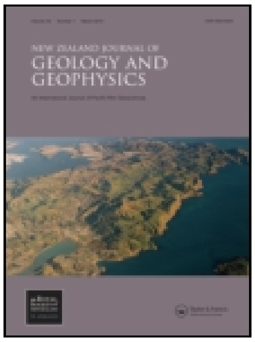

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J. C. Schofield

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Coastal change at Omaha and Great Barrier Island

J. C. SCHOFIELD
New Zealand Geological Survey
Department of Scientific and Industrial Research
P.O. Box 61 012
Otara, New Zealand*

Abstract Since 1966, the relative greater degree of erosion at Omaha, on the east coast north of Auckland, near which substantial inshore dredging had occurred up until 1963, compared with that at Great Barrier Island where there has been scarcely any dredging, has been due to an offshore buildup of an ebb-tide delta at Omaha rather than to a continuing effect of the earlier period of dredging of sand for industrial use. Change in predominant wind direction has probably been a factor, particularly in the marked erosion at the sensitive northern end of Mangatawhiri Spit at Omaha. Five different orders of sea-level change and associated sea-floor and coastal change are recognised. Time is an important factor in determining whether or not full equilibrium is reached and in controlling the area of sea floor that is affected by sea-level change. The longer the period of time, the greater the area of sea floor affected. Another probable limiting factor is the offshore coarse belt.

Keywords coastal environment; erosion; changes of level; climate effects; time factor; fluctuations; Omaha; Great Barrier Island

INTRODUCTION

From 1965 to 1968, a number of beach profiles across the contiguous Kaitoke and Palmers Beaches on Great Barrier Island, and across Omaha Beach 60 km north of Auckland (Fig. 1), were surveyed at approximately monthly intervals. Comparison of the beaches in the two areas (Schofield 1975a) appeared to show that Omaha Beach eroded at a "tentatively calculated rate" of 4750 (m^3/km)/year over and above naturally caused change in beach volume proportional to similar changes at Great Barrier. It was concluded (Schofield 1975a), that this rate of 4750 (m^3/km)/year "may include the continued effect of a more localised removal of sand" that is, the effect from shallow offshore dredging of sand for industrial use that took place in Omaha Bay between 1942 and 1963, but not at Great Barrier.

During this initial monitoring of the Great Barrier and Omaha beaches, it was assumed that, as both are exposed to the east and at no great distance apart, they would be subjected to similar natural influences such as sea-level change and wind and swell direction. As the Great Barrier beaches do not lie along the same coast as that at Omaha, dredging off Omaha would have no effect on the Great Barrier beaches and thus they would provide a baseline for determining whether or not Omaha Beach was being eroded by some additional cause. However, one factor was not taken into account, namely, the presence of Whangateau Harbour behind Omaha Beach. This has led to the development of an ebb-tide delta at the entrance to Whangateau Harbour at the northern end of the Omaha Beach. The growth of this ebb-tide delta (Riley et al. 1985, this issue) accounts for all the sand that appeared to be missing from Omaha Beach. There is thus no need to ascribe continued beach losses to delayed reaction from the earlier period of nearshore dredging.

The 1980 period of monthly surveys along the same beach profiles as those surveyed across Omaha and the Great Barrier beaches during 1965–68 (Schofield 1975a) has enabled a reasonably accurate determination of the volumetric changes of the coastline that have occurred up to 1980 in these two areas. However, coastal behaviour at the northern end of Omaha Beach, which lies at the entrance of Whangateau Harbour, has been substantially different from that of the rest of the coastline. It is thus treated separately in the description of the 1966–80 coastline changes that forms the first part of this paper. The second part is concerned with probable causes for coastal change and the possible influence of a number of different orders of sea-level change.

The beach profiles were surveyed from a number of stations established within surveyed networks at Omaha and the Great Barrier beaches. Their positions are shown in diagrams given by Schofield (1975a). More accurate positions and copies of all beach-profile surveys are housed by the New

*Present address: 43 Whakarite Rd, Ostend, Waiheke Island, New Zealand

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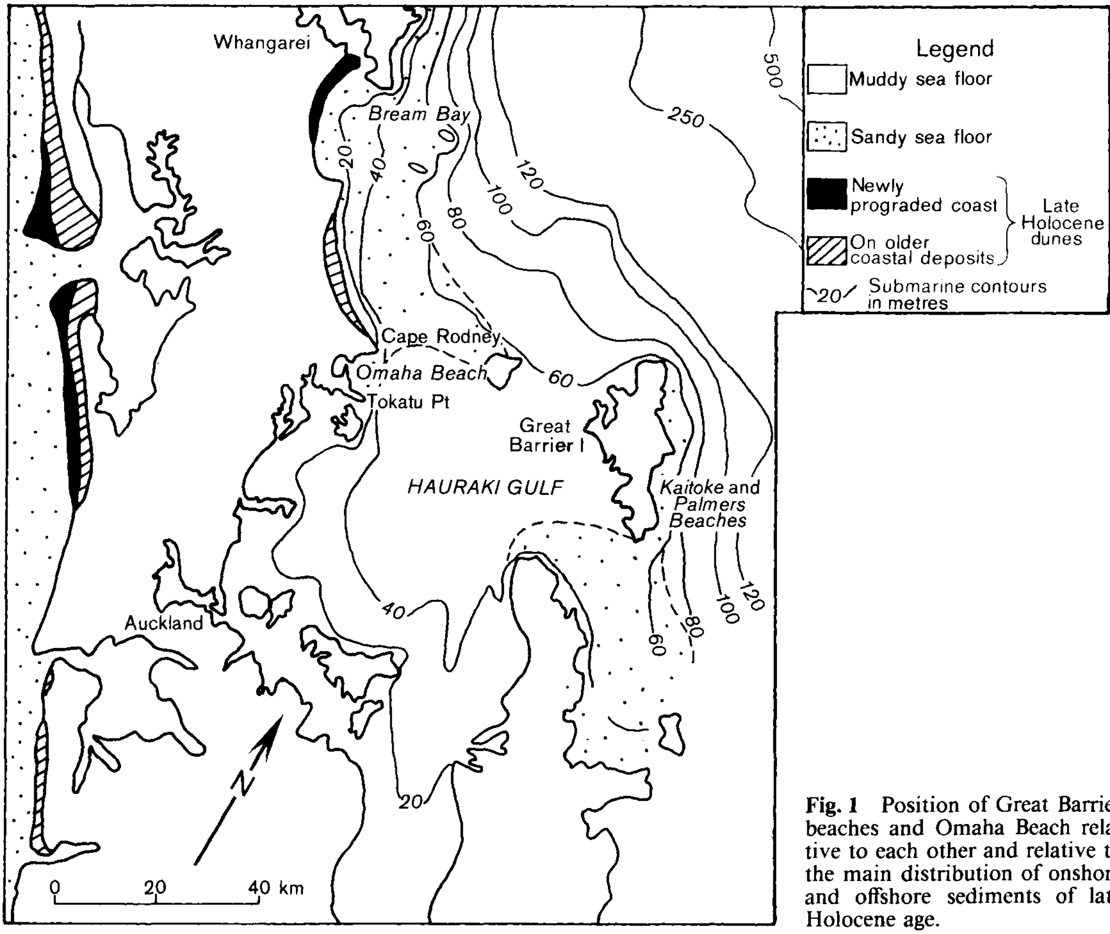

Fig. 1 Position of Great Barrier beaches and Omaha Beach relative to each other and relative to the main distribution of onshore and offshore sediments of late Holocene age.

Zealand Geological Survey at Otara and by the Survey Section of Ministry of Works and Development, Auckland, who were responsible for the beach-profile surveys.

COASTAL CHANGE

Summary of major natural changes

Prior to the 1979 groyne construction at the northern end of Omaha Beach (see fig. 1 in Riley et al. 1985), the greatest degree of surveyed change for almost the full length of the ocean beach, within the last century, has been a building forward of about 35–40 m between the 1871 and 1934 surveys, and a subsequent retreat of a similar distance. In addition, the northern end of the spit receded by an overall distance of 330 m, similar to a temporary 400 m cut-back that occurred sometime prior to 1871. For further details of coastal change up until 1968, including the pre-1871 period of erosion, see Schofield (1967, 1975a).

Man-made coastal change

During the 1978 storm-destruction of the wooden wall built in front of the Omaha Subdivision (see fig. 1 in Riley et al. 1985), prior to groyne construction, the full length of Omaha Beach was examined. It was found that the average storm-induced retreat of the dunes, both to the north and to the south of the subdivision, was about 12 m. The retreat in front of the subdivision was twice as great due to: (1) destruction of the natural vegetation when the natural foredunes were levelled during subdivision; (2) the presence of the wooden sea wall, once it was breached (Healy 1980); and (3) the purposeful reduction, during subdivision, of the level of the land behind the sea wall to about one-half the height of the original foredune, thus reducing the quantity of sand available for immediate wave erosion.

During 1979, groynes were built at the northern end of the beach (see fig. 1 in Riley et al. 1985). 450 000 m^3 of shelly sand and shingle were artificially added to the beach immediately south of the groynes. By January 1980, this easily recognisable artificial replacement, redistributed by the sea, had built the coast forward by approximately 70 m at the northern end of the subdivision, diminishing to about 50 m near the southern end of the subdivision, and to about 20 m near the southern end of the beach. In front of this artificially fed strip, the beach had been further prograded in the form of a high-tide berm, about 30 m wide, constructed of sand containing little or no shingle (i.e., derived naturally from the adjacent sea floor). Except for the southernmost 700 m of the beach, and for the area north of the southernmost groyne, this natural berm extended for the full length of the beach.

Beach volume change down to mean sea level between 1966 and 1980 (excluding the northern end of the spit)

During the early period of monthly cross-sectional surveys of the beaches at Omaha and Great Barrier, the most complete were those from February 1966 to September 1966. This period is used for comparison with the results of the 1980 surveys (Fig. 2). The cross sections have been calculated to approximate mean sea level which is 1.75 m above the Omaha datum and zero metres at Great Barrier. (Although the 1980 surveys can be accurately extended to low tide at Omaha, the olders surveys were only rarely down to this level. Thus, for strict comparison between the two periods, calculations have been limited to above mean sea level.) During the early period of surveys, control pegs at the inland end of the beach sections were placed well back from the edge of the dunes but, for some, not far enough back to withstand the amount of erosion during the last 14 years. Accurate comparison of the 1966 and 1980 surveys is restricted to distances inland as far as the original control pegs. Where sea erosion has continued further inland, estimates, based on assessed average heights for the eroded dunes, have had to be used. At Great Barrier, the excess erosion occurred along the southern sections 8 and 9 which lie not far from the Claris Aerodrome (see fig. 6 in Schofield 1975a). A very detailed levelling survey of the sand dunes near this aerodrome, together with further levelling surveys conducted by the writer, forms the basis for the Great Barrier correction of 32.5 m^2 cited in Fig. 2. At Omaha, erosion inland of the 1966 control pegs averages just over 10 m. As the average foredune heights have already been documented (Schofield 1967), the assessed excess erosion is likely to be reasonably correct. Additional erosion has been due to man's removal of much of the foredune in front of the Omaha Subdivision. As two of the 1966 surveyed sections crossed this foredune, the volume removed by man can be calculated and taken into account when correcting the Omaha curve. When all the above factors are taken into account, a total correction of 25.0 m^2 is subtracted from the monthly average surveyed Omaha Beach cross section (Fig. 2).

The Great Barrier beaches are less sheltered than Omaha Beach and thus their seasonal changes are of a different magnitude from, but of the same nature as, that at Omaha (see also Schofield 1975a). This difference in magnitude can be offset by using different scales for the average changes that occurred in the beach sections for the two regions. The two scales shown in Fig. 2 are those that produce the best fit for the period between February 1966 and September 1966. Figure 2 shows that, from the beginning of 1966 until mid 1980, the area of the average beach cross section down to mean sea level had decreased at Omaha by about 95 m^2. This means that, for all but the northern tip of the spit, 342 000 m^3 (95 $m^2 \times$ 3600 m, the length of the beach) of sand had been removed from above mean sea level (approx. 350 000 m^3). Of this amount, 150 000 m^3 was eroded from the dunes, and 200 000 m^3 was eroded from between high tide and mean sea level. (This does not take into account sand artificially fed to the beach—see below.)

Erosion down to low tide level at the northern end of the Mangatawhiri Spit

Erosion down to low tide level from the northernmost few hundred metres of the spit is atypical of the spit as a whole and is thus calculated separately. It is estimated as 200 000 m^3 which is of the same order as the 150 000 m^3 calculated by Beca, Carter, Hollings and Ferner Ltd (1976).

Erosion down to low tide level for full length of Omaha Beach

Quantitative comparison of beach cross sections that were surveyed down to low tide during the 1980 period of beach observations shows that the volume of sand lost from between mean sea level and low tide level is similar to that lost between high tide and mean sea level (i.e., 200 000 m^3—see above). Thus, the apparent volume of erosion down to low tide level for Omaha Beach, excluding the northern end, is approximately 550 000 m^3 (350 000 m^3 down to mean sea level, including dune losses, plus 200 000 m^3 between this level and low tide).

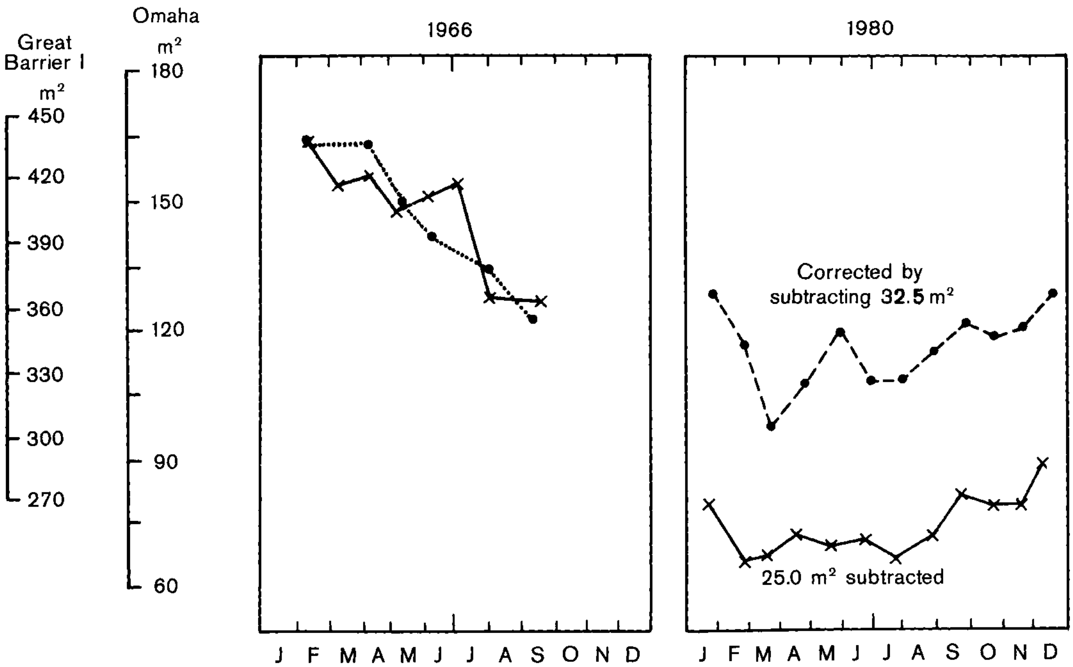

Fig. 2 Average cross sections above mean sea level for seven beach profiles at Omaha (solid line) and across nine beach profiles at Great Barrier, Kaitoki Bay (dotted line). Scales are chosen to give best fit during the 1966 observations. The difference between any two months on say the Omaha curve, when multiplied by 1000, gives the beach-volume change above mean sea level in cubic metres per kilometer for that period of time. The gap between the two curves in 1980 means that another factor, not applicable to Great Barrier, has caused additional beach erosion at Omaha.

This figure does not include 450 000 m^3 of sand fed artificially to Omaha Beach during the latter half of 1979 before the 1980 surveys. It is assumed that none or little of this sand has moved off the beach, and hence the total loss of sand from Mangatawhiri Spit, down to low tide level and between 1966 and 1980, equals 550 000 m^3 (apparent loss) plus 450 000 m^3 (artificially fed sand) plus 200 000 m^3 (loss from northern tip)—a total of 1 200 000 m^3. Beca, Carter, Hollings and Ferner Ltd (1976) gave a total estimate of 1 350 000 m^3.

Erosion from natural causes at both Omaha and Great Barrier

By using the same scales for the 1980 beach surveys as those used to produce the best fit for the 1966 beach change at Omaha and Great Barrier, it is possible to ascertain if there has been any substantial difference in behaviour between these two beach systems. The displacement between the two curves (Fig. 2) means that there is an erosion factor over and above other causes of change that apply to the full lengths of both beach systems. As well as the 200 000 m^3 of sand eroded from the northern end of Mangatawhiri Spit, the sand removed as a result of this additional factor can be calculated as 280 000 m^3* of sand from the remainder of Omaha Beach. Thus, the total volume of sand removed from Omaha Beach, over and above that expected from comparison of changes at Omaha and Great Barrier, is 480 000 m^3 between 1966 and 1980. This additional loss has been relocated in the buildup of the ebb-tide delta, just outside the entrance to Whangateau Harbour, by an amount of 450 000 $\pm$ 80 000 m^3 of sand (see Riley et al. 1985).

CAUSES OF COASTAL CHANGE

The main coastal trends have been: (1) a relatively long period of beach erosion from some time between 1871 and 1934 until the present day, which

*280 000 = l × d × f where l = length of Omaha Beach other than the northern tip; d = extra Omaha erosion approximately 40 m^3/m of Omaha Beach (calculated from displacement of the two curves in Fig. 2). Thus, l × d gives the volume loss above m.s.l. f is a factor of 2 to give volume loss down to low tide level.

is probably part of a second-order trend (for discussion on a first-order trend see Conclusions); (2) shorter periods of third-order change, such as the periods of marked erosion culminating in the 1960–62 and 1975–79 periods of erosion; (3) the marked retreat of the northern end of Mangatawhiri Spit which is interrelated with the marked buildup of the adjacent ebb-tide delta at the harbour entrance; and (4) fourth-order or seasonal coastal change.

Other than the effects of groynes, reasons for coastal change along a sandy beach may include one or more of the following factors—storms, man-removal or addition of sand, change in longshore drift or the incoming of fresh sand supply, and sea-level change. Of these factors, longshore drift and the incoming of fresh natural sand supplies are almost negligible and of little significance in the Omaha region (for discussions see Beca, Carter, Hollings and Ferner Ltd 1976 and Schofield 1975a). Thus, the main factors causing erosion of the Omaha Beach are dredging and removal of inshore sand for industrial purposes, sea-level rise, and storms. However, although spectacular in their results, storms do little more than hasten the effects of the other causes of erosion.

Removal of sand

The period of shallow inshore dredging from 1942 to 1963 has caused some erosion of the coast probably of about the same volume as that dredged. However, the recorded amount of the latter was 376 000 m^3 which is approximately only one-quarter of the total volume of sand eroded from Omaha Beach since 1934. Nevertheless, man's activities, such as dredging and the lowering of the frontal dunes along the Omaha Subdivision, have exacerbated a situation which tended naturally towards one of coastal erosion.

Sea-level change

Bruun's (1962) rule that sea-level rise promotes erosion of sandy beaches was initially given the formula of S = f (Ae, Te) by Schwartz (1968) where S = coastal change, Ae = equilibrium amplitude of sea-level change, and Te = the equilibrium of time. It has been further elaborated by Dubois (1977) and Weggel (1979). This rule depends on equilibrium between the beach and the adjacent sea floor—the response to sea-level rise being erosion of the beach to provide material to raise the sea floor in sympathy with sea-level rise. The converse, that sea-level fall promotes sea-floor erosion and concomitant coastal accretion has been discussed by Schofield (1975a, b). The converse long-term trend has been particularly likely in Omaha Bay where there is regional evidence for a sea-level fall of 2 m during the last 4000 years (Schofield 1973) and where mineralogical evidence shows that almost all of the coastal sand must have been derived from the sea floor (Schofield 1970).

Omaha Bay lies along the western side of the Hauraki Gulf, halfway between Whangarei Harbour to the north, which is situated near the entrance to the gulf, and Waitemata Harbour to the south, which lies at the head of the gulf. Tidal records have been kept at Queens Wharf, Waitemata Harbour, since 1903 and at Marsden Point, just inside the entrance to Whangarei Harbour, since 1964. Although sea-level trends since 1964 have been similar to both these tide gauges (Fig. 3) there is sufficient "noise" to make it uncertain if there has been any minor overall divergence which might arise from land tilt or volumetric changes in the tidal compartments of the two harbours.

After considering factors affecting variations of mean sea level around New Zealand, Heath (1976) concluded that they "might indicate" that "the Auckland tide gauge is sinking about 0.05 cm^{-1}". This possible subsidence rate of 0.5 mm/year is in the opposite direction to the 0.3 mm/year crustal rise thought by Chappell (1975) to apply to the Auckland region. Hence, barring sinking of the actual Queens Wharf (which from evidence supplied by B. R. Le Clere, Chief Engineer, Waitemata Harbour Board, is most unlikely) it is assumed that the Queens Wharf gauge records true sea-level change within the Waitemata Harbour.

However, the question arises, "do the tidal records at Marsden Point and Waitemata Harbour, neither of which lie within the open waters of the Hauraki Gulf, represent changes in sea level that have occurred at Omaha Bay?" Gauges along the open coast of California "show a mainly constant level" for the Pacific Ocean, whereas those within the harbours of San Diego and San Francisco "showed a steady rise with time" (O'Brien 1981). O'Brien considered this could be due to changes in the "hydraulic regime" as a result, for example, of known surface area changes within San Francisco Bay (i.e., the result of the alterations to the volumes of the partially landlocked tidal compartments). It is not known if there has been any major change in the tidal compartment of the Waitemata Harbour, which has been reclaimed in some areas and deepened by dredging in others. Nor are there any long-term tidal records for gauges in the Hauraki Gulf. Nevertheless, for the following discussion, it is assumed that the changes in sea level at Omaha Bay have been the same in kind, if not precisely the same in magnitude, as those recorded at Marsden Point, Whangarei Harbour and Queens Wharf, Waitemata Harbour.

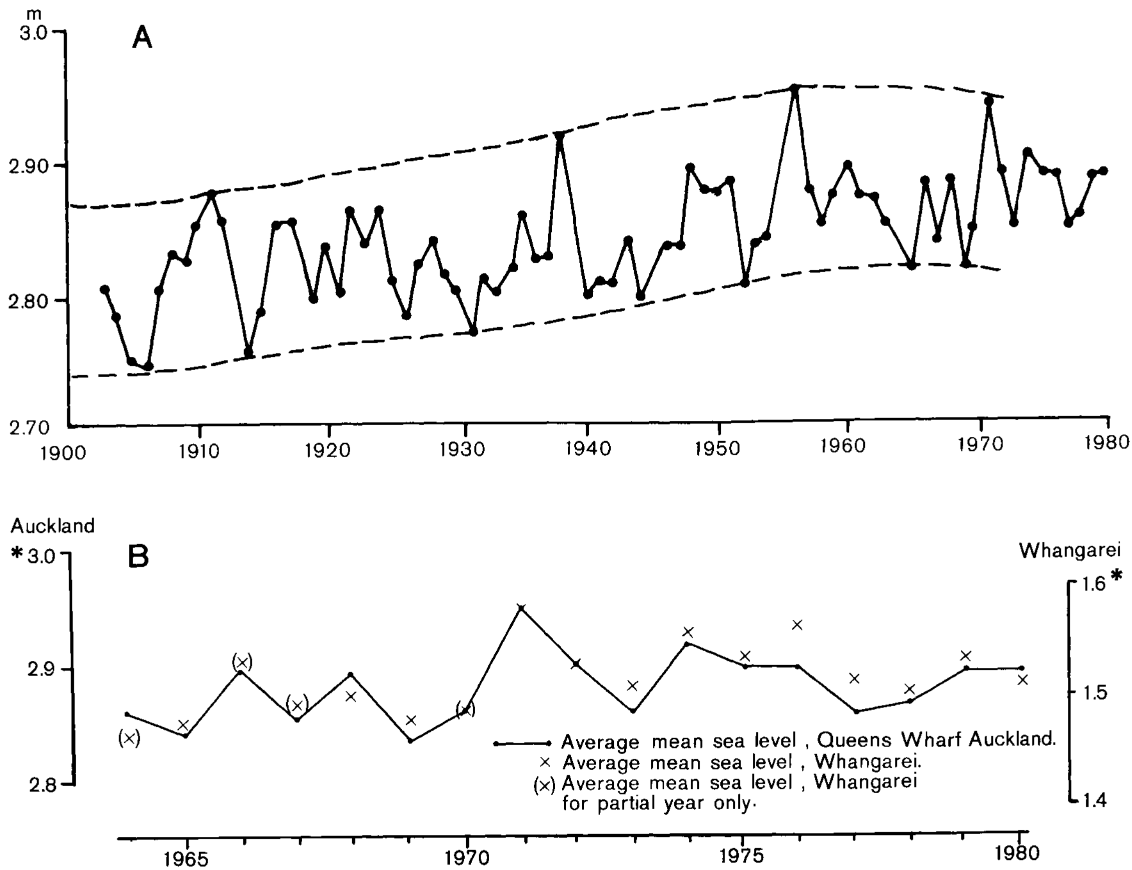

Fig. 3 **A** Annual averages for mean tide recorded at Queens Wharf, which is on the east coast at Auckland, south of Omaha Bay (Fig. 1). **B** Similar results, but for a shorter period of time are shown by the annual averages for mean tide recorded at Marsden Point at the entrance to Whangarei Harbour which lies on the east coast north of Omaha Bay (Fig. 1). The asterisk (*) indicates metres above local datum.

Second-order erosion since 1934

The loss of sand from the full length of Omaha Beach since the 1934 coastal survey is calculated as approximately 1 375 000 m^3 from above low tide, of which 376 000 m^3 was probably as a result of dredging of sand for industrial use, and of which 450 000 m^3 was deposited in the ebb-tide delta at the entrance to Whangateau Harbour (Riley et al. 1985).

This leaves 550 000 m^3 of sand unaccounted for which could result from: (1) unrecorded dredging; (2) sand entering and remaining within Whangateau Harbour (as is happening in Ohiwa Harbour (Gibb 1977) and possibly within Tauranga Harbour (Davies-Colley & Healy 1978)); (3) sand spread thinly over the floor of Omaha Bay as a result of an approximate 0.05 m rise in sea level that has occurred since 1934 (Fig. 3); and (4) sand exported out of Omaha Bay by longshore drift.

There are insufficient data to show which of the four possibilities have contributed the most to the 550 000 m^3 of sand unaccounted for. Nevertheless, if we assume that the sea floor, shoreward of the offshore coarse belt (see fig. 2 in Riley et al. 1985) within the Omaha Sand System, from Cape Rodney in the north to Tokatu Point in the south (Fig. 1), has been on the average built up by 0.05 m (the amount of sea-level rise), it would require an addition of 900 000 m^3 which is 350 000 m^3 more than that estimated to be available as a result of erosion of Omaha Beach. However, there are other smaller sandy beaches within the Omaha Sand System along the coast between Little Omaha Bay and Tokatu Point. If we assume that they were eroded to a similar degree, their proportional contribution would be 400 000 m^3 which is slightly more than the additional requirement of 350 000 m^3 to bring about equilibrium between sea-level rise and the

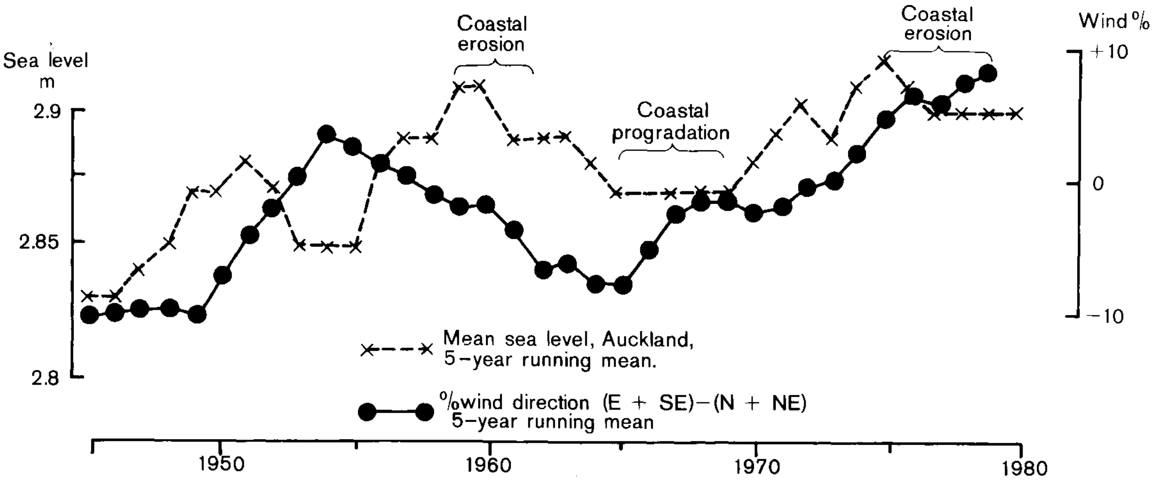

Fig. 4 Five-year running means for sea level recorded at Auckland and for the (E+SE)-(N+NE) airflow (see Fig. 5). All wind velocities are included, for it is the direction of net longshore drift of water that is important for the net direction of sand transport, once the sand has been distributed by breaker and swash turbulence.

sea floor within the Omaha Sand System during the last half century. Thus, it is possible that all of the 550 000 m^3 of sand unaccounted for could be due to a thin layer of sand being built up on the sea floor as a result of the rise in sea level since 1934.

Periods of third-order erosion

If the whole of the sea floor within a sand system is involved in the equilibrium between coastal change and sea-level change, there could be a time lag between them (i.e., coastal change is probably a sum-effect of past sea-level events, particularly at Omaha where longshore drift and incoming of fresh sand has been negligible—(see above). For third-order change, this lag for the Omaha Sand System appears to be about five years. As Fig. 4 shows, there is a fair correlation between a five-year running mean for sea level and the major coastal events of erosion and progradation since about 1960. Changes to the coast prior to 1960 are not well enough documented to be able to carry this third-order correlation back in time.

Erosion on the northern end of Mangatawhiri Spit

The northern end of Mangatawhiri Spit appears to have remained relatively stable from the first coastal survey of 1871 until the early 1970s. It was cut back by 60–80 m during the period of erosion in the early 1960s, but was much more markedly cut back by an additional 250–270 m during the erosion of the later 1970s. This total recession in the length of the spit of 330 m since 1934 is of the same order as the 400 m cut-back that occurred prior to 1871 (Schofield 1967) and after which the spit regrew to its 1871–1934 position. These pre-1871 events were documented in the foredunes at the northern end of the spit but have now been largely destroyed by the late 1970s erosion. The pre-1871 event is good evidence that the more recent cut-back of 330 m from the northern end of the spit has probably been due to natural rather than man-made causes, and that these marked changes at the northern end of the spit are probably cyclic.

The concurrent late 1970s event of a marked buildup of the adjacent ebb-tide delta at the entrance to the harbour is almost certainly related to erosion of the spit. As the delta was built up by a volume that was twice as great as that lost from the northern end of the spit, it is probable that the net northward longshore drift had been relatively greater during this period than is normal for the beach. This could mean that more waves met the beach at an angle at its northern end than is normal and promoted a greater degree of erosion. Evidence for this exists within the records of local wind directions, which promote the locally developed erosive wave. As the overall trend of Omaha Beach is 15° west of north, winds from the east and southeast would promote northward longshore drift, whereas those from the north and northeast would promote a drift in the opposite direction. The only nearby coastal station where wind records have been kept is at Leigh, just north of Omaha. These records show that there has been marked increase in the net air flow from the east and southeast since the late 1960s (Fig. 5).

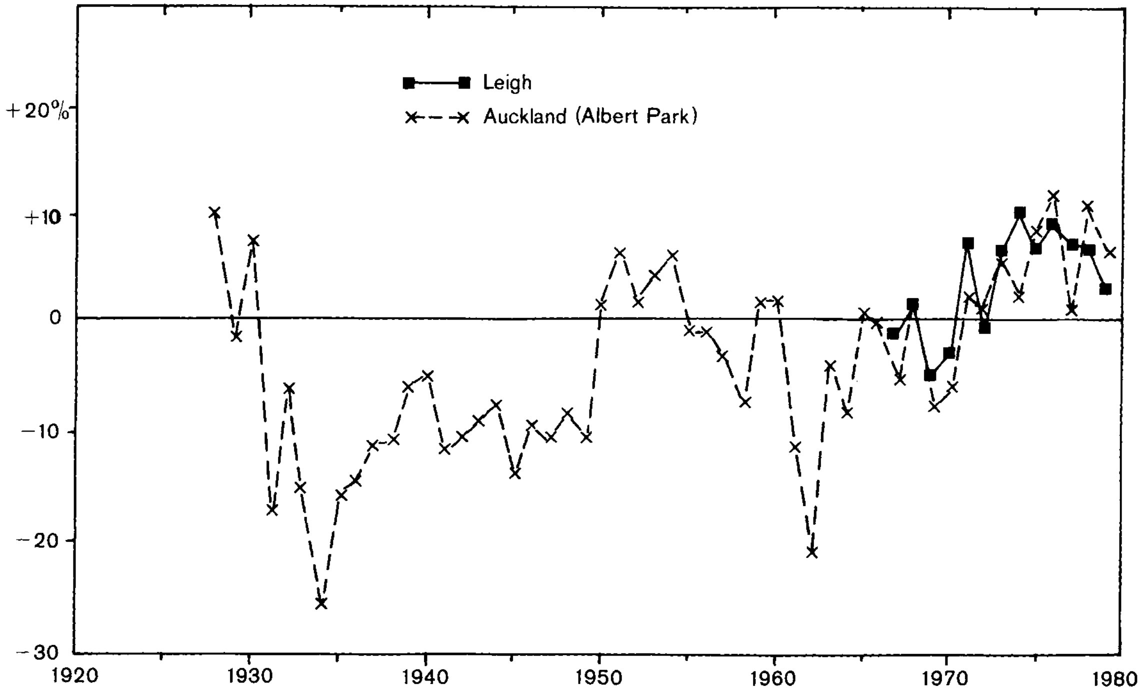

Fig. 5 Sum percentage wind direction (E+SE)–(N+NE) for Leigh (solid line) and Albert Park, Auckland (dashed line), all wind velocities included.

The Leigh wind records commenced in 1967 but, as the Albert Park, Auckland, wind records show a parallel trend (Fig. 5), these earlier records can be used to determine the wind changes at Omaha prior to 1967. Five-year running means for both mean sea level and percentage wind direction (E+SE)–(N+NE), are shown in Fig. 4; counter or parallel trends of one with the other are likely to modify their individual effect. Both periods of recorded coastal erosion around 1960 and late 1970s, can be correlated with peaking on the sea-level graph. However, whereas sea level has peaked to about the same level at both these times, the counter wind trend may have lessened the impact of erosion at the northern end of the spit during the early 1960s erosion, while the continued upward trend for the E+SE wind percentages may have enhanced its more recent erosion.

Fourth-order or seasonal coastal change

The seasonal coastal change is often one in which the coast is eroded by winter storms and subsequently rebuilt by summer swell (see, e.g., Harray & Healy 1978; Healy 1978). Figure 6 shows that this has been more or less the trend at Omaha Beach during 1980. The relationship of the 1980 trends with sea-level change is not a direct one but is rather the sum effect of sea-level change over a period of time. Thus, the best fourth-order correlation of coastal change is with either a running four-monthly mean for sea-level change or the cumulative departure from the sea-level monthly average (Fig. 6), both of which represent an averaging out of past sea-level. For further discussion concerning a possible reason for the implied lag between cause and effect, see Riley et al. (1985).

CONCLUSIONS

1. The relatively greater loss of sand from Omaha Beach than from beaches on Great Barrier Island has been due to an offshore buildup of the ebb-tide delta close to the northern end of Omaha Beach rather than a continuing effect of past inshore dredging at Omaha.
2. The marked late 1970s cut-back of the northern end of Mangatawhiri Spit at Omaha was probably the combined result of sea-level rise and a shift in predominant wind direction from west of north to east and southeast.
3. The timing of the response of coastal change to sea-level change shows five different orders. The first-order event has been a lowering of sea level

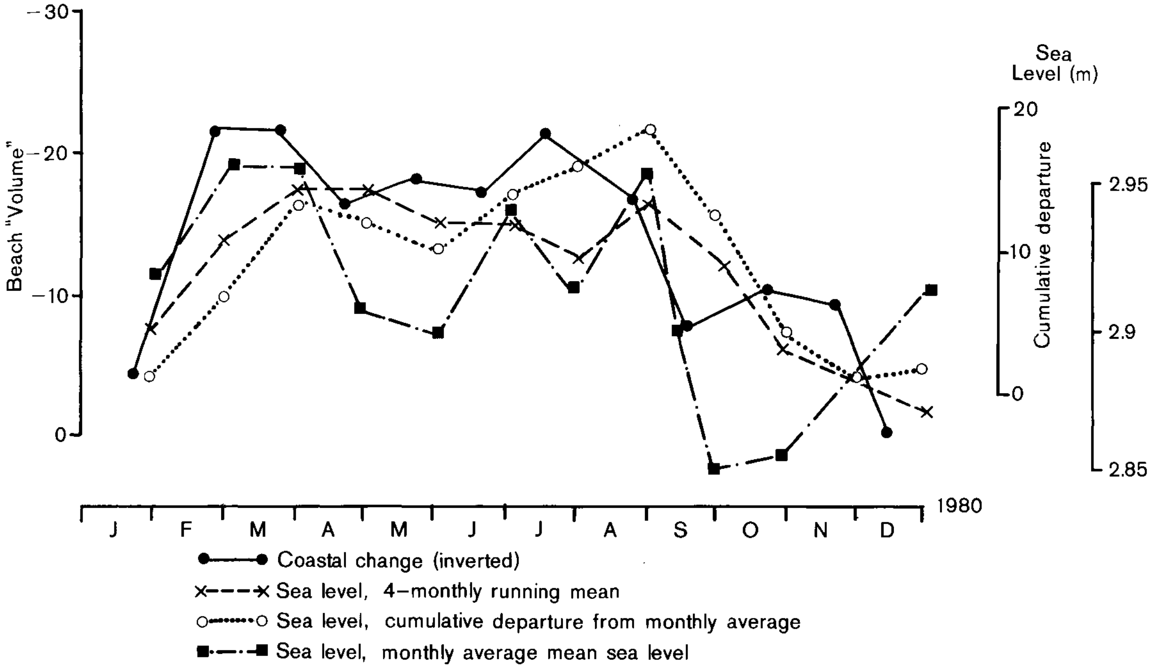

Fig. 6 Relationship of coastal change at Omaha Beach to various representations of sea-level change.

by 2.1 m during the last 4000 years (Schofield 1973; 1975a, b). The resulting coastal change may still be in progress, but is hampered by the armouring effect on the sea floor by the offshore coarse belt, which is probably a lag developed during this first-order drop in sea level (Riley et al. 1985). The removal of this protective offshore coarse lag could well lead to further sea-floor erosion as a result of this first-order event and a consequent further progradation of the coast (Schofield 1978). Sea level regression during second-order sea-level fluctuations of about 600 year duration and superimposed on this first-order event may have produced additional shellbed lags found inshore of the offshore coarse belt (Riley et al. 1985). The rise in sea level during the present century may be part of a second-order transgression of the sea, or possibly part of the third-order event. It is assumed to be the former. Quantitative considerations (see above) and sand movement on the sea floor (Riley et al. 1985) suggest that the whole of the sea floor down to the coarse offshore belt is probably in equilibrium with this second-order transgression. Third-order changes have durations of about 15–20 years in which a period of high sea level coincides with several years of beach erosion, and appear to have an inherent lag of several years. A fourth-order change occurs more or less annually with winter-storm erosion alternating with summer-swell progradation. Whereas the second-order and possibly third-order events may involve the whole of the sea floor down to the offshore coarse belt, the annual fourth-order event mainly affects the beach, nearshore bar, and breaker region; time is insufficient for the concurrent changes in sea level to fully affect the sea floor at greater depths. However, Riley et al. (1985) provide possible evidence for partial annual change of these deeper parts of the sea floor during fourth-order changes. Similarly, fifth-order daily tidal changes, although substantially greater so far as sea-level amplitude is concerned, when compared with the third and fourth-order sea-level change, have only partial affect on the beach and breaker zone, with little or no affect at greater depths.

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