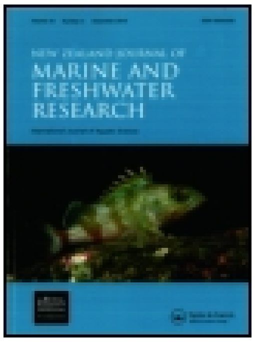

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# Harbour entrance morphology and sediments at a river mouth port, Westport, New Zealand

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**Abstract** Entrance morphologies and sediment characteristics were studied at Westport Harbour, a river mouth port located on the Buller River, New Zealand. The most frequent morphology found was that in which two submarine bars were present off the river mouth. When present, these bars were separated by a transverse channel running east from Carters Beach and terminating in the principal inlet channel. Sediment samples were collected and analysed for grain size, rollability (grain shape), and, in a few instances, mineralogy. The data collected suggested that longshore sediment transport is predominantly west to east and that river derived sediment is deflected to the east. The inner bar is predominantly a littoral drift related event whereas the outer bar, which is composed mainly of littoral drifted sediment, forms as a submarine extension of Carters Beach. Both bars can be modified by floods in the river, although modification of the outer bar is much less frequent because of the very high river flows required. Sediment can bypass directly across the river mouth only when the inner bar is present. On other occasions bypassing can only occur by transport through the transverse channel or over the outer bar, into the river channel and then onshore.

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**Keywords** Westport; river mouth port; river mouth bars; sediment analysis; sediment transport; grain size; grain shape; rollability; mineralogy

## INTRODUCTION

Westport Harbour is located near the mouth of the Buller River on the west coast of South Island, New Zealand (Fig. 1). The port is typical of many river mouth ports throughout the world in that it is plagued by changing bar formations at the entrance and shipping is frequently hampered by insufficient water depths.

The entrance problems at Westport have been studied on many occasions throughout the history of the port and various solutions have been proposed (e.g., Furkert 1947; Hagyard et al. 1969). The most frequently adopted solution has been training wall development, although bar dredging has also been undertaken on numerous occasions. A history of training wall development is shown in Table 1. Improvements in entrance conditions have occurred following each phase of development but all have been only short-term because of the continued progradation of the beaches on either side of the entrance. Bar dredging has also been largely unsuccessful because the dredges were unable to remove sufficient volumes of sediment. Several attempts were made to correlate bar depths with dredging but it was found that on some occasions depths improved though dredging was minimal, but on other occasions depths were poor despite intensive dredging. There is little evidence that such dredging was well planned with respect to littoral drift.

One solution favoured by many reports (e.g., Rendel et al. 1946), but which has never been adopted, is to increase the tidal compartment. This solution was based on the assumption that by increasing tidal flow into and out of the harbour, exit velocities and hence scour would be increased.

In spite of the efforts made to improve bar conditions at Westport the problems have persisted. It is clear, however, that past studies have been carried out without a definitive understanding of sediment movement patterns in the vicinity of the harbour entrance. As can be seen from Fig. 1 the sedimentary system at Westport can be divided into four chief units:

1 The river bed and banks up stream of the tidal limit — a reach in which sedimentation is controlled by river processes alone.
2 The wharf and channel area where the tides and the river in variable combinations both influence sedimentation.
3 The submarine delta and bar complex off the harbour entrance where river, tide, wave, and inshore currents are active.
4 The two prograding beaches adjacent to the training walls where waves and winds are the primary agents of change.

The present study was concerned principally with the latter three units and aimed at gaining an understanding of the sediment transport regime in these areas. This is considered an essential prerequisite to any further attempts to alleviate the entrance problem. This paper describes bar morphologies and sediments of the entrance area together with inferred sediment transport paths. Tidal hydraulics, inlet stability, and sediment bypassing are discussed in Kirk et al. (in press.).

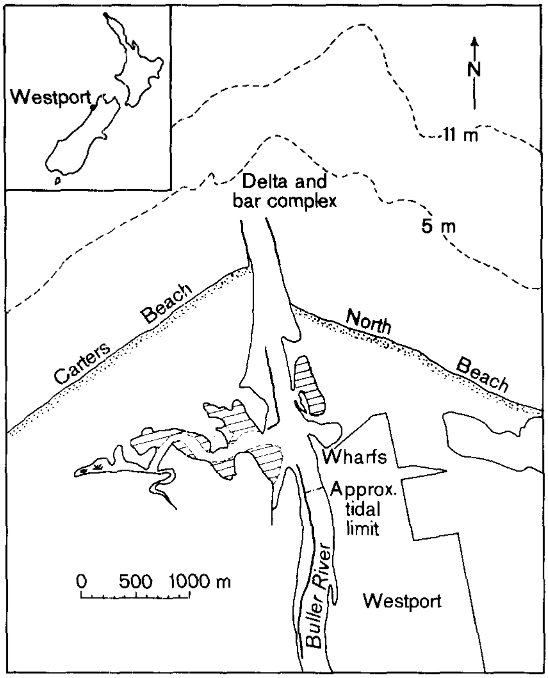


**Fig. 1** Locality map of Westport Harbour, South Island, New Zealand. Hachured areas represent tidal mud flats.

**Table 1** History of training wall development at Westport.

| Date | Development |
|---|---|
| 1891 | 1341 m training wall on the west formed; 1829 m training wall on the east formed; entrance width 213 m |
| 1913 | 215 m extension of the east training wall |
| 1916 | 160 m extension of the west training wall |
| 1931 | 30 m extension of the west training wall |
| 1968 | 91 m extension of the west training wall; 183 m extension of the east training wall; entrance width narrowed to 183 m |

## METHODS

Bar morphologies were determined largely by studying existing bathymetric surveys of the entrance area. The intention was to ascertain major changes in the form of the submarine delta and bar complex relevant to controlling processes and entrance water depths rather than to present a detailed quantitative analysis of bathymetric and volume change. Surveys suitable for the latter purpose have been made only since March 1984 and only two were available during the study.

A total of 47 surficial sediment samples were collected in December 1984 from the lower reaches of the Buller River, the nearshore seabed, and the beaches on either side of the harbour entrance. The samples were subjected to grain size analysis using standard sedimentation laboratory practice (Krumbein & Pettijohn 1938; Folk 1965). The sand-sized portion of each sample was also subjected to rollability analysis (Winkelmolen 1969a, 1969b, 1971) — a technique utilising grain shape characteristics to infer sediment dispersal pathways. In addition, mineralogical analysis on a number of selected samples was undertaken to assist with the interpretation of dispersal pathways.

Sample sites are shown on Fig. 3–7. The sites were selected to represent the principal morphological units and to maintain a suitable areal spread and density. Sample 45, not shown on the figures, was located c. 4.4 km up stream from the river mouth. This site was chosen on the assumption that it was beyond the influence of coastal sediment transport and would, therefore, represent sediment derived entirely from the river catchment.

The sea and riverbed samples were collected by hand from the surface 100 mm by divers using SCUBA equipment. The divers also made a number of useful observations on the nature of the bottom at each site. Where bedforms were present their height, crest-to-crest wavelength, and compass orientation were measured and recorded. Position fixing was achieved using a radar.

Rollability analysis was performed on sand-sized fractions (1.00–0.053 mm) of all samples possessing appreciable material in this range.

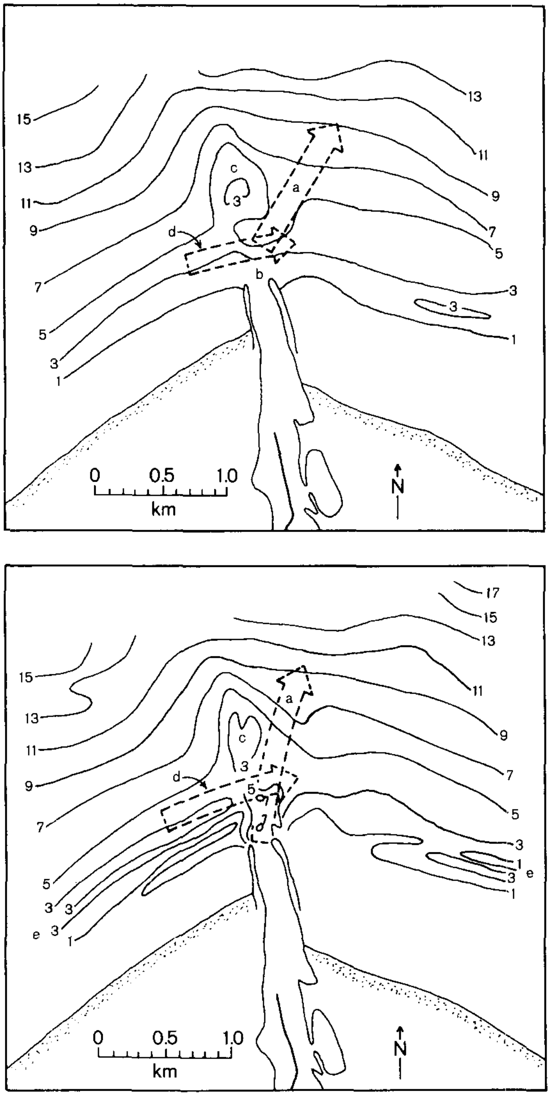


**Fig. 2** Typical morphologies of the submarine delta complex shown on two surveys, March 1984 (upper) and October 1984 (lower). Bathymetry is in metres below chart datum. Features are: a, principal inlet channel; b, inner bar; c, outer bar; d, transverse channel; e, shore parallel bars and scour channels.

Rollability is a functional measure of sand-grain shape which has been correlated with the processes of erosion, transportation, and deposition of sediment in wind tunnels, flumes, wave tanks, and a variety of field environments (Winkelmolen 1969a). The rollability value for a given sample is taken as the median time for that sample to travel through a smooth-walled, inclined, rotating cylinder. By controlling grain size by sieving, it is possible to compare the rollability values obtained from a number of samples and to calculate relative rollability values by expressing each individual value as a relative deviation from the average value for that size. It is then possible to discover whether there are areas where relatively more rollable and relatively less rollable grains are concentrated. This assists in establishing the sites of sources and sinks of sediment, and can identify major transport vectors between them, although no information on quantities or rates of transport is obtained. It is important to note that relative rollability values are a contra-indication of transport susceptibility for sand grains. Positive values indicate low transportability and negative values denote relatively higher susceptibility.

A plot of relative rollability against sieve sizes is known as a "shape distribution character" for a given sample. Typical receiving deposits (sinks) show low rollabilities for the coarsest grains and increasingly higher rollabilities for the finer grains. Lag deposits (sources) have the opposite character (Winkelmolen 1969b: 302). A number of composite shape distribution characters have also been described by Winkelmolen to indicate mixing and winnowing of sediments. Shape distribution characteristics were plotted and used to interpret the present data set.

Five samples were selected for mineralogical analysis to provide additonal information on sediment dispersal pathways. The samples selected were from the river mouth scour hole (Site 18), the outer bar (Site 19), North Beach (Site 37), Carters Beach (Site 44), and the Buller River (Site 45).

The mineralogical analysis was undertaken by the New Zealand Geological Survey, Department of Scientific and Industrial Research, Christchurch (Smale 1985). The heavy minerals were separated from 0.25 to 0.06 mm fractions in tetrabromoethane and examined microscopically in refractive index oils.

## RESULTS AND DISCUSSION

### Bar morphology

Fig. 2 shows the results from bathymetric surveys carried out in March and October 1984. These surveys show the typical entrance morphologies occurring at Westport. The submarine delta comprises a primary feature in the form of broad convexity of the contours out to a depth of 15 m (LWOST), and which is present all the time, plus a number of secondary features which are not always present and which change form, position, and volume. The secondary features are:

1 A main inlet channel and distributaries over the submarine delta surface.
2 Inner and/or outer bars which lie off the training wall ends or across the inlet axis line up to 700 m off the walls.
3 A transverse channel running east from Carters Beach past the west training wall end and between the inner and outer bars. When present, it terminates in the principal inlet channel.
4 Shore parallel bars and scour channels which occur from time to time off both Carters and North Beach.

Examination of past surveys showed that the most frequent delta morphology, and that which presents the most severe navigation problems, is that shown for the survey of March 1984 in which two bars (Feature 2 above) were present.

The March 1984 survey shows that the outer bar takes the form of an elongated "spit" or banner bank developed on the inner margin of the delta and occurring as a submarine extension of the contours of Carters Beach. In this survey, the main channel carrying river and tide water from the harbour was deflected away to the north-east. An inner bar with a minimum depth of 2.7 m (LWOST) occurred immediately seaward of the training wall ends, and an "outer shoal" (here termed the outer bar, which is in fact the crest of the banner bank), also with a shallowest depth of 2.7 m, was present about 700 m from the ends. In October 1984 the inner bar was absent and water depths at the entrance were up to 8 m.

Whether both bars or only the outer bar are present, a transverse channel (Feature 3 above) runs from west to east around the west training wall and joins the principal river/tide channel in a scour hole up to 8 m deep. This channel relieves water circulation built up at the west end of Carters Beach by wave breaking, wave-driven longshore currents, and wind drift currents in westerly or south-westerly weather. The presence of this channel and the form of the outer bar are important clues to the processes acting around the entrance to the harbour.

A further clue is provided by the fact that the main channel is strongly asymmetric in cross-section. The western wall across the transverse channel terminus and along the face of the outer bar is extremely steep, whereas the eastern face is much flatter and featureless. Steep walls are very common on the updrift sides of both tidal inlets and dredged channels.

A final aspect revealed by both the March 1984 and October 1984 surveys is the nature of the inshore seabed off the two beaches. In March 1984 the bed was relatively featureless, but in October 1984 shore-parallel bars occurred. It is important to note that in storms sandy beach foreshores are eroded and sand is transferred to the nearshore seabed where it accumulates as one or more shore-parallel bars separated by troughs and scour holes. During intervals of swell waves following storms, these bars are slowly broken down and the sand is fed both onshore and alongshore. It seems reasonable to conclude that the featureless seabed off the beaches shown in March 1984 resulted from a protracted phase of beach accretion, whereas the features shown in the October 1984 survey resulted from a period of beach erosion; all the morphological states discussed here were the outcome of an antecedent history of river flow and sea-states before a survey date. Should an episode of beach erosion be followed by a long interval of extremely low wave energy (particularly light northerly conditions), breakdown of the shore-parallel bars will be extremely slow and sand feed to the inner bar area will be correspondingly slight.

A number of features of note are not revealed by the surveys shown in Fig. 2. The outer bar is not always present as a prominent obliquely aligned banner bank, but may have a more dispersed form following large floods in the river. The time scale of change for the outer bar is much longer than that of the inner bar. The inner bar is very much larger and more persistent when the outer bar form is weakly developed (Capt. C. Baugh, Harbourmaster 1985, pers. comm.).

The appearance of the inner bar is believed to be a littoral drift-related event with its disruption being a function of river scour. Development of the inner bar is not massive but is linked to phases of storm erosion and swell accretion on Carters Beach. Storms provide an abundant supply of sand in the form of beach bars extending to the west training wall tip on the restricted area of seabed inshore of the transverse channel. In low river flow conditions this beach material can be admixed with river sediment, drifted across the entrance, and accumulated by swell waves where they encounter the outflow from the river channel. It is also possible that sand can be bypassed directly to North Beach when the inner bar is present. When the inner bar is absent, sand from the west can only reach the eastern shore by transport through the transverse channel or over the outer bar (where it contributes to growth), into the river channel, and thence onshore by wave action and counterdrift. The existence of an appreciable area of sediment mixing and recirculation offshore and east of the training walls is indicated. This will be examined further when sediment characteristics are described.

When the outer bar has been dispersed and reshaped by large floods down the river, the bulk of the littoral drift is concentrated in the inner bar and it becomes strongly developed. Direct sediment bypassing to North Beach is more intense. The time scale for the outer bar sequence of change

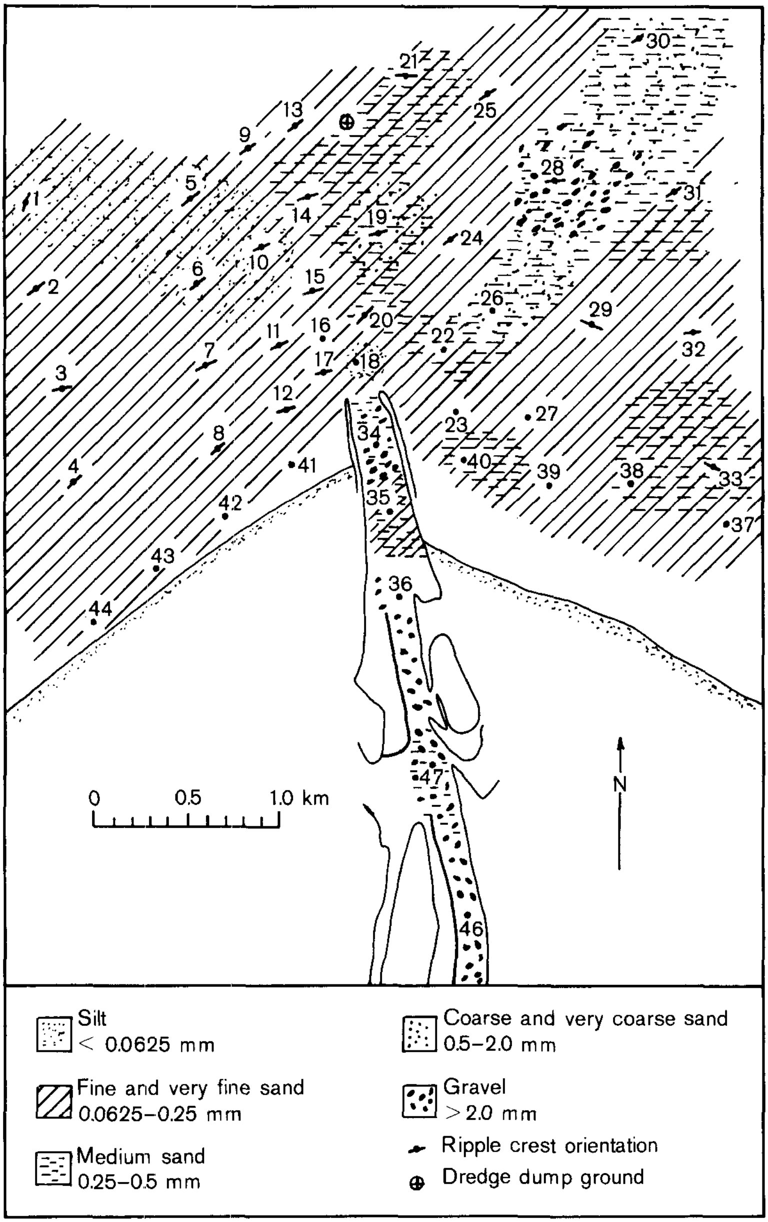


**Fig. 3** Sediment texture and bedform orientation. Texture indicates the presence of at least 20% of a given size class in a sample.

is much longer than that for the inner bar because of the larger sediment volumes involved and because it requires a very large flood to dominate flow over a sufficient area of the nearshore seabed.

## Sampling observations

Ripples were found at all offshore sites, indicating active bedload transport. The orientation of the ripples is shown in Fig. 3. By far the majority of ripples were oriented with crests parallel to the shore suggesting that wave-induced oscillatory currents are the prime agents responsible for bedload transport. Some longshore component to the east is indicated at most sites suggesting that, although on-offshore transport dominates, this is associated with a secondary component of longshore movement.

During the sampling operation a saltwater wedge up to 500 mm thick was observed extending for c. 2.5 km up stream from the river mouth. There was little movement of water in this wedge and thus

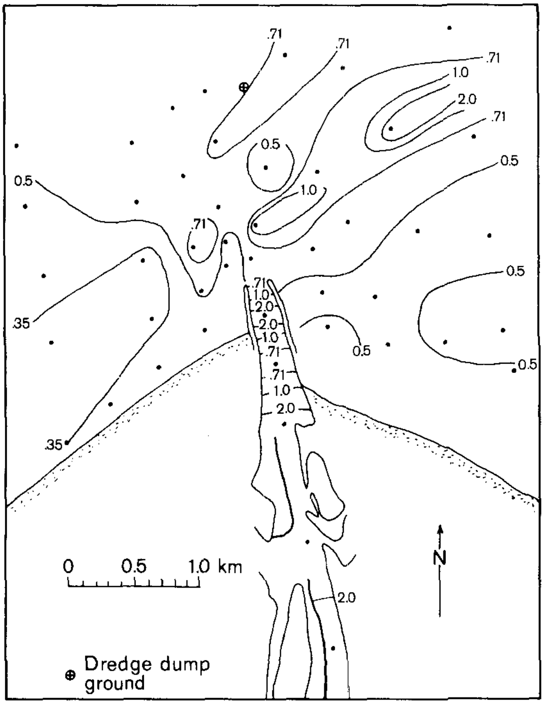


**Fig. 4** Sediment sorting. Limits from Folk (1965). < 0.35 ϕ, very well sorted; 0.35–0.50 ϕ, well sorted; 0.50–0.71 ϕ, moderately well sorted; 0.71–1.0 ϕ moderately sorted; 1.0–2.0 ϕ poorly sorted; 2.0–4.0 ϕ, very poorly sorted. For sample identities see Fig. 3.

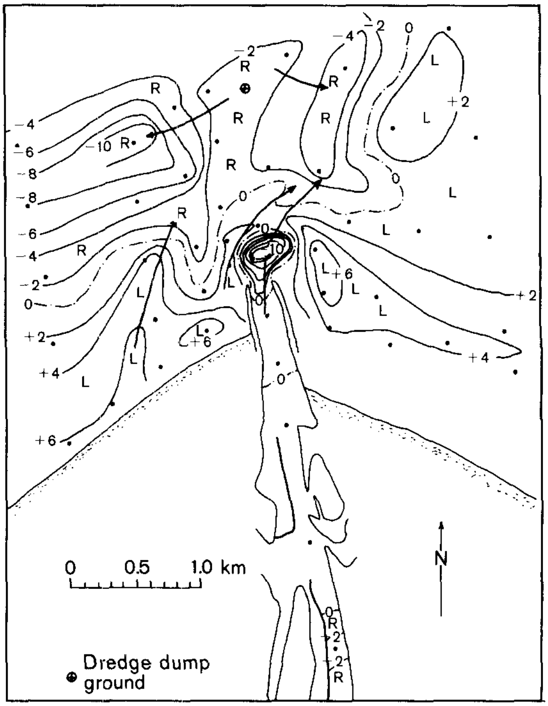


**Fig. 5** Whole sample average rollability values (%). L, lag deposits; R, receiving deposits. For sample identities see Fig. 3.

the river was not carrying any bedload over this reach, although the overlying freshwater was quite dirty with suspended fine sediment. Up stream from the limit of the saltwater wedge strong currents were experienced on the bottom and at the uppermost site coarse sand was observed being transported as bedload.

## Sediment texture

Fig. 3 is a sediment texture map showing the presence of at least 20% of a given size class in a sample. General features shown include the presence of silt immediately offshore from the river mouth and offshore to the west. No silt was present to the east of the river. Very fine and fine sands were present over most of the beach and offshore area but were generally absent from the river. Coarser sediments were absent from the western seafloor but were present over much of the remaining area.

Also shown in Fig. 3 is the location of the dump ground currently used for spoil derived from river dredging. The diagram shows that at the dump ground very fine to medium sands predominate and that slightly inshore from the dump ground medium, coarse, and very coarse sands predominate.

The inclusive graphic standard deviation or sorting coefficient as defined by Folk (1965) was calculated for each sample. The results were then plotted and contoured according to the limits proposed by Folk. The resulting diagram, shown in Fig. 4, displays a complex pattern. Very generally, sorting is poorest within the river and in an area offshore to the north-east of the river mouth, and there is an area of very well sorted sediments in a band offshore from Carters Beach. The sediments on Carters Beach were found to be better sorted than the North Beach sediments.

The very well sorted sediments to the west of the river appear to have been derived from longshore transport from the south. The poorly sorted sediments appear to have been derived from the river, either naturally or by dredging, as well as from longshore transport.

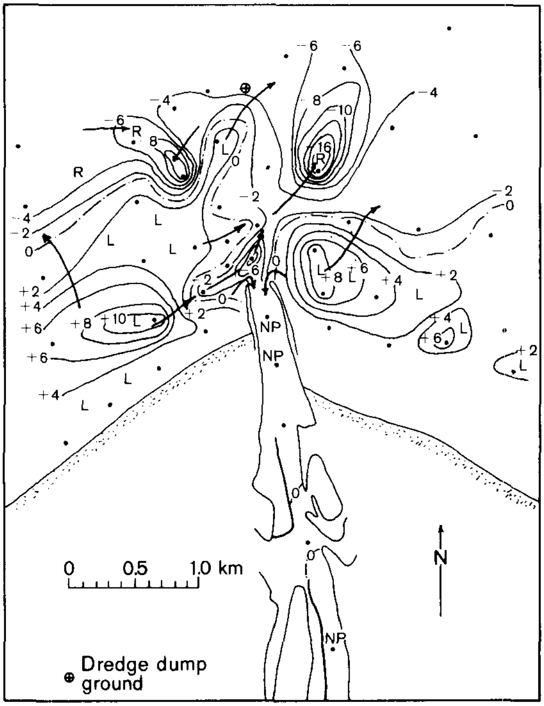


**Fig. 6** Relative rollability values (%) for a fraction of very fine sand (0.090 mm). L, lag deposits; R, receiving deposits; NP, fraction not present in sample. For sample identities see Fig. 3.

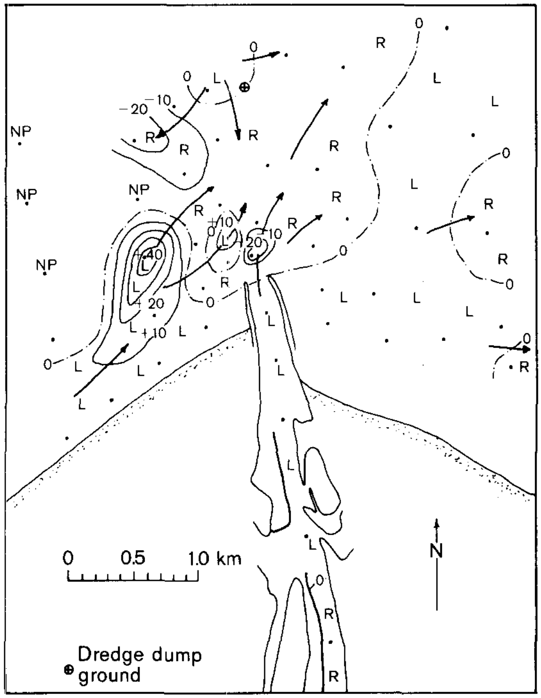


**Fig. 7** Relative rollability values (%) for a fraction of medium sand (0.30 mm). L, lag deposits; R, receiving deposits; NP, fraction not present in sample. For sample identities see Fig. 3.

**Grain shape**

Fig. 5 presents a contoured plot of whole sample average rollability values. As a check on the efficacy of the method it is worth noting that a known sink of sand, the dredge dump ground, is correctly indicated as an area of receiving deposits (negative values). The inlet entrance area where the principal and transverse channels converge is also indicated as a sediment sink.

Seaward of the entrance, distinct differences occur between the western and eastern sides of the harbour. To the west, in the finer sediments, the deeper samples all have a receiving character indicating a high potential for transport. Inshore the materials have lag character where they are winnowed in the high-energy surf zone and the contours present distinct lobe-like patterns which have axes parallel to that of the outer bar. East of the harbour, a more uniform lag character occurs as would be expected in mixed sediments pre-sorted by the river, by the circulation through the bar and by recirculation east of the training walls.

A large receiving area occurs to the north-east of the river mouth and it is here that river, Carters Beach, and dredge-dumped sands are mixed before dispersal northward, offshore, or onshore for recirculation.

Further elaboration is provided by plots of individual size fractions. Fig. 6 presents relative rollability values for a fraction of very fine sand (0.090 mm). Material in this size fraction is derived mainly from the continental shelf and littoral drift systems to the west of the harbour. A further source is the suspended load of the Buller River. The distribution shows strong lags off both beaches and transport into deeper water. There is also strong evidence of streaming past the west training wall through the transverse channel and along the outer bar. Drift materials are also admixed with river sediments and deposited among coarser materials including gravels around Site 28.

Strong sinks for very fine sand occur east, west, and somewhat inshore of the dredge dump ground which may indicate transport in both longshore directions away from the apex of the submarine delta as well as some inshore recirculation of the finer components of the dredged sand.

The map also shows a sink for fines in the scour hole immediately seaward of the river mouth and that some fine sand transport can occur between the training wall ends. However, no significant transport into the inner reaches occurs because very fine sand is absent from Sites 34 and 36.

The distribution of rollability values for medium sand (0.30 mm) is shown in Fig. 7. A notable feature is the absence of medium sand from extensive areas to the west of the entrance and the fact that it has an intense lag character adjacent to the updrift face of the outer bar. Very large receiving areas exist north-east of the river mouth and inshore of the dredge dump site, and it is from here that sand is recirculated. An intense local sink exists in the scour hole at the junction of the transverse and principal channels. Over much of the lower river channel the sands have a lag character but receiving conditions are again indicated up stream of what appears to be the saltwater intrusion limit.

It is concluded that the major sources of this fraction are the river and the dredge dump grounds with the littoral drift in a sub-equal role. Dredge dumpings therefore contribute to outer bar sedimentation.

**Table 2** Heavy-mineral contents of sediments around the Buller River mouth. Results are percentages of the heavy fractions given to the nearest whole number (0 represents 0 – 0.5%). Reproduced with permission from Smale (1985).

| | Sample number and location | | | | |
|---|---|---|---|---|---|
| | 18 | 19 | 37 | 44 | 45 |
| Mineral | Scour hole | Outer bar | North Beach | Carters Beach | Buller River |
| Ilmenite | 17 | 32 | 33 | 31 | 23 |
| Magnetite | 3 | 13 | 1 | 1 | 9 |
| Semi-opaque debris | 11 | 18 | 27 | 32 | 21 |
| Biotite | 29 | 0 | 8 | 1 | 11 |
| Chlorite | 8 | | 3 | 1 | 6 |
| Garnet | 1 | 21 | 11 | 19 | 2 |
| Zircon | | 1 | | | |
| Sphene | 1 | 1 | 1 | | 2 |
| Epidote | 5 | 4 | 4 | 4 | 6 |
| Clinozoisite | 3 | 1 | 1 | 1 | 1 |
| Tourmaline | 1 | 0 | 1 | | 0 |
| Andalusite | | 0 | 1 | | |
| Sillimanite | | | | 1 | |
| Amphibole | 12 | 6 | 9 | 9 | 10 |
| Orthopyroxene | 1 | 1 | 0 | 0 | 2 |
| Clinopyroxene | 5 | 0 | 1 | | 3 |
| Olivine | 1 | 1 | 1 | | 2 |
| Apatite | 2 | 1 | 0 | 1 | 2 |
| Percentage heavy minerals in sample | 1–5 | > 5 | 1–5 | > 5 | 1–5 |

## Mineralogy

Results from the mineralogy analysis undertaken by Smale (1985) are reproduced in Table 2. Smale found that both the Buller River and scour hole samples contained lesser amounts of garnet and ilmenite, greater amounts of pyroxene, and marginally more hornblende and apatite. He noted this suggested that sediments in the river mouth scour hole were derived from the river. Smale also suggested that similarities in ilmenite, garnet, and perhaps hornblende between the beaches and the outer bar indicated a greater beach input into the outer bar than river input. However, he found that the outer bar sample had lower amounts of semi-opaque debris and greater amounts of magnetite than the beaches, suggesting some contribution of river sediment to the outer bar as well.

## CONCLUSIONS

This paper describes morphological features and sediments of the area adjacent to the Buller River mouth, the entrance to Westport Harbour. The most frequently occurring morphology is that in which two submarine bars are present off the river mouth. The formation of an inner bar is believed to be a littoral drift-related event, whereas the outer bar is believed to form as a submarine extension of Carters Beach. The outer bar is therefore composed principally of littoral drifted sediments, although the mineralogical analysis suggested that some contribution from the river does occur.

Both the inner and outer bars can be removed or modified by floods in the river. Modification of the outer bar, however, requires very high river flow and is, therefore, a less frequent event than modification of the inner bar.

Longshore sediment transport at Westport is predominantly from west to east and river derived sediment is deflected to the east. Direct sediment bypassing from Carters Beach to North Beach can only occur when the inner bar is present. On occasions when the inner bar is absent, bypassing can only occur by transport through the transverse channel or over the outer bar into the river channel and then onshore by wave action.

The observations of the saltwater wedge in the river indicate that an accumulation of river sediment will occur at the upper limit of the saltwater penetration. Under normal river flow conditions this would appear to correspond to the location of the berth areas. It is, therefore, expected that dredging of this area will be required to maintain suitable water depths.

Sediment analysis indicated that spoil from the dredge dump ground may be contributing to the growth of the outer shoal. In terms of sediment movement, the dump ground would be more appropriately located to the east of the harbour entrance.

Further study has been undertaken into the processes operating to produce the morphological features and sediment transport patterns described in this paper.

## ACKNOWLEDGMENTS

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