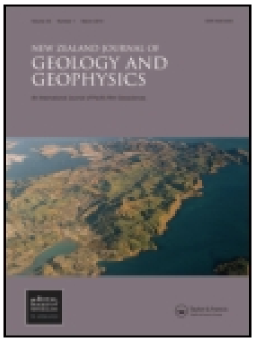

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BEACH CHANGES IN THE HAURAKI GULF, 1965–68: EFFECT OF WIND, SEA-LEVEL CHANGE, AND OFF-SHORE DREDGING

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ABSTRACT

Beach changes in an area where the sea floor is in equilibrium with sea level are not only a function of the local energy input and time, but also of sea-level change. The magnitude of beach change, erosional and progradational, is related to maximum depth of the local sea-floor profile of equilibrium and both are a function of local wind strengths and directions. Removal of sand by man from shallow depths and from beaches within the essentially closed Ocean Beach–Mangatawhiri Sand System exceeds natural input by an average of about 1750 m^3 per kilometre of coast per year. Starvation of the local beaches is tentatively shown by the difference in behaviour of Mangatawhiri Spit and beaches of Great Barrier Island; the latter are part of another system where sand is not being removed by man. Mangatawhiri Spit beach is apparently being starved at a rate of about 4750 m^3 per kilometre per year; this rate may include the continued effect of a more localised removal of sand. Starvation of beaches in the Ocean Beach–Mangatawhiri Sand System may accelerate their erosion now and for some time in the future, particularly during periods of rising sea level.

INTRODUCTION

One of the main factors governing erosion or building-up of a beach is the rate of sedimentary supply, and if man removes sand at a greater rate than the natural rate of replenishment he must promote erosion, either immediately or in the future.

The coastal observations recorded here were mainly made to determine the effects of sea-level change, wind, and shallow off-shore dredging of sand between Ocean Beach and Mangatawhiri Spit (Fig. 1). Previous sedimentary studies have been made of the 4-km-long Mangatawhiri Spit (Schofield 1967) and hence its ocean beach was chosen for further observation. Although dredging from shallow depths off this spit ceased in 1963, it has continued within, the Ocean Beach–Mangatawhiri Sand System (see below) of which Mangatawhiri Spit is a part. For comparison, beaches, similar to the ocean beach at Mangatawhiri Spit, were chosen on the east coast of Great Barrier Island, where environmental factors are as closely similar as possible but where there is no possible chance of interference due to off-shore dredging. Although the results show that dredging is probably promoting erosion, further observations are required to determine the degree and rate of interference. Such observations are postponed for 10 years or so, during which time any net difference in behaviour between the Mangatawhiri Spit and Great Barrier Island beaches should be more clearly established. For this reason, permanent markers have been surveyed and levelled so that future observations can be related to the 1965–68 surveys. Details of the latter are available from the Ministry of Works, Auckland, or the Geological Survey, Otara Research Station, Auckland.

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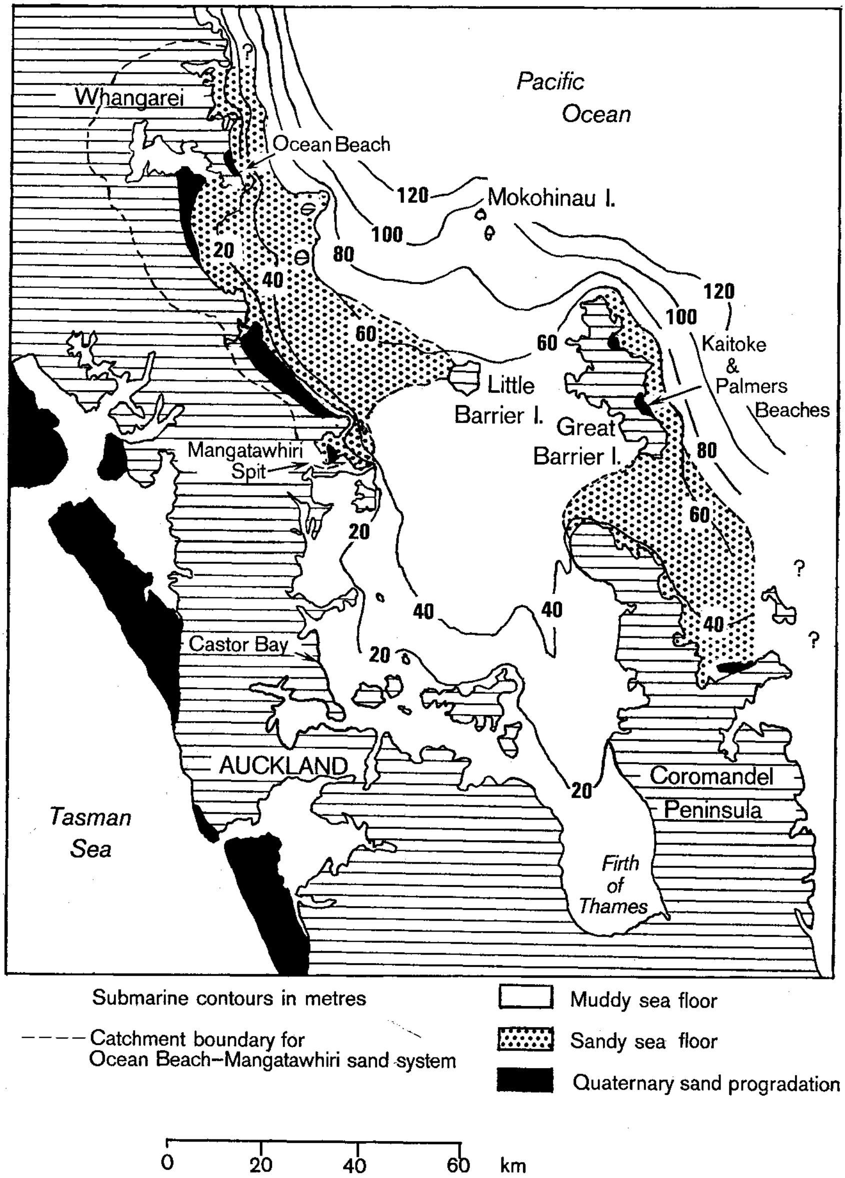

FIG. 1—Locality plan of Hauraki Gulf, which extends from Firth of Thames to Little Barrier and Great Barrier Islands; the Ocean Beach–Mangatawhiri Spit–Little Barrier Island sand system (= *Ocean Beach–Mangatawhiri Sand System*); and observed beaches at Castor Bay, Mangatawhiri Spit, and Great Barrier Island.

REGIME

Sedimentology

The Hauraki Gulf extends from the Firth of Thames to Little Barrier and Great Barrier Islands, beyond which it lies open to the Pacific Ocean (Fig. 1). Marine Charts (Nos 1108, 1998, 3565, and NZ532) show that its floor is mainly muddy with the exception of very narrow, sandy, coastal strips and two large areas of sand that adjoin its northern, less protected limits. These two areas of sand extend down to depths slightly greater than 60 m, beyond which the sea floor is steeper and covered with mud. Mineralogical studies of these outer, sandy portions show that they are partially reworked remnants of a terrestrial plain formed when sea level was more than 60 m below the present, and when the Waikato River flowed into the Firth of Thames, during the Last Glaciation (Schofield 1965; 1970). This plain has since been largely coated with marine mud; the outer sandy portions are sufficiently exposed to greater sea-current activities to be kept clean of any mud deposition. These currents are mainly generated by onshore winds; this is strikingly shown by the protective nature of Great Barrier Island, which allows the deposition of a belt of mud west of the island (Fig. 1).

Recent study has shown that there are several distinct sand facies along the eastern coast of Northland, north of Auckland, including three within the Hauraki Gulf (Schofield 1970, fig. 14). The highly feldspathic sand from the outer sandy portions of the Gulf is called Hauraki (A) Sand Facies to differentiate it from its coastal derivative, Hauraki (B) Sand Facies which forms the prograded regions between Ocean Beach and Mangatawhiri Spit (Fig. 1). Whereas some pumice is still retained in Hauraki (A) it has disappeared from (B), and the latter also contains fewer rock fragments and mafic minerals. These differences are no doubt due to wear and tear of the sand during its marine transport from the sea floor onto the coast. Between Mangatawhiri Spit and Castor Bay (Fig. 1), i.e., within the mud-covered, more protected, inner region of the Hauraki Gulf, the local beach sand belongs to the more highly quartzose Orewa Sand Facies, which, as mineral studies show, is derived by erosion of the local Miocene strata that predominate in the hinterland and along the cliffs of this area. North of Ocean Beach the coastal sand consists mainly of the Bay of Islands Sand Facies, which is largely composed of locally derived rock and shell fragments; there is some mixing of this and the Hauraki (B) facies immediately north of Ocean Beach.

The presence of the Hauraki (B) facies in the post-glacial dunes between Ocean Beach and Mangatawhiri Spit is important in that it shows that the nearby sandy sea floor has contributed almost all the sand to these dunes. This, plus the appearance of different sand facies not far north of Ocean Beach and south of Mangatawhiri Spit, means that the beaches and shallow marine floor between Ocean Beach, Little Barrier Island, and Mangatawhiri Spit form an essentially closed sand system with only minor amounts of longshore drift northwards. For ease of discussion this is called the **Ocean Beach–Mangatawhiri Sand System.** If longshore drift into or out of this system were at all significant, there would be a development of a widespread, thoroughly mixed, "East Auckland Sand Facies" equivalent to the West Auckland Sand Facies of Schofield (1970).

Sand Budget for the Ocean Beach–Mangatawhiri Sand System

Input

The actual amount of sand transported from the hinterland into the Ocean Beach–Mangatawhiri Sand System is not known. However, a rough estimate can be obtained by comparing the catchment area with that for the Waikato River for which an approximate rate of sedimentary transport is known. The latter, as calculated by Schofield (in press), is 42 000 m^3 per year from a catchment area of 14 000 km^2. This catchment is more than 11 times greater than that for the Ocean Beach–Mangatawhiri Sand System and generally consists of more easily eroded rocks (mainly unconsolidated rhyolitic sands and soft ignimbrite) so that the annual sedimentary supply for the Ocean Beach–Mangatawhiri Sand System is likely to be considerably less than 42 000/11 or 3800 m^3. Furthermore, the percentage of sand is probably less than 50% so that maximum annual input of sand into the Ocean Beach–Mangatawhiri Sand System is almost certainly below 1500 m^3, which is far less than the output (see below).

Output

From records kept by both the Mines Department and Marine Department it is calculated that the average annual output of sand from the Hauraki Gulf for the period 1955–67 rose from 100 000 to 106 000 m^3. Practically all of this was dredged or taken from beaches within the Ocean Beach–Mangatawhiri Sand System. This far exceeds the annual input and represents a potential starving of beaches within the system of 1750 m^3 per kilometre. This is the average potential; the actual interim amounts of starvation must depend on time and proximity of coast to area of sand extraction.

Sea-Level Change

Because of local wind and atmospheric pressure change and outside influences such as the melting or formation of ice, sea level is constantly changing. The nearest records are the continuous tidal records kept at Queens Wharf in the Auckland harbour which lies in the inner part of the Hauraki Gulf; they recorded a net rise of 110 mm between 1910 and 1960, similar to the average world sea-level change (Schofield 1967).

Bruun (1962) and Schwartz (1965) have demonstrated that where the sea floor is in equilibrium with sea level, a rise in sea level promotes coastal erosion. This arises from the following situation. During storms, sand, eroded from the coast, is temporarily deposited in shallow water and is returned during calmer conditions. If, however, sea level is rising not all of the sand is returned because some is retained on the sea floor to keep the sea floor in equilibrium with the increased ocean level. Conversely, a fall in sea level promotes coastal progradation. Time for equilibrium to be established is important, as is the related factor of the width of the sea-floor equilibrium profile (Bruun 1962). The greater the sea-level change the longer the time required to produce equilibrium, i.e., $S = f(A_e, T_e)$ where S equals coastal change, A_e equals equilibrium amplitude of sea-level change, and T_e equals the equilibrium time (after Schwartz 1968). Examples of how the Mangatawhiri Spit has changed as the result of sea-level change have already been described (Schofield 1967): the spit is of post-glacial age and contains approximately 17×10^6 m^3 of sand, which correlates well with the 18×10^6 m^3 calculated to be thrown shoreward as the result of a 2·1-m fall of sea level during the last 4000 years. The calculation assumes a net movement of sand westward from the Tawharanui area into Little Omaha Bay and eventually onto Mangatawhiri Spit (see Schofield 1967, fig. 11B), and also takes into account the wedging effect (see Schofield in press). Similarly, the spit has also been sensitive to an overall rise in sea level during the last 30 years; the bulk of the erosion up to at least 1962 was probably due to this cause.

Wind

Records of wind velocity and direction, recorded at 6-hourly intervals, on Mokohinau Islands near the head of the Hauraki Gulf (Fig. 1) were used in the following calculations.

Wind is important for two reasons: it imparts energy to the sea by forming waves, and it can create temporary sea currents. Steep, locally generated waves cause coastal erosion, whereas the more gentle swell, which is often generated by wind outside the local regime, promotes progradation. On-shore winds tend to pile sea water shorewards which in turn generates an off-shore-directed undertow which assists in erosion of the beach. On-shore winds also have the advantage of a long fetch in which to generate steep erosive waves. Off-shore winds, on the other hand, have not the fetch in which to generate steep waves but tend to flatten any previously formed waves, whilst at the same time they amass water away from the coast which tends to create a shoreward-directed sea-bottom current. This assists the swell in returning any sand that may have been eroded from the beach during previous periods of strong on-shore winds.

Although the effects of wind, as described above, are commonly accepted, there have been no absolute values assigned to either its erosional or progradational powers. This is not surprising because of the complexity of the subject. However, the effect of wind on the sea and thus on the coast depends on its velocity, direction, fetch, and duration; except for direction, Neumann (1953) took these factors into account when he attemped to give empirical values for wind-generated wave energies. His co-cumulative power spectra show that wave energies for a 24-hour duration and optimum fetch are almost log-normal and hence his values can be extended beyond his 20–36 knot range.

Because of the siting of Mangatawhiri Spit, and Kaitoke and Palmers Beaches on Great Barrier Island (Fig. 1), it can be assumed that fetch has been at its optimum for almost all on-shore winds but that for all off-shore winds fetch has been almost nil. So far as short fetch is concerned, Neumann's graphs are only clear in that the effect of any wind across a short fetch must be small. However, a value of 1% of Neumann's wave-energy values given to winds across an optimum fetch is probably close to the wave energies derived from off-shore winds and, in practice, this results in such small additions that the effects of off-shore winds could probably be neglected.

In an attempt to produce an empirical wind-energy curve for comparison with coastal change several other factors have to be taken into account. Those wind energies that cause erosion are given a positive value, whereas those that promote progradation are negative. Because off-shore winds either tend to flatten existing steep erosive waves or promote a shoreward directed sea-bottom current, they produce negative wind energies. On he other hand, not all on-shore winds produce positive values, because only the prolonged, very strong winds are able to produce steep erosive waves. At some particular strength, therefore, a division has to be made between the on-shore winds that produce negative and those that produce positive wind energies. As a first approximation this threshold is chosen as 20 knots, above which Neumann's wave energies for faster winds begin to increase very rapidly (Fig. 2). Furthermore, wind direction, be it at right angles or at some other angle to the coast, is also important. An on-shore wind at right angles to the beach has more effect than a similar wind that lies parallel to the beach, and thus the former, being at 90° to the coast, has been weighted by an empirical factor of 9, the latter by 0, and all winds between by intermediate values. This form of empirical weighting can only be applied in an essentially closed system where longshore drift into or out of that system is not an important factor. Within the Ocean Beach–Mangatawhiri Sand System there are probably individual cells of sand circulation producing local longshore drifts as shown by Schofield (1970, fig. 15) and in particular within Omaha Bay, off the Mangatawhiri Spit (Schofield 1967). The net effect of on-shore movement of sand, however, must be generated by on-shore winds and thus the weighting as adopted for this region is thought to be essentially correct. This empirical vector factor is multiplied by Neumann's empirical wave energies, to produce empirical wind energies, (see Figs 12, 13); their positive or negative values are determined by the equally empirically derived threshold described above. Obviously such methods, which have had to be employed to show some sort of working relationship between wind and coastal change, must make the results tentative. Nevertheless, the empirical-wind-energy (EWE) curve shows a better correlation with coastal change than does the sea-level curve (see discussion below).

The empirical-wind-energy units employed in the EWE curves (see Figs 12, 13) have no absolute values but have meaning only in their relativity. In determining their effect on the coast it has not been possible to include the direct effect of swell which is generated by winds outside the local regime. As a result the number and relative value of the positive energies (those that cause erosion) exceeds those of negative value (those that cause progradation). Swell promotes progradation and hence, if it could have been included, it may have balanced the difference between the average negative and positive energies. Its inclusion may also have produced a better correlation between the EWE and coastal-change curves. Its average effect is almost certainly shown by the shift in base-line for the EWE curves (see Figs 12, 13) relative to zero wind energy.

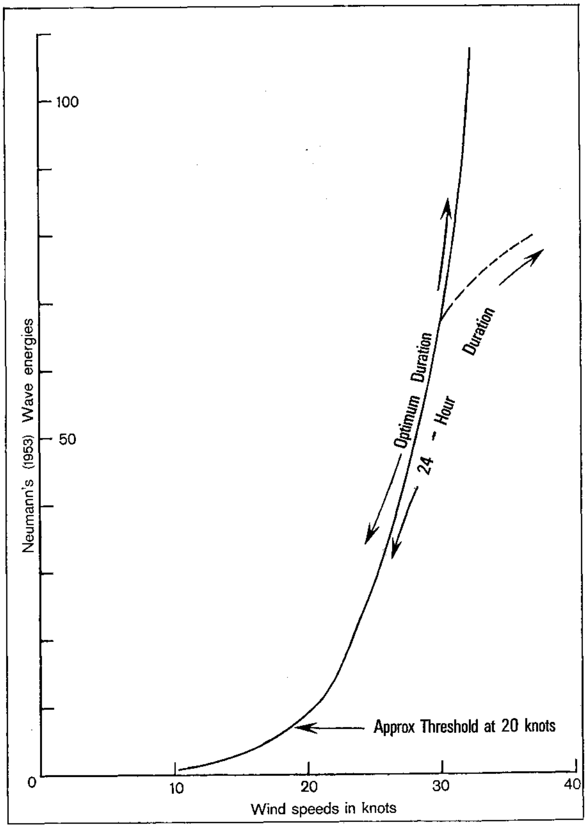

FIG. 2—Relation of Neumann's (1953) wave energies to wind speed and duration.

BEACH OBSERVATIONS

A number of sections across the foreshore, from stable dunes in the upper portion down to approximately low tide, were chosen for observation, namely 14 for the Castor Bay region (Figs 3, 4), 7 for Mangatawhiri Spit (Fig. 5), and 9 for the combined Palmers and Kaitoke Beaches at Great Barrier Island (Fig. 6). These were instrumentally levelled at approximately fortnightly intervals from April 1966 to April 1967 at Castor Bay; and at monthly intervals from February 1965 to August 1968 at Mangatawhiri Spit, and from February 1966 to August 1968 for Great Barrier. From these observations it has been possible to determine the departures from average in cross section (Figs 7–9) and the departures from average calculated as volume change per kilometre (Fig. 10; see also Figs 12, 13).

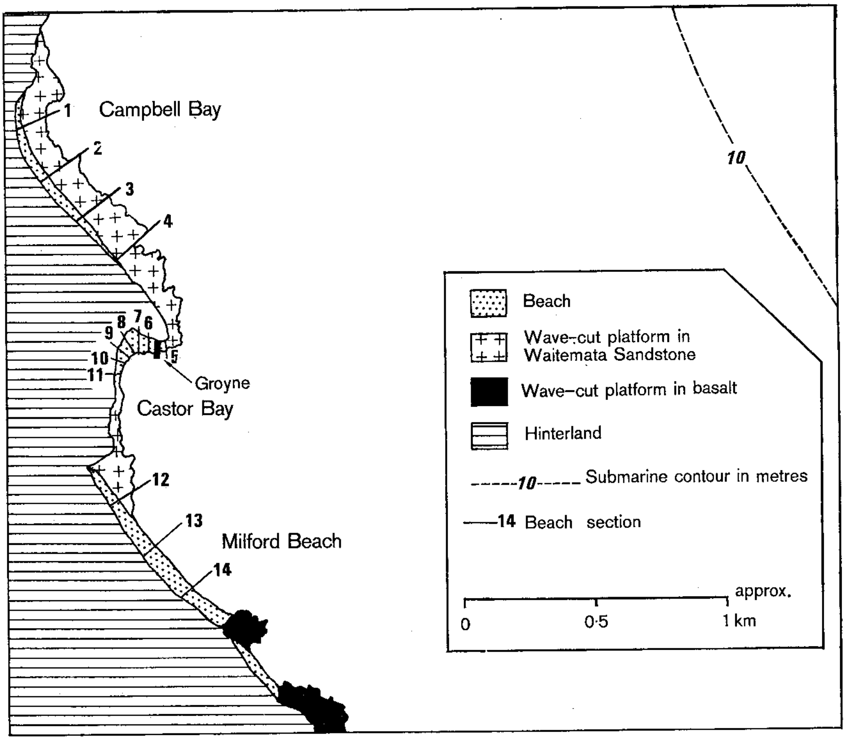

FIG. 3—Locations of beach sections observed in the Castor Bay area. For details of Castor Bay see Fig. 4.

DISCUSSION

Coastal Change Related to Energy Input

Coastal fluctuations at the three localities—Castor Bay, Mangatawhiri Spit, and the Great Barrier beaches—are shown in Fig. 10. Although differing quantitatively, the curves show the same trends. Undoubtedly a major controlling factor has been effective in all three areas, the differences in the amounts of change being due to differences in local wind, wave, and sea-current energies. Castor Bay is in the inner part of the Hauraki Gulf (Fig. 1) and is thus in a relatively low-energy environment and shows the least magnitudes of change. The Great Barrier beaches lie outside any protective influence of the gulf and show the greatest magnitudes of change. Predictably Mangatawhiri Spit, which lies in an intermediate-energy area, shows intermediate magnitudes of change.

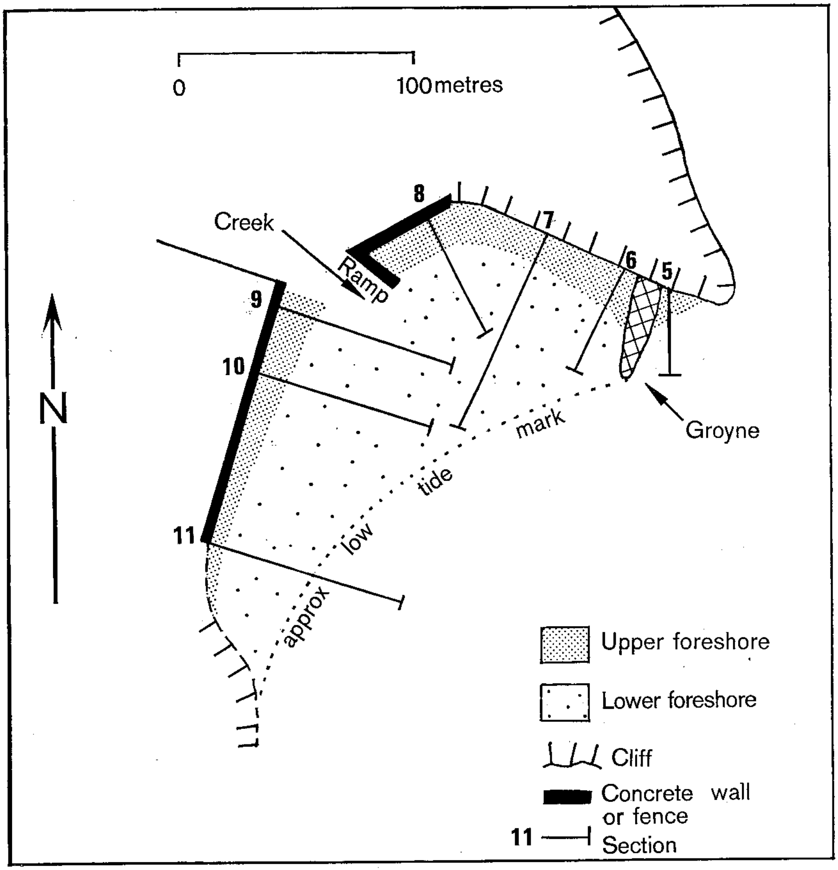

FIG. 4—Location of beach sections observed within Castor Bay.

There also appears to be a direct relationship between the magnitude of coastal change and the maximum depth to which the local sea-floor equilibrium profile extends; both are dependent on energy input. The off-shore movement of sand has been studied in some detail off Mangatawhiri Spit; mineralogical, malacological, and grain-size analyses were all used (Schofield 1967) to determine the main off-shore regions in which there had been movement of sand during coastal progradation of June 1963, and coastal erosion of December 1963 (summarised in Fig. 5). This work showed that for these periods the main movement of off-shore sand transport occurred down to an average depth of 20 m. This was also the depth used in calculating the amount of progradation that resulted from a 2·1-m sea-level fall during the last 4000 years, and the fact that the amount almost coincides with the actual volume of sand within the spit (see section on *Sea-Level Change* above) confirms that this is the most likely average depth for

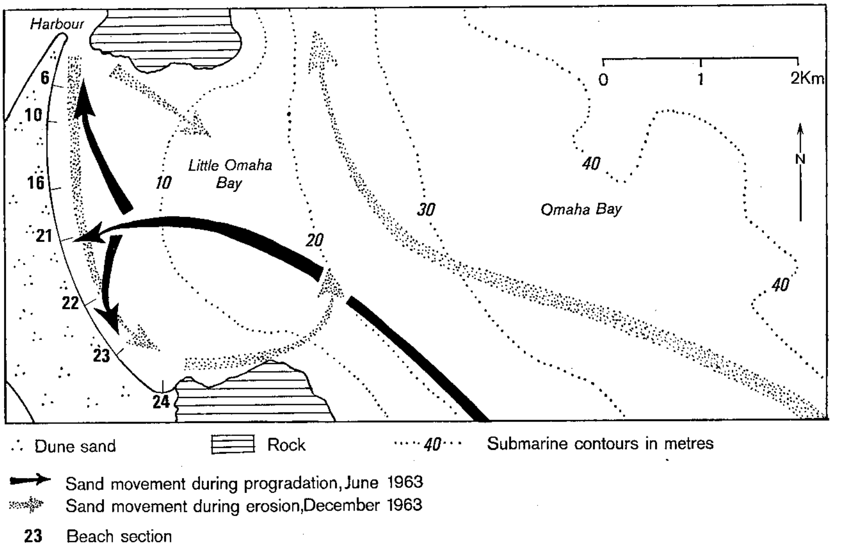

FIG. 5—Location of beach sections along the Mangatawhiri Spit and position of main off-shore currents during progradation and erosion of 1963 (after Schofield 1967). Note the relative irregularity of the 40 m contour which is approximately the boundary between sand and mud.

sand transport in the Mangatawhiri Spit area. At depths greater than approximately 20 m in the Mangatawhiri area the sand becomes finer and is eventually replaced by mud at approximately 40 m (Schofield 1967, and Marine Charts). At about this depth there is also a distinct change in the sea-floor slope (Fig. 11). This suggests that the profile of equilibrium for the sea floor off Mangatawhiri Spit extends down to approximately 40 m but that the bulk of sand movement extends down to only half this depth. Similarly, a change from sand to mud almost certainly coincides with the sudden change in off-shore profile at a depth of about 65 m off Great Barrier Island (Figs 6, 11), and probably at less than 10 m off Castor Bay where Marine Chart NZ532 consistently records mud below depths of 5 fathoms (10 m). Assuming the effectual depth of off-shore transport is half these depths, as it is for the Mangatawhiri Spit sea-floor profile, we find that the ratio of average volume change (in m^3/km) to effectual transport depth (in m) is closely similar for the three beaches, i.e., approximately 750 for Castor Bay, 700 for Mangatawhiri Spit, and 960 for Great Barrier Island.

Beach-Volume, Sea-Level, and Wind-Energy Correlations

The departures from the average for beach-volume, sea-level, and empirical-wind-energy (EWE) changes are shown in Figs 12, 13. These cease at February 1968, because after that date a number of the beach cross-sections

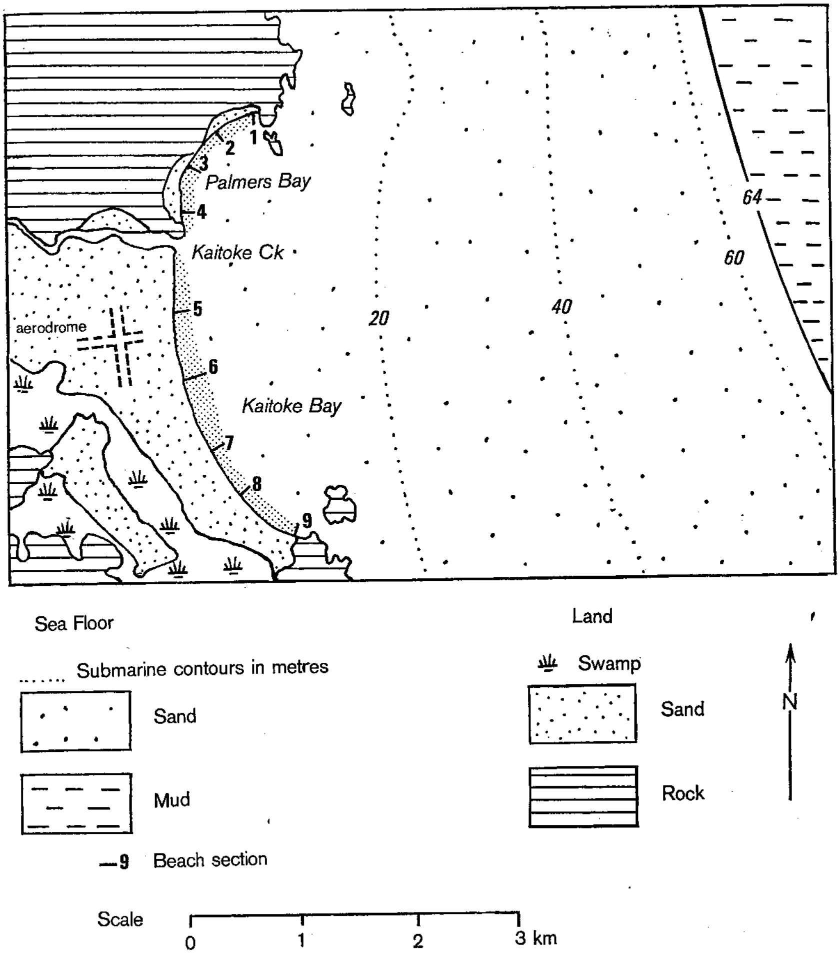

FIG. 6—Location of beach sections observed along Palmers and Kaitoke Beaches, Great Barrier Island. The boundary between mud and sand in this diagram is based on Marine Chart 3565, and shows that all samples collected from levels deeper than 64 m (35 fathoms) consisted of mud or sandy mud, whereas shallower samples consisted of sand.

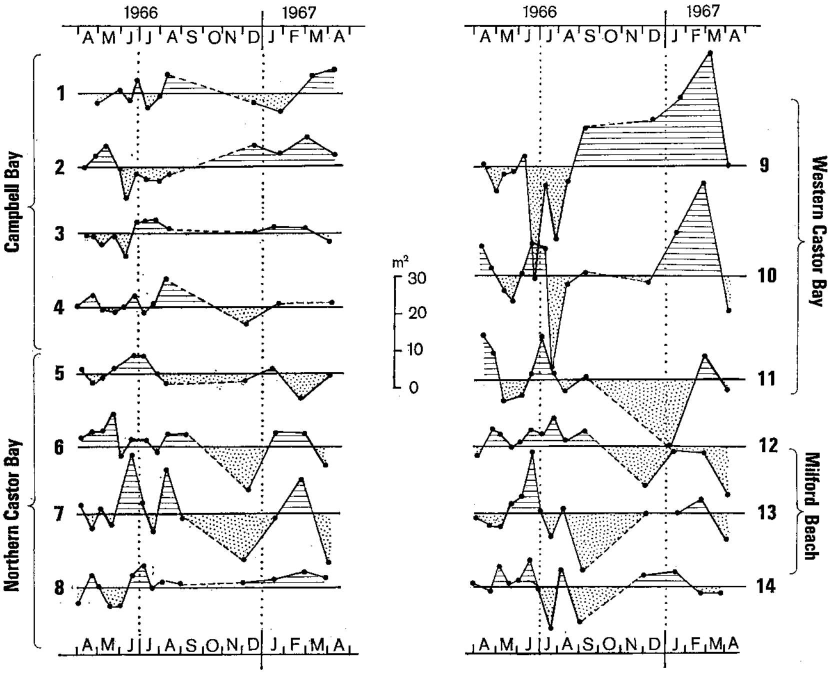

FIG. 7—Departures from average for beach cross-sections in the Castor Bay area; those above the zero line are positive, those below are negative.

were not surveyed (see Figs 8, 9) and hence the average volume change per kilometre could not be as accurately calculated. A direct comparison of the coastal change for Mangatawhiri Spit and Great Barrier Island is shown in Fig. 12 but because a lesser number of surveys were made for Great Barrier Island, only those of a similar date for Mangatawhiri Spit have been used in determining the departures of average for that beach. Furthermore, greater changes, both negative and positive, have taken place at Great Barrier Island than at Mangatawhiri Spit and hence the scales used are different. Their comparison shows that there has been a relative loss at Mangatawhiri Spit and that the Great Barrier changes are more closely parallel to the EWE curve. The period of observation is short and broken by a 6-month gap which makes this conclusion tentative, but nevertheless it is in agreement with other conclusions below.

The better-kept, longer-period observations at Mangatawhiri Spit permit a more accurate comparison of coastal change with both sea-level and EWE changes; the correlation with the latter (Fig. 13B) is better than with the former (Fig. 13A). The best fit for both of these correlations is obtained when a 2-week lag is accepted and when the average or zero-base line for coastal change is tilted relative to the average base line for both of the sea-level and EWE curves.

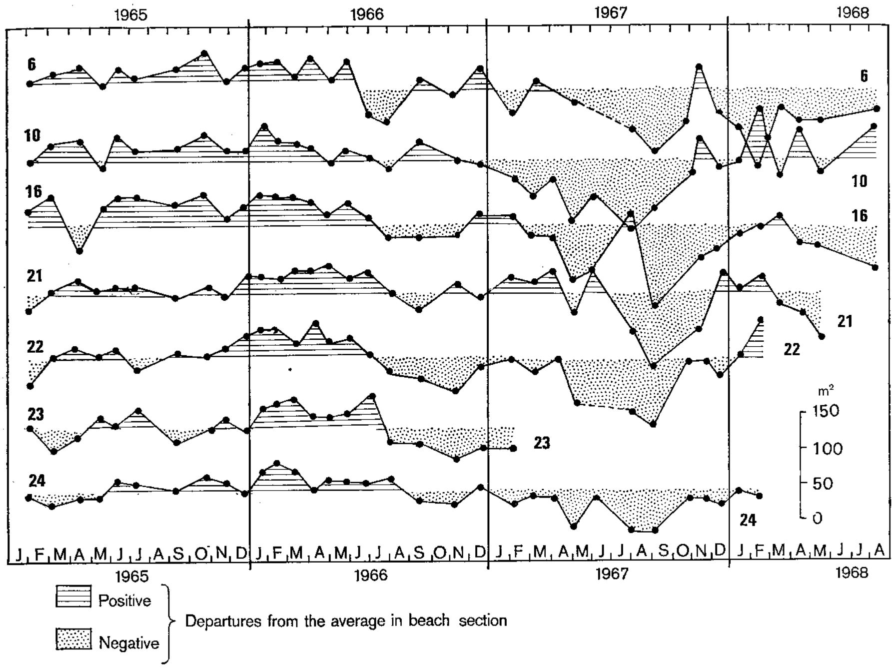

FIG. 8—Departures from average for beach cross sections at Mangatawhiri Spit; those above the zero line are positive, those below are negative.

Effect of Wind on Sea Level

Hamon (1966) discussed the complex issue of the effect of wind and atmospheric pressure on sea-level change off the east coast of Australia. He concludes, "it is not possible to say definitely on the basis of multiple regression studies alone if the nonisostatic barometer factors are due to omission of wind stress. But when other factors are taken into account, it seems most unlikely that the wind stress effect is large enough." Nevertheless, he records that Miller (1958) "found measurable wind effects on the Atlantic coast of the United States", and that these are in good agreement with estimates for off the east Australian coast "if allowance is made for the larger depth-to-fetch ratio on the Australian coast, and also if daily means are used instead of peak winds." Hence it is not surprising that there is partial correlation of the EWE curve with sea-level change in the Hauraki Gulf (Fig. 13C). The reason for the major discrepancy during March to May of 1966 is not known but is most likely due to some outside cause.

Effect of Sand Removal

As a result of localised studies up to 1963, it was concluded (Schofield 1967) "that dredging has had no noticeable effect" but that further surveys of selected beaches should be made. Since then, not only has there been

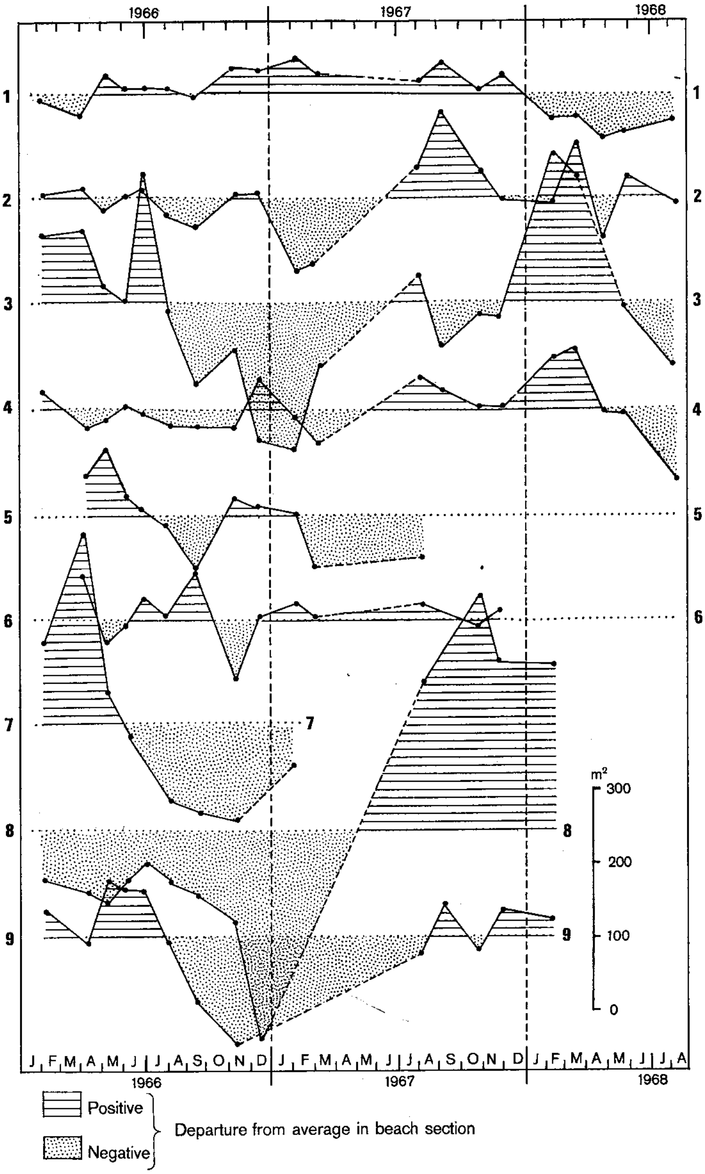

FIG. 9—Departures from average for beach cross-sections at Great Barrier Island; those above the zero line are positive, those below are negative.

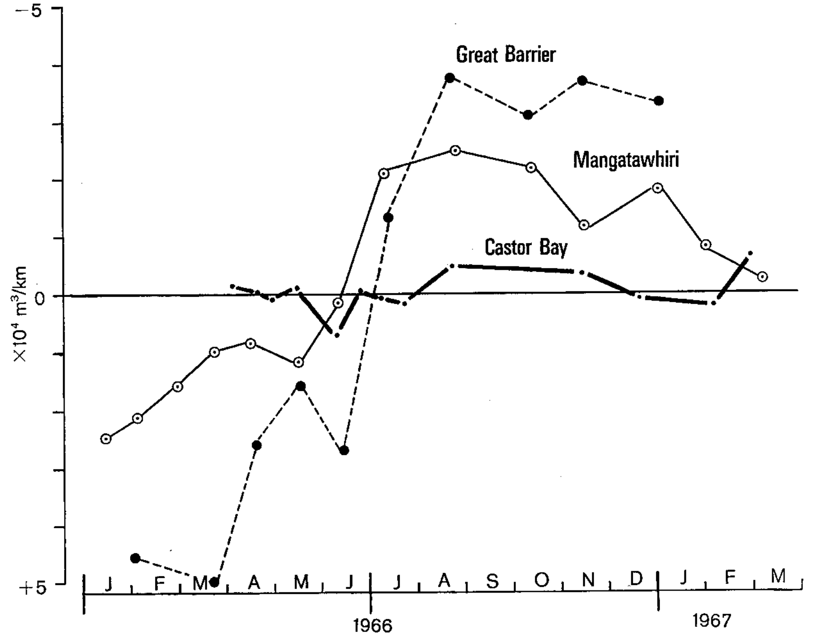

FIG. 10—Comparison of beach volume changes (with departures from average calculated as volume change per kilometre) at Castor Bay, Mangatawhiri Spit, and Great Barrier Island. Note that the negative values for volume change are above the zero line, as in Figs 12 and 13.

prolonged beach observation but there is a better understanding of the coastal sand systems and it is concluded above that Mangatawhiri Spit lies close to the southern end of the essentially closed Ocean Beach–Mangatawhiri Sand System and that the total output from his system as a result of mans' removal of sand far exceeds the natural input. Thus beach starvation can be expected, and its probability is shown by the differences in behaviour of the Mangatawhiri Spit and Great Barrier beaches (see above) and by the tilted relationships of the coastal change at Mangatawhiri Spit with both sea-level and EWE curves (Fig 13A, B). This tilt represents a deficit of about 4750 m^3 per year per kilometre of coastline and is 3000 m^3 more than the average starvation per kilometre calculated for the whole of the Ocean Beach–Mangatawhiri Sand System (see *Sand Budget for the Ocean Beach–Mangatawhiri Sand System* above). The difference could be due to a continuing effect of dredging close to Mangatawhiri which from 1942 to 1963, when it ceased, yielded a recorded total of almost 380 000 m^3 of Sand (Schofield 1967). This, at an average rate of effect on the local coast from 1942 until 1968 (the year when beach observations ceased), represents more than enough to account for the above difference.

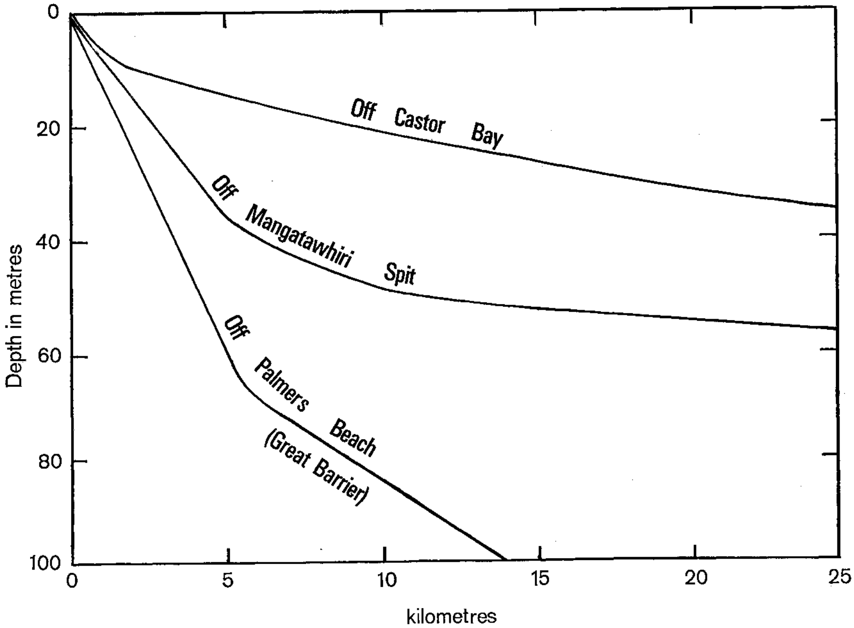

FIG. 11—Approximate sea-floor profiles of equilibrium off Castor Bay, Mangatawhiri Spit, and Great Barrier Island. The sudden flattening of these curves is approximately at the change from sand to mud on the sea floor.

However, a slight alteration in tilt between beach-volume and EWE, or beach-volume and sea-level curves significantly changes the calculated rates of coastal starvation and hence these results must remain tentative until confirmed by future observations.

CONCLUSIONS

(1) Beach change is a function of energy input—the more exposed the beach the greater its degree of alternate erosion and progradation.

(2) The sea-floor equilibrium profile is also a function of energy input; there is a direct relationship between maximum depth of profile and magnitude of beach change.

(3) Although most sand movement, seaward of the breaker zone, occurs at relatively shallow depths within the sea-floor equilibrium profile, at or shallower than the "effectual depth" of transport, some movement occurs at deeper levels. This conclusion agrees with the following observations made by Ingle (1966), "Recent observations by divers and from deep submersibles have emphasised the fact that sediment is in motion across the breadth of the shelf environment. The relative importance of sediment transport seaward

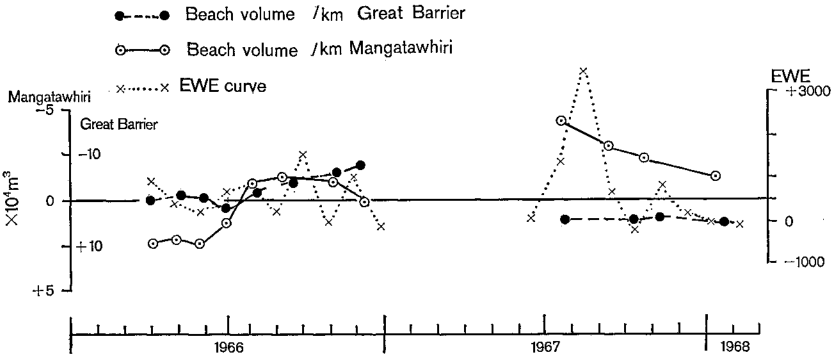

FIG. 12—Comparison of the empirical-wind-energy (EWE) curve with beach changes at Great Barrier and Mangatawhiri Spit. Because of an inverse relationship the negative departures from average for beach change are shown above the zero line.

of the breaker zone and mechanisms of transport have yet to be delineated. To date most authorities have assumed that the foreshore–inshore zone constitutes the zone of greatest volumetric transport of sediment per unit of time."

(4) Sea-level fluctuations are an important cause of coastal change where sea-floor is in equilibrium with sea level and where the coast consists of previously prograded sand deposits; a rise promotes erosion whereas a fall promotes progradation. Although empirically derived wind energies correlate better with coastal change than do sea-level fluctuations, they also correlate well with sea-level changes. This means that wind is a partial agent for local sea-level change and that probably both affect the coast.

(5) Mangatawhiri Spit is part of an essentially closed sand system from which output, as a result of sand removal by man, greatly exceeds natural replenishment. The excess output represents an average of about 1750 m^3 per kilometre of coast.

(6) Thus starvation of the coast can be expected and is tentatively shown by the difference in behaviour of Mangatawhiri Spit and the Great Barrier beaches which are part of another sand system from which sand is not being taken by man. Comparison of the Mangatawhiri Spit beach-volume change with sea-level and EWE curves also shows that the beach is being starved at a tentatively calculated rate of 4750 m^3 per kilometre per year. This rate may include the continued effect of a more localised removal of sand.

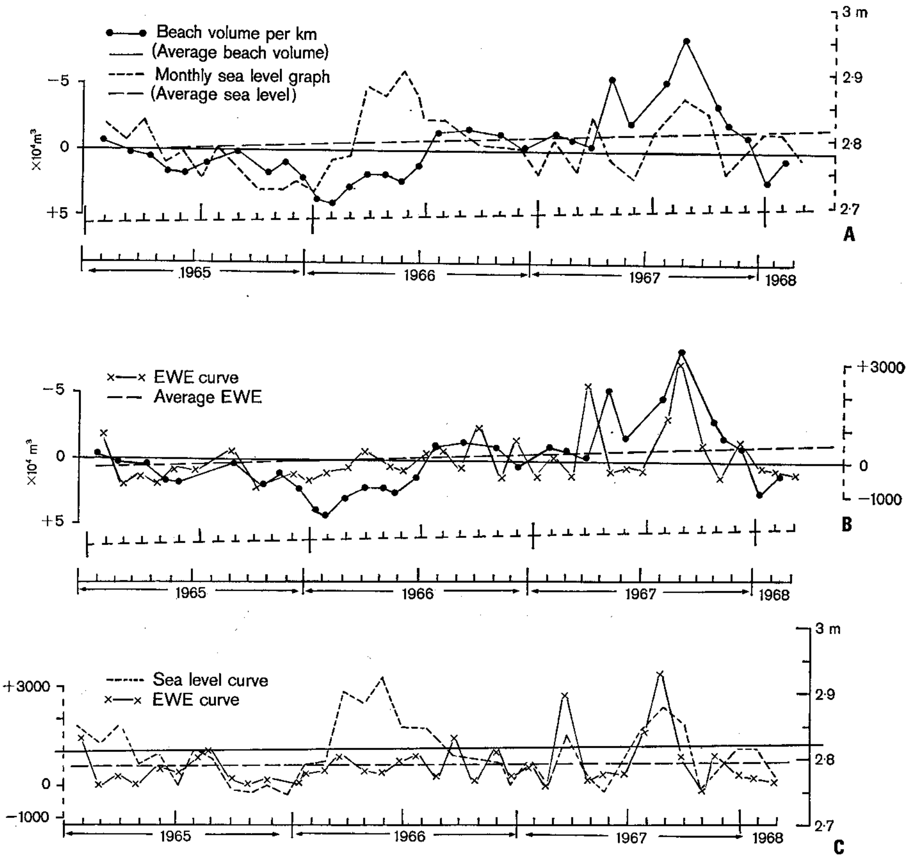

FIG. 13—Partial correlation of beach-volume changes at Mangatawhiri Spit with sea level (A), and the empirical-wind-energy (EWE) curve (B). *Note*: Because of inverse relationships the negative departures from average for coastal change are plotted above the zero line. Comparsion of the full and dashed time lines (divided into months) shows the lag and tilt required to give optimum correlation. (C) Shows the partial correlation of sea-level and EWE curves.

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