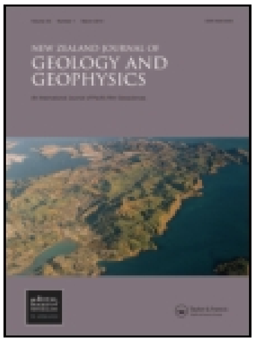

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SAND MOVEMENT AT MANGATAWHIRI SPIT AND LITTLE OMAHA BAY

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ABSTRACT

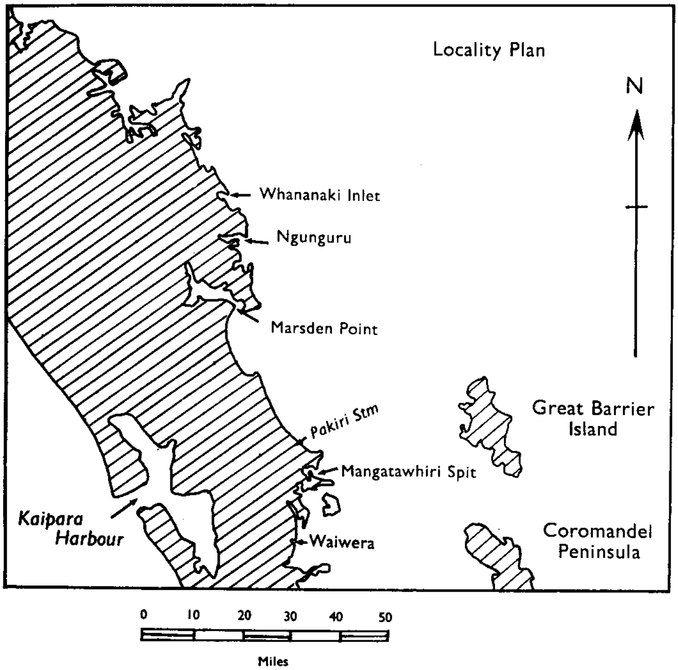
Evidence that sea-level fluctuation is probably an important cause of coastal change is presented. Grain size and feldspar/quartz ratios of sand samples, together with malacological evidence, show that sand is transported to Mangatawhiri Spit from depths of 15 fathoms during periods of progradation, and that effective sand movement probably also occurs down to depths of 20 fathoms. Effects of grain size on feldspar content are given in Appendix 3.

INTRODUCTION

Dredging of sand from Little Omaha Bay began in 1942, and has continued since at an average rate of 21,600 cu. yd. per year, a total of 496,600 cu. yd. having been extracted up to the end of November 1963. Because there had been previous dredging and erosion of Mangatawhiri Spit about 1961–62, it has been suggested that the two were related. Furthermore, as dredging of marine sand will undoubtedly become more extensive, it is important to know its likely effects; hence this investigation.

Mangatawhiri Spit lies 35 miles north of Auckland and is formed of sand dunes separating Whangateau Harbour from the oceanic waters of Little Omaha Bay (Fig. 1). The spit is joined to hard rock which forms the southern headland of Little Omaha Bay. The northern headland of the bay is also hard rock, and thus forms an immovable buttress on the outside of the entrance channel to Whangateau Harbour. The inside of the channel, at the northern tip of Mangatawhiri Spit, consists of soft sands, which may be easily removed or replaced, depending on many factors.

The spot most sensitive to any change is the free end of a sand spit, i.e., the end not joined to land—the north end in the case of Mangatawhiri Spit and of all other spits along the east coast of Northland. The free ends of other spits along the east coast of Northland have undergone similar changes at similar times to those at Mangatawhiri Spit. The causes may have included short-term effects of gales or "tidal waves", or the longer-term effects of changes in the wind regime or sea level.



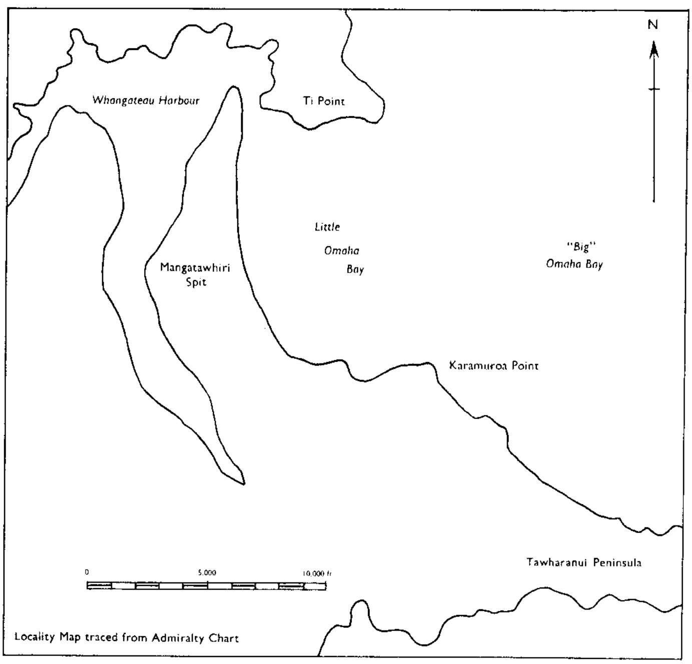


FIG. 1—Locality plans of: (A, *above*) east coast of Northland; (B, *below*) Mangatawhiri Spit.

Detailed investigations of sand samples (particularly of grain size and feldspar/quartz ratios) and malacological evidence show that marked changes are felt not only along the beach or at shallow depths, but down to depths of 20 fathoms within Omaha Bay. Thus, the deposition of 200,000 cu. yd. of sand along Mangatawhiri Spit within the two months of December 1963 and January 1964 is probably only part of the total shift of sand within Little Omaha Bay during this period. On the other hand it is about 10 times the average annual amount of dredging, or half of the total quantity of sand dredged from Little Omaha Bay within the last 20 years.

Thus, because vast quantities of sand are probably seasonally transported in and out of Little Omaha Bay, and because natural causes have effected similar coastal changes in other areas of Northland, it is believed that dredging has had little, if any, effect.

COASTAL CHANGES

Long-term Trends—Mangatawhiri Spit

For a width of up to 24 ch. the seaward portion of Mangatawhiri Spit is made up of foredunes which still retain sufficient of their original elongated shape to show the manner in which the spit has been built seawards. The oldest of these foredunes is post-glacial in age and unlikely to be older than 5,000 years (Schofield, 1962). These growth lines of parallel foredunes show that seaward growth has been slightly less in the southern 20–30 ch. than in most of the spit to the north (Fig. 5).

Some of the foredunes, for a width of about 2 ch. along all but the northern 20 ch. of the ocean coast of the spit, were added between 1871 and 1934. This is suggested by comparison of the 1871 and 1934 surveys (Fig. 2). Although the accuracy of the 1871 survey was not up to present-day standard, the fact that the relative positions of the harbour coastline along the spit and the rock coastline of Karamuroa Point are the same for both the 1871 and 1934 surveys suggests that there has been a very real building out of the ocean coastline of the spit for all but the northernmost 20 ch.

Confirmatory evidence is given by plentiful coke buried by later dune deposits found near the southern end of the spit and 2–3 ch. inland of the present coastal dune. This coke is in a definite bed formed by being washed ashore and up the slope of an old foredune. It is associated with scallop shells, lies parallel to the shore, and is seaward of middens without scallop shells. The scallop shells may have been washed ashore at the same time as the coke, for, during storms, live scallops are still washed ashore at the southern end of the spit; however, judging by the lack of other shells washed ashore during storms, the scallops probably represent middens developed since the arrival of the pakeha. The coke is almost certainly derived from the trading vessel *Phoenix,* which was wrecked in 1879 and driven ashore in Omaha Bay (Ingram and Wheatley, 1951). Although the *Phoenix* is listed as a cutter, it was a reasonably large vessel (46·3 ft long) and could have carried coke for an auxiliary steam engine and a galley.

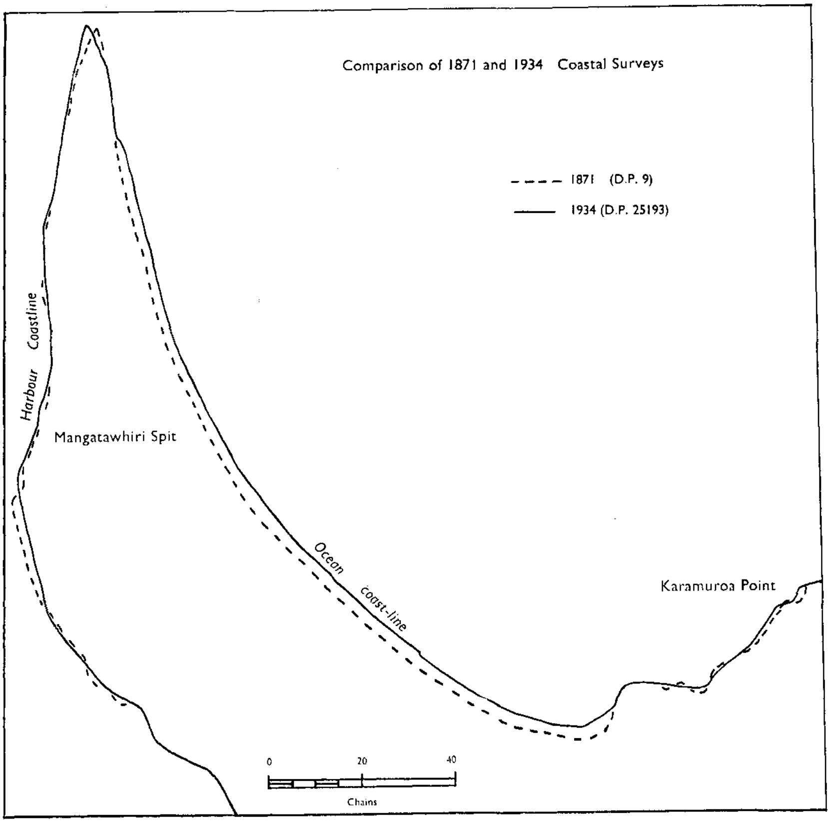


FIG. 2—Mangatawhiri Spit. Comparison of 1871 nad 1934 high-water marks.

Some of the most recent fluctuations of the northern end of the spit (described in the section "Changes since 1942") are minor compared with other changes which affected particularly the northernmost 20 ch. of the spit across its full width. This is shown by the abrupt change from 15–20-ft-high dunes south of the affected area to dunes less than 6 ft high in the affected area. Native vegetation, common to the high dunes, is absent on the 6 ft dunes, indicating that these are young.

Although all but the northern end of the seaward coast of the Mangatawhiri Spit has been building out during the last 5,000 years, this is only net movement of what could have been alternate periods of building out, standstill, and/or erosion. This process is continuing.

Changes Since 1942

In this section detailed descriptions of shifts of a harbour bar to the north of the spit, and of a bar just outside the harbour to the east of the spit, have not been included, as their changes were in sympathy with changes along the spit. Whether these changes were the cause or the effect of the changes at the end of the spit is not known, but it is thought that all changes were due to some outside cause. This section is restricted to describing the coastal changes of the Mangatawhiri Spit, and comparing these changes with changes in spits elsewhere along the east coast of Northland.

North End of Mangatawhiri Spit

Toe-of-dune surveys made from aerial photographs taken in 1942, 1953, and 1963 (Fig. 3A), toe-of-dune surveys made on the ground in 1950 and 1963 (Fig. 3B), together with mean high-water-mark ground surveys made in 1934, 1961, and 1963 (Fig. 3C) show that: the coastal positions at 1934 and 1942 were approximately the same; some time between 1942 and 1950 there was a building out of the coastline seawards of the 1934 and 1942 positions; between 1950 and 1953 there was some erosion back to approximately the 1934 line (Fig. 3D), and at some time between 1953 and 1961 there was a greater amount of erosion. Since 1961, the building of a high-water berm or bench has brought the mean high-water mark back to the 1934 position, except for a very small area right at the tip of the spit.

Central and Southern Portions of Mangatawhiri Spit

Except for the southern 20 and northern 40 ch., the 200-ch.-long ocean beach is backed by a modern foredune standing 6 ft above high-tide level at its southern end, increasing to 12 ft at its northern end. The crest is usually about 6 yd wide in the south, but only 1 yd towards the north; the width at the very northern end cannot be estimated, because it merges with an area of moving sand derived from older dunes from which the vegetative cover has been removed.

This foredune has been formed since 1942, as the 1942 aerial photograph shows quite clearly that the foredune was absent along the southern 60 ch. of the beach, although the photographs are not clear enough to show whether it was absent over the rest of the spit. Examination of later aerial photographs shows that it was present in 1953 and 1961, and that its seaward limit lies somewhere between 15 and 35 yd seaward of the 1942 foredune. The latter shift in coastal position is measured from a point near the southern end of the spit and one common to both the 1942 and 1953 aerial photographs.

Sharp cliffs exposing roots in the old vegetation-covered foredunes within the southern 20 ch. show that this portion of the spit is being, or has been, eroded.

Coastal Trends Elsewhere Along the East Coast of Northland

Spit at Whananaki

Whananaki Inlet is approximately 60 miles north-west of Mangatawhiri Spit (Fig. 1A). Aerial photographs taken at four periods show that the coast of Whananaki Spit (Fig. 4A) built seawards between 1942 and 1951 and that in 1961 and 1963 it had been eroded back to the 1942 position.

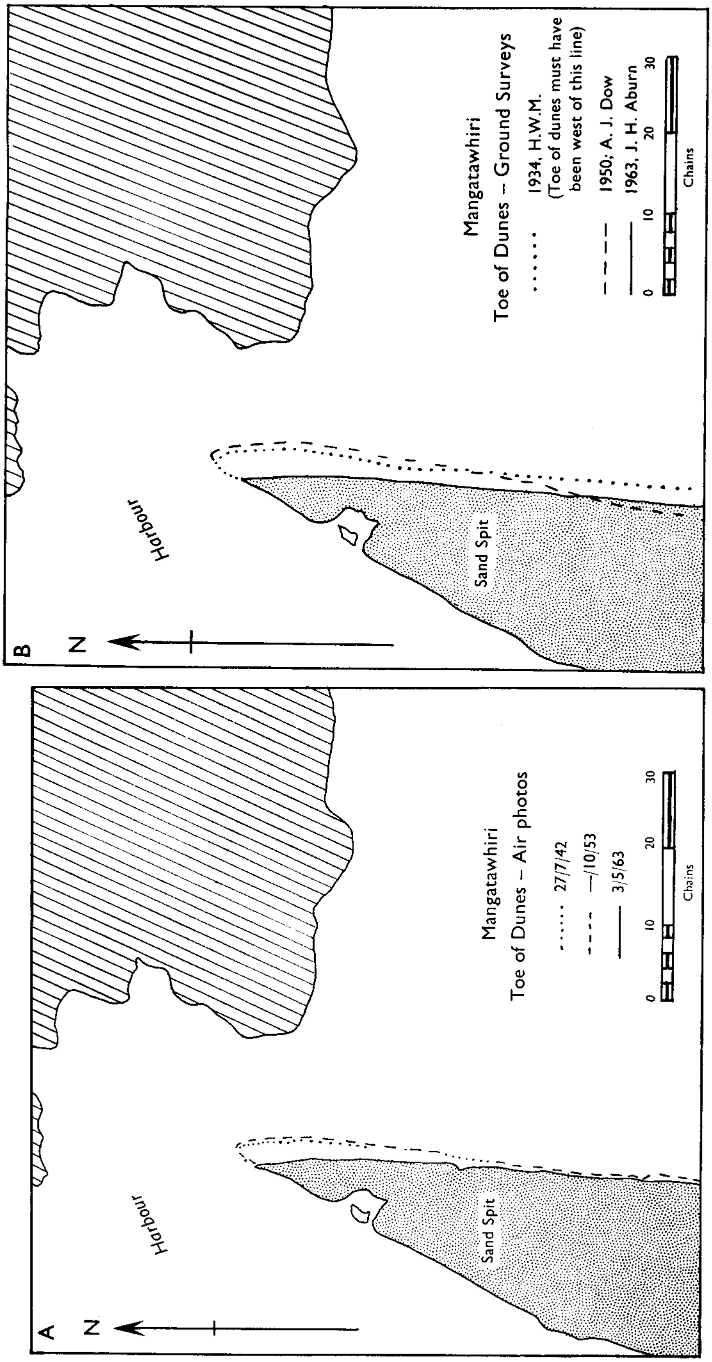


FIG. 3 (A, B)—Changes along northern portion of Mangatawhiri Spit (from aerial photographs).

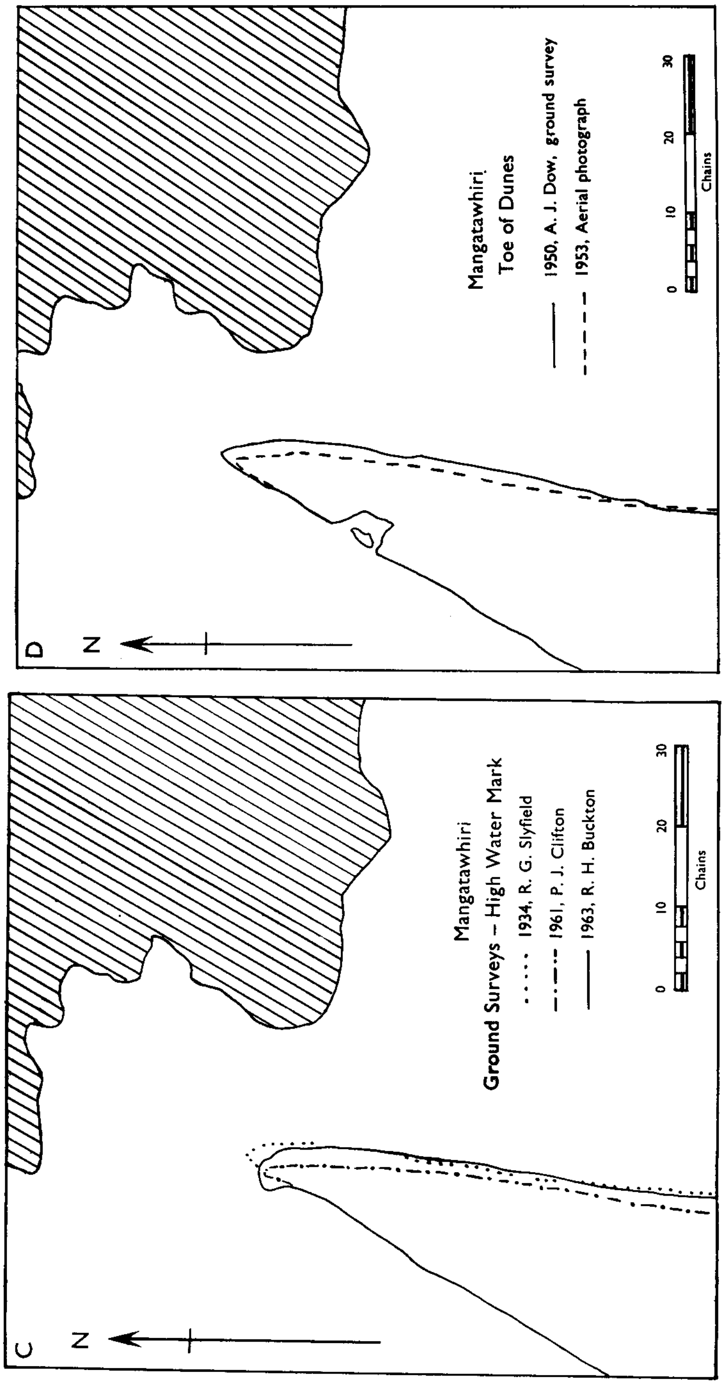


FIG. 3 (C, D)—Changes along northern portion of Mangatawhiri Spit (from aerial photographs).

Spit at Ngunguru

The spit at Ngunguru (Fig. 4B) is about 10 miles south of the Whananaki Spit. Three periods of aerial photography show slight coastal erosion at the north end of the spit at some time between 1942 and 1959, but since then the coast appears to have been stable (1963 photograph).

Waiwera Estuary

The Waiwera Estuary is approximately 15 miles south-west of Mangatawhiri Spit (Fig. 1A). Four periods of aerial photography show that a small spit of 1941 had been enlarged several times and migrated eastwards by 1957 (Fig. 4C). At this time it was also dune covered. By 1960 it had disappeared, and had been replaced by a smaller non-dune-covered spit within the inner part of the estuary. Since 1960 it has reappeared in the 1957 position, in a more extensive form but without dunes.

Changes Since June 1963

During June and July 1963 the high-tide berm for most of its length along Mangatawhiri Spit ranged from 8 to 12 yd wide, widening within the northern 35 ch. to 46 yd near the northern tip. By early December 1963 this high-tide berm had been eroded 8 yd back along its full length, and slight erosion has also occurred at the toe of the foredune. By early February 1964 observations along the northern 120 ch. of the spit showed

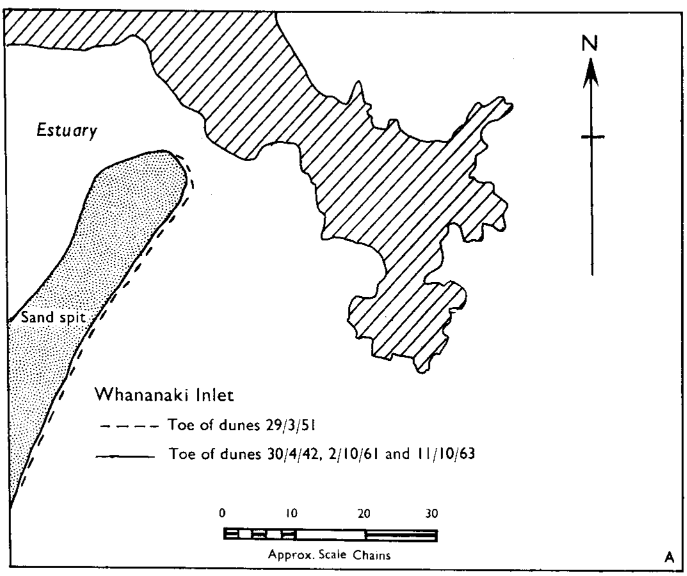


FIG. 4 (A, *above*, B, C *opposite*)—Changes at other sand spits along east coast of Northland (from aerial photographs).

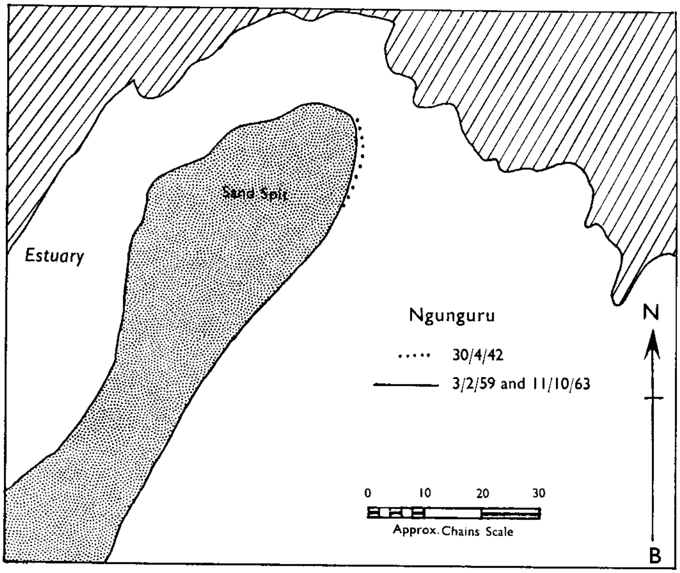

Sand Spit
Estuary
Ngunguru
30/4/42
3/2/59 and 11/10/63
N
0 10 20 30
Approx. Chains Scale
B

FIG. 4B

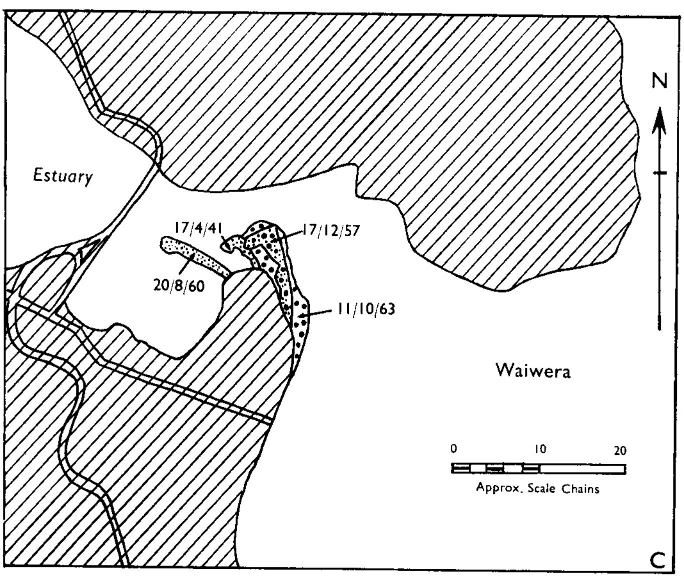

Estuary
17/4/41
17/12/57
20/8/60
11/10/63
N
Waiwera
0 10 20
Approx. Scale Chains
C

FIG. 4C

that this erosion had been healed and that the width of the high-tide berm had increased by from 21–30 yd. This increase appears to have taken place in two stages. The 8 yd lost before December had been replaced along the full length of the beach up to the northern tip, whereas the additional width of 13 yd had by early February reached to within only 30 ch. of the northern tip. At the time of observation the shape at the northern end of this 13-yd-wide berm showed that deposition was due to a northward-directed, long-shore drift, and that the berm could ultimately grow along the full length of the beach. These changes mean that about 200,000 cu. yd. of sand had been added to the coast between early December 1963 and early February 1964. This figure is based on an average increase in width of 20 yd for the high-tide berm along 150 ch. of the 200-ch.-long coastline between mean high water and mean low water.

Summary of Coastal Changes

The Mangatawhiri Spit, for all but its northern extremity, has been consistently widened by the additions of new foredunes, the latest being added between 1942 and 1953. The history of its north end appears to have been one of coastal extension during 1942 to 1950, recession to 1961–62, and then building out again. Between December 1963 and February 1964 200,000 cu. yd. of sand was added to the shore. There has been a similar history for Whananaki Spit, and it could have been the same for Ngunguru Spit, but there are no photographs available for 1950–51 when elsewhere there was coastal extension. Movements of a different kind, but possibly related to the same causes, are shown at Waiwera.

SAND SOURCE AND MOVEMENT

The immediate source of the sand being deposited along most of the ocean coast of the Mangatawhiri Spit must be Little Omaha Bay. The origin of sand within Little Omaha Bay is critical, for if sand is not being transported from Big Omaha Bay or Whangateau Harbour into Little Omaha Bay, dredging must eventually affect the coast of Mangatawhiri Spit. If, however, sand is being transported into Little Omaha Bay, and some of this sand is being deposited on shore, the rest being transported out of the bay again, the effects of dredging are not necessarily detrimental. It is also important to determine the movement of sand within the bay, because different positions of dredging could have different effects on the coastal equilibrium. Information on these problems was obtained from mineralogical, grain-size, and malacological studies of Little Omaha Bay and nearby areas.

Sand Movement During May and June 1963

(A period of coastal building-out)

Mineralogical Evidence

A study of the sands (Appendix 4) along the shore of the spit, in Little Omaha Bay, and in Whangateau Harbour shows no differences in the type of mineral grains present, but highly significant changes were found in the percentages of quartz and feldspar. It has long been known that the feldspar content of sand within a river tends to decrease downstream. This is because the extremely small particles into which the feldspar breaks are quickly washed out to sea and the coarser, tougher, unbroken fragments of quartz remain in the river. However, reduction in feldspar content need not always be due to wear and tear. It can be due to mixing of a feldspathic sand with a quartzitic sand, which is thought to be the more important cause of changes of feldspar content in the Omaha Bay area.

Fig. 5 shows the distribution of feldspar/quartz ratios for Little Omaha Bay during May and June 1963. The areas of similar ratios are divided by lines called iso-ratios of feldspar to quartz. These suggest that: sand was transported north-westwards into Little Omaha Bay from an area south-east of Karamuroa Point, otherwise the ratios should be the same throughout the bay; this sand reached close inshore of the Mangatawhiri Spit, slightly south of its mid-point, then spread northwards and southwards; some of the highly feldspathic sands reached the outer limits of the entrance to Whangateau Harbour; and the low feldspathic sands of the Whangateau Harbour (iso-ratios of 1·35, 1·57, and 1·7 in upper reaches of the harbour and 1·88 in bar just north of spit) had been* transported into Little Omaha Bay, where they mix with the highly feldspathic sands to the east, and south of the south-east tip of Ti Point.

These movements are shown in Fig. 5 as lines that show only the approximate centre of broad bands over which movement takes place but nevertheless probably show the approximate positions of fastest movement. It must also be remembered that Fig. 5 does not necessarily show the direction of sand movement at any given time, but shows the effective direction of movement of sand at June 1963. Superimposed on these average directional movements will be wave-generated currents that tend to redistribute the sand and thus produce the submarine contours that tend to be parallel to the coast of the spit (Fig. 6). These show that the floor of Little Omaha Bay slopes seaward at about 1 ft in 120 ft.

Grain-Size Evidence

The grain size of any sediment deposited on the sea floor depends on the strength of the sea currents, since the grains left are normally larger than those the sea current is able to carry. No sand is perfectly sorted, but in well-sorted sands, such as those in the area under discussion, the mean size or median of a particular sand sample is an important criterion, for it depends mainly on the average strength of the local sea current. The plot of median grain sizes shown in Fig. 6 is supplementary to the iso-ratios

*There may have been no active movement of sand from the harbour during May and June of 1963, and these harbour-derived sands could have been deposited earlier. The fact that effects of past sand movement are unlikely to be completely obliterated by subsequent sand movement must be kept in mind. For example, the high feldspar content (feldspar/quartz ratios 3 : 3·3) at the southern end of Mangatawhiri Spit in December (Fig. 7) can only be derived from the earlier influx of feldspathic sands in June (Fig. 5). Notice how the sands of highest feldspar content have moved southwards along the beach as is suggested by other evidence (Fig. 11B).

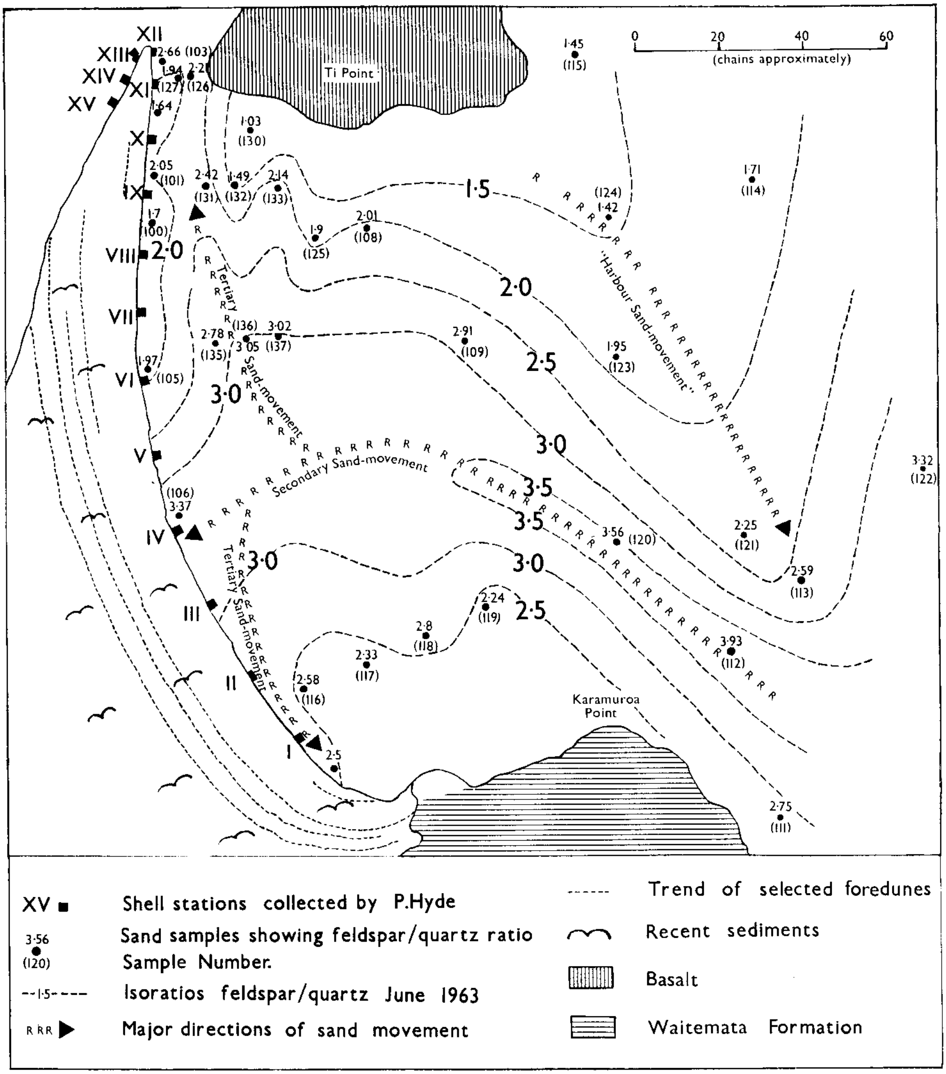


FIG. 5—Iso-ratios of feldspar/quartz during progradation of Mangatawhiri Spit, June 1963.

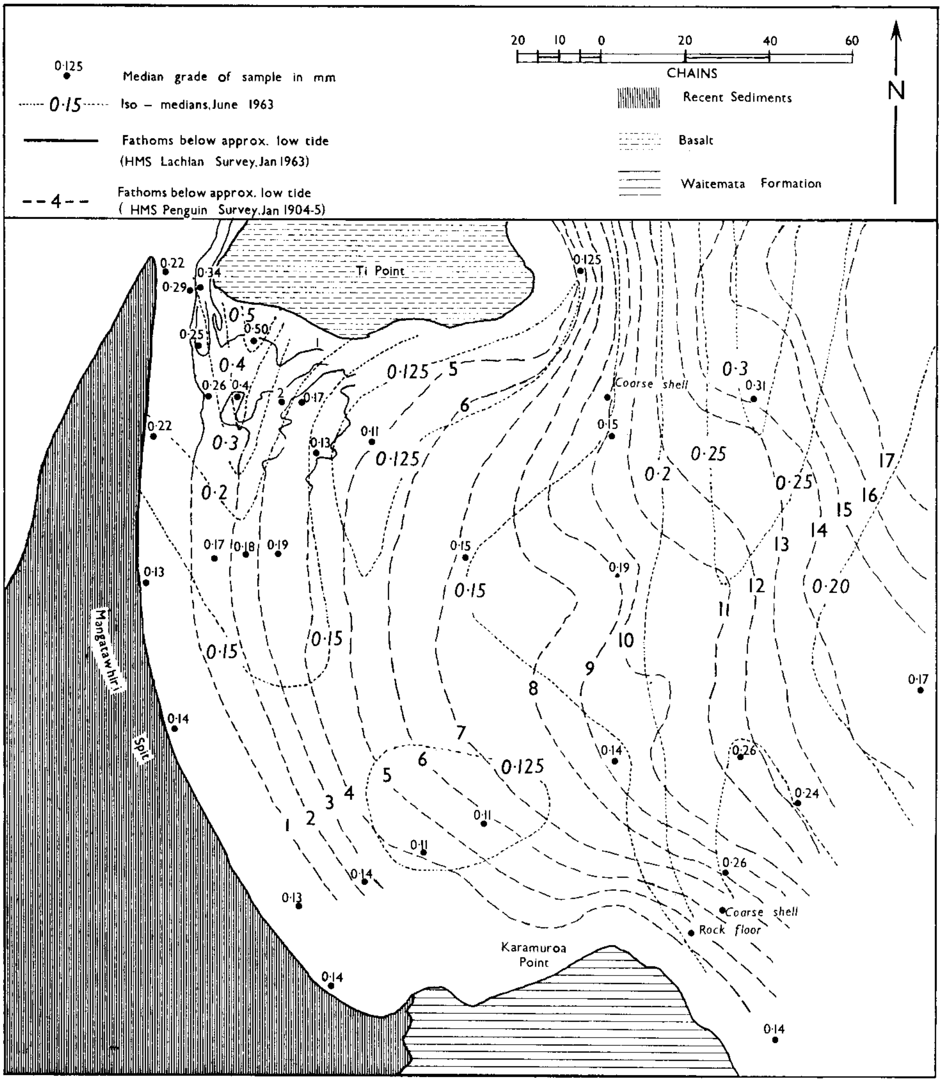


FIG. 6—Iso-medians during progradation of Mangatawhiri Spit, June 1963, and submarine contours.

of feldspar to quartz. It shows the strongest sea currents to be: (1) near the entrance to Whangateau Harbour, as might be expected because of the strong ebb and flood tide rips; and (2) off-shore tidal currents effective down to depths of 12–15 fathoms just outside Little Omaha Bay.

Zoological Evidence

Fifteen shell samples from along the coast of the Mangatawhiri Spit were collected and studied by Mr P. E. Hyde of the Zoology Department, University of Auckland (Appendix 1). None of this information conflicts with the above evidence, and the most significant contribution is as follows: A census of shells along the ocean shore of the spit (*see* Figs. 5 and 14) shows a steady rise from 25% to nearly 50% of "off-shore channel species" from station I to station IV and then, despite a marked scatter in the results, there is a definite decrease northwards. The highest value at station IV coincides with the highest shoreline value for feldspar/quartz ratio, both being the result of the same tidal current sweeping into the southern part of Little Omaha Bay and impinging on the coast at this point.

Sand Movement During December 1963

(*A period of erosion*)

Figs. 7, 8, 9, and 10 show the movement of sand suggested by feldspar/quartz ratios, grain size, and shell distributions. The latter are based on work by Mr W. F. Ponder, Zoology Department, University of Auckland (Appendix 2). Interpretation of these figures and the differences shown by the two periods of sampling are discussed in the next section.

Discussion of Sand Movements

Grain-size evidence alone is insufficient to show effective movement of sand in and out of Little Omaha Bay. A zone of fine sand at shallow depths in Little Omaha Bay separates coarse near-shore sand from the coarse sand that lies outside the bay, and there appears to be no connection between the two. On the other hand, grain size has little effect on feldspar/quartz ratios (Appendix 3), particularly within the limits of most medians of samples collected in this area. Hence the feldspar/quartz ratios are important in determining sand movements where grain-size evidence is masked by opposing currents. Thus these two lines of evidence, together with the confirmatory malacological evidence, are essential to give the clearest picture of the off-shore conditions and changes.

The median grain size of a sample is easy to determine and is subject to little error (maximum of 10%), but, because of sampling errors and the personal factor, a maximum error of 25% is possible in the feldspar/quartz ratios. Hence it was necessary to investigate statistically the sand movement suggested by these ratios. These investigations (*see* Appendix 3) show that the changes in off-shore conditions between June 1963 and December 1963, as shown by the feldspar/quartz rtios, are real, and the absence of conflict in the grain-size and shell-distribution evidence (Fig. 11) supports this.

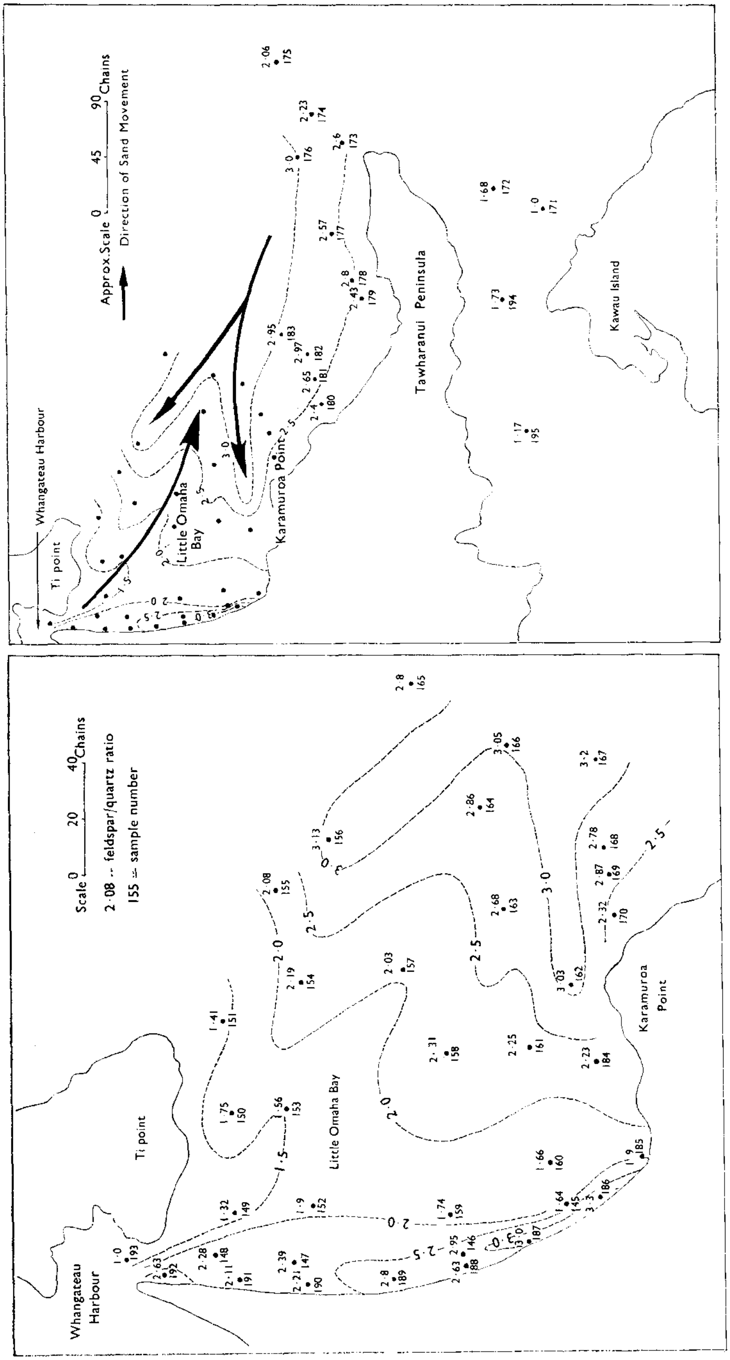


FIG. 7—Iso-ratios feldspar/quartz during coastal erosion, December 1963.

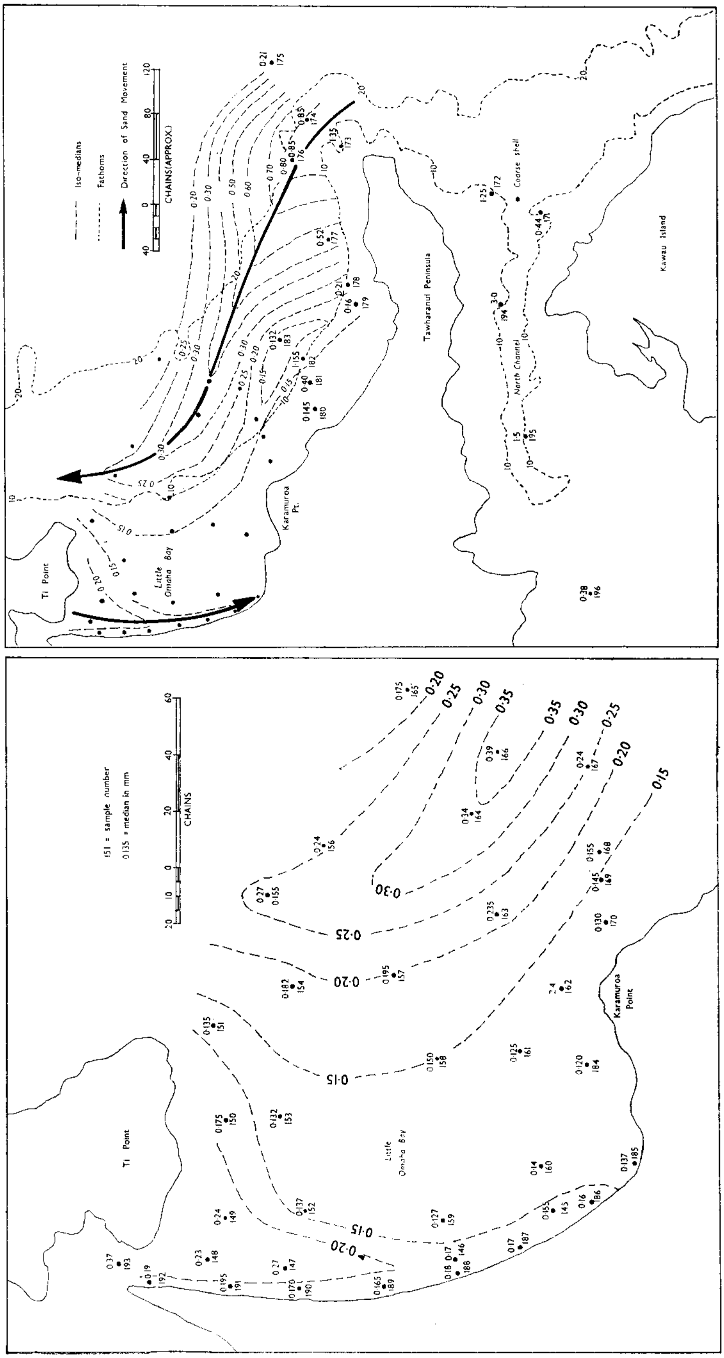


FIG. 8—Iso-medians during coastal erosion, December 1963.

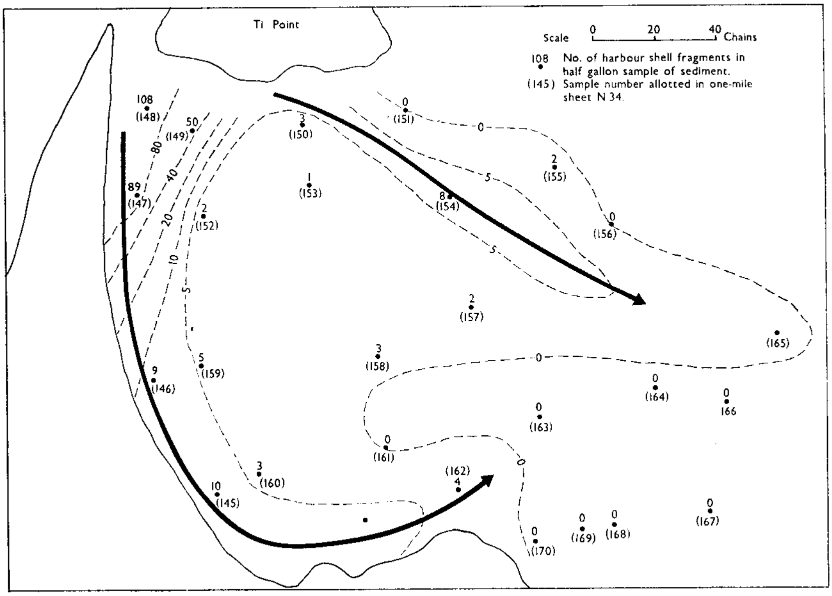


FIG. 9—Distribution of harbour species in Omaha Bay, December 1963, by W. F. Ponder.

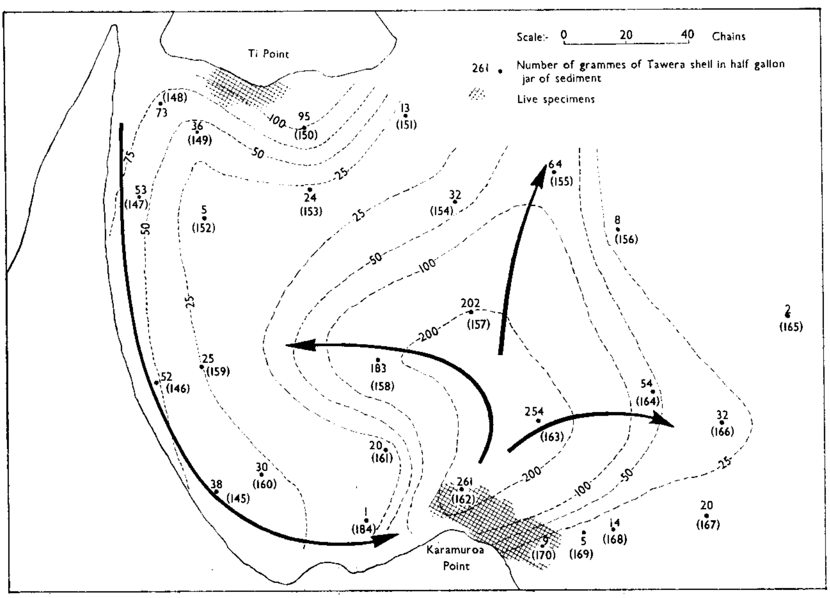


FIG. 10—Distribution of *Tawera spissa* in Omaha Bay, December 1963, by W. F. Ponder.

Fig. 11A shows that, during coastal building in June 1963, sand was being transported from outside Little Omaha Bay and deposited on shore. On the other hand, Fig. 11B shows that, during erosion there is a strong off-shore movement of sand directed south-eastwards across the bay from the harbour mouth and southwards along the shore of the spit.* The important aspect of these movements is that they occur over wide areas and at considerable depths. Perhaps the most striking evidence for long-shore movement of sediment at depth is the change in median grain size from off the point of Tawharanui Peninsula towards Little Omaha Bay (Fig. 8). This shows that a strong current sweeps sand northwards around Tawharanui Peninsula, and the movement is felt at 20 fathoms. Beyond the influence of the point, this current becomes weaker, so that, as Little Omaha Bay is approached, smaller grains of sand are transported at shallower depths. Nevertheless, in the area immediately outside Little Omaha Bay, sand which is coarser than the sand along the ocean beach of Mangatawhiri Spit is being moved in depths between 10 and 15 fathoms.

*See footnote, p. 707.

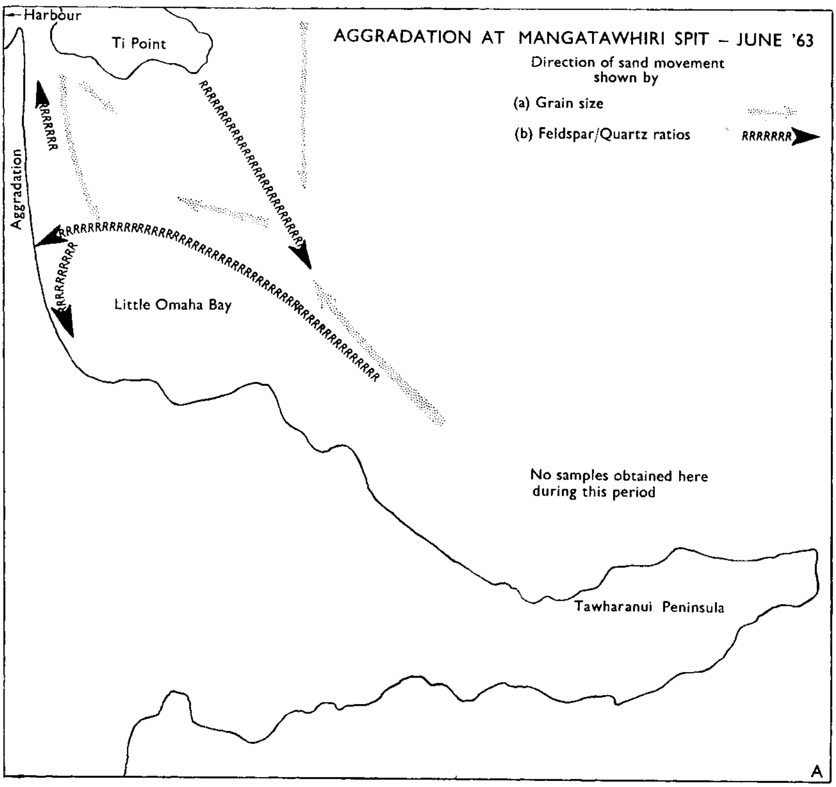
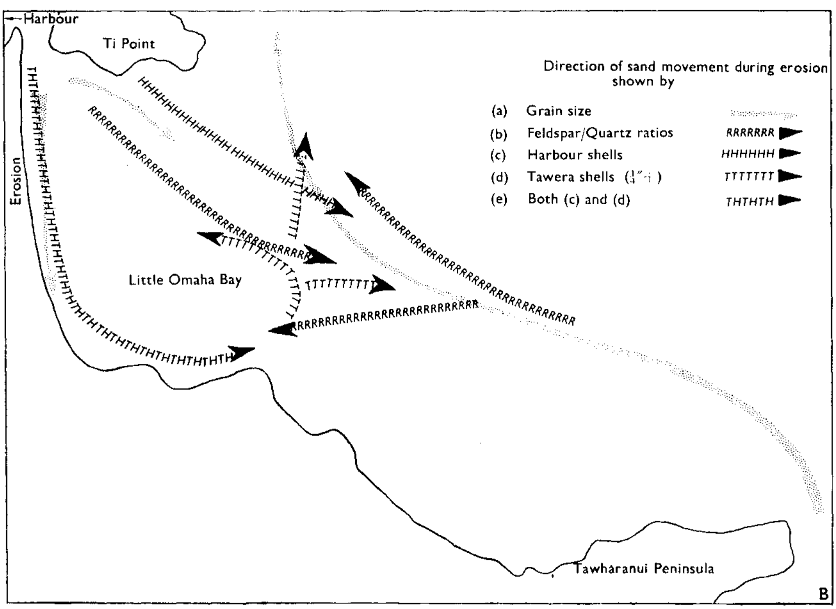


FIG. 11—(A, *above*) Summary of evidence for sand movement during progradation of Mangatawhiri Spit, June 1963, and (B, *opposite*) during erosion, December 1963. (See also footnote p. 707.)

Sand Sources

Preliminary mineralogical investigations suggest that some of the sand is derived from erosion of the nearby rocks, but that the bulk of it is derived from volcanic rocks in the Rotorua–Taupo region via the Hauraki Gulf. Apart from admixture of locally derived sand and the absence of pumice, the coarser fraction of sand is similar to the Hinuera Formation, particularly in its high feldspar content, type of feldpsar, the high angularity, and the common pyramid crystal shape of the quartz grains. The Hinuera Formation was derived from volcanic rocks in the Rotorua–Taupo region and is widespread in the Hauraki Plains, where it was deposited by the Waikato River during the Last Glaciation. During the maximum of the Last Glaciation, sea level was some 300 ft lower than now, so that the Hinuera Formation could have underlain much of the terrestrial plains that would have covered the whole of the Hauraki Gulf and extended many miles north of Omaha Bay. At that time the islands of Hen and Chickens, Mokohinau, Little Barrier, and Great Barrier would have appeared as hills and ranges standing above afforested plains or marshlands. During rise in sea level some of this material would have been in continual transport. By 4,000 years ago the sea had risen to a level about 7 ft higher than it is now (Schofield, 1960), and the fall in sea level since then has probably caused a great movement of sand towards the coast to produce such areas of aggradation as the Mangatawhiri Spit; moreover, it is possible that such bulk movements of sand are still in progress. Thus it is believed that most



of the sand being transported into Little Omaha Bay is derived from erosion of soft sediments on the sea floor, and not by the slower process of erosion of hard rocks along the sea coast. This thesis (the effects of sea level fluctuations on sedimentary supply along the coast) is explained more fully below.

Summary of Sand Movement and Source

Mineralogical, grain-size, and zoological evidence for June 1963 shows that: (1) there were off-shore currents that kept depths of 10 to 15 fathoms clear of sand with medians less than 0·25 mm; (2) some of the sand removed by these currents was swept from the south-west into the southern portion of Little Omaha Bay, impinging slightly south of the mid-point of the ocean coast of Mangatawhiri Spit, from whence it was deposited both northwards and southwards along the coast of the spit; and (3) although tidal currents are probably the main transporting agents of sand in and out of Little Omaha Bay, the sand is redistributed by wave motion to give the apparently smooth, almost flat floor of the Bay (*see* submarine contours of Fig. 6).

The mineralogical, grain-size, and zoological evidence for December 1963 showed that: (1) movements of sand away from the shore were greater than those towards the shore, which coincided with a period of coastal erosion at that time; (2) the bulk of the off-shore movement outside Little Omaha Bay, and in depths greater than 10 fathoms, was being deflected northwards; (3) substantial currents move sediment around Tawharanui Peninsula, and these currents are shifting, at 20 fathoms, sediment that is much coarser grained, on the average, than the sand along Mangatawhiri Spit; and (4) although this current loses intensity as it approaches Little Omaha Bay, it carries sediment that is still coarser than that along the spit.

Mineralogically, the bulk of the sand appears to have come from the Rotorua–Taupo volcanic region via the Hauraki Gulf. A fall of 7 ft in sea level within the last 4,000 years has caused mass movements of sand from the sea floor towards the coast so that all the spit has been built up in that time. This mass movement, despite minor fluctuations in rates of movement, could still be in progress.

Possible Causes of Change

There are many possible causes for erosion of the Mangatawhiri Spit. Apart from dredging, which will be dealt with separately, these can be listed under two main headings, namely "long-term" and "short-term" causes.

Long-term Causes

The most probable long-term causes are rates of sedimentary supply, long-term changes in wind and wave regime, and changes in sea level.

Rates of Sedimentary Supply. Rates of sedimentary supply into Little Omaha Bay must be good, otherwise the greater part of the seaward coast of Mangatawhiri Spit could not be building out into the ocean.

Long-term Changes in Wind and Wave Regime. Detailed knowledge of local wind changes and conditions that produce swells coming in from the Pacific Ocean is necessary before the full effects of any long-term changes in wind and wave regime could be assessed in terms of sedimentary supply. These factors are so complicated that only a record of the number and types of waves, and their direction into Little Omaha Bay during the last 20 years, would be of assistance.

Sea-level Changes. Changes in sea level relative to the sea floor could alter the amounts of sediment that reach the coast. For example, during a period of sea-level rise, the sand necessary to raise the sea floor within the bay to keep it in equilibrium with the rising sea level might be supplied by erosion of the coast. Whether there would be actual erosion or a slowing down in building out of the coastline would depend on relative rates of sedimentary supply and amount and rate of rise in sea level.

Evidence for this possible relationship between sea-level change and coastal change can be obtained from coastal sediments formed over a long period, or more laboriously from coastal observations over tens of years. If all minor superimposed fluctuations are ignored, the last major trend in sea level has been a drop of 7 ft in the last 4,000 years (Schofield, 1960). To maintain equilibrium in Little Omaha Bay down to 11 fathoms (the approximate limit at which sand moves either to or from the coast of Mangatawhiri Spit; Fig. 11) would require the removal of 23,500,000 cu. yd of sand. This correlates well with the 22,000,000 cu. yd roughly calculated to be in Mangatawhiri Spit above low-tide level, and which was built during this period of falling sea level.

Observations during the last 30 years at Mangatawhiri Spit suggest that even minor changes in sea level during this period could be the main factor in coastal changes, but the evidence is not conclusive. Fluctuations of average mean sea level at Queen's Wharf, Auckland (Fig. 12), from 1903 to the present, fall within a band that shows sea level rising at an average rate of 4 in. per 100 years for the first 30 years of this century, and at double this rate since. This is identical with average world-wide rates (Gutenberg, 1941; Valentine, 1952; Cailleux, 1952). Some minor changes in sea level may differ from one part of the world to another, due to local climatic differences such as wind and barometric pressures, but these are not likely to be effective in the short distance between Auckland and Little Omaha Bay. Because the high-water-mark ground surveys of 1934 and 1961 were both made in late autumn, one in May and the other in June, the seasonal effect is unlikely to be great. The average extent of erosion between 1934 and 1961 was 1·7 ch., which, assuming that only sand between low and high tides was removed, would require the removal of approximately 500,000 cu. yd. The rise in sea level from 1934 to 1961 was 2·4 in., both in actual amount and as calculated from a smoothed cumulative departure curve for sea levels between 1903 and 1962. Maintenance of equilibrium in Little Ohama Bay down to 11 fathoms (*see above*) would require the addition of 666,000 cu. yd of sand.

Further evidence that sea-level fluctuations may be very important is in a report by Bruun (1962). Dr Bruun, Head of the Coastal Engineering Laboratory, University of Florida, not only equates erosion with rise of sea

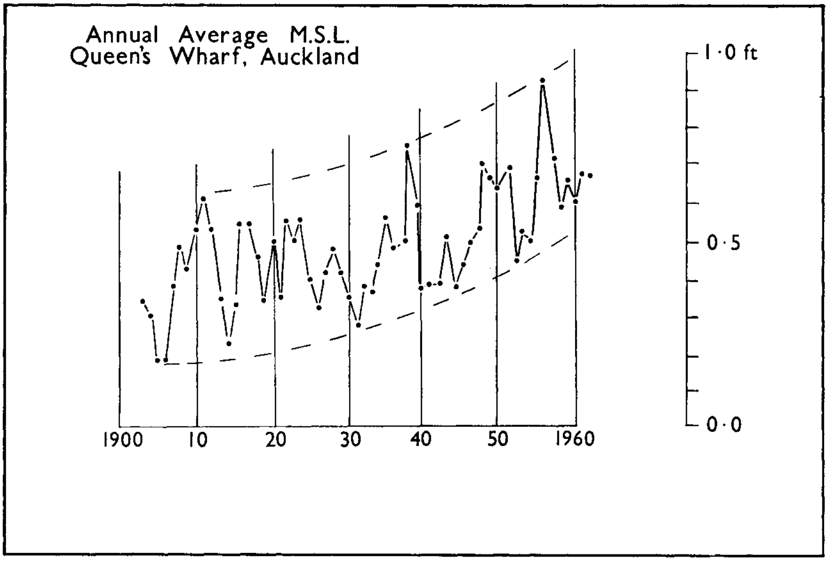


FIG. 12—Sea-level fluctuations from tidal records of Queen's Wharf gauge, Auckland. (Published by permission of the Chief Engineer, Auckland Harbour Board.)

level, but demonstrates that the area of sea floor that is most likely kept in equilibrium with sea-level movements is that between the coast and a depth of 18 m, or 9 fathoms. Bruun also believes that there is a lag (of unspecified limits) between cause and effect; the lag and effect depend on width of sea floor between coast and 18 m depth. He considers that where this width of sea floor is about 2,000 m (approx. 100 ch.) or less, there will be coastal adjustments to the smaller fluctuations of sea level, such as those considered above. Where the width is several miles, only sea-level fluctuations over a much longer period may cause noticeable effects along the coast.

Short-term Causes

Gales and "tidal waves" could cause temporary changes, but there is no satisfactory local information.

DREDGING

The effect of dredging on the stability of a coastline will depend firstly on the position of dredging relative to currents supplying sand to the coast, and secondly on the volume of sand being extracted.

Position of Dredging

The bulk of the dredging of Little Omaha Bay has been close to the north-west corner, so that only the effects of in-shore and off-shore dredging within that area need be considered.

The dividing line between in-shore and off-shore can be defined in two ways—the in-shore area in this case is the area in which there shall be no dredging: (1) There is the purely arbitrary method of stating that 3 fathoms, 5 fathoms, or any other depth shall be the point at which in-shore changes to off-shore. Such an arbitrary depth may have to be accepted in some areas. However, where knowledge of sand movement is sufficient, more precise definition of in-shore and off-shore is possible; (2) In Little Omaha Bay the limiting line between in-shore and off-shore positions may be defined as the "tertiary sand-movement" lines that have been determined by the iso-ratio pattern of feldspar to quartz (Fig. 5).

In-shore Dredging. Prolonged or much dredging at an in-shore position, as described above, is likely to affect temporarily the stability of the shore line, but it need not have any permanent effect.

Off-shore Dredging. The coastal effects of dredging at an off-shore position will be less apparent than those caused by dredging at an in-shore position, and, depending on the actual position and rates of dredging, could range from a spectacular effect to no effect at all. Thus dredging close to the "harbour sand-movement" line at the northern end of Little Omaha Bay (Fig. 5), where the sand is being transported out to sea at rates of dredging not greater than the rate of sand movement, would have no effect on Mangatawhiri Spit. On the other hand, dredging at rates greater than sand movement along, or close to, the "tertiary sand-movement" line would have some ultimate effect on the spit. The lag between cause and effect would differ according to the excess rates of dredging and position of dredging. Thus the lag would be longest if dredging were close to the "harbour sand-movement" line. The shortest period of lag for an off-shore position, and for effect to be felt at the north end of the spit, would be in an area close to the "tertiary sand-movement" line, and also close to the harbour entrance. The actual position of dredging probably lay somewhere between these extremes. However, if dredging is affecting the coast, there should be some lag shown between cause and effect, but there is none, whether the quantities of dredging sand are shown as a running total, actual amounts per year, or cumulative departures from the mean (Fig. 13). Therefore it seems that dredging has had no noticeable effect, and that the rates of dredging have been less than the normal rates of sand movement in and out of Little Omaha Bay. This latter rate is unknown and would take several years to determine.

CONCLUSIONS

(1) From 1942, the east coast of Mangatawhiri Spit built out slightly seawards to a new coastal position east of the 1934 position. This period of progradation lasted until about 1950. Between 1950 and 1953 the seaward

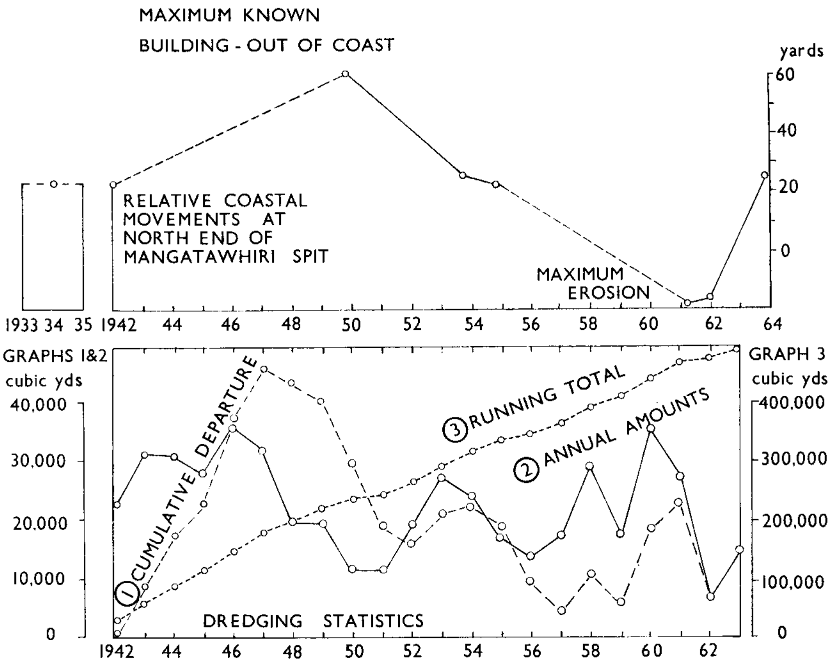


FIG. 13—Comparison of coastal movements at end of Mangatawhiri spit with volume of dredging.

coast, at the north end of the spit, was eroded back to about the 1934 position, but it was probably not until after 1957 (*see* major changes at Waiwera, Fig. 4) that erosion was rapid along the full length of the coast and well west of the 1934 coastline. A high-water berm has now reclaimed most of the land lost during this period of erosion so that the legal land boundary is once again at the 1934 position, with the exception of about 1 acre at the northern extremity of the spit. This high-water berm could herald the replacement of the foredune sand that was also lost during erosion at the north end of the spit.

(2) Similar changes during the same time as those at Mangatawhiri Spit are shown by aerial photographs of spits at Whananaki Inlet and Ngunguru. This shows that natural causes have been largely, if not wholly, responsible for the changes along Mangatawhiri Spit.

(3) The natural causes responsible for coastal changes almost certainly include, and are possibly headed by, sea-level rise.

(4) There is ample mineralogical, grain-size, and zoological evidence of sand movement down to depths of 20 fathoms off the Tawharanui Peninsula,

and at 15 fathoms outside Little Omaha Bay. The same evidence demonstrates constant movement of sand in and out of Little Omaha Bay from these depths, and makes it probable that there is much more sand movement within Little Omaha Bay than would appear from seasonal and long-term volume changes along the coast. This movement far exceeds the average annual quantities of sand required to replace that dredged out of the system. Moreover, the absence of any correlatable lag between dredging rates and coastal changes indicates that dredging has had no noticeable effect.

(5) Before areas are set aside for dredging they should be investigated along the lines of those followed by the present survey so that working areas may be more accurately defined. To help in observing any possible effects of dredging, and to provide information to combat coastal erosion or harbour silting, seasonal surveys of selected beaches and periodic vertical aerial photography of others are recommended. This should be done not only in areas being dredged, but also along selected coasts away from such areas, so that comparisons can be made with coastlines undergoing natural changes.

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