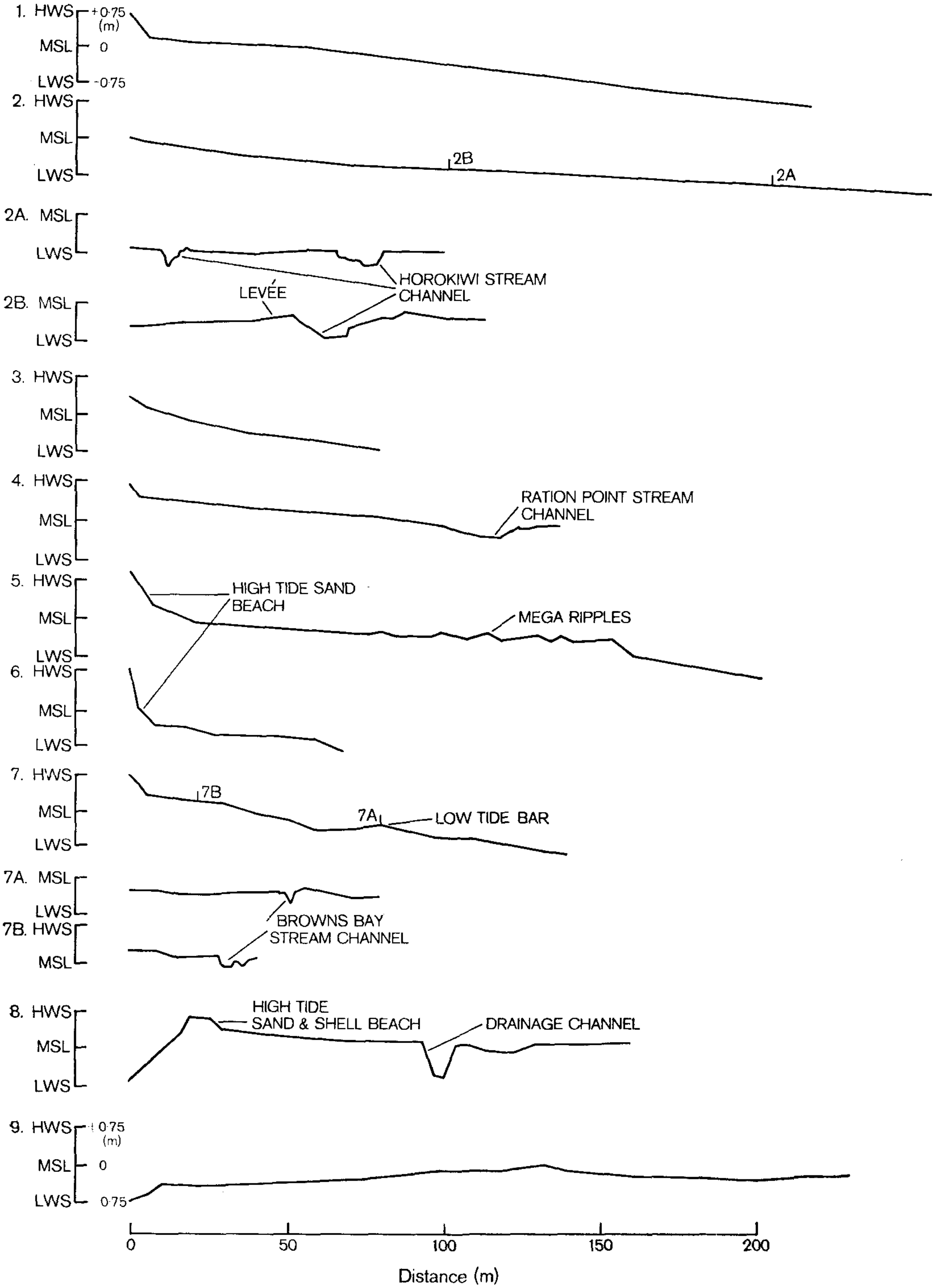

Fig. 2. Surveyed intertidal cross-sections marked in Fig. 1, showing major morphological features; position of mean sea level approximate.

become meaningless. This is particularly true of long profiles across intertidal flats such as at Pauatahanui Inlet.

Intertidal transects were surveyed with a Quick Set level and a series of 6 mm diam. galvanised steel rods driven into the surface as reference markers, from which all future changes in surface elevation were measured. Altogether 122 rods were laid out on 1.85 km of transects, and spaced at roughly 15 m intervals. Changes in surface elevation were assessed by measuring differences in the length of rod exposed; initially the rods were driven 800 mm into the sediment, leaving approximately 120 mm exposed. The measuring device (Fig. 3) is designed to slide over the rods and sit on the substrate on a 150 mm diam. circular foot. A sliding indicator with a locking head is lowered on to the top of the rod, the device is removed, and the length of rod exposed is read off against the graduated scale to the nearest 0.5 mm. Similar systems have been used on open coastal beaches to measure changes over single tidal cycles (Duncan 1964, Strahler 1966). Strahler considered this system to be accurate to 0.01 inches (0.3 mm); the present system is considered to have an error of 0.5 mm. Burrowing by benthic animals, such as that visible in Fig. 3, disturbed the surface at some stations. Any animals or casts protruding above the generally smooth sediment surface were carefully removed while a measurement was taken, and then replaced. Over a 15-month period starting March 1976, 1350 readings were scheduled to be taken at approximately monthly intervals. However, permanent loss of markers due to vandalism, or temporary loss because of insufficiently low tides, meant that only 80% of these readings were obtained. Surface sediment samples were taken at representative stations along each profile and analysed for texture.

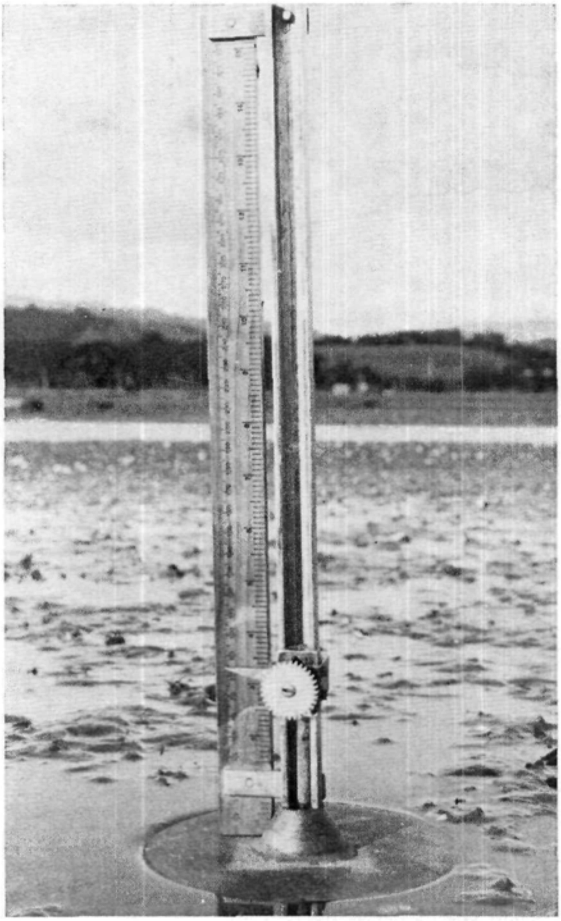

Fig. 3. Instrument used to measure small changes in elevation of sediment surface (see 'Methods' for description).

RESULTS AND DISCUSSION

MONTHLY CHANGES IN THE SEDIMENT SURFACE

Monthly changes at each site are tabulated as erosion or deposition by comparing the length of rod exposed with that exposed the previous month (Fig. 4). Changes in the bed are very small (excluding the creek crossing transects), ranging from maximum deposition of 47 mm of sediment at one station on Profile 2 to erosion of 28 mm at one station on Profile 1. The histogram combining all stations shows that 55.5% of all monthly changes fall within the range of ±2 mm; less than 6% exceed ±15 mm. Clearly, over this monthly time scale the intertidal surface is stable, and is thus particularly suitable for colonisation by benthic organisms.

On most of the profiles the distribution of changes is nearly symmetrical and centred at, or close to, zero change. This is significant in indicating that estuarine infilling is not a continuous depositional process, but rather that periods of deposition and erosion are intermixed, the sediment surface oscillating within a limited range. The general symmetry of the distribution of changes also suggests that erosional and depositional events are of similar magnitude and frequency, i.e., there is no long, slow, steady build-up of sediment followed by a short, rapid period of erosion, or vice versa. Periodic small fluctuations in the sediment surface are produced by complex interactions between wave and tidal processes and varying rates of sediment supply. However, this is not to say that over longer periods there is not some overall net trend towards infilling, smoothing out these fluctuations of shorter periodicity.

ANNUAL CHANGES AND SEDIMENTATION RATES

Average monthly changes were plotted as a function of the original surface elevation (Fig. 5). The overall

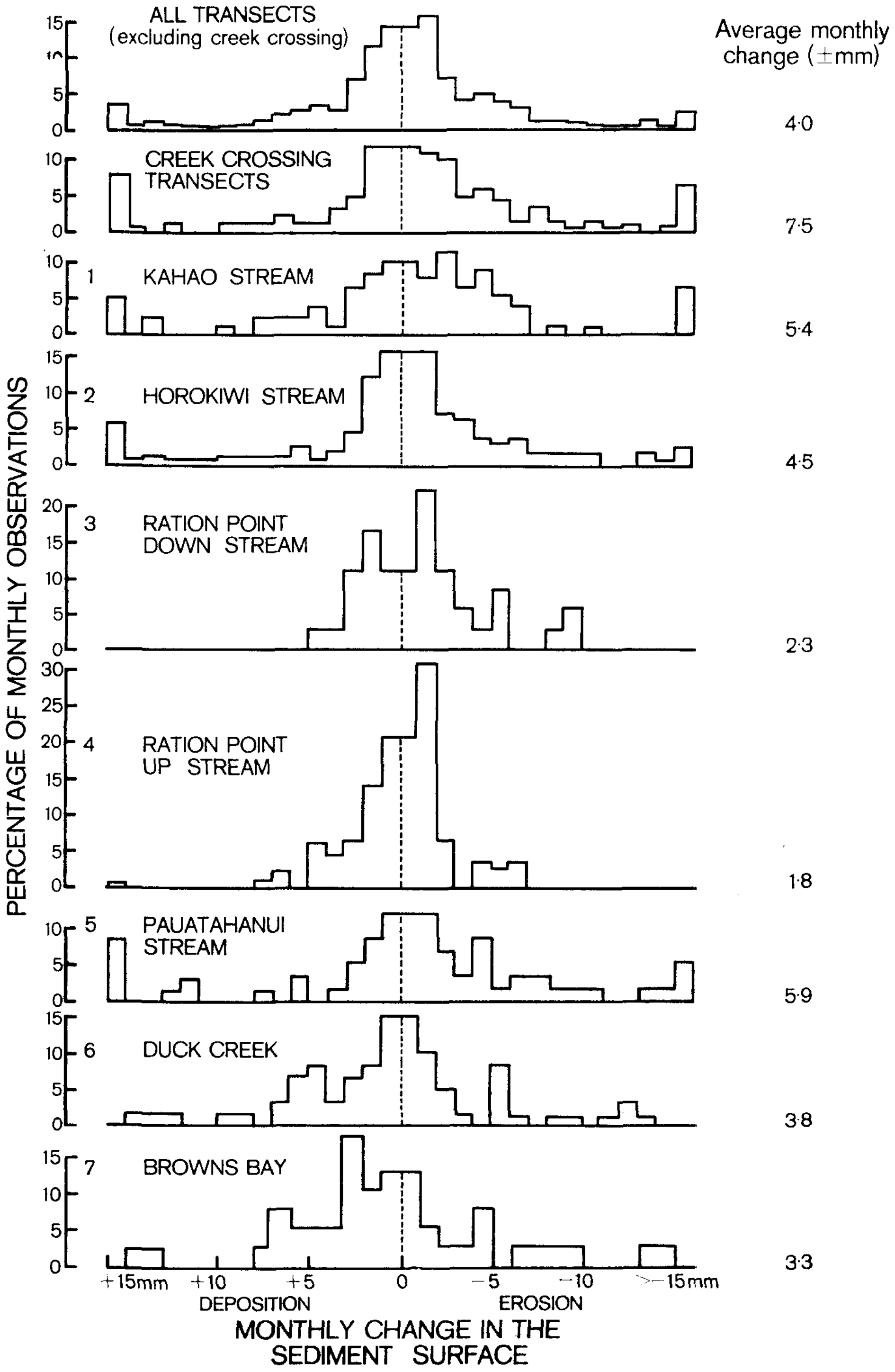

Fig. 4. Frequency distribution of monthly changes in elevation of the sediment surface for 1082 measurements made on 7 inter-tidal transects and delta-crossing transects, Pauatahanui Inlet. The average monthly change (mm) shown averages all changes, ignoring the sign.

trend on all profiles, except number 3, was towards deposition. However, deposition is not continuous; monthly averages show periods of erosion and deposition to be mixed (except in November, when for no apparent reason all but one of the profiles eroded). Despite this episodic raising and lowering of the sediment surface there was a net gain of sediment to the intertidal area after 15 months' observation.

Over the whole inlet, some stations displayed annual net deposition and others annual net erosion. Most changes were less than ±20 mm.y^{-1}, with a maximum erosion of 64 mm.y^{-1} and a maximum deposition of 47 mm.y^{-1}. However, the mean annual trend is towards deposition, and hence infilling of the intertidal flats, at the rate of 2.9 mm.y^{-1}. Not too much emphasis should be placed on a sedimentation rate derived from measuring changes in morphology over a relatively short period. However, this rate is similar to the 2.4 mm.y^{-1} derived from the stratigraphic record for the past 3600 y (Healy, in press), and compares favourably with values for other temperate-latitude estuaries, where typical rates of sedimentation are 2–3 mm.y^{-1} (Rusnack 1967, Skempton 1970).

Except on Transects 3 and 4, the average monthly changes in the sediment surface (Fig. 4) are larger than the annual rate of sedimentation. Therefore a monthly change of ±20 mm (recorded 22% of the time) effectively reworks the previous 7 years' sedimentation. Short-period fluctuations in the sediment surface are several times the annual sedimentation rate.

INFLUENCE OF STORM EVENTS ON SEDIMENTATION RATES

Rates of freshwater inflow and sediment input to the estuary are extremely variable, with maximum inputs during storm events. During the period of observation, two storm events contributed 31% of the total annual suspended sediment supply in 9 days (Healy 1977). One might expect such large sediment inputs over a short period to be reflected in changes in the sediment surface, but no marked deposition or erosion was found in the monthly surveys immediately following these two storm events (Fig. 5). Since large volumes of sediment apparently do not settle in the intertidal zone during storm events, sediment is presumably either worked offshore to settle in the deeper, calmer waters of the subtidal zone or removed from the inlet altogether by tidal currents.

Despite this lack of evidence for widespread deposition during floods, high rates of scour and deposition were found locally on the lower deltas close to the flood channels of streams. Most of the accretional deposits were made up of three distinctly separate beds: an underlying, poorly sorted muddy sand; a well sorted medium sand up to 20 mm thick; and an overlying veneer of mud often only 1–2 mm thick. These three beds probably represent three distinct depositional stages through the storm event, the basal muddy sand being the pre-flood surface, the medium sand the stream bed load flood deposit, and the veneer of mud a post-flood suspension load deposit derived from either the stream or the turbid estuarine waters. Although such sequences are locally preserved immediately after storm events, they are not preserved between monthly surveys or over the longer time scales of the geological record. McDougall (1976) found no stratified layering in any of 19 short cores (28–58 cm long) taken from the inlet; most of them comprised poorly sorted silty sands or sandy silts. There is no direct evidence of bioturbation in any of the cores, but the intertidal area is rich in benthic infauna such as bivalves and polychaetes, which are capable of turning over large volumes of sediment. Bivalves can rework the top 70 mm of sediment (Haven & Morales-Alamor 1966), and polychaetes can rework sediment from greater depths (K. R. Grange, pers. comm.). Any stratified flood deposits are therefore probably capable of being rapidly reworked by the benthic infauna into poorly sorted silty sands and sandy silts, as preserved in the cores. Thus, in any examination of core stratigraphy the effects of bioturbation restrict precise interpretation.

SHORE-NORMAL CHANGES IN THE SEDIMENT SURFACE

The absolute average monthly changes in elevation over the observation period are plotted against the surveyed profiles in Fig. 6. Although there are differences between stations on each profile, overall trends are hard to depict; but some generalisations can be made.

The largest changes are assumed to be on the steep sand beaches developed at high water level in response to breaking waves (Fig. 6, Profiles 5–7). It proved impossible to maintain reference rods over long periods on these beaches, because the rods were buried or eroded out of the sediment surface. The well sorted sediments and steep profiles suggest that these beaches respond to wave activity in a similar manner to open coastal beaches, but on a smaller scale. They are also subject to similar cycles of change. Changes were generally smallest at the seaward end of each transect, in the area uncovered only during spring tides. Likewise, changes were small at the top of those transects with salt marsh vegetation inundated only for short periods at high water. Excluding the high tide beaches, changes were largest around mean water level in the area most frequently swept by tidal fluctuations in water level.

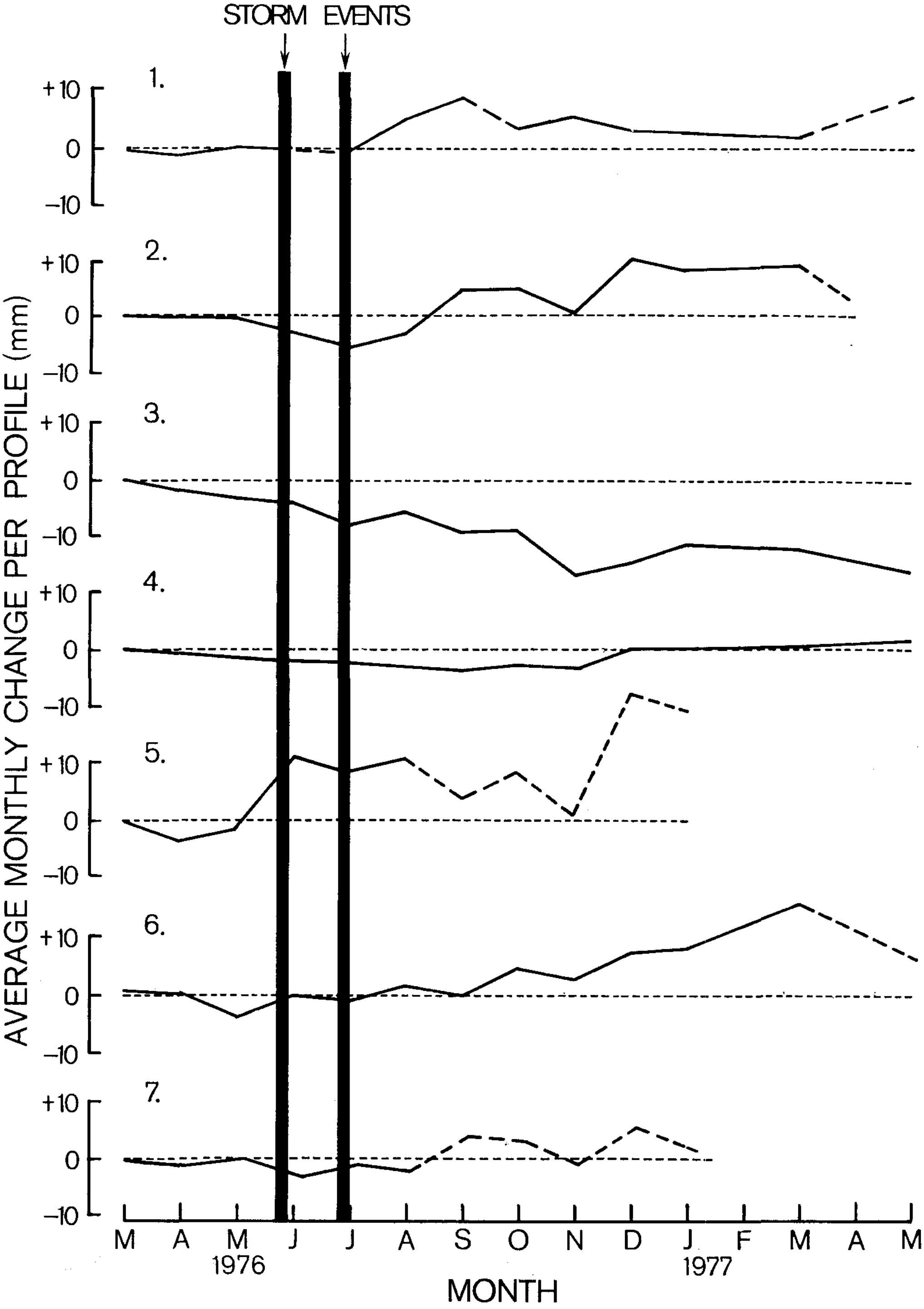

Fig. 5. Seasonal distribution of mean monthly changes in sediment surface elevation, Pauatahanui Inlet (--, less than 50% of the original stations sampled).

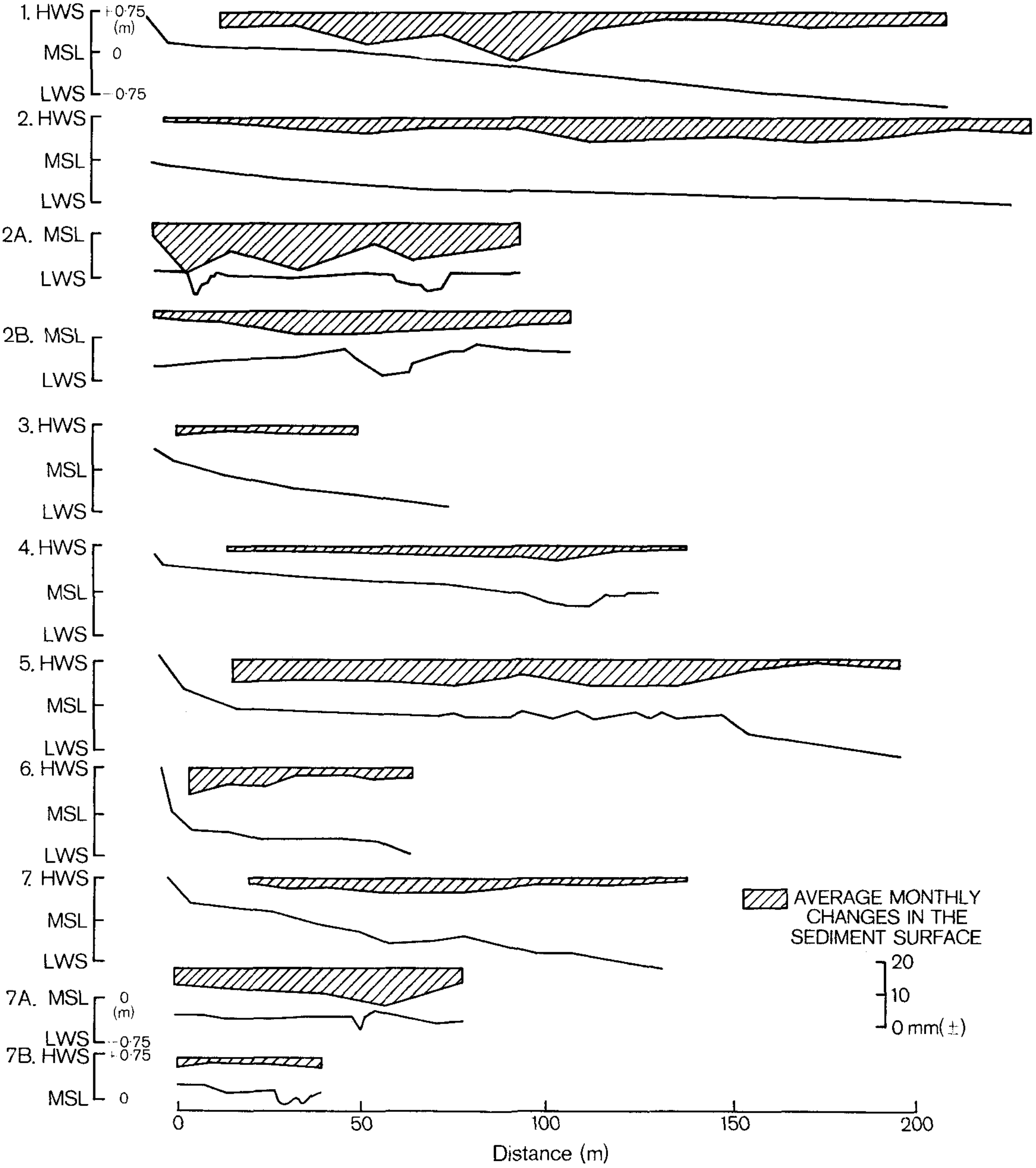

Fig. 6. Mean monthly changes in the sediment surface on each transect, Pauatahanui Inlet. To provide some idea of continuity of change down each transect, successive means are connected by a continuous line.

VARIATION IN SURFACE STABILITY BETWEEN TRANSECTS

The most stable profiles were at the head of the inlet, in the most sheltered area (Fig. 4, Profiles 3 & 4). However, the spacing of the transects around the inlet complicates detection of any further energy differences and associated differences in the stability of the sediment surface. Nor do temporal variations in the stability of the surface follow any obvious pattern. Storm events have no overriding influence on the stability of the surface, and there were no common trends through the period of observation.

Sediment texture affects the stability of a sediment surface, and this might cause local variations in the inlet. Hjülstrom (1935) and others have produced "competency curves" to predict the initiation of sediment movement at the bed for a wide range of grain sizes. Sediment requiring the lowest critical erosion velocities to initiate movement would form the most mobile, unstable surface, and vice versa. The results obtained at Pauatahanui do not follow any pattern (Fig. 7A), suggesting that grain size is not the dominant factor. There is, however, a strong negative relationship between mean monthly change and the sorting of the sediments – the best-sorted sediments provide the most unstable surface (Fig. 7B). The sorting parameter (inclusive graphic standard deviation) has been used as an environmental indicator, well sorted sediments reflecting efficient sorting processes in the hydraulic environment (Folk 1968). If this is so, the well sorted sediments at Pauatahanui would form the most mobile, unstable surface, as indicated in Fig. 7.

STABILITY OF STREAM DELTAS

Six transects were laid across the deltas of four of the inflowing streams (Fig. 1). The monthly variability in the elevation of the sediment surface increases towards the channels (Fig. 6), but reference markers in the channels themselves show the stream beds to be relatively stable, with monthly changes only slightly larger than those measured on the nearby flats. On Profiles 2 and 7 (Fig. 1) transects were laid across the upper delta, where the stream occupies a single channel, and across the bifurcated bird's-foot of the lower delta. On both streams the upper cross-section was most stable, with monthly changes similar to those on the shore-normal transects. Changes on the lower transects were at least twice those on the upper transects, so the more mobile lower delta is probably the zone of active sediment input to the estuary. From comparison of aerial photographs taken over a 31-year period, Irwin (1976) also found the greatest long-term changes on the lower deltas of the streams.

THE SEDIMENT BUDGET

In any estuary there is a balance between sediment entering the system, sediment leaving the system, and sediment being eroded from or deposited on the bed. If inputs, outputs, and sedimentation rates are known a sediment budget can be calculated. Sediment inputs to Pauatahanui Inlet originate from freshwater inflow and from material worked into the inlet from the open sea. Output consists of material carried seaward through the entrance to the open sea, and changes in the sediment surface reflect changes in the storage of sediment within the estuary itself.

Sedimentation of 2.9 $\mathrm{mm.y^{-1}}$ in the intertidal area results in the deposition of 3300 t of sediment. If it is assumed that this sedimentation rate is uniform over the entire inlet (not an unreasonable assumption, considering the average sedimentation rate of 2.4 $\mathrm{mm.y^{-1}}$ derived from ^{14}C dating), then a total of 9600 t of sediment would be added each year.

The texture of the surface sediments in the inlet reflects the processes of sediment transport. Approximately 55% of sediments are sandy or coarser, and the remaining 45% muddy (McDougall 1976). The muddy sediments are deposited out of suspension, and the coarser material originates as bed load. On this basis, of the 9600 $\mathrm{t.y^{-1}}$ added to the inlet approximately 5300 t probably originated as bed load and 4300 t as suspended load.

Over the period for which the sedimentation rate was derived, 13 300 t of sediment was introduced to the inlet in suspension from the surrounding streams, plus an unknown quantity of coarse bed-load material. However, only 4300 t of suspended sediment was retained. Therefore 9000 t, or more than two-thirds of the sediment input, is flushed through the inlet to the open sea.

The year of study was an exceptional one in that suspended sediment input was more than three times the long-term mean annual sediment yield of 3900 tonnes. In less extreme years a much higher proportion of sediment input might be retained in the inlet.

CONCLUSIONS

Over a period of 15 months the surface of the intertidal flats in Pauatahanui Inlet was very stable; mean monthly changes in surface elevation were of the order of a few millimetres. No distinction can be made between erosional and depositional events on the basis of either the frequency or the magnitude of changes. However, monthly oscillations in the intertidal surface resulted in an annual sedimentation rate similar to that found in other temperate-latitude estuaries. The surface of the intertidal flats is most stable in the low tidal to subtidal zone, in the more

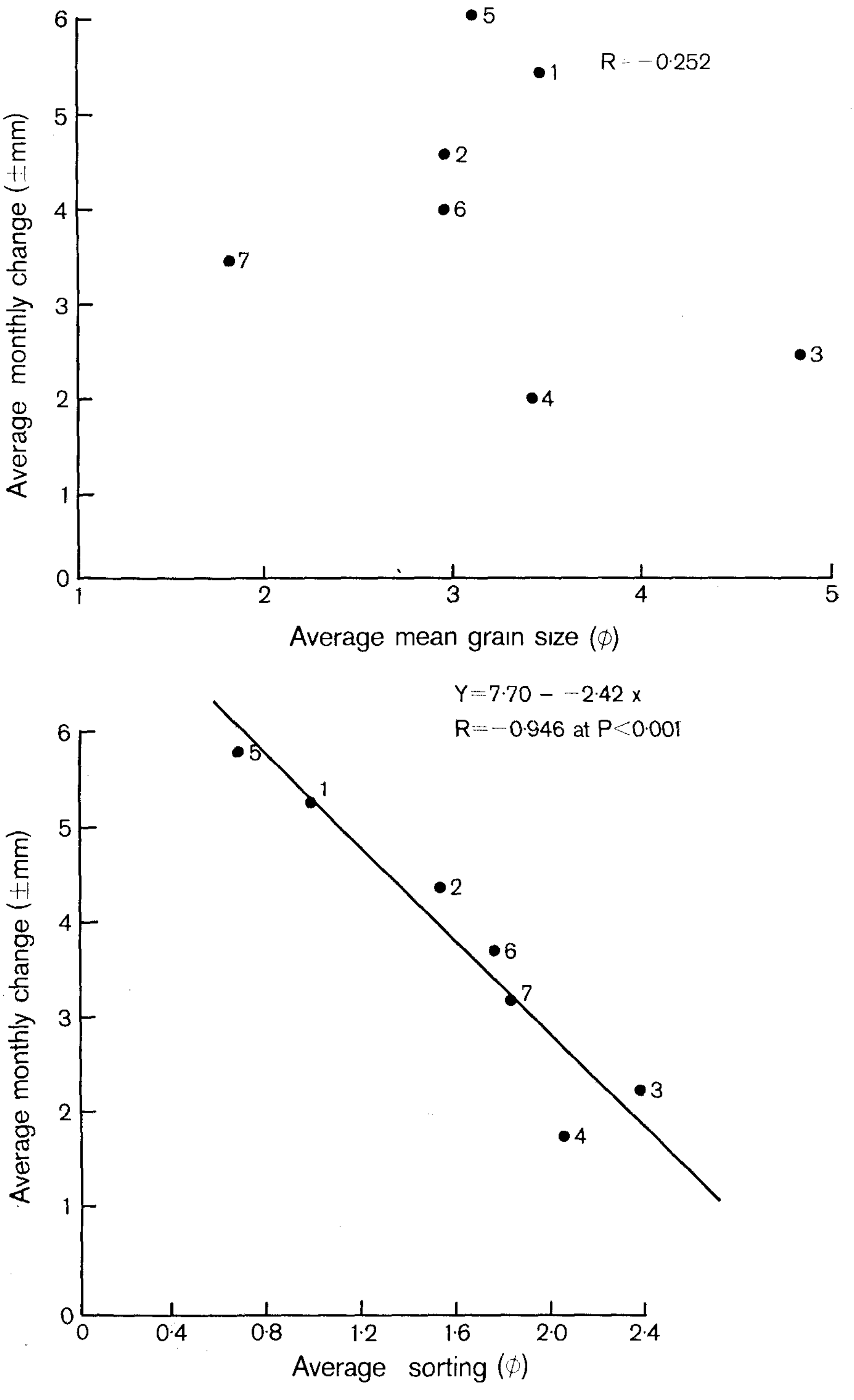

Fig. 7. Scattergrams showing relationship between mean monthly change in the sediment surface and (A) average mean grain size, (B) average sorting on each profile, Pauatahanui Inlet.

sheltered, lower-energy parts of the inlet, and in areas mantled with poorly sorted sediments. The most unstable sites are the steep beaches developed at high water level in response to breaking waves, and the lower deltas of the inflowing streams. Flood events apparently had no overriding erosional or depositional influence on intertidal morphology. Bioturbation by benthic organisms probably destroys any stratified evidence of flood events that might be preserved in the geological record. Of the suspended sediment introduced to the inlet from freshwater sources, probably more than two-thirds is flushed through to the open sea.

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REFERENCES

ADKIN, G. L. 1921: Porirua Harbour. A study of its shoreline and other physiographic features. *Transactions & Proceedings of the N.Z. Institute* 53: 144–56.

ALLEN, G. P. 1971: Relationships between grain size parameter distribution and current patterns in the Gironde Estuary (France). *Journal of Sedimentary Petrology 41*: 74–88.

DUNCAN, J. R. 1964: The effects of water table and tide cycle on swash-backwash sediment distribution and beach profile development. *Marine Geology 2*: 186–97.

FOLK, R. L. 1968: *Petrology of Sedimentary Rocks.* Hemphills, Austin (Texas).

HAVEN, D. S.; MORALES-ALAMOR, R. 1966: Use of fluorescent particles to trace oyster biodeposits in marine sediments. *Journal du Conseil Permanent International pour l'Exploration de la Mer 30*: 267–69.

HEALY, B. (Ed.) 1977: Pauatahanui Environmental Programme. *Newslettter 6.* (Available from Soil Bureau, DSIR, Wellington.)

——— (Ed.) (in press): Pauatahanui Inlet—an environmental study. *DSIR Information Series.*

HJÜLSTROM, F. 1935: Studies of the morphological activity of rivers as illustrated by the River Fyris. *Bulletin of the Geological Institution of the University of Uppsala 25.*

IRWIN, J. 1976: Morphological stability of Pauatahanui Inlet, Porirua Harbour. *N.Z. Journal of Marine & Freshwater Research 10*: 641–50.

——— 1978: Pauatahanui Inlet - Provisional Bathymetry. *N.Z. Oceanographic Institute Chart, Miscellaneous Series* (1:5000).

MCDOUGALL, J. C. 1976: Distribution of surface sediments of Pauatahanui Inlet. *NZOI Oceanographic Field Report 7.*

RUSNACK, G. A. 1967: Rates of sediment accumulation in modern estuaries. In LAUFF, G. H. (Ed.), 'Estuaries'. *Publications of the American Association for the Advancement of Science 83.*

SKEMPTON, A. W. 1970: The consolidation of clays by gravitational compaction. *Quarterly Journal of the Geological Society of London 125*: 373–408.

STEVENS, G. R. 1974: *Rugged Landscape — the Geology of Central New Zealand.* Reed, Wellington.

STRAHLER, A. N. 1966: Tidal cycle of changes in an equilibrium beach, Sandy Hook, New Jersey. *Journal of Geology 74*: 247–68.