Frontispiece: An aerial view of the upper Raglan Harbour from the south west. Photo - M.J. Selby.

SURFICIAL SEDIMENTS OF RAGLAN HARBOUR

Thesis submitted as a partial requirement for the degree of Master of Philosophy in Earth Sciences.

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CONTENTS

ABSTRACT

Raglan Harbour is a drowned river valley system lying in a structurally depressed fault block. Much of the upper reaches of the harbour consist of tidal flats formed by sediment veneered shore platforms, and dissected by relatively deep channels. Estuarine conditions occur in the tidal reaches of major streams entering the harbour.

Sediment textures reflect a gradual decrease in energy conditions passing up the harbour from clean, well-sorted sands near the harbour entrance to mainly muddy sands and sandy muds that characterise the tidal flats. Tidal currents result in highly variable energy conditions. Modes of sediment transport and deposition and a generalised scheme of current patterns and relative current strengths throughout the harbour are interpreted from textural analyses.

The coastal iron-sands are the principle source heavy minerals in sediments throughout Raglan Harbour. Bulk sediment mineralogies and clay mineralogies indicate detrital inheritance from hinterland rocks as the main source of terrigenous sediment supplied to the harbour as fluvial sediment load and by shoreline erosion. Benthonic organisms supply most of the carbonate and organic matter in the sediments, as well as causing considerable sediment reworking. Phosphatic concretions

found in certain areas of the harbour appear to be of Recent to Sub-recent diagenetic origin.

Much of the present aerial extent of Raglan Harbour is probably the result of shore platform development within the harbour during the last 8-10,000 years. The bulk of the material eroded during this process has been removed from the sedimentary system of the harbour and deposited on the continental shelf.

CHAPTER I

INTRODUCTION

Raglan Harbour is one of three harbours of generally similar physiography on the west coast of the North Island, New Zealand, between Port Waikato and Albatross Point (Fig. 1.1). The narrow entrance lies between the volcanic cone of Karioi to the south, and the stretch of black-sand beaches backed by fixed dunes to the north.

Raglan Harbour has been formed by the drowning of the lower part of a branching river system carved in a structurally depressed block.

The Harbour covers 32.8 km^2, much of which consists of extensive tidal flats, which are dissected by relatively deep channels. Estuarine conditions are confined to the lower reaches of streams under tidal influence, as only here is sea water measurably diluted by fresh water from land drainage.

Average tidal range in the harbour is 2.3m. The maximum current velocity recorded is 150 cm /sec (3 knots) at the harbour entrance (Admiralty Chart N. Z. 4421).

Mean annual air temperature for the area is about 13°C,mean annual rainfall is 140 cm., and west to south-west winds prevail (de Lisle , 1967).

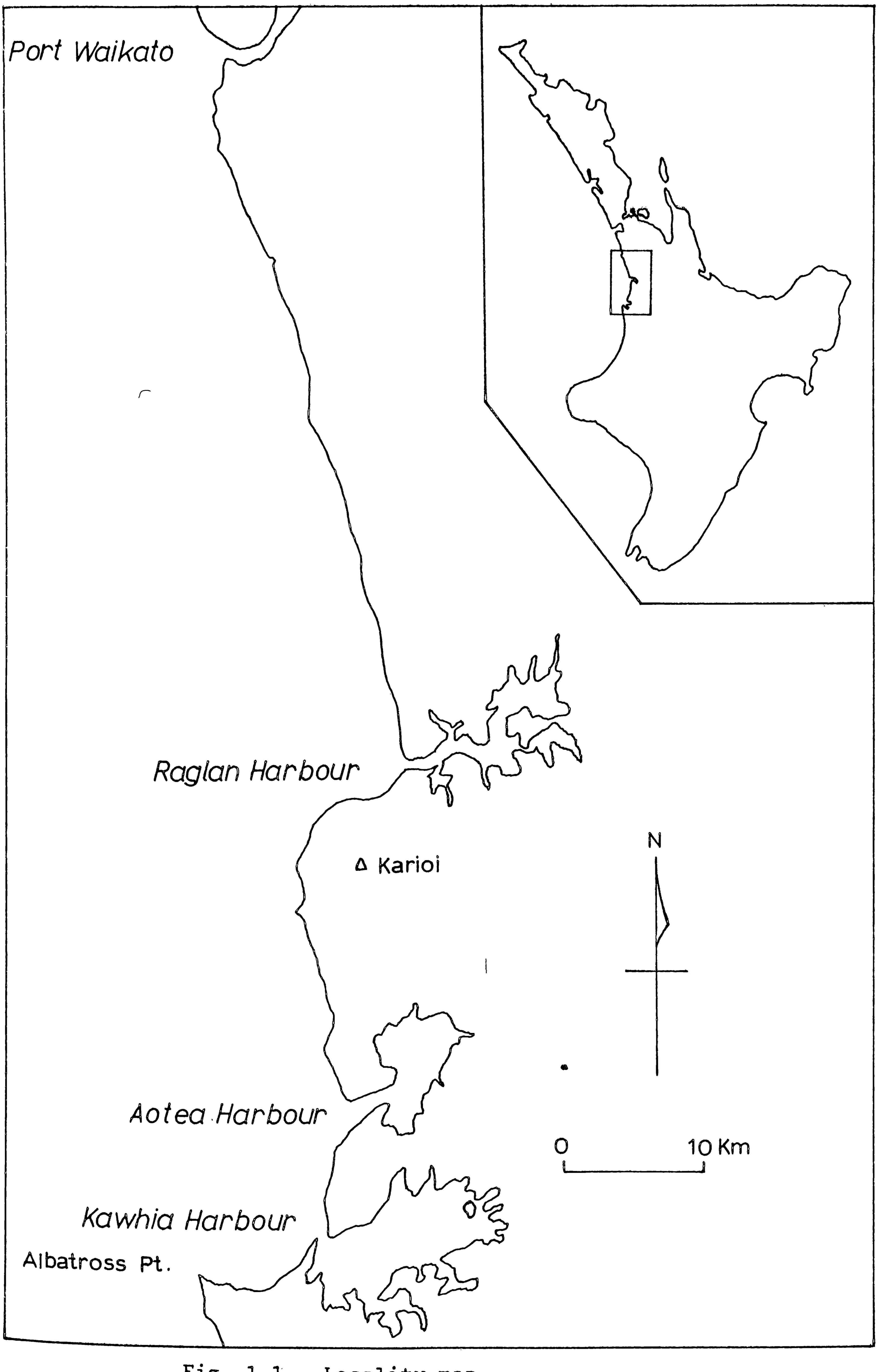


Fig. 1.1 Locality map.

1.1 PURPOSE AND METHODS OF STUDY

The purpose of this study was to describe the texture and composition of the surficial sediments of Raglan Harbour, and to determine the provenance and the mechanisms of transport and deposition of these sediments.

A total of 95 sediment samples were collected for laboratory analysis. Bottom samples were collected using a grab sampler. Samples were also collected from streams entering the harbour, and from sand dunes, beaches and off-shore bars near the harbour entrance. In the laboratory samples were split for textural and mineralogical analysis. Detailed analytical methods are discussed in the relavant sections.

Sample numbers 1 to 95 and locations are shown on the bathymetric map in the back pocket.

1.2 BATHYMETRY

The bathymetry of Raglan Harbour is shown on the map in the back pocket. This map was compiled using information from Admiralty Chart N. Z. 4421, air photographs, and data obtained from soundings made during field work.

The method of correcting soundings to chart datum is discussed in Appendix I, and the corrected soundings for all sample localities are given in Appendix II.

For ease of discussion throughout this study, Raglan Harbour is divided into four areas (Fig. 1.2); the lower, middle and upper harbour , and the south-east arm.

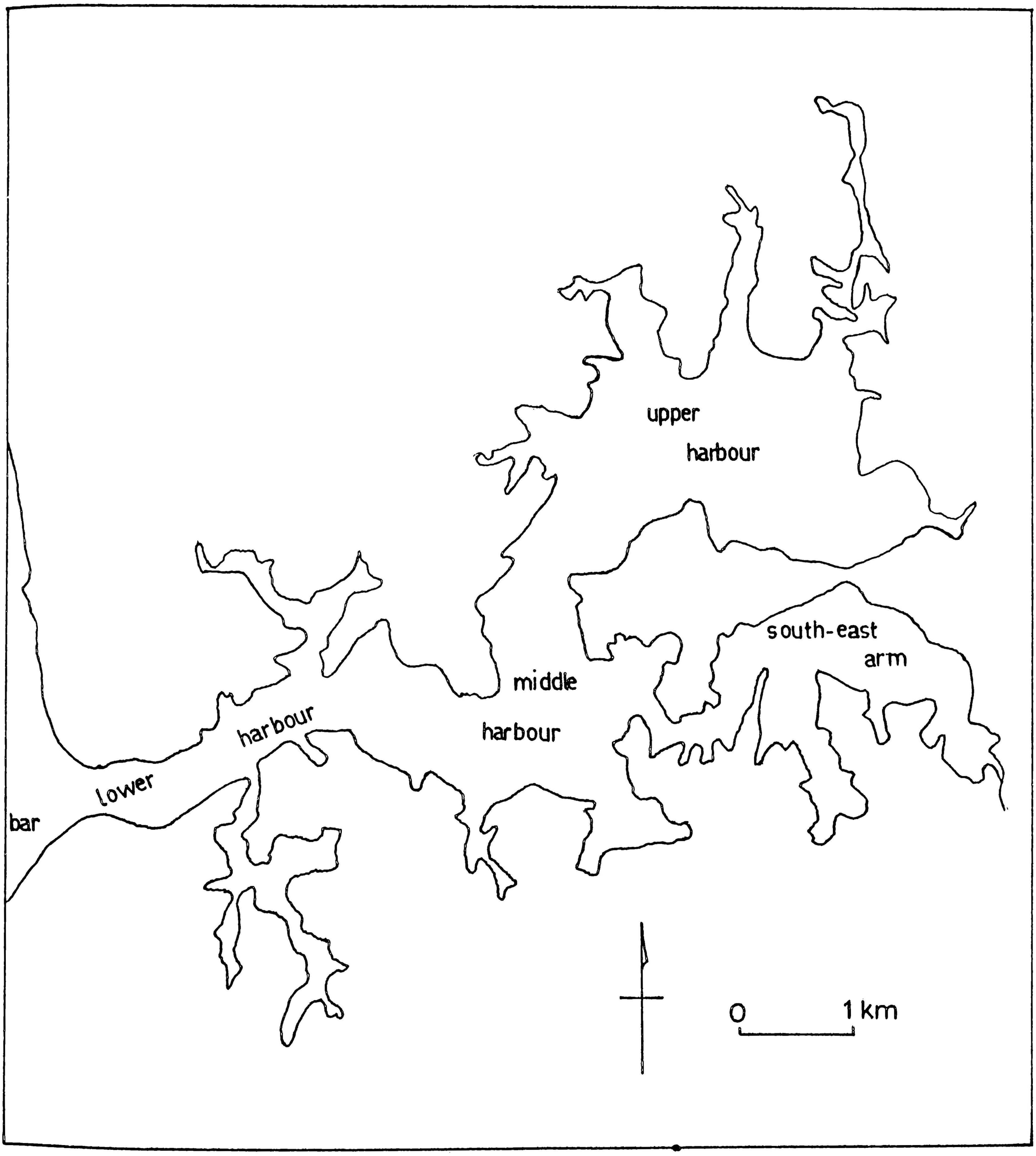


Fig. 1.2 Division of Raglan Harbour into areas referred to throughout the text.

The harbour entrance consists of a channel up to 15m deep flanked by off-shore sand bars seaward of broad iron-sand beaches backed by sand dunes.

The channel continues up the northern side of the lower harbour, gently curving towards a central position opposite Raglan Wharf. Sand flats form the southern margin of the lower harbour. The middle harbour has a relatively flat bottom, with broad tidal mud-flats on the eastern and southern margins dissected by channels draining the south-east arm and Okete Bay. The wide channel passing into the upper harbour is bissected by two intertidally exposed sediment bars and flanked by tidal mud-flats.

Broad tidal mud-flats (Fig. 1.3) cover much of the upper harbour which is drained by channels up to 5m deep passing into the main arms.

The south-east arm connects to the middle harbour via a deep narrow passage through which tidal currents attain considerable velocities. This channel joins the Waitetuna River, with a branch draining Hauroto Bay. Tidal mud-flats flank both channels.

The large expanses of tidal flats in the upper harbour and the south-east arm are drained by a system of meandering channels cut in the soft, fine grained sediment (Figs. 1.4, 1.5).

Fig. 1. 3 Broad tidal mud-flats, which cover much of Raglan Harbour. This photograph was taken from near the main channel in the south-east arm. The nearest shoreline, visible at far left, is over 700 m distant.

Fig. 1.4 A meandering channel draining the upper reaches of a tidal flat. The channel is about 40cm wide and the photograph was taken at mid-tide.

Fig. 1.5 Meandering channels draining tidal flats. This photograph was taken at low tide from the main channel of the south-east arm.

1.3 DRAINAGE BASIN

The drainage basin for Raglan Harbour covers approximately 165 square kilometres. The drainage pattern is largely under tectonic control imposed by the Late Upper Tertiary Kaikoura Orogeny. A few streams still follow their pre-Kaikoura dip-consequent courses (Chappell, 1970). Radiating consequent drainage patterns are established on the volcanic cones of Karioi and other eruptive centres.

A striking feature of the drainage basin physiography is the small size of the streams entering the various arms of the harbour. These streams could not have eroded the valleys that contain them, or their extensions into the now drowned lower reaches of the drainage system. There are a number of possible explanations for the apparently underfit character of the present day streams.

(1) The streams were more active during a cold period corresponding to the Last Glaciation, when rainfall was almost certainly higher than at present.

(2) The lower sea level during the Last Glaciation probably resulted in far more groundwater drainage into the stream system. As much of the drainage system is developed on porous rocks of the Te Kuiti Group this may have been an important factor in increasing the erosive capacity of streams.

(3) The streams have aggraded in response to the post-glacial sea level rise, reducing their ability to further erode their valleys.

1.4 GENERAL GEOLOGY

The stratigraphy, lithology and ages of the rocks of the area surrounding Raglan Harbour are summarised in Table 1.1. Fig. 1.6 shows the geology of the drainage basin of the harbour. The eastern part is mainly highly indurated sandstones and mudstones of the Oparau Facies Mesozoic basement rocks (Kear 1971). Te Kuiti Group rocks, mainly Aotea Sandstone and Whaingoroa Siltstone, dominate the northern part of the drainage basin. Andesites and basalts of the Alexandra Volcanics and pumiceous aluvium of Pleistocene age are the main rock types to the south of Raglan Harbour. Volcanic ash mantles much of the area, but has not yet been adequately mapped.

The region is extensively faulted by north-north-east and south-west tending faults produced by the crustal movements associated with the Kaikoura Orogeny. The Harbours of Raglan, Aotea, and Kawhia occupy depressions formed by south-west tending faults and associated down-warps formed during the Miocene (Chappell, 1970). Only the east bounding fault of Raglan Harbour is definitely known (Henderson and Grange, 1926), although basalt flows and scoria cones may mark the north and south bounding faults.

Marginal erosion of shoreline rocks is a major potential source of terriginous sediment. Most of the shorelines of Raglan Harbour consists of Te Kuiti Group rocks. Of these

GROUP	FORMATION	LITHOLOGY	AGE	
Kaihu Group; Tauranga Group	Mitawi Sand	drifting and fixed black-sands	Holocene	
	alluvium			
	alluvium in low terraces			Pleistocene
	volcanic ash	mainly andesitic	Hawera	
	Waioneke Fm	pumiceous sand and silt below coastal terraces at about 7m and 15 m		
	Awhitu Sands	coastal brown clayey sands	Wn-Wc	
	Puketoka Fm	pumiceous alluvium and conglomerates	Wn-Wc	
	Alexandra Volcanics	andesites and basalts		
REGIONAL UNCONFORMITY (Main Kaikoura Orogeny)				
Waitemata Group		calcareous and non-calcareous sandstones and siltstone	L. Miocene	
UNCONFORMITY (Early Kaikoura Orogeny)				
Te Kuiti Group	Waitomo Sandstone		Lw	M. Eocene - Oligocene
	Te Akatea Siltstone	calcareous sandstone and siltstone	Lw-Ld	
	Aotea Fm (with Waitetuna Limestone Members)	calcareous sandstone, siltstone and limestone	Lwh-Ld	
	Whaingaroa Siltstone	calcareous siltstone	Lwh	
	Glen Massey Fm	calcareous sandstone	Lwh	
	Mangakotuku Siltstone	non-calcareous siltstone	Basal Lwh	
	Waikato Coal Measures	carbonaceous zst. with coal seams	Arnold-Lwh	
REGIONAL UNCONFORMITY (Post Hokonui Orogeny)				
Oparau Facies		Indurated sandstones and siltstones ("greywackes and argillites")	Mesozoic	

Table 1.1 Stratigraphic summary for the drainage basin of Raglan Harbour (after Kear and Schofield, 1959; Kear, 1960, 1966).

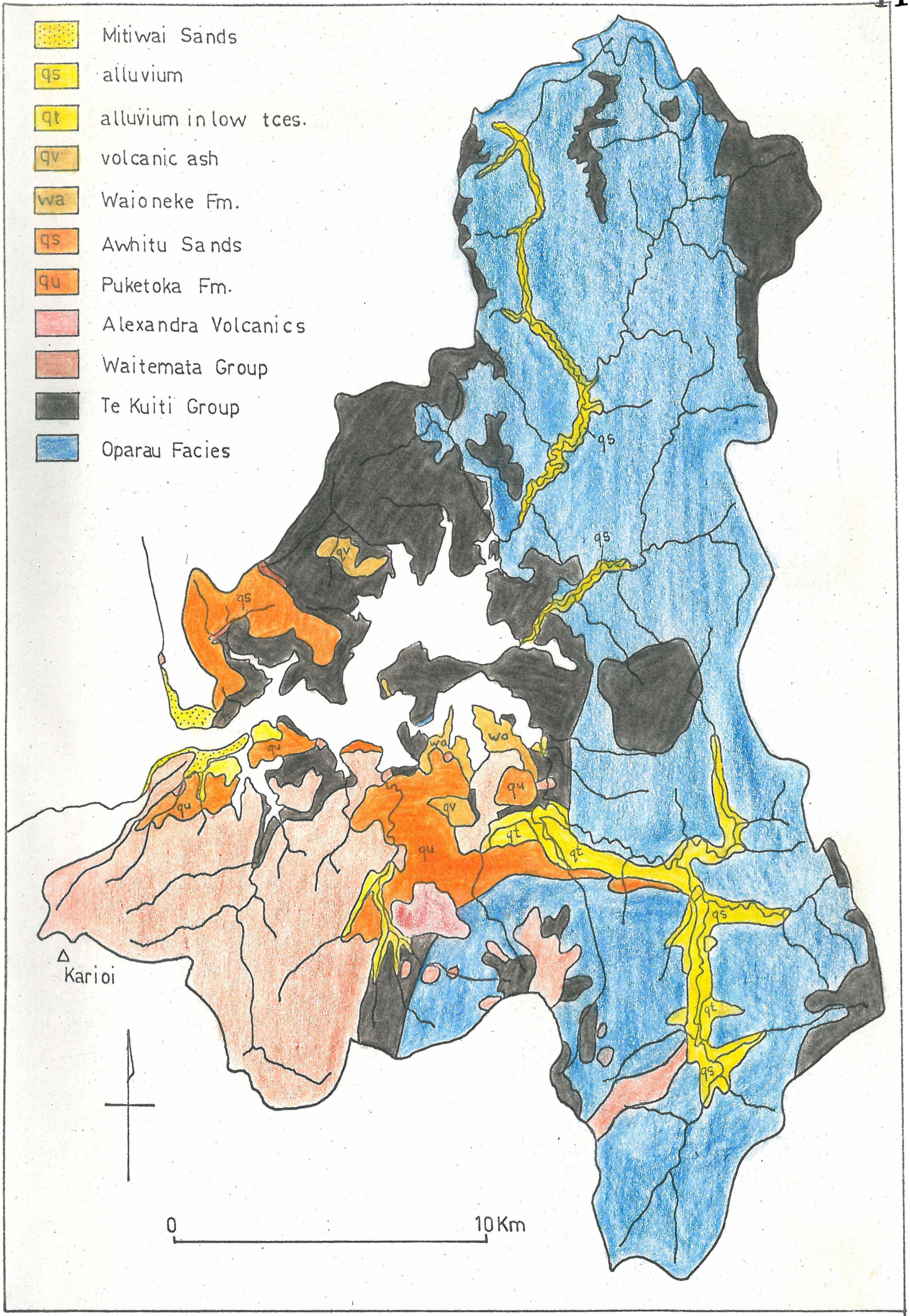


Fig. 1.6. Geology of the drainage basin for Raglan Harbour.

the Whaingoroa Siltstone and the Aotea Sandstone are predominant, forming shore platforms backed by cliffs up to 35m high, in places showing evidence of very active erosion (Fig. 1.7).

Extensive sand dunes without vegetation cover occur at the northern entrance to the harbour, and are another important potential sediment supply to the harbour. These dunes are fully exposed to prevailing winds and sand grains of eolian origin have been found in harbour sediments up to 10 km from the coast.

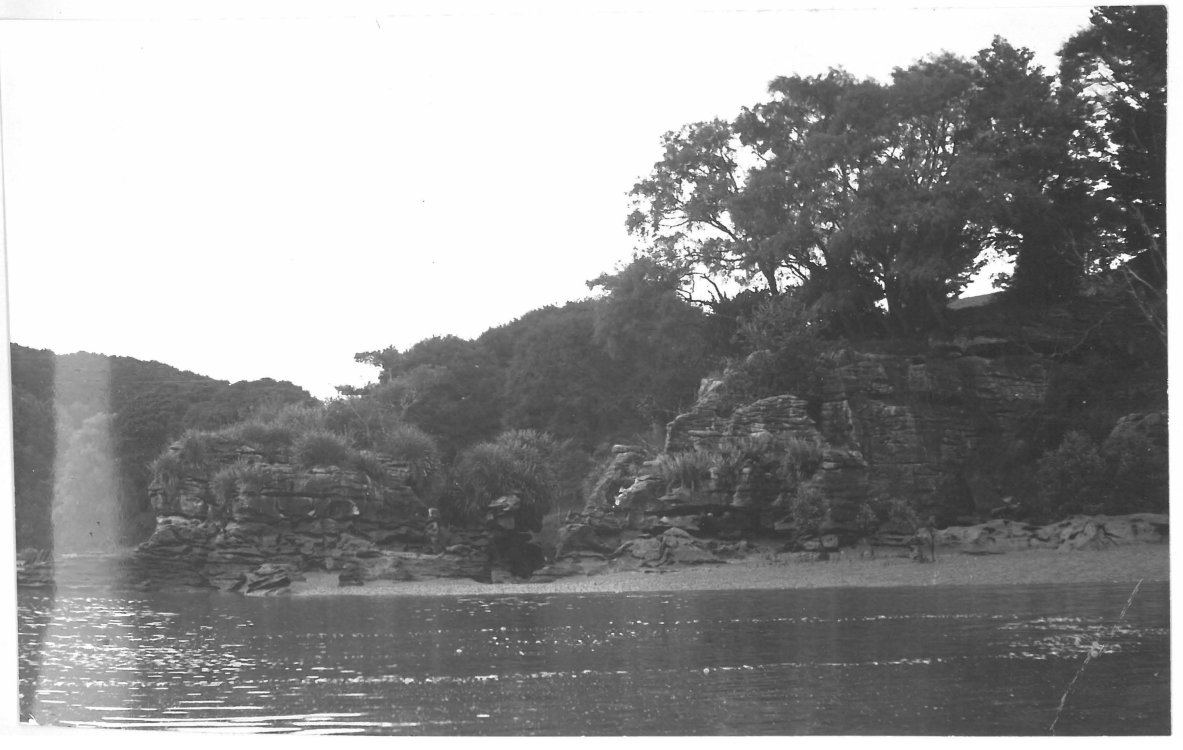
Other rock types outcropping around the margins of the harbour are less important for sediment provenance. Of these, the Waitetuna Limestone is the most conspicuous locally forming steep, flaggy bluffs (Fig. 1.8).

1.5. GENERAL SEDIMENT CHARACTERISTICS

The sediments of Raglan Harbour reflect a gradual decrease in energy from the highly turbulent sand bar environment near the harbour entrance, to the very tranquil waters that cover the upper reaches of the tidal flats at high water. The lower harbour is characterised by well sorted black-sands derived from the coastal beaches and dunes. Sediments become progressively more muddy passing up the harbour, with muddy sands and sandy muds characterising the upper reaches. Muds fill the restricted estuarine areas of the harbour. Sediments containing gravel sized material occour throughout the harbour and

Fig. 1. 7 Cliff of actively eroding Whaingaroa Siltstone. Talus is formed into a series of bifurcating linear ridges.

Fig. 1.8 Flaggy bluffs of Waitetuna Limestone. Small mangroves are growing in the muddy sediment at the base of the limestone.



are generally the product of marginal erosion or are lag deposits in channels. The most common sediments in Raglan Harbour are the soft, sticky, very fine grained sandy muds of the tidal flats.

Most of the muddy sediments throughout the harbour have a thin (1-2cm), brown oxidising layer overlying an olive grey to black reducing layer.

The tidal flats are sites of considerable sediment reworking by benthonic organisms, which probably accounts for the apparent lack of inorganic sedimentary structures in these deposits. Molluscs are the dominant macro-organisms of the tidal flats. (Fig. 1.9). The cockle, *Chione stichburyi* is the most abundant; other common species are the bivalves *Cyclomactra ovata, Leptomya retiaria* and *Paphirus lagillierti,* and the gastrapods *Amphibola crenata, Cominella maculosa, C. glandiformis, C. adspera,* and *Zeacumantus lutulentus. Maoricolpus roseus* and *Myadora striata* are common additions to the benthic fauna in deeper water. Several species of burrowing and sediment injesting worms also contribute to sediment reworking.

1.6. SHORE PLATFORMS

Shore platforms occur round much the harbour margins. They are variable in vertical and aerial dimensions, and are most conspicuously developed on shorelines of Whaingoroa Siltstone and Aotea Sandstone facing the south-west. Most have a uniform gently dipping profile , and are frequently covered with a thin layer (0-10cm) of muddy sediment (Fig.1.10).

Fig. 1.9 Close up view of the surface of a tidal flat, showing extensive sediment reworking by benthonic organisms. The cockle *Chione stichburyi* and the gastrapod *Amphibola crenata* are the most common species present. A faecal cast from a sediment-ingesting worm is visible in the top left-hand corner of the photograph. The gastrapods are about 2cm across.

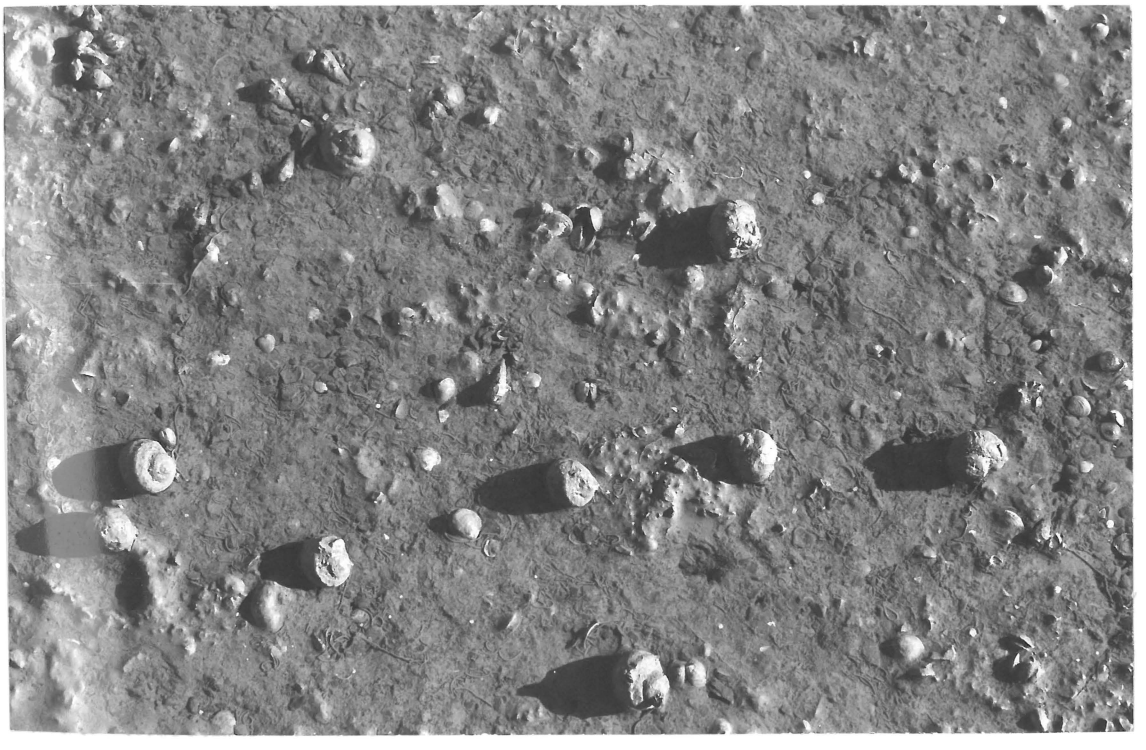


Fig. 1.10 Removal of the sediment cover over a shore platform. The hammer is resting on hard, virtually unweathered Whaingaroa Siltstone.

Most of the landward sections of the tidal flats are sediment veneered shore platforms (Fig. 1.11). The platforms appear to continue under the tidal flats for considerable distances (up to 500m) and may extend as far the main channels.

Two small stacks form islands near the centre of the upper harbour. The stacks are surrounded by broad shore platforms up to 300m wide, cut mainly in gently dipping Aotea Sandstone (Fig. 1.12). Stronger currents than generally occur around the margins of the harbour largely prevent any sediment deposition on these platforms, except where a long curved spit projects from each island (Fig. 1.13).

The shore platforms of Raglan Harbour have probably been eroded by a combination of weak wave action and subaerial weathering above the zone of permanent water saturation. The high expandable clay content of the Aotea Sandstone and Whaingaroa Siltstone (Nelson, 1973) renders these rocks very susceptible to mechanical erosion by wetting and drying. Healy (1967) has shown that this is the dominant mechanism in the erosion of mudstones during shore platform formation.

When fresh, the Whaingoroa Siltstone is a fairly hard, massive rock with a sub-conchoidal fracture. Outcrops around the shores of the harbour have a block, frittered appearance (Fig. 1.14) and crumble readily. Boring organisms (Fig. 1.15), in situ mechanicl weathering (Fig. 1.16), and wave action rapidly break up fallen blocks of material.

Fig. 1.11 The upper section of a tidal flat in the south-east arm consisting of a veneer of sediment, up to 10 cm in thickness, covering a shore platform cut in Whaingaroa Siltstone. This photograph was taken at mid-tide, and only the upper 100m of the tidal flat is exposed. At low water, atidal flat over 300m is exposed.

Fig. 1.12 Shore platform near the centre of the upper harbour, cut in gently dipping Aotea Sandstone.

Fig. 1.13 Sediment spit developed on the surface of a shore platform near the centre of the upper harbour.

Fig. 1.14 The blocky, frittered appearance of Whaingaroa Siltstone in outcrops around the margins of Raglan Harbour. Shoreline erosion of the Te Kuiti Group rocks, particularly Whaingaroa Siltstone and Aotea Sandstone, is a major source of terrigenous sediment for Raglan Harbour. A high expandable clay content makes these rocks very susceptible to weathering by wetting and drying.

Fig. 1.15 Break-up of a block of Whaingaroa Siltstone by the action of boring organisms.

Fig. 1.16 Physical desintegration by wetting and drying of a block of Whaingaroa Siltstone derived from shoreline erosion.

In the relatively sheltered environment of Raglan Harbour, rain is probably the main wetting agent. Wave action acts mainly as a transporting medium, or causes abrasion between particles, reducing erosional debris to a sufficiently small size for transportation by tidal currents. The importance of wave action is shown by the preferential development of shore platforms on shorelines facting the prevailing wind. In more sheltered areas, erosional debris is removed at a very much slower rate, protecting the shore from further attack.

Marginal erosion as part of the process of shore platform development, particularly in Whaingaroa Silt-stone, is probably a major source of terrigenous sediment for Raglan Harbour.

1.7 ACKNOWLEDGEMENTS

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CHAPTER II

TEXTURE

2.1 TEXTURAL ANALYSIS TECHNIQUES

A sub-sample from each of the 95 samples collected was wet-seived through 4ϕ(63μ) sieve to separate the mud fraction from sand and gravel. The latter was treated with 4.4 M acetic acid to remove calcium carbonate then dried and sieved at ½ϕ sieve intervals. Grain size parameters of mean and median grain size, sorting, skewness and kurtosis were calculated for the sand and gravel fractions by graphical methods. Modal grain sizes were determined from sieve analysis data. The mud fraction was dispersed using Calgon (sodium hexametaphosphate buffered with sodium carbonate) and the silt and clay percentages determined for all samples by pipette methods. Grain size distributions or six selected fine-grain samples were obtained by pipette analysis.

The unconventional method of using only the carbonate-free sand and gravel fraction to determine textural parameters was used in an attempt to obtain more meaningful and realistic information on sediment transport and depositional mechanisms than would otherwise be the case from an analysis of the total sediment. The separate use of sieve and pipette analysis data to derive total grain size distribution curves for mixed sand-mud sediments is likely to result in a statistically wide margin of error through the combination of data derived on an entirely different basis, and erroneous conclusions may be drawn.

Carbonate material, consisting largely of bivalve shell material hydraulically equivalent to quartz of smaller grain size was removed to eliminate what would otherwise appear as a tail at the coarse end of the grain size distribution. This may lead to interpretation of the modes of transportation and deposition of the sediment.

Problems inherent in the derivation of textural parameters from a combination of sieve and pipette analysis are eliminated by using only the $<4\phi$ fraction for grain size analysis. However, a number of other problems arise which necessitate a different interpretational approach than would be taken for conventionally derived textural parameters.

By using only the sand and gravel fraction for textural analysis, the suspension population is effectively eliminated from sediment transport interpretation. Grain size distribution curves show only fraction and saltation load populations. However, the importance of the suspension load in any sediment is gauged from the percentage of mud in each sample, and a number of selected grain size distributions were recalculated to include the $<4\phi$ fraction, enabling accurate determination of truncation points between saltation and suspension populations.

Textural parameters (Appendix III) refer only to the gravel and sand fraction, and, although having a different meaning than they would if applied to the whole sediment, can provide information concerning provenance, transportation, mechanisms, competence of currents and depositional mechanisms if interpreted in the correct context.

2.2 SEDIMENT TEXTURES

2.2.1 SEDIMENT COMPONENTS

Isopleth maps of the percentages of sand, mud, silt, and clay in the total sediment are shown in Figs. 2.1 to 2.4 respectively.

Sediments of the lower harbour are pure sand (Fig. 2.1) indicating that either sediment supplied from the upper reaches of the harbour suffers very efficient sorting in this area, or that well sorted sands have been transported to the area from outside the harbour. From the lower harbour to the middle harbour and into the south-east arm the proportion of sand in the sediments decreases, consistent with decreasing current velocities. This trend is reversed in the upper harbour however, where extensive areas of the tidal flats contain relatively high percentages (25%-70%)of sand, while sediments from the deeper channels generally contain less than 25% sand.

The isopleth map of mud percentage (Fig. 2.2) shows a reciprocal relationship to that for sand. The proportion of mud present in the sediments increases towards the distal reaches of the harbour and from the centre of the channels towards the adjacent shoreline, except in the upper harbour. Here the proportion of mud in the channels exceeds 90%, while the tidal flat sediments commonly contain less than 60% mud.

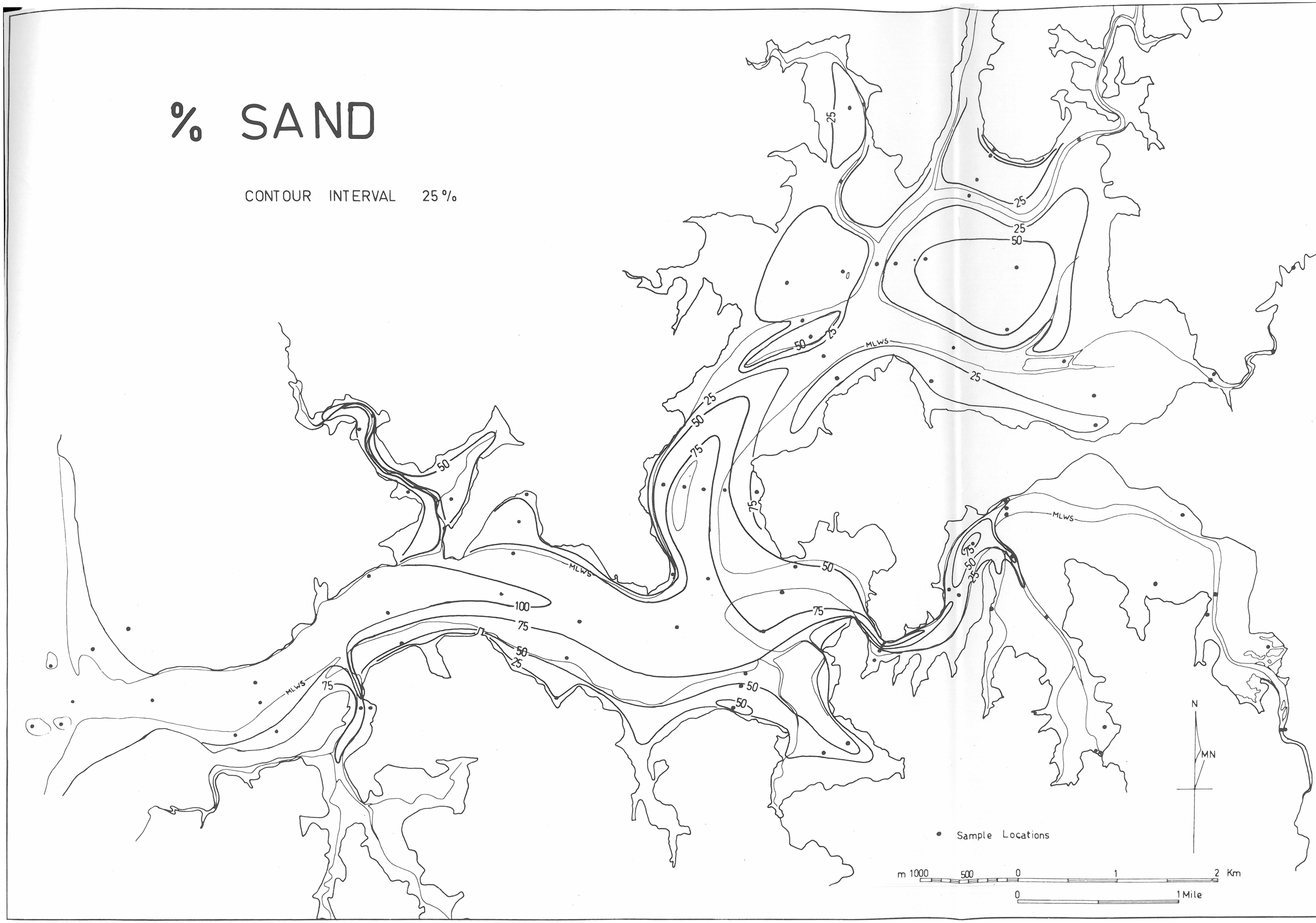


Fig. 2.1 Isopleth map of the percentage of sand in Raglan Harbour sediments.

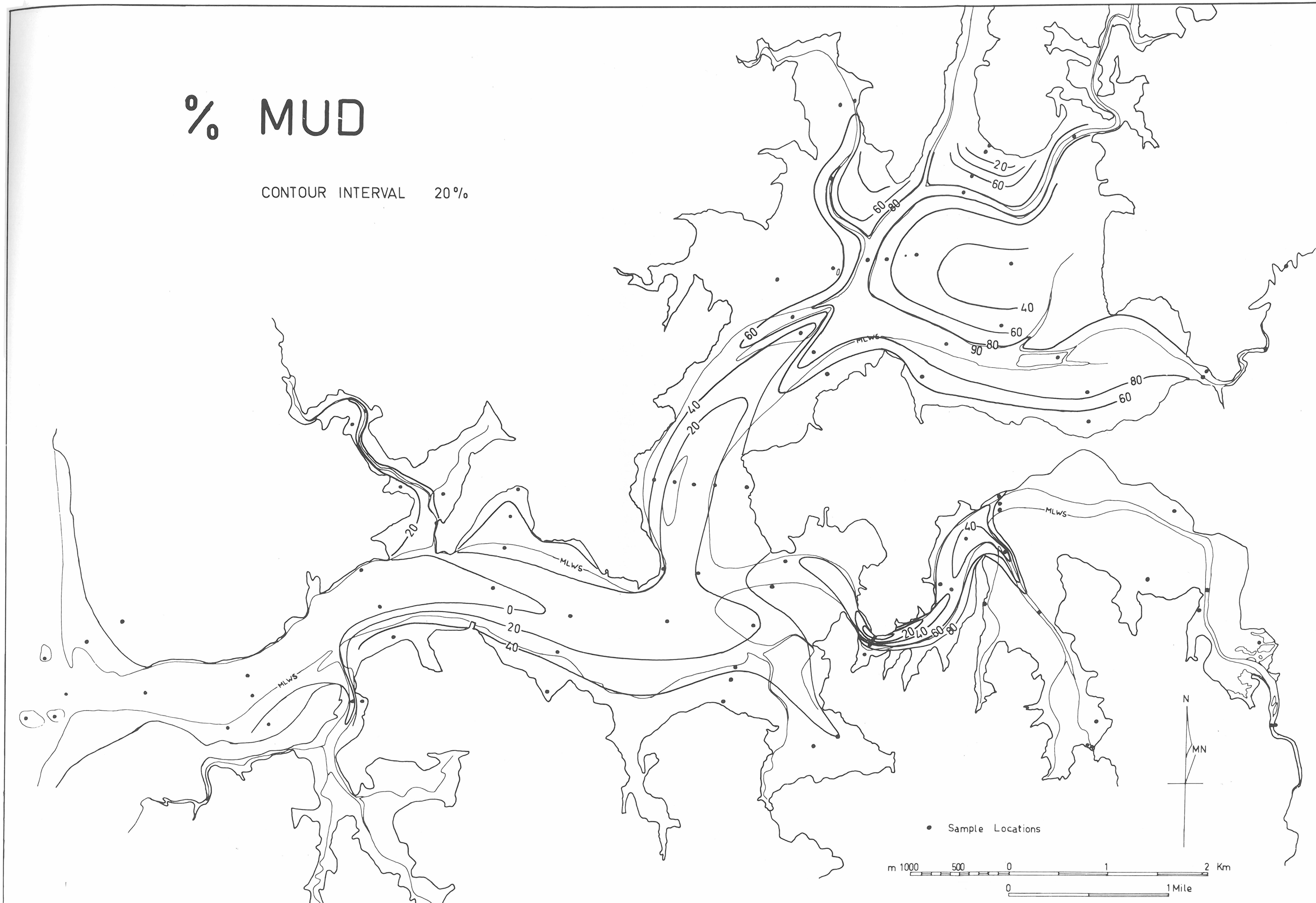


Fig. 2.2 Isopleth map of the percentage of mud in Raglan Harbour sediments.

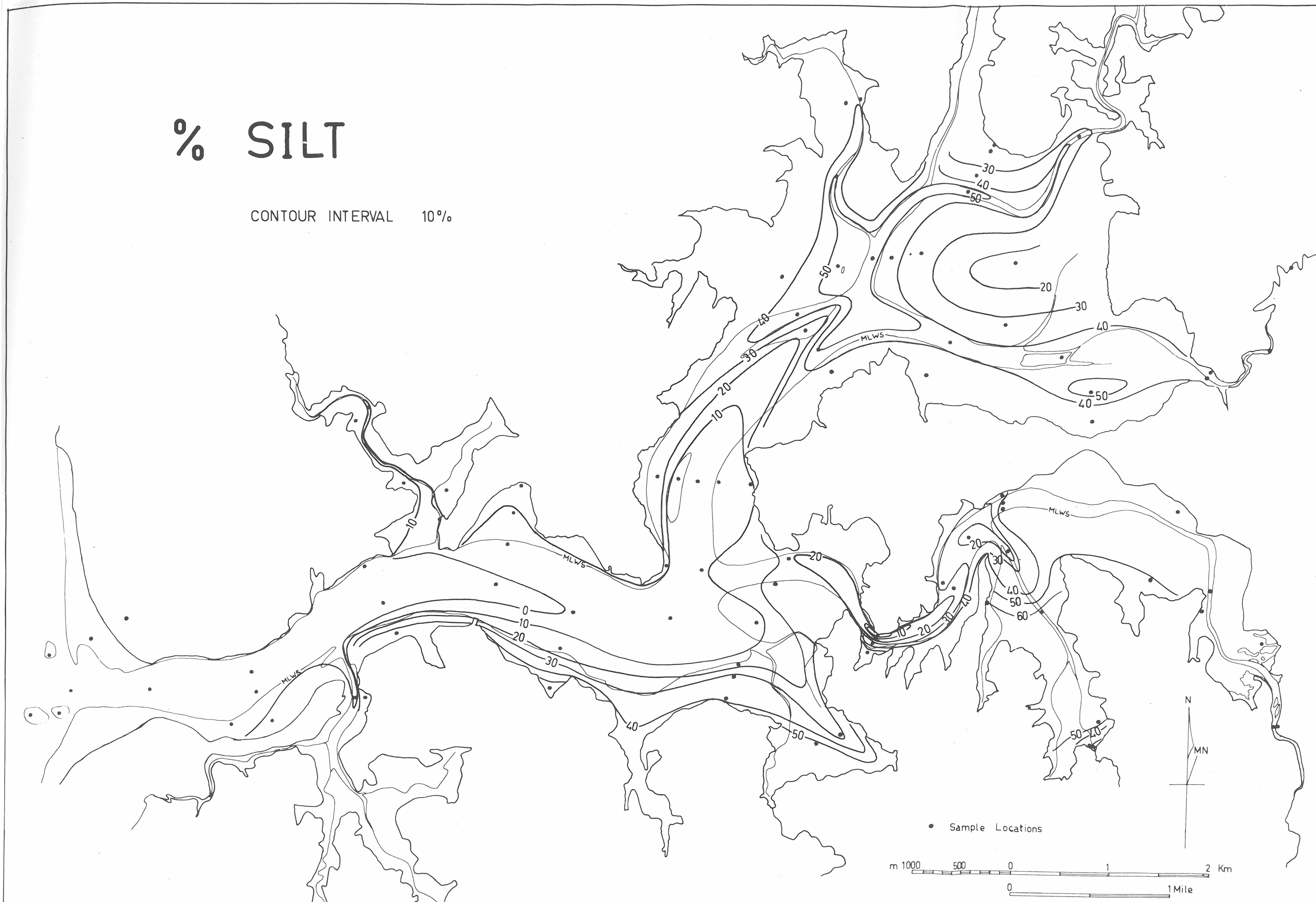


Fig. 2.3 Isopleth map of the percentage of silt in Raglan Harbour sediments.

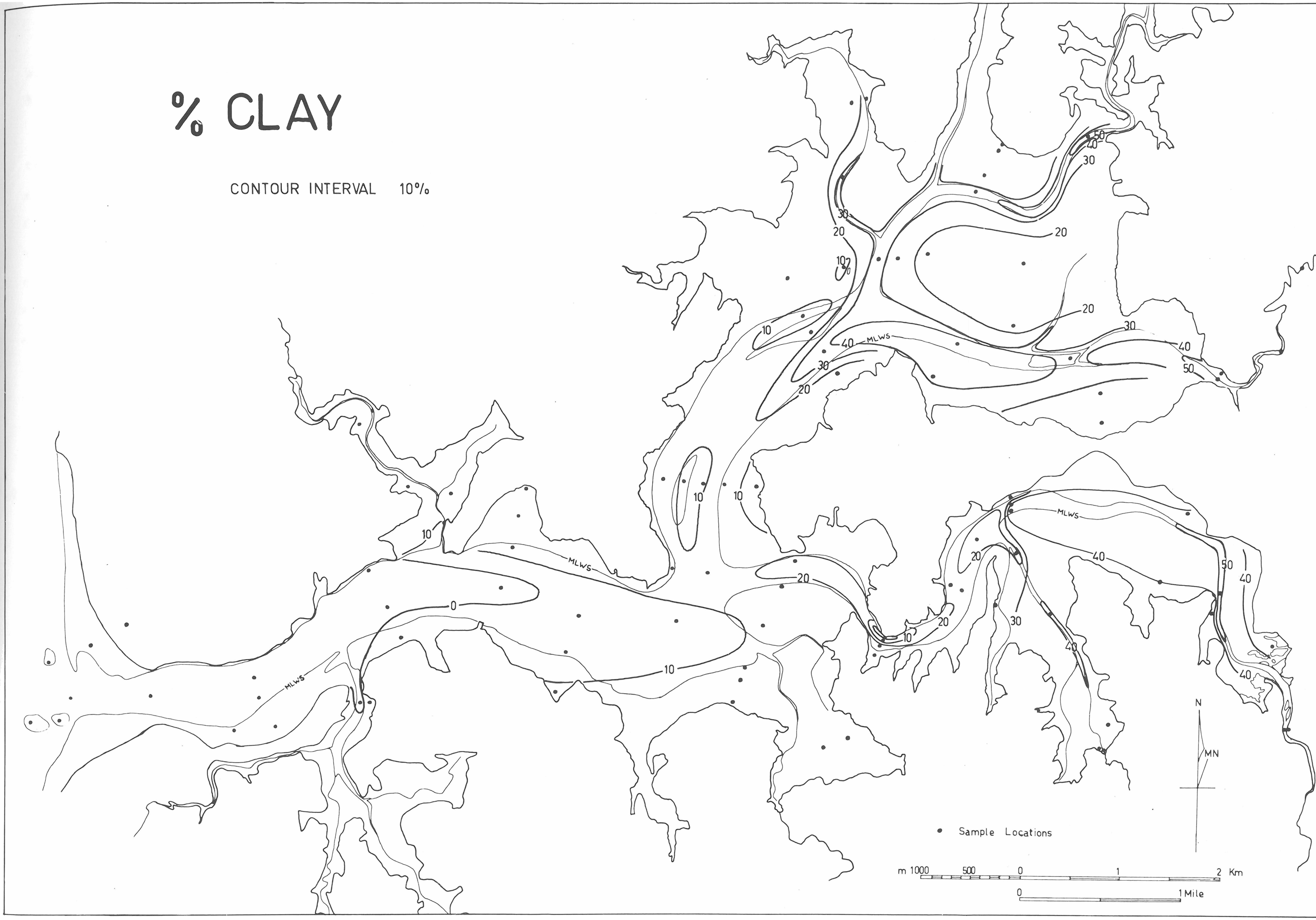


Fig. 2.4 Isopleth map of the percentage of clay in Raglan Harbour sediments.

Isopleth maps of the percentages of silt (Fig. 2.3) and clay (Fig. 2.4) show generally similar trends to the % mud isopleth map.

The proportions of clay present in the sediments of the middle harbour, and the seaward part of the south-east arm are lowest in the channels and increase with decreasing depth, a trend readily explained by differences in current velocities; the strongest currents are confined to the channels. If similar reasoning is used to explain the textures of sediments in the upper harbour, and to a lesser extent the distal reaches of the south-east arm, a reciprocal conclusion is reached. In these parts of the harbour, the finest grained sediments are found in the channels, indicating that current velocities are higher on the tidal flats.

2.2.2 TEXTURAL PLOTS

The proportions of gravel, sand, mud, silt and clay for 94 samples were plotted on the appropriate triangular gravel-sand-mud (Fig. 2.5) or sand-silt-clay (Fig. 2.6) diagram (Folk, 1968). The sediments cover a large number of textural classes reflecting the wide range of variables acting on the sedimentary system in Raglan Harbour. Similar textural classes are combined and plotted in Fig. 2.7 which shows the distribution of major textural groups.

Gravel-bearing sediments are scattered about the harbour, and appear to represent either lag deposits in areas of strong currents, or sediments derived in part

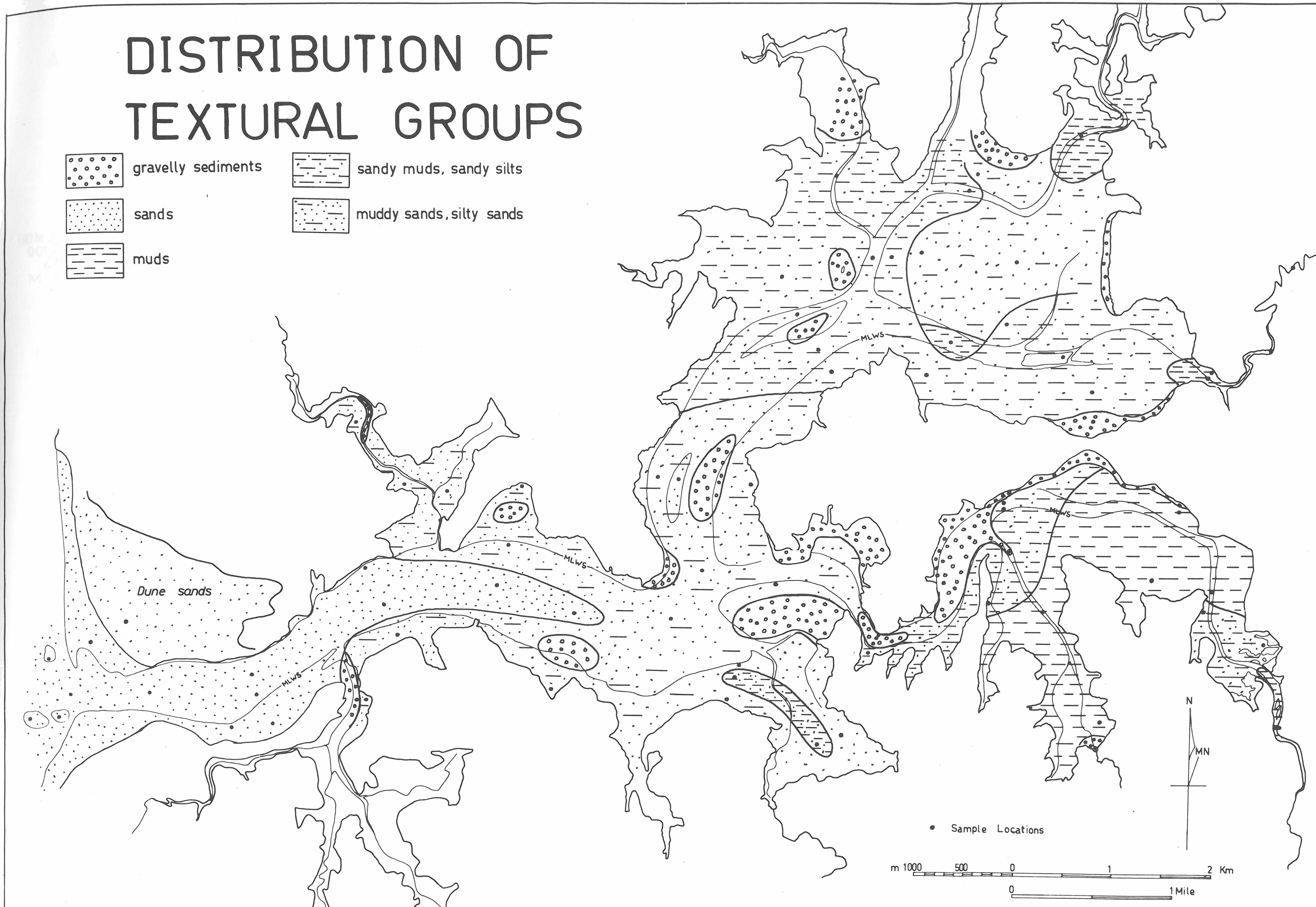


Fig. 2.7 Distribution of major textural group of sediments in Raglan Harbour.

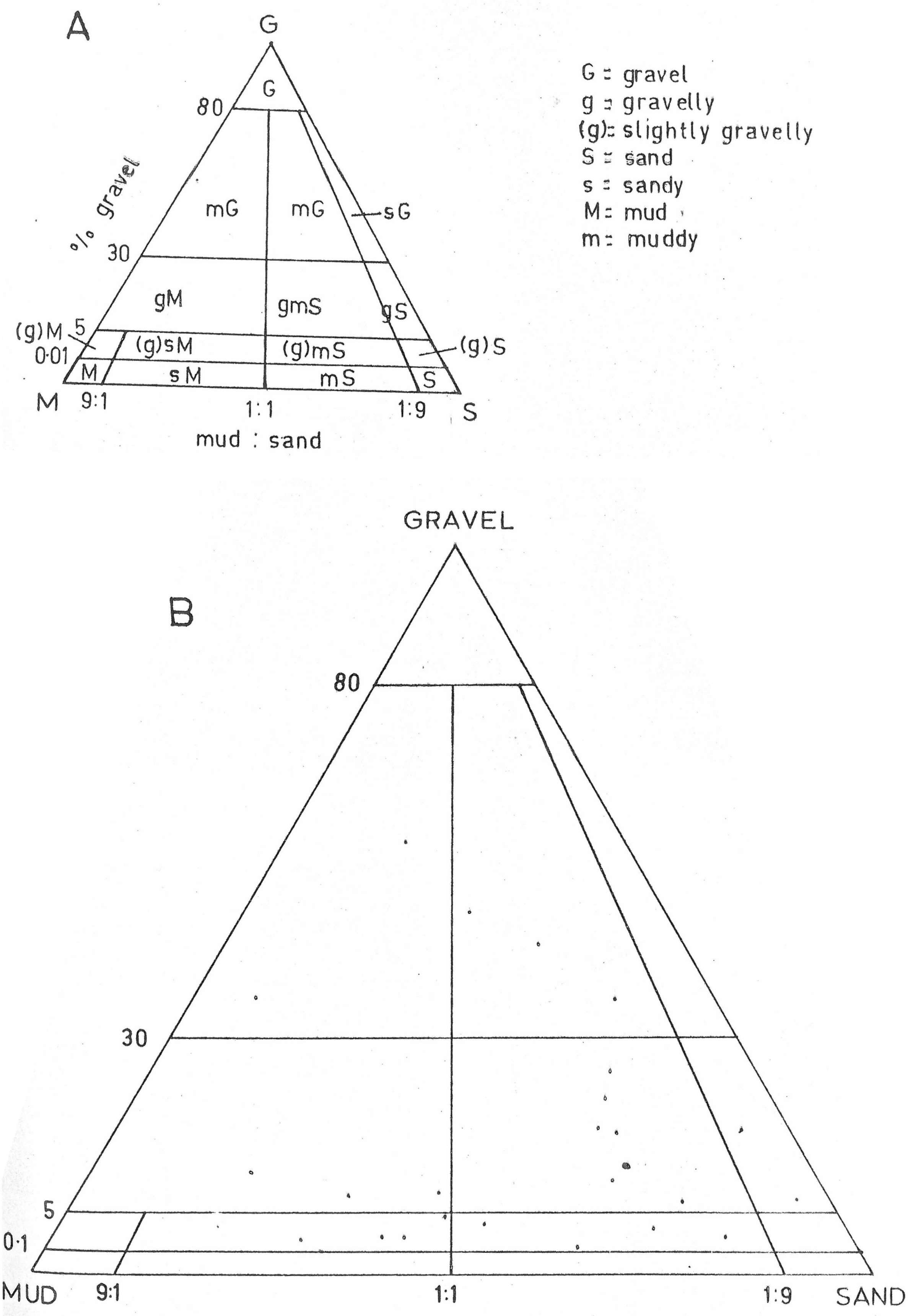


Fig. 2.5 A Textural classes of gravelly sediments (after Folk, 1968).

B Textural plot of gravelly Raglan Harbour sediments.

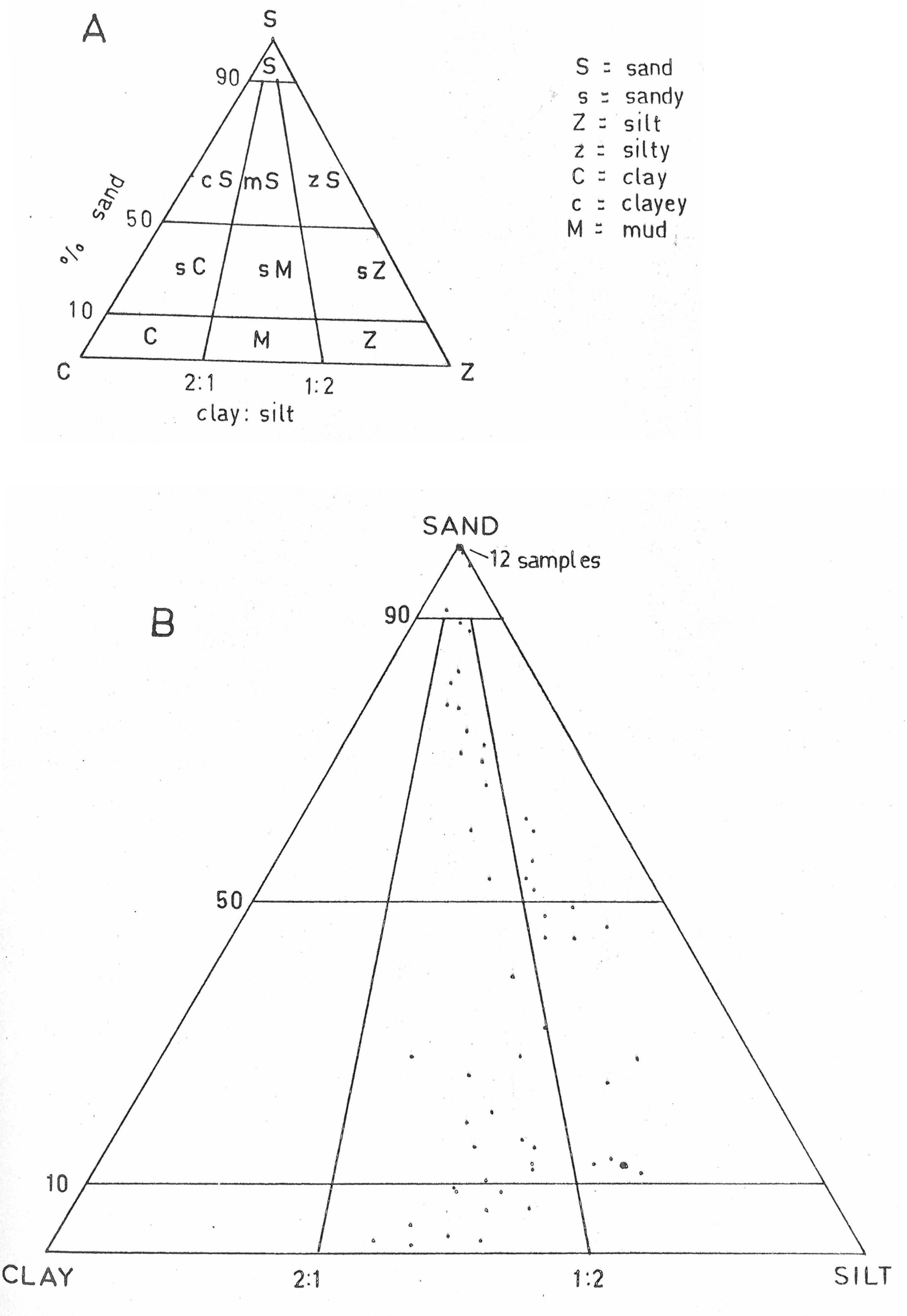


Fig. 2.6 A Textural classes of muddy sediments (after Folk, 1968).

B Textural plot of muddy Raglan Harbour sediments.

from shoreline erosion from which the gravel-sized material has not been removed. Pure sands are found only in the lower harbour and as dune, bar, or beach sands around the harbour entrance. The fact that pure sands are not found elsewhere in the harbour even where very strong currents occur, is in itself strongly indicative that their provenance is different from that for sediments elsewhere in the harbour.

The latter, excluding gravel-bearing sediments, consist mainly of muddy sands, sandy muds, and muds, with less abundant silty sands and sandy silts. These textures indicate transport of sediment under variable energy conditions, with deposition of coarser grain sizes as the tidal currents cyclically decrease in velocity, and deposition of fines from suspension at periods of slack water.

2.3 GRAIN SIZE DISTRIBUTION CURVES

Grain size distribution curves for 84 sediment samples from Raglan Harbour were plotted on arithmetic probability paper with the abscissa scale in phi units, giving log-probability plots generally consisting of a number of straight line segments.

Sediment may be transported in open channels in three ways (Allen 1970); as suspension, saltation and contact or traction carpet loads. The contact load and the saltation load, together form the bed load. The major problem in the study of grain size distributions of sediments is the relation of sedimentary processes to textural responses. Visher (1965, 1969) related grain size distributions to modes of sediment transport , with each straight line segment of the log-probability plot interpreted as a separate log-normal population representing material transported by a different physical process.

Grain size distributions may be characterised by the number, degree of mixing, size range, percentage and degree of sorting of each log-normal population, providing information on currents, sediment transport, rates of deposition, and provenance. The position of trancation points between populations is also environmentally diagnostic.

2.3.1 GENERAL TRENDS SHOWN BY GRAIN SIZE DISTRIBUTION CURVES

The grain size distribution curves for Raglan Harbour sediments show considerable variability which may be explained in terms of the above modes of sedimentation.

Dune sands adjacent to the harbour entrance show a very well sorted saltation population (Fig. 2.8a), without the contact or suspension load population reported by Visher (1969) for dune sands.

Beach sands around the mouth of the harbour show similar grain size characteristics (Fig. 2.8b) but differ in the nature of the saltation population. A contact or suspension load is again lacking, but two log-normally

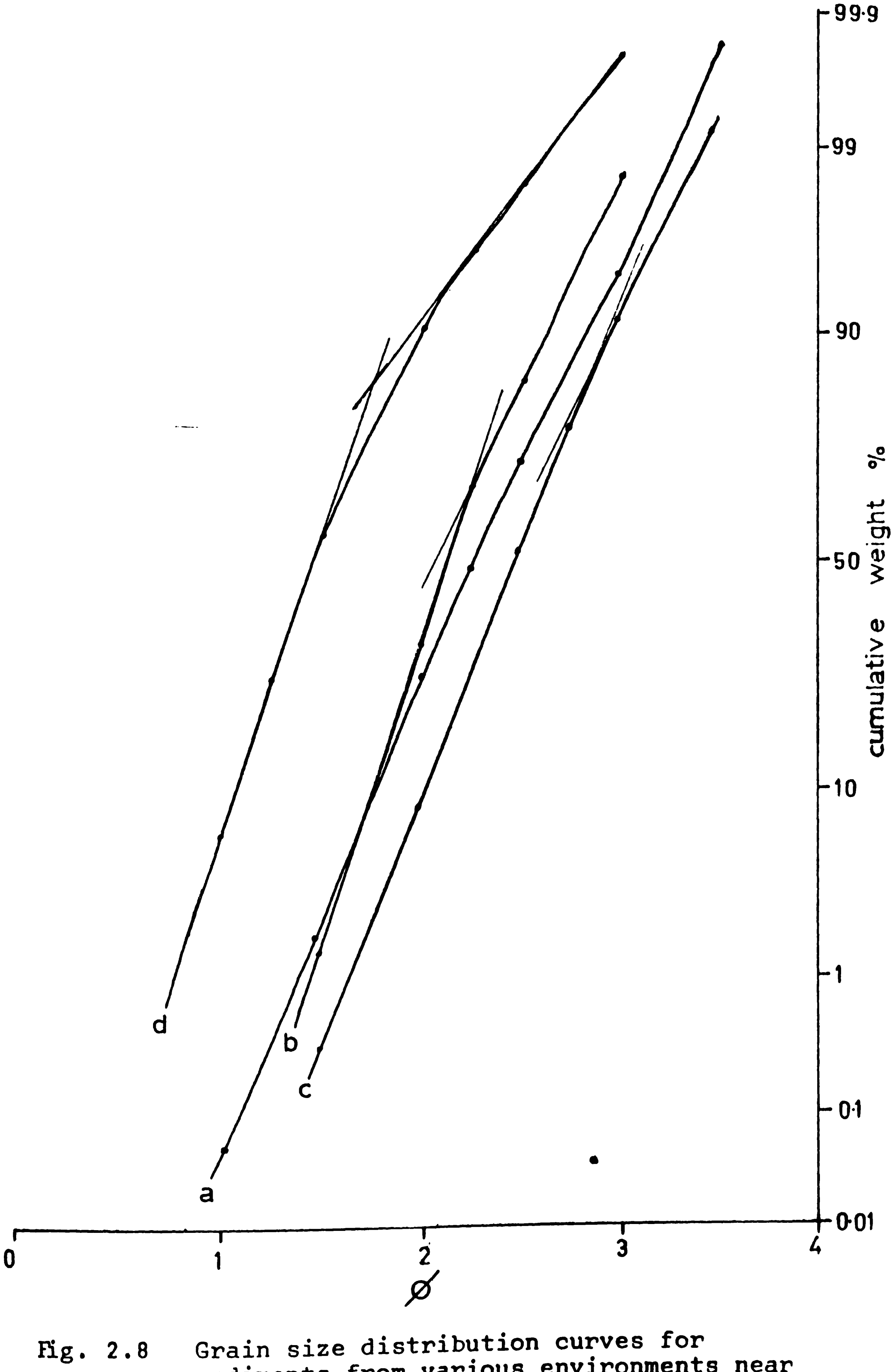


Fig. 2.8 Grain size distribution curves for sediments from various environments near the entrance to Raglan Harbour.
a = dune; b = beach; c = bar; d = channel;
With the exception of the dune sands, all show the development of two log-normally distributed populations.

distributed saltation populations are present. There are no apparent textural differences between the beach sands (Fig. 2.8b) the sands of the bars which flank the main channel at the harbour entrance (Fig. 2.8c), and the sands in the main channel itself (Fig. 2.8d). All are sites of constant sediment reworking, but have marked differences in their hydraulic characteristics.

The beach environment is characterised by swash and backwash, the channel by the strong ebb and flood tidal currents, and the bars, with breaking waves seldom less than 2 or 3 metres high, by extremely high turbulence. The two saltation populations in the beach sands are probably the result of sorting by swash and backwash, while those in the channel result from different strengths of flood and ebb tidal currents. It is more difficult to explain how such sorting processes occur in a turbulent sand bar environment. The textural similarity of sediments in the dune, beach, bar and channel environments indicates a high degree of mixing between them. The lack of a contact population in all four is provenance controlled, as the coastal sands of the west coats have already undergone considerable sorting during long-shore transportation from coastal Taranaki.

From the lower harbour towards the middle harbour and in the small arms of the lower and middle harbour, the slope of the grain size distribution curves decreases, indicating a decrease in sorting of the sediments. A concomittant development of contact and suspension population takes place

(Fig. 2.9a and b). Sediments in this region of the harbour are characterised by:

(1) a poorly sorted contact population comprising between 1 and 55% of the sediment. The amount of contact population is partly dependant on the supply of coarse detritus and partly on the capacity of the currents acting on the sediment.

(2) a contact-saltation load, truncation point between 1.75 and 3.0ϕ. This truncation point is directly dependant on current competence, and its wide size range reflects variation in current strengths in this region of the harbour.

(3) a moderately sorted saltation population comprising between 35% and 75% of the sediment.

(4) a saltation-suspension load truncation point at about 3.5ϕ in all sediments.

(5) a suspension population comprising up to 50% but generally less than 20% of the sediment.

(6) highly variable degrees of mixing between the saltation population and the contact and suspension populations, reflecting variable energy conditions.

In comparison to the well sorted sands in various environments around the harbour entrance, the grain size distributions of sediments from the middle harbour and the arms of the lower harbour reflect a generally lower, but more variable energy environment, less sediment reworking, and supply of a wider range of grain sizes to the sedimentary system.

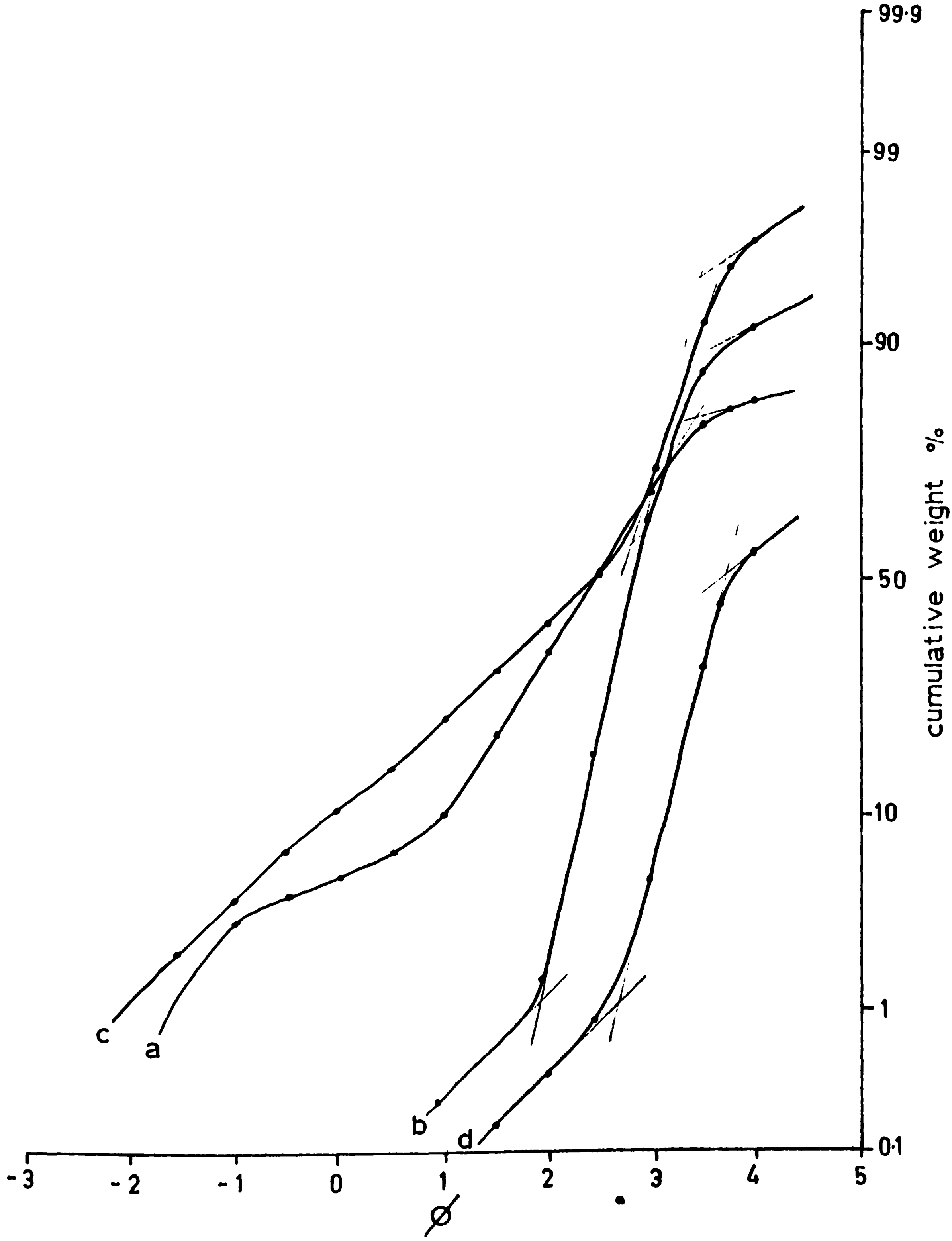


Fig. 2.9 Grain size distribution curves for sediments from the middle harbour (a and b) and from tidal flats in the upper harbour (c and d).

The fine grained sediments from the extensive tidal flats of the upper harbour and the south-east arm have very similar grain size distribution curves(Fig. 2.9c), characterised by:

(1) a very small contact population, generally less than 20% and often as low as 2% by weight.

(2) a truncation point between contact and saltation populations at about 2.75ϕ.

(3) a very well developed suspension population, usually comprising 40% or 50% of the sediment.

(4) a truncation point between suspension and saltation populations.at 3.75ϕ.

(5) little mixing between populations.

These grain size distribution characteristics are consistent with deposition of the bulk of the sediment out of suspension, and periodic activity of low velocity, low turbulencecurrents. The small contact population and the fine coarse truncation point of the saltation populations suggest low competence of these currents. The position of the fine truncation point of the saltation population reflects low turbulent energy at the depositional interface.

Not all the sediments from the tidal flats of the upper harbour indicate deposition in a low energy environment however. Some samples have a mean grain size in the medium sand range and show moderately sorted contact populations.comprising up to 50% of the sediment (Fig. 2.9d).

Their grain size distribution characteristics are consistent with relatively high velocity, high turbulence currents.

Sediments from the channels of the upper harbour closely resembled the fine grained sediments of the tidal flats, which would appear to indicate deposition in a very low energy environment. In contrast, the channel sediments of most of the south-east arm show relatively well developed contact populations after washing out of much of the fines by strong currents. Samples from the channels of the upper reaches of the south-east arm, are however, mainly suspension deposits,and are similar to the fine grain sediments of the tidal flats.

2.3.2 ANALYSIS OF GRAIN SIZE DISTRIBUTION CURVES ACROSS A SAMPLING TRANSECT.

Fig. 2.10 shows a bottom profile across the entrance to the northern arm of Raglan Harbour, and the grain size distribution curves of sediments collected across the profile. Analysis of these curves in terms of the characteristics by their log-normally distributed grain size populations provides information on the hydrodynamics of this part of the harbour, the modes of sediment transportation, and the consequent modification of the grain size distributions.

The bottom profile shows a broad shallow eastern channel and a narrow, deeper western channel separated by an intertidally exposed sediment bar. The bifurcated main channel is flanked by intertidal flats, wide on the eastern side and narrow on the west.

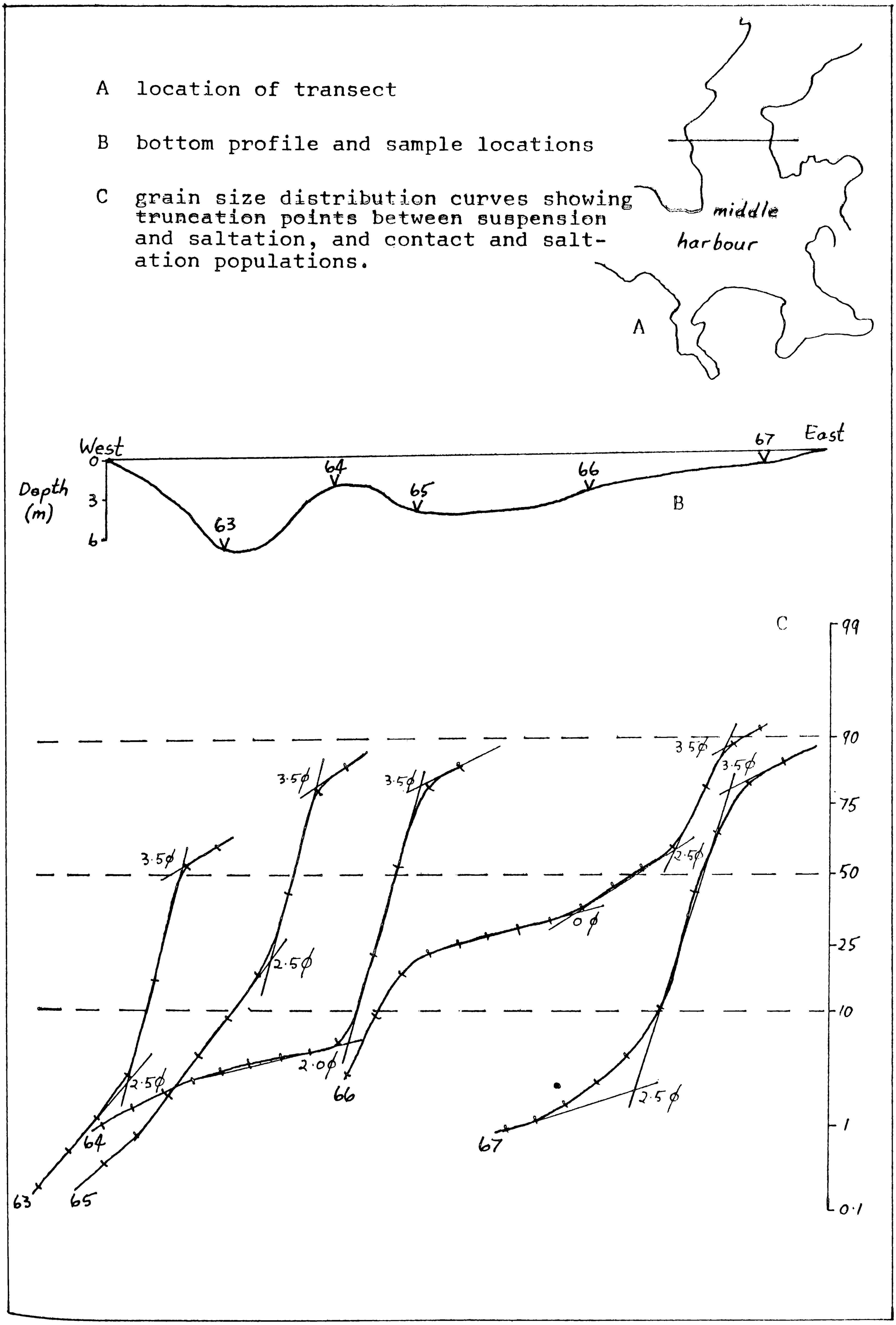


Fig. 2.10 Grain size distribution curves for sediments collected from a transect across Raglan Harbour.

Table 2.1 summarises the characteristics of the grain size distribution curves for sediments across the profile. Sediment from the deeper channel (sample 63) has been transported by relatively low velocity, low turbulence currents, and deposited almost entirely from suspension and saltation. The grain size distribution of sediment from the intertidal bar (sample 64) indicates the action of more turbulent currents of slightly greater velocity which have prevented deposition of large amounts of fines from suspension.

The very poorly sorted contact population present in the sediment sample from the bottom of the broad shallow channel (sample 65) probably represents a lag deposit. The coarse truncation point (-2ϕ) of the contact population indicates the presence of high current velocities. The coarse coarse truncation point of the saltation population reflects high shear at the depositional interface caused by high bed layer velocities, although low turbulence currents are suggested by the very small amount of mixing between saltation and contact populations.

High velocity currents near the margin of the shallow channel have removed or prevented deposition of all but a small quantity of fines (sample 66). Sediments here have been deposited almost entirely from bed load material. A large traction load is present, which appears to have been sorted into two log-normally distributed populations, possibly as a result of differences in velocities of the ebb and flood tides.

Sample No.	Saltation population (A)				Suspension population (B)			Traction population (C)			
	%	σ_I	C.T (ϕ)	F.T (ϕ)	%	σ_I	Mixing A & B	%	σ_I	Mixing A & C	C.T (ϕ)
63	45	Good	2.5	3.5	50	Poor	Little	5	Moderate	Little	1
64	65	Good	2.5	3.5	25	Poor	Average	10	"	Average	0
65	70	Good	2.0	3.5	25	Poor	Average	5	V-poor	Little	-2
66	40	Moderate	2.5	3.5	10	Poor	Much	50	2 populations V-poor	Average	-3
67	65	"	2.5	3.5	20	Poor	Much	10	Poor	Much	0

Table 2.1 Characteristics of grain size distribution curves for sediments from a profile across part of Raglan Harbour. σ_I = sorting; C.T. = coarse truncation point; F.T = fine truncation point.

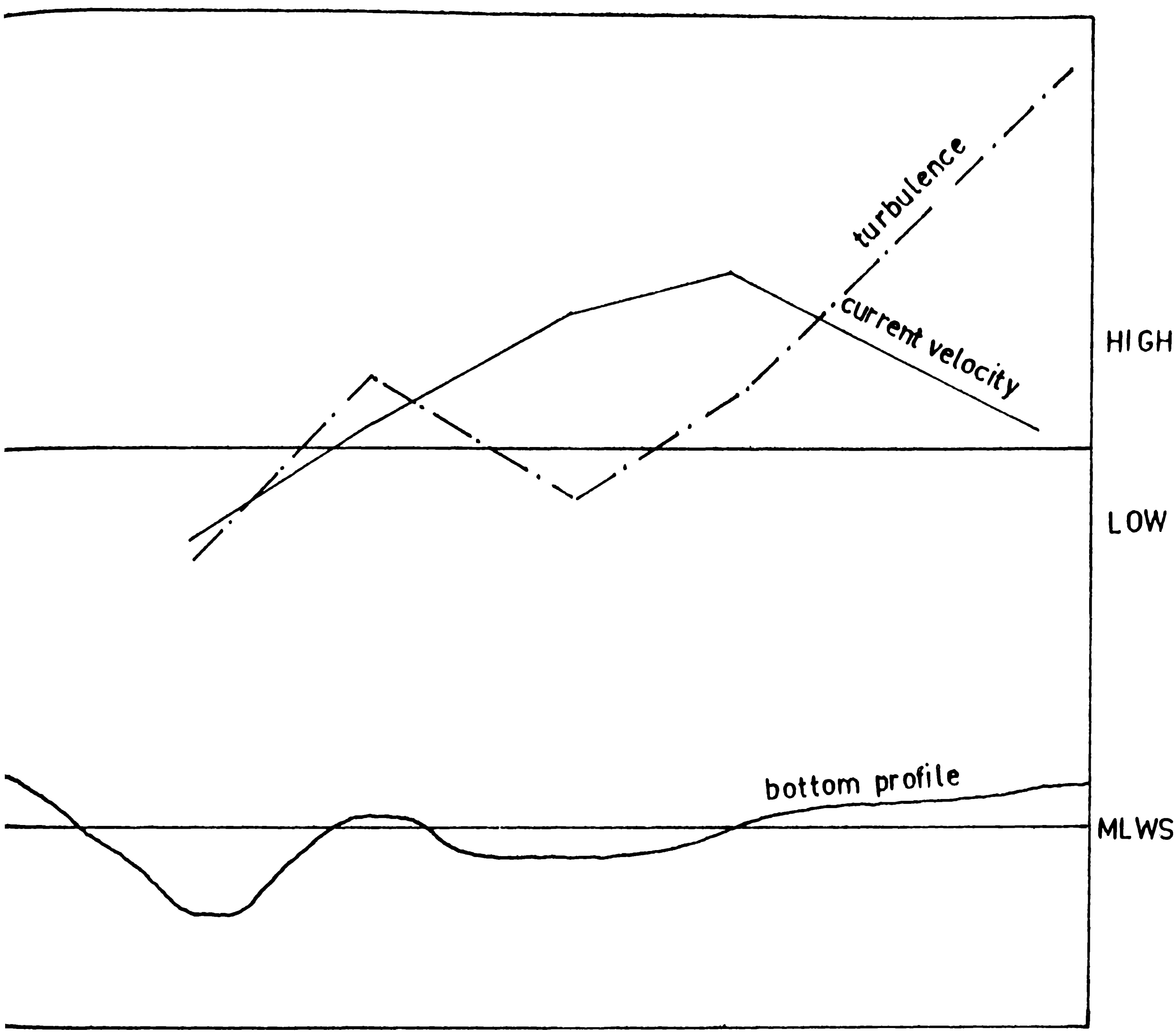


Fig. 2.11 Turbulence and current velocity trends as determined from analysis of grain size distribution curves over a profile across part of Raglan Harbour.

Some sediments with large contact loads from other parts of the harbour where high current velocities would be expected show similar characteristics.

Sediment from near the eastern shoreline (sample 67) is still dominated by bed load material, indicating that currents remain strong in this area, although of lower velocity than in the channel. The grain size distribution is characterised by an extreme amount of mixing between populations which indicates high turbulence, possibly the result of eddying of tidal currents close to the shoreline.

Current velocities and turbulence across the profile as indicated by grain size distributions are summarised in Fig. 2.11

2.4 GRAIN SIZE PARAMETERS

Grain size parameters (Table 2.2, after Folk and Ward 1957) were calculated for 84 samples. The verbal limits for these parameters, as suggested by Folk(1968),are included in Table 2.2. The results of analysis are presented in Appendix III. A grain size scale with verbal equivalents, is presented in Table 2.3. It is stressed that grain size parameters used in this section refer to the sand plus gravel fraction only.

2.4.1 AVERAGE GRAIN SIZE

Two measures of average grain size for the $<4\phi$ are used in this study; modal and mean grain size.

Mean size is a function of the size range of materials available, and the amount of energy imparted to the sediment

Graphic Mean

$$M_z = \frac{\phi16 + \phi50 + \phi84}{3}$$

Inclusive Graphic Standard Deviation

$$\sigma_I = \frac{\phi84 - \phi16}{4} + \frac{\phi95 - \phi5}{6.6}$$

Verbal Classification:

σ_I under 0.35ϕ	very well sorted (vws)
0.35 to 0.50ϕ	well sorted (ws)
0.50 to 0.71ϕ	moderately well sorted (mws)
0.71 to 1.0ϕ	moderately sorted (ms)
1.0 to 2.0ϕ	poorly sorted (ps)
2.0 to 4.0ϕ	very poorly sorted (vps)
over 4.0ϕ	extremely poorly sorted (eps)

Inclusive Graphic Skewness

$$Sk_I = \frac{\phi16 + \phi84 - 2\phi50}{2(\phi84 - \phi16)} + \frac{\phi5 + \phi95 - 2\phi50}{2(\phi95 - \phi5)}$$

Verbal Classification:

Sk_I from +1.00 to +0.30	strongly fine-skewed (sfs)
+0.30 to +0.10	fine-skewed (fs)
+0.10 to -0.10	near-symmetrical (ns)
-0.10 to -0.30	coarse-skewed (cs)
-0.30 to -1.00	strongly coarse-skewed (scs)

Graphic Kurtosis

$$K_G = \frac{\phi95 - \phi5}{2.44(\phi75 - \phi25)}$$

Verbal classification:

K_G under 0.67	very platykurtic (vpk)
0.67 to 0.90	platykurtic (pk)
0.90 to 1.11	mesokurtic (mk)
1.11 to 1.50	leptokurtic (lk)
1.50 to 3.00	very leptokurtic (vlk)
over 3.00	extremely leptokurtic (elk)

Table 2.2 Statistical Parameters (after Folk and Ward, 1957).

MILLIMETERS	PHI (ϕ)	WENTWORTH SIZE CLASS	
		Boulder	GRAVEL
256	-8.0		
		Cobble	
64	-6.0		
		Pebble	
4	-2.0		
		Granule	
2	-1.0		
		Very coarse sand	SAND
1	0		
		Coarse sand	
0.5	1.0		
		Medium sand	
0.25	2.0		
		Fine sand	
0.125	3.0		
		Very fine sand	
0.063	4.0		
		Silt	MUD
0.0039	8.0		
		Clay	

Table 2.3 Grain size scale for sediments.

which depends on current velocity or the turbulence of the transporting medium (Folk, 1968).

Fig. 2.12 shows an isopleth map of mean grain size. For clarity of presentation, actual values are given for samples collected from where streams discharge into the harbour. The map clearly shows a number of significant features of the mean grain size distribution:

(1) mainly medium sand in the lower harbour indicating the supply of material mainly in that size range or the presence of relatively strong currents or both.

(2) fine sands in the deeper parts of the middle harbour consistent with the supply of finer material, or the presence of less vigourous currents, or both.

(3) very fine sand over most of the tidal flat areas of the harbour, indicating the supply of large quantities of fine material and deposition in a low energy environment.

(4) concentration of coarse material in the region of the Narrows , which is consistent with the high velocity tidal currents in this part of the harbour.

(5) coarse material along some of the margins of the harbour. This material is derived from shoreline erosion, and appears to be more common in those parts of the harbour with the least current activity. In these areas coarse material is produced by erosion of the shoreline rocks, commonly the Whaingaroa Siltstone, the material remaining more or less <u>in situ</u>

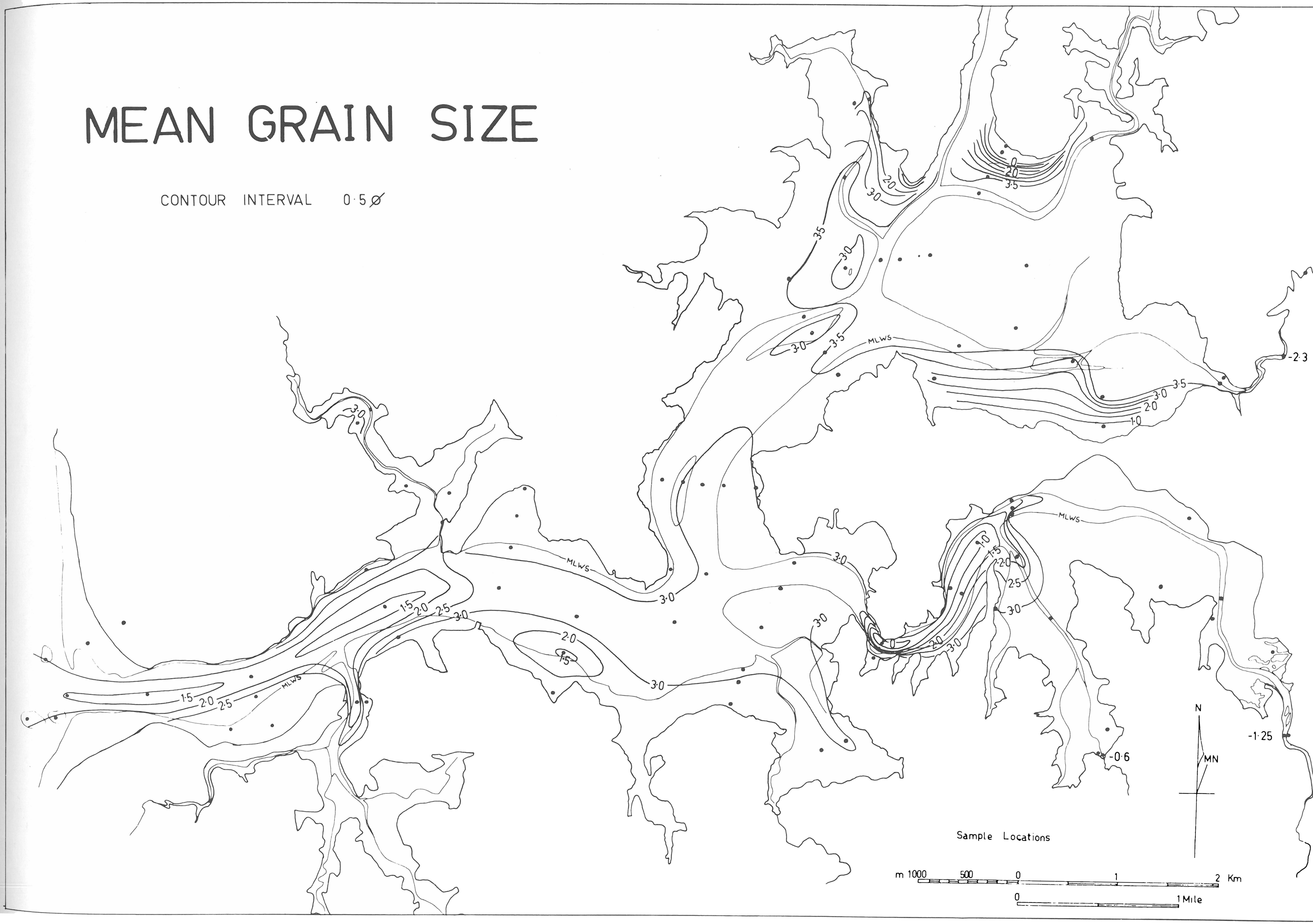


Fig. 2.12 Isopleth map of mean grain sizes for the <4ϕ fraction of Raglan Harbour sediments.

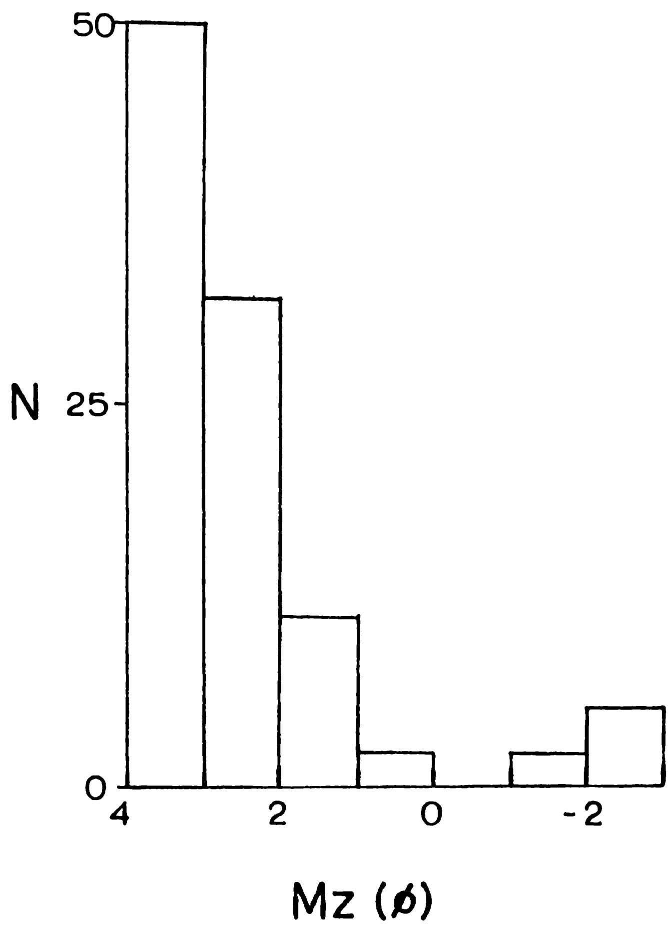


Fig. 2.13 Histogram of mean grain sizes (Mz) of Raglan Harbour sediments plotted as a function of their numerical occurrence (N).

until it is physically weathered to a sufficiently small grain size to be transported.

(6) very coarse (gravel sized) material at the points where streams discharge into the harbour. Only fine material supplied by the streams is transported past these points because of the incompetence of the weak tidal currents in the distal regions of the harbour.

Almost all the sediments from Raglan Harbour are unimodal with modes in the medium to very fine sand range. A few bimodal samples showed on additional mode in the granule to small pebble range. Pipette analysis data indicates that the fine grained sediments of the tidal flats have truemodal grain sizes in the silt range.

A histogram of modal grain sizes for the $<4\phi$ fraction of Raglan Harbour sediments is shown in Fig. 2.13, and reflects (though less clearly) the provenances and current energies demonstrated by the mean grain size distribution.

2.4.2 SORTING

Sorting is dependant on four major factors (Folk 1968):

(1) the size range of material supplied;

(2) the type of deposition;

(3) current characteristics; and

(4) the rate of detritus supply compared with the efficiency of the sorting process.

Fig. 2.14 shows the sorting of the sand plus gravel fraction of Raglan Harbour sediments. The often considerable suspension population is ignored, and sorting values are more indicative of maximum rather than mean energy conditions of the depositional environment. It is obvious that provided a sufficiently wide range of grain sizes is supplied, a sediment deposited largely from suspension in a dominantly low energy environment, will be poorly sorted. Determination of sorting values of the $<4\phi$ is indicative of the sedimentary processes acting at times other than slack water.

The distribution of sorting values shows complex interaction of the determinate factors, which are themselves highly variable throughout the harbour. Samples from the lower harbour and much of the middle harbour are well or very well sorted, consistent with a combination of strong current action and the supply of well sorted material. Marginal sediments of the middle harbour together with those of the seaward part of the south-east arm and the more distal regions of the upper harbour are mainly poorly sorted, which suggests that the supply of detritus in these areas is greater than the sorting capacity of the currents.

Sediments from the distal part of the south-east arm and the central regions of the upper harbour are moderately to very well sorted. This suggests that the supply of detritus, which may be initially sorted

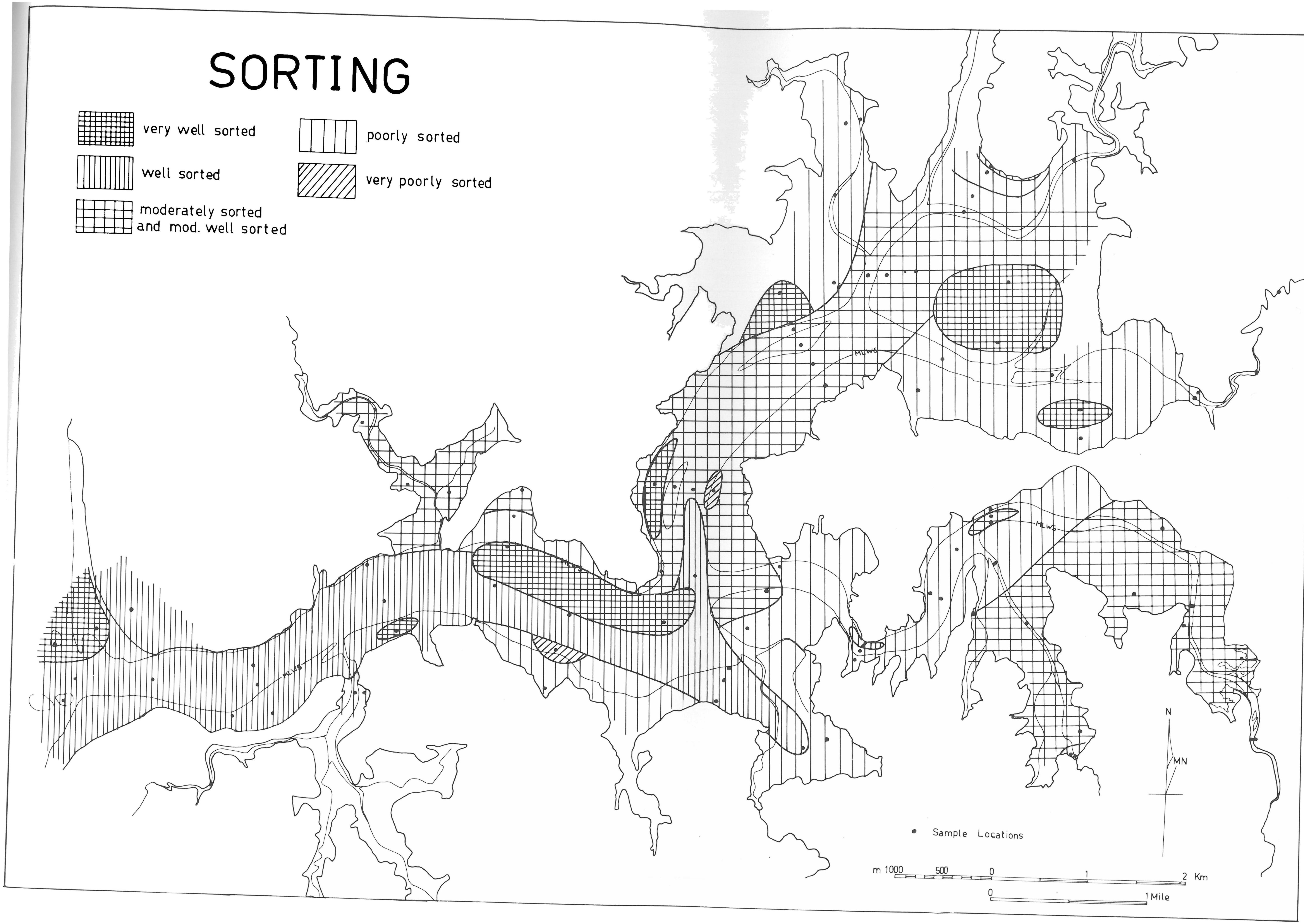


Fig. 2.14 Sorting (σ_I) of the <4ϕ fraction of Raglan Harbour sediments.

to some degree, is low compared with the sorting efficiency of the currents in these generally shallow parts of the harbour. If this is so, then it would appear that part of the sediment supply to the south-east arm is transported from the middle harbour via the Narrows by the flood tide.

2.4.3 SKEWNESS

Skewness is a measure of the asymmetry of the grain size distribution of a sediment; negative skewness values result from an excess of coarse material, positive skewness values from an excess of fines.

Fig. 2.15 shows the skewness of the $<4\phi$ of Raglan Harbour sediments. Near symetrical skewness values are confined to the well sorted sands in the main channel of the lower harbour. Dune, beach and some bar sands are fine skewed, probably resulting from the concentration of titanomagnetite in the very fine sand range. Only a small number of samples elswhere in the harbour were fine skewed.

Apart from the sands of the lower harbour region, almost all of the sand plus gravel fraction in Raglan Harbour sediments is coarse or strongly coarse skewed which indicates an excess of coarse grain sizes in the sediment deposited from bed-load material. This is consistent with removal or non-deposition of fines during periods of highest current activity.

2.4.4 KURTOSIS

Kurtosis is a measure of the ratio between the sorting

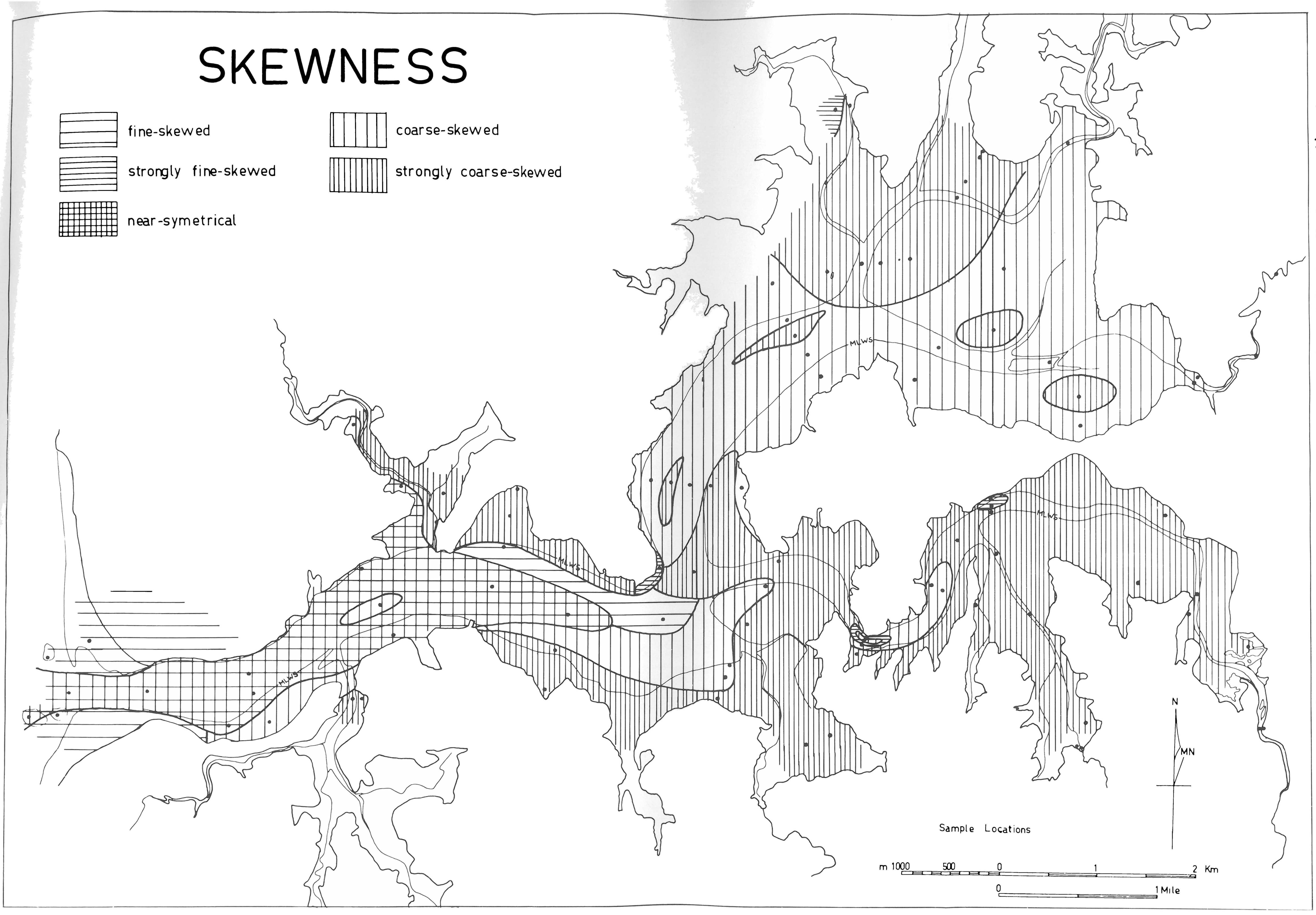


Fig. 2.15 Skewness (Sk_I) of the <4ϕ fraction of Raglan Harbour sediments.

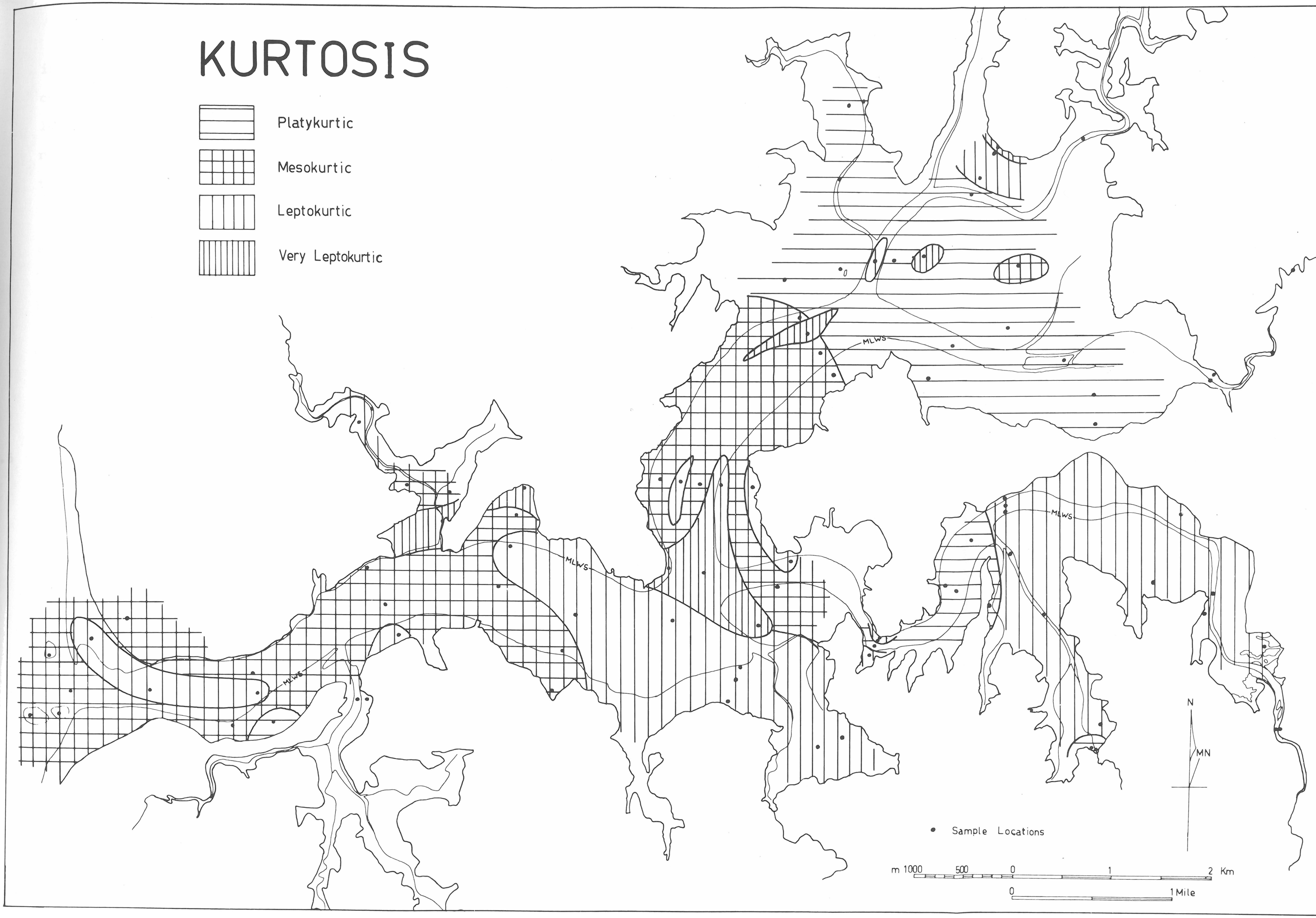


Fig. 2.16 Kurtosis (K_G) of the $<4\phi$ fraction of Raglan Harbour sediments.

in the central portion of the grain size distribution curve to the sorting in the tails; platykurtosis and leptokurtosis indicate a poorer and better sorting respectively in the central part of the curve as compared to the tails.

The sand plus gravel fractions of Raglan Harbour sediments range from platykurtic to very leptokurtic. There are doubts to the exact significance of kurtosis, and no readily interpretable pattern emerges from the distribution of kurtosis values shown in Fig. 2.16. Baker (1968) has concluded that the use of graphic kurtosis as a descriptive parameter should be abandoned.

2.5 PIPETTE ANALYSIS

Six fine-grained sediment samples collected from selected localities throughout Raglan Harbour were analysed by pipette methods.

Table 2.4 shows the textural classes, depositional environments, and median grain sizes of the sediments analysed.

The results from the pipette analyses were combined with sieve analysis data to give total sediment grain size distribution curves. It was not possible to calculate grain-size parameters by graphical methods, as, with one exception, the 75th, 84th and 95th percentiles could not be read from the grain-size distribution curves obtained. Curves for two samples are presented in Fig. 2.17.

Sample No.	Textural class	Median Grain size (ϕ)	Depositional environment.
55	(g) M	9.5	Tidal flat
58	M	9.7	Channel
59	sM	6.5	Tidal flat
72	sZ	4.0	Tidal flat
85	M	10.0	Estuary
93	mS	3.7	Tidal flat

Table 2.4: Textural classes, depositional environments and median grain sizes for samples analysed by pipette methods. Median grain size is the 50th percentile of the grain size distribution curve.

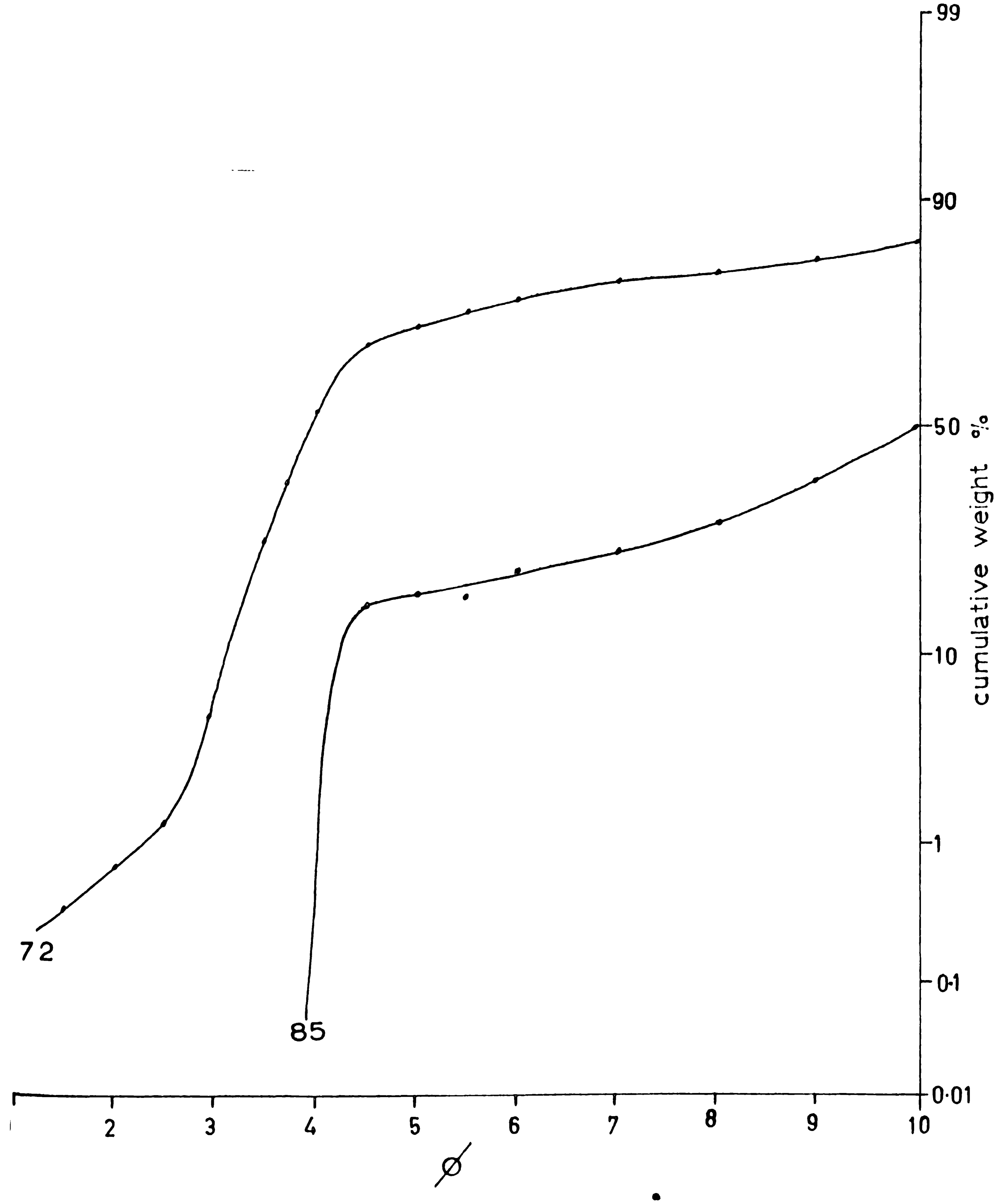


Fig. 2.17 Grain size distribution curves for two sediments (sample numbers 72 and 85) analysed by pipette methods. Extrapolation of the lower curve is based on a <4ϕ fraction of 0.2% by weight for sample 85.

Pipette analysis results endorse the conclusions of Section 2.2.1, that in certain areas of Raglan Harbour, channel sediments are of considerably finer grain size than sediments from the tidal flats. Sediments in the estuarine regions appear to be finer grained than sediments from elsewhere in the harbour, although this conclusion is based on analysis of only one sample.

Grain size distributions of clay-rich sediments obtained by laboratory analysis probably bear little relation to those existing in nature. Pipette analyses are performed on dispersed samples, whereas particularly in marine environments, clay-rich sediments are generally transported in a flocculated state.

Pipette analysis of Raglan Harbour sediments shows that up to 50% of some sediments consists of particles less than 1μ in diameter. However, it is likely that much of the $<1\mu$ fraction is transported and deposited as coarser floccules, especially as most of this material consists of 2:1 lattice illite and montmorillonite.

CHAPTER III

3.1 BULK SEDIMENT MINERALOGY

3.1.1 BULK SEDIMENT ANALYSIS

Randomly oriented particle mounts for XRD analysis were prepared by growing a bulk sediment sub-sample at 50° C, crushing to a fine powder in a ring mill grinder, and mounting in aluminium sample holders.

The mineralogy of the 19 sediment samples analysed was determined by identification of the X-ray diffraction peaks obtained, and semi-quantitative estimations of the percentages of quartz, plagioclase feldspar, potash feldspar, clay minerals and calcite present were obtained by the method outlined by Nelson and Cochrane (1970).

The bulk sediment mineralogy of Raglan harbour sediments is characterised by quartz, potash feldspar, plagioclase feldspar (usually more than one type) clay minerals (illite, montmorillonite, mixed-layer montmorillonite, chlorite and kaolinite), calcite, aragonite, titanomagnetite, and ferromagnesian minerals (augite, hornblende and hypersthene).

XRD analysis indicates a generally higher percentage of clays than obtained by sedimentation analysis. This is a predictable result and the discrepancy may be accounted for by a number of factors:

(1) The presence of silt-to pebble-sized aggregates of clay-rich material, particularly fragments of Whaingaroa Siltstone.

(2) Quantities of kaolinite still attached to weathered and partly weathered feldspar grains.

(3) Floccules of clay which were not dispersed before sedimentation analysis.

Representative X-ray diffraction patterns for bulk sediment samples are shown in Fig. 3.1 and the result of modal analysis of quartz, felspars, clays and calcite are given in Table 3.1

Samples (7 and 15) taken from near the mouth of the harbour differ markedly from those taken from other localities. Their mineralogy is dominated by titanomagnetite and ferromagnesian minerals, and clay minerals are lacking, closely resembling the composition of the coastal ironsands (Gow, 1967). Beyond the harbour entrance the amount of quartz, plagioclase feldspar and clay minerals increases considerably as the heavy minerals become a less important but nevertheless appreciable compnent of the sediments. Calcite and potash feldspar remain minor constitutents. However, there is no obvious distributional pattern of these minerals and composition of the stream sediments is essentially the same as the sediments throughout the harbour.

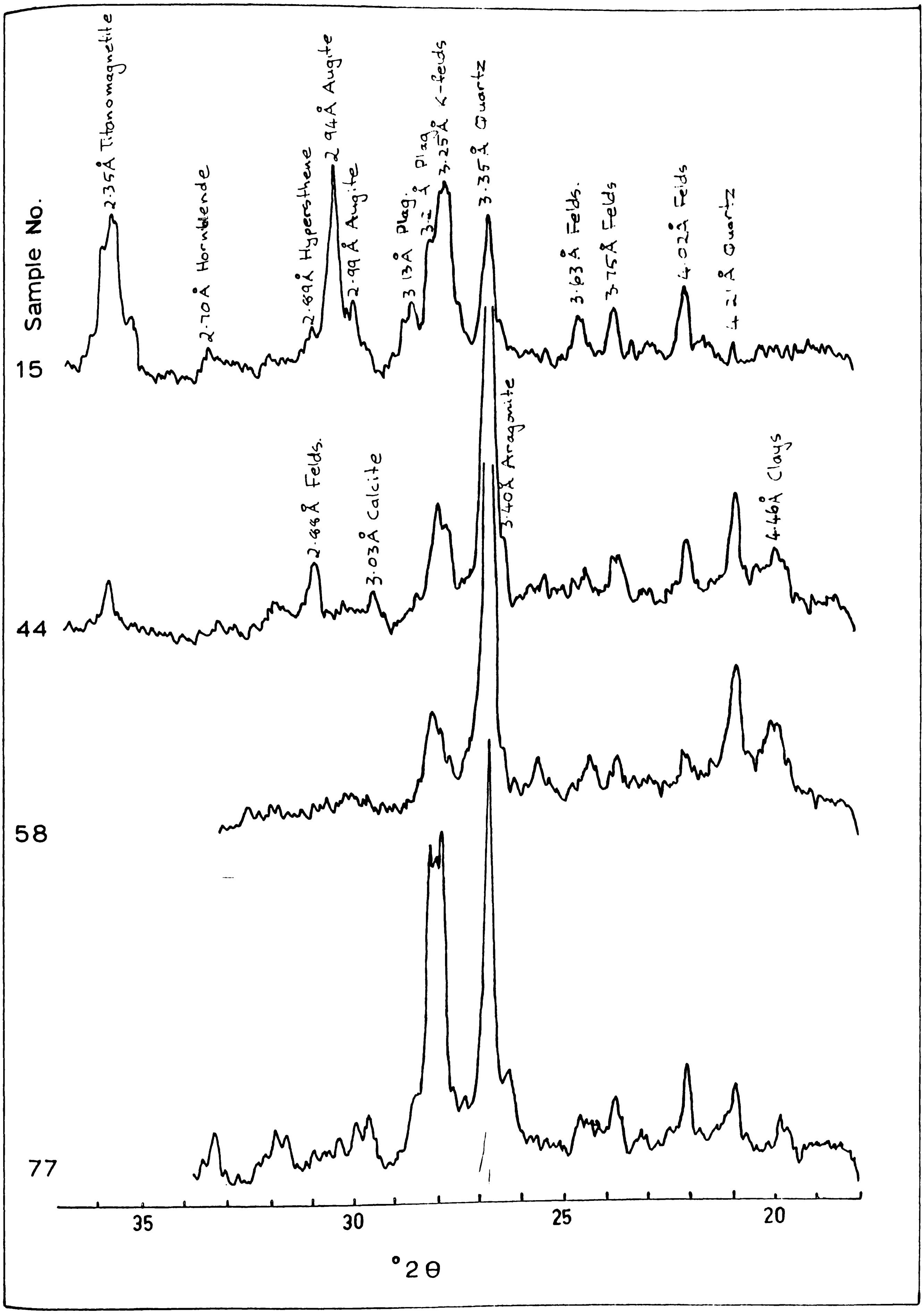


Fig. 3.1 Representative X-ray diffraction patterns for bulk sediment samples.

Sample number	Quartz %	Potash Feldspar %	Plagioclase Feldspar %	Clay minerals %	Calcite %
7	3	8	13	0	2
15	5	15	8	0	4
25	35	7	28	35	3
33	45	7	20	40	3
38	35	10	25	35	5
44	15	8	8	50	3
53	20	3	13	40	<1
56	25	7	7	60	<1
58	20	55	7	65	<1
61	25	6	12	60	<1
65	13	6	13	35	10
69	15	7	18	40	4
75	15	6	15	18	6
77	10	6	25	35	4
79	23	5	7	55	3
82	25	5	14	55	4
85	17	4	8	65	4
87	23	6	12	40	<1
89	20	5	24	40	3

Table 3.1 X-Ray modal analysis of bulk sediment samples from Raglan Harbour.

3.1.2 ORIGIN OF THE BULK SEDIMENT MINERALOGY

Total sediment analysis of the sediments of Raglan Harbour strongly suggest detrital inheritance from Tertiary and Mesozoic rock as the most probable origin. Figs. 3.2.0 and 3.2.5 show a comparison of mineralogical compositions of Raglan Harbour sediments with those of the major source rocks (Nelson, 1973). Both the potash feldspar-pagioclase feldspar and the quartz-feldspar-clay minerals ratios are strikingly similar for the harbour sediments and the hinterland rocks. The slightly lower proportion of clays in the sediments of the harbour is probably the result of the removal from the local sedimentary system as suspended load by the ebb tide.

On the basis of X-ray analysis it would appear that erosion of the rocks within the harbour's drainage basin forms the major sediment supply to Raglan Harbour, however, titanomagnetite and other heavy minerals were not considered in modal analysis and it is apparent from the dominance of the mineralogy near the mouth of the harbour and appearance in all the sediments examined that another provenance is supplying sediment. This aspect of the mineralogy is developed further in the next section.

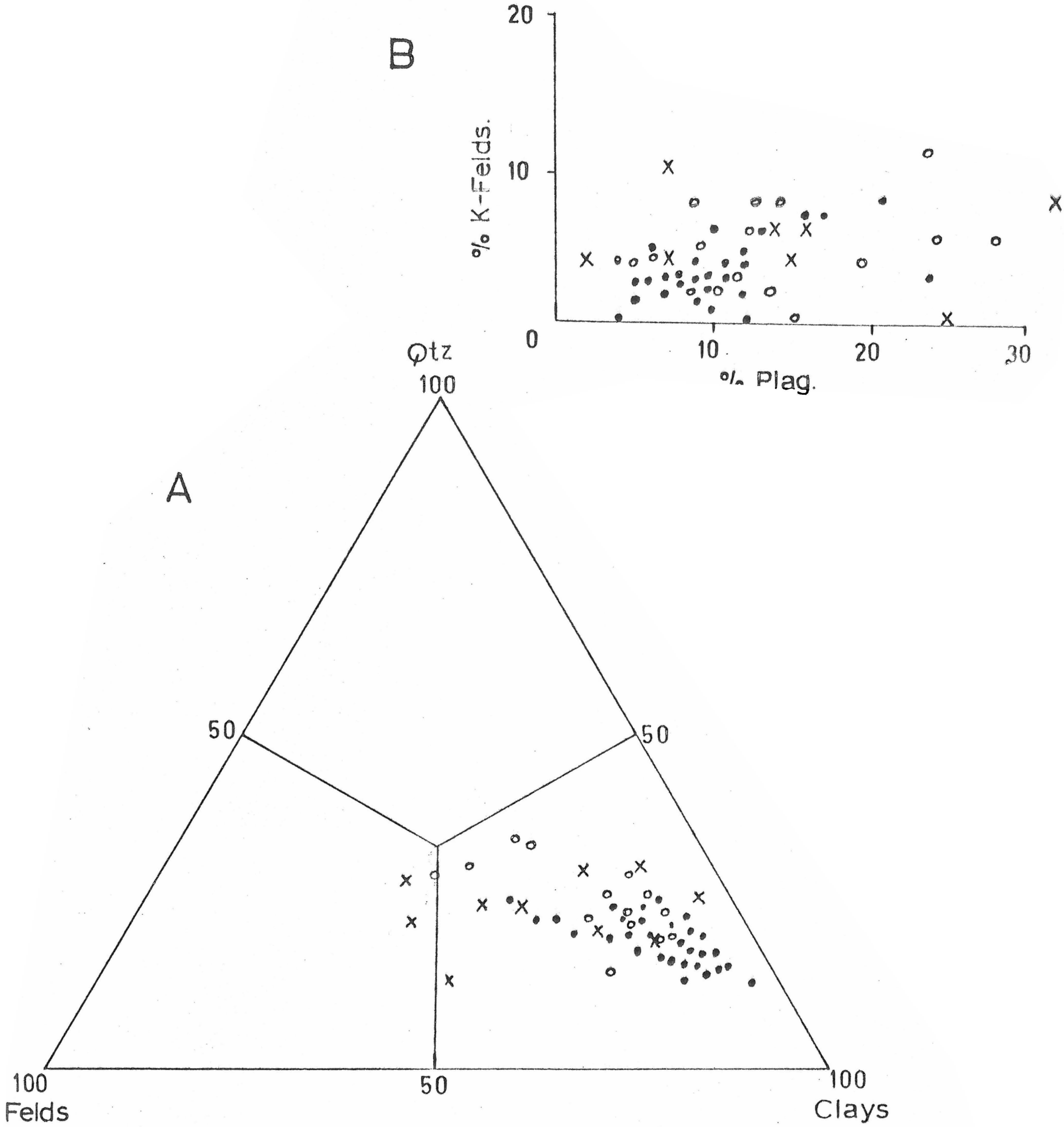


Fig. 3.2.0 Mineralogical composition of major source rock types for Raglan Harbour, recalculated without calcite. Data from Nelson (1973). A = total mineralogy; B = feldspare mineralogy.

- ● Whaingaroa siltstone
- o Aotea Sandstone
- x Mesozoic Basement rocks.

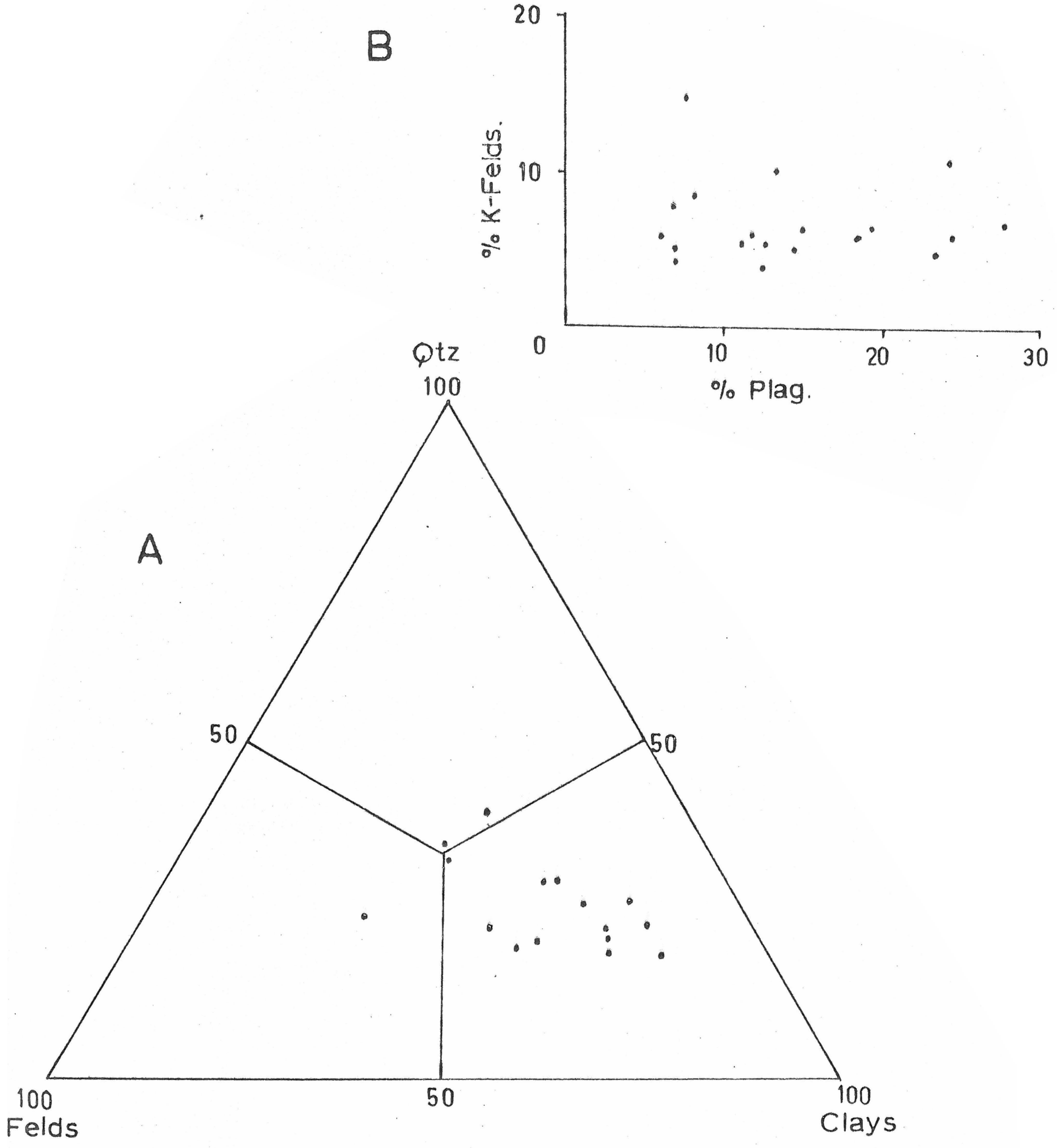


Fig. 3.2.5 Mineralogical composition (using XRD) of Raglan Harbour sediments, recalculated without calcite. A = total mineralogy; B = feldspar mineralogy.

3.2 HEAVY MINERALS

The heavy minerals in 20 samples was separated with tetrabromoethane(S. G. = 2.97) in steep-sided funnels, sieved to obtain the 2.5 - 3.0ϕ (lower fine sand) and 1.5-2.0ϕ (lower medium sand) fractions, and mounted for petrographic examinations. Percentages of individual heavy mineral species were determined for 14 samples by point-counting an average of 300 grains from the finer fraction.

3.2.1 MINERALOGY OF THE HEAVY CONCENTRATES

The percentages of heavy minerals in the lower fine sand fraction of the samples studied are given in table 3.2 which shows a very wide range of heavy mineral concentrations. The determination of percentages of individual mineral species is given in table 3.3. Opague minerals vary between 11% and 98% of the heavy fraction. Volumetrically the most important non-Opaque heavy minerals are diopsidic augite and hornblende.

3.2.1A OPAQUE MINERALOGY

The Opaque minerals are dominated by titanomagnetite with minor leucoxene and rare haematite. Titanomagnetite is blue-black in reflected light and strongly magnetic. The larger grains are commonly sub-rounded, tending to euhedral with decreasing grain size. Grains commonly show evidence of solution pitting, often in the form of hexagonal-shaped cavities. This may be related to exosolution of the rhombohedral phase as described by Wright (1964). Titanomagnetite also occurs as inclusions in augite, and, less commonly, in hornblende,

Sample No.	% Heavy minerals
7	69.7
10	24.5
15	70.6
17	11.1
21	11.1
23	1.1
26	14.3
36	2.2
39	4.8
43	35.3
44	5.6
48	40.7
54	33.3
59	6.7
61	36.4
65	24.4
70	26.2
81	11.1
91	85.9
93	2.2

Table 3.2 Percentages of heavy minerals in the fine sand fraction.

Sample No.	Opaques	Diopsidic Augite	Green-brown Hornblende	Red-brown Hornblende	Hypersthene	Epidote	Biotite	Others
7	67	24	4	2	R	R	I	R
10	5	67	13	7	5	3	-	R
15	74	20	4	R	R	R	-	R
21	56	7	28	7	1	R	-	R
26	49	21	19	3	3	2	2	1
36	14	31	28	-	4	4	16	4
44	34	28	18	R	7	5	2	6
59	30	32	18		5	8	2	R
61	28	21	23	R	3	13	-	11
65	12	57	18	4	3	4	-	R
70	11	26	41	R	9	6	4	2
81	49	19	23	-	5	4	-	R
91	98	R	1	R	R	-	-	R
93	29	50	12	3	4	1	-	R

Table 3.3 Percentages of individual mineral species in the fine sand fraction. R = rare.

hypersthene, epidote.

Leucoxene is recognised by its dusty grey appearance in reflected light. Haematite occurs as coatings on foraminifers and other biofragments (e.g. echinodermal and bryozoan grains).

3.2.1B NON-OPAQUE HEAVY MINERALOGY

Augite: Diopsidic augite is the dominant non-opaque heavy mineral (Table 3.3). Its appearance is variable and may be confused with both epidote and hypersthene. Augite occurs mainly as sub-rounded euhedral to subhedral grains, but ranges from well-rounded grains to angular euhedral prisms. Pale bottle green is the most common colour with yellowish green pleochroism in many grains, although thin cleavage flakes are almost transparent. Many grains show solution embayments on (110) faces and some show ragged (001) faces, indicative of solutional alteration. Some grains are reduced to a remnant rim of augite surrounding an opaque inclusion. Inclusions are common and are mainly titanomagnetite and apatite.

Hornblende: The hornblende content varies considerably between samples (Table 3.3). In some concentrates it is only of minor occurence; in approximately one third of the samples studied it exceeds or is sub-equal to augite in abundance. Hornblende is characterised by very strong pleochroism and a very deep body colour which frequently causes the grains to appear opaque. Elongate grains with well developed cleavages are the most common some showing ragged (001) terminations indicate of solutional alteration. Two varieties are distinguished on the basis of pleochroic schemes:

yellowish-green or green to very dark green; and reddish brown to deep red-brown The first is the most abundant and commonly shows opaque inclusions.

Hypersthene: Hypersthene generally occurs as sub-angular prisms with a squarish outline, but subrounded to rounded prisms sometimes elongate are common. Some grains show ragged (001) terminations. Colour is light green or greyish green to pinkish green or pinkish brown and most grains are pleochroic in these tints. Inclusions of opaque minerals, gas bubbles and apatite occur, but are generally not as abundant as in augite.

Epidote: Minor quantities of epidote occur in most of the concentrates studied (Table 3.3). Subrounded grains and subhedral plates, often exhibiting severe solutional alteration are the most common forms; some grains are well rounded. Most grains contain some inclusion of opaque minerals and apatite. Colour varies from light bottle green to yellowish green or greenish brown, often with pleochroism in these tins.

Biotite: Irregularly shaped brown or green cleavage plates of biotite occur in minor amounts in about half the samples examined.

Zircon: Most heavy mineral concentrates contained a few worn prismatic grains of colourless to very pale pink zircon.

Apatite: Colourless, generally equidimensional, subrounded grains of apatite with opaque inclusions with occasional brown-stained margins and fractures were present in minor amounts in most samples.

Sphene: A few worn grains of sphene showing incomplete extinction and very high order gold-blue-grey interference colours were identified.

Garnet: Rare, worn and fractured grains of pale pink almandine garnet were present in a few samples.

Tourmaline: Very rare prismatic grains of strongly pleochroic tourmaline were present in some samples.

3.2.2 ORIGIN OF THE HEAVY MINERALS

A number of sources contribute to the heavy mineral fraction of Raglan Harbour:

(1) The Quarternary volcanics and associated ash showers of Mt. Egmont, mainly augite-andesites and augite-hornblende andesites (Gow 1968). Erosion and long shore drift transport have concentrated heavy minerals from these rocks in beach and dune sands along the west coast of the North Island. These sands are a major potential source of heavy minerals in the sediments of Raglan Harbour and presumably other west coast harbours. The mineralogy of these sands is described by Hutton (1945), Wright (1964), Kear (1965) and Gow (1967). Titanomagnetite and diopsidic augite are the dominant minerals. The sands also contain hypersthene, green-brown horblende, red-brown hornblende, and with the exception of leucoxene all of the minor heavy minerals occurring in

Raglan Harbour sediments. However, it is important to note that epidote is rare on west coast beach sands.

(2) Re-cycling of heavy minerals from the Mesozoic basement and the Te Kuiti Group rocks. From the detrital mineral data of Reed (1957), Martin (1967) and Mayer (1969), the most abundant heavy minerals in the Mesozoic sandstones are biotite, ilmenite, leucoxene, hornblende and augite. The dominant heavy minerals in the Te Kuiti Groups are ilmenite, leucoxene, limonite, zircon, epidote and apatite (Nelson, 1973). Magnetite and hypersthene are not recorded from either Group rocks and it may be inferred that any other ferro-magnesium minerals from these rocks would not survive weathering and transportation and hence not be deposited in the sediments of Raglan Harbour.

(3) Erosion of the Alexandra Volcanics of Plio-Pleistocene age, particularly Mt. Karioi. These dominantly basaltic and olivine andesitic cones (Henderson and Grange, 1926) may provide a minor source of augite, hornblende and opaque minerals.

(4) Erosion of andesitic ashes of Hawera age, containing minor amounts of augite, hornblende, hypersthene, ilminite, magnetite and zircon (N. Z. Soil Bureau, 1968).

The importance of each of these provenances in controlling the heavy mineralogy of Raglan Harbour sediments can be gauged from their supply potential or volume and the range of heavy minerals they contain.

Examination of the drainage pattern in relation to the geology of the drainage basin for Raglan Harbour shows that Mt. Karioi constitutes the bulk of the Alexandra Volcanics present, and that erosion of these would supply the detritus to the lowermost part of the Harbour. The general similarity in mineralogy of the coastal sands and the Alexandra Volcanics means that any influx of heavy minerals from the latter source would only reinforce the coastal provenance. The supply of detritus to other parts of the Harbour from erosion of the Alexandra Volcanics is of minor significance.

The importance of Hawera ash beds as a source of terrigenous material is more difficult to ascertain but as a supply of heavy minerals its influence is probably minor.

With the exception of ilmenite in the Alexandra Volcanics, which has probably largely altered to leucoxene before being deposited in Raglan Harbour, the range of heavy minerals supplied by these two sources is the same as that of the coastal sands. The latter would effectively swamp any effect of the more minor sources on the heavy mineralogy.

The remainder of the drainage basin is made up of Mesozoic and TeKuiti Group rocks and of alluvial deposits largely dervied from these rocks.

On the basis of this it is apparent that the heavy minerals supplied by the coastal sands and erosion of the Mesozoic and tertiary rocks will dominate the heavy mineral populations of Raglan Harbour. The relative importance of these two provenanaces (i.e. coastal sands versus Mesozoic - Lower tertiary sedementary rocks) in any particular place is indicated by a number of key heavy minerals which distinguish the two sources. Titanomagnetite, augite, hypersthene and hornblende indicate derivation almost exclusively from the coastal iron sands. Leucoxene, epidote zircon and apatite can be taken as indicative of derivation from Mesozoic and Tertiary rocks as they are rare or absent in the coastal sands.

Fig. 3.3. shows the distribution of heavy minerals in Raglan Harbour. In the lower and middle harbour, titanomagentite is concentrated in the deepest parts of the harbour as a result of washing out of lighter minerals by strong current activity. The high percentage of titanomagnetite in the small northern arm containing Ponganui Creek is the result of deposition of sand grains blown from the nearby coast by the prevailing south-westerly wind, rather than by hydraulic action, as shown by the abundance of frosted quartz grains in the light mineral fraction.

Fig. 3.4a plots the change in concentration of titanomagnetite , augite and epidote from the lower harbour through the south-east arm to the Waitetuna River. The concentrations of titanomagnetite and epidote show a recipricol relationship, with the titanomagnetite percentage decreasing

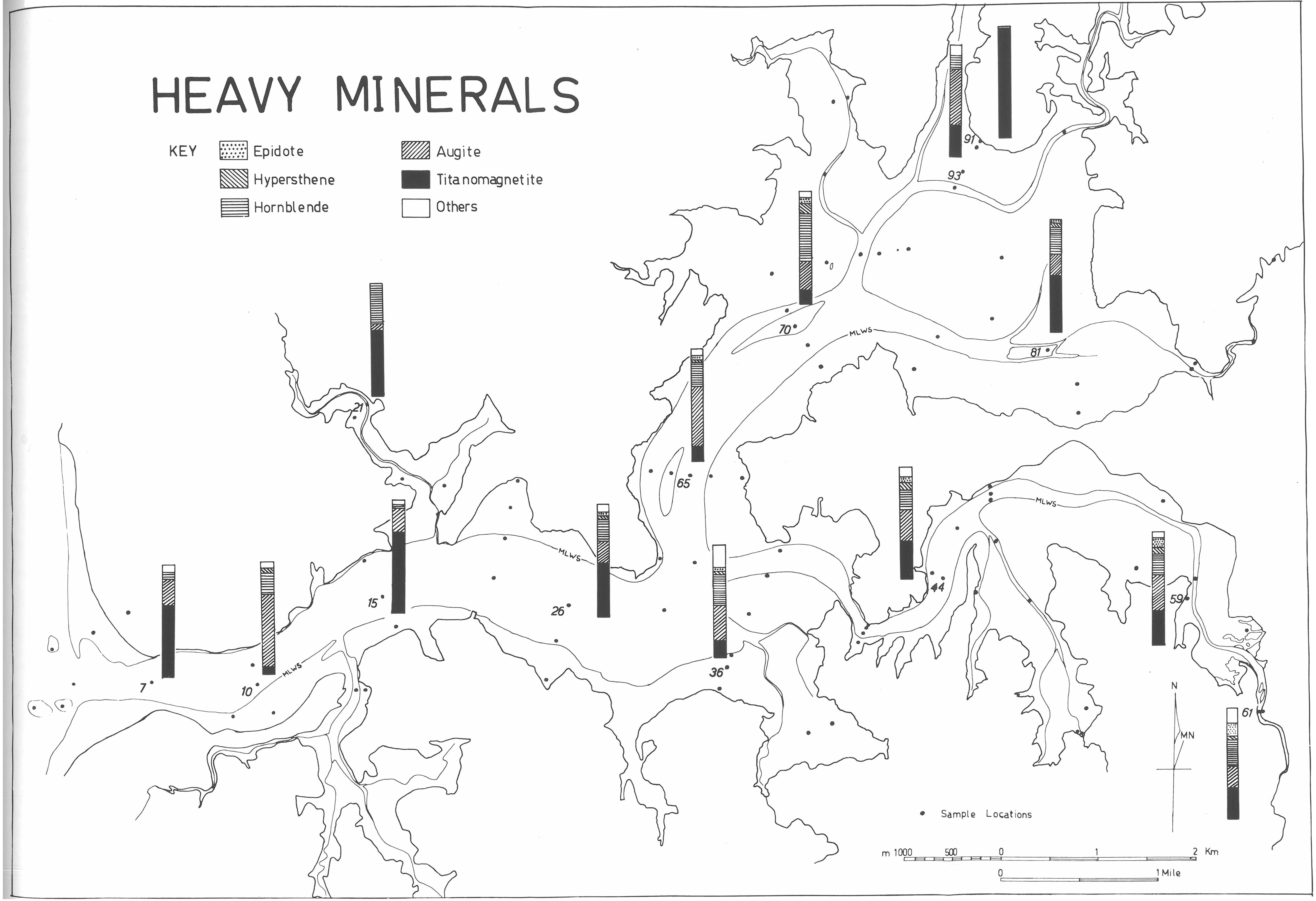


Fig. 3.3 Distribution of heavy minerals in Raglan Harbour.

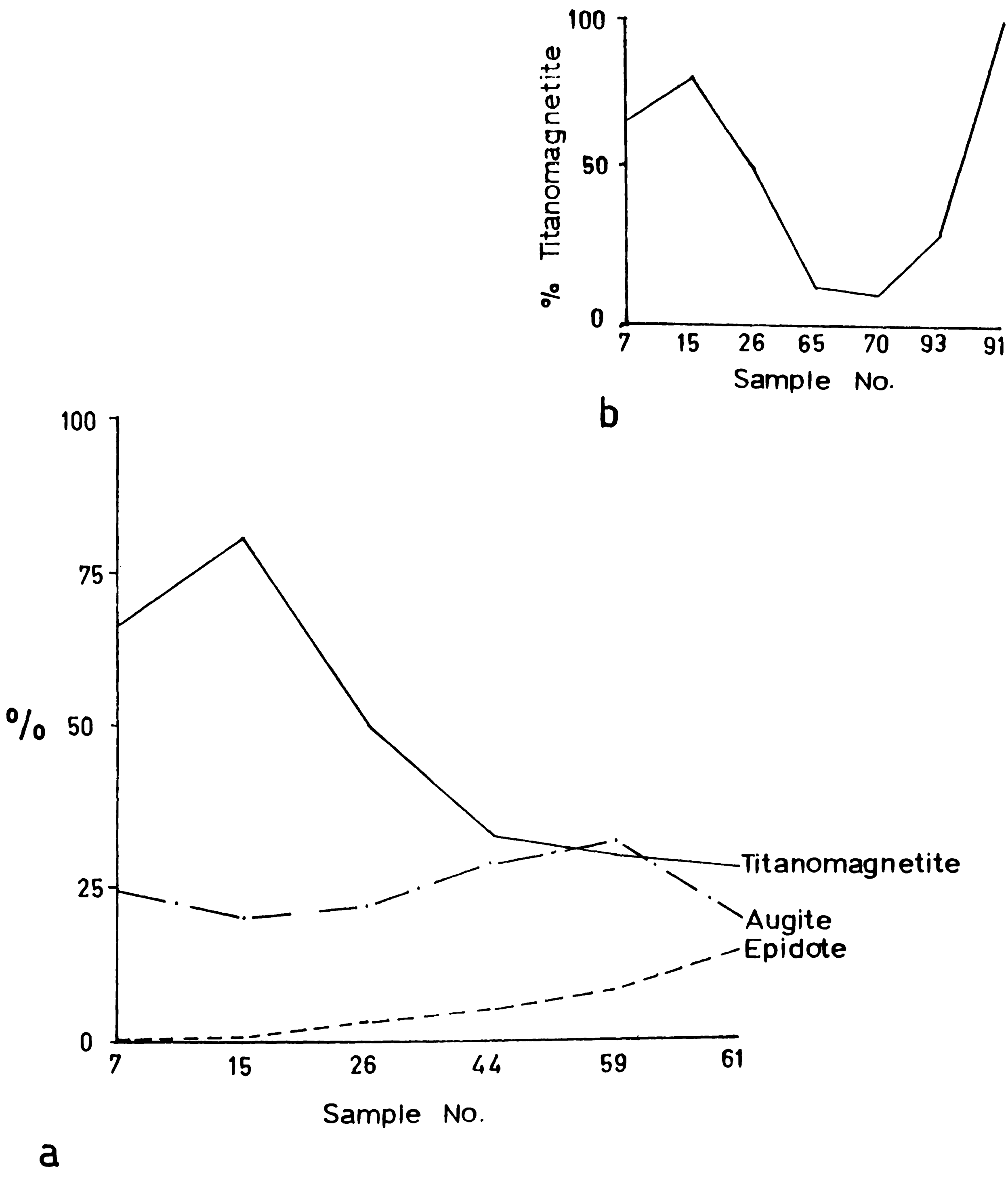


Fig. 3.4 Changes in concentrations of heavy minerals. See text for explanation.

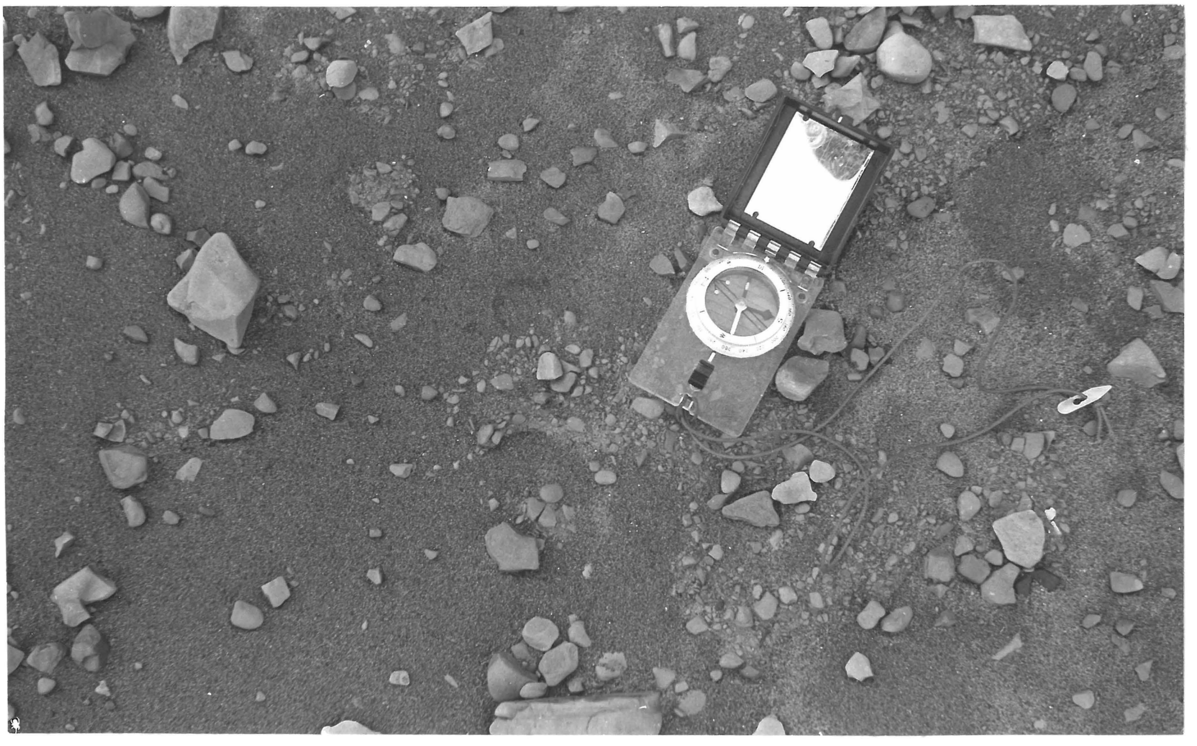
steadily away from the coast as the epidote percentage increases. The augite concentration is relatively uniform and the difference between the trends of titanomagnetite and augite, both from the same provenance, is interpretated as due to a difference in their specific gravities causing selective sorting and transport of the lighter mineral further up the harbour on the flood tide.

The change in concentration of titanomagnetite from the lower harbour to the north eastern extremity of the upper harbour is plotted in Fig. 3.4b, decreasing from the coast to the middle harbour then increasing towards the north east of the upper harbour. The south west to north east trending area from the middle harbour into the upper harbour has the longest fetch (7km) in the harbour lying in the direction of the prevailing south westerly wind, and the reversal in the general trend of titanomagnetite concentration in this region is attributed to a piling up by wind-wave action. Titanomagnetite concentration increases with decreasing depth and increasing wave action up the upper harbour, culminating in an extremely high concentration on small beaches facing the south-west (Fig.3.4.5).

Minor heavy minerals are not quantitatively tabulated, as their occurence was too low to be expressed as percentages. usually less than a dozen grains in each sample. However, zircon, leucoxene, liminite and apatite, derived from Tertiary and Mesoziic rocks, were conspicuously more common in the distal regions of the harbour.

Volcanic ash is the likely source of most of the biotite

Fig. 3.4.5 Well sorted, titanomagnetite-rich sands forming a beach in the upper harbour. The beach faces the prevailing winds and is about 10km from the source of titanomagnetite at the coast. Gravel-sized fragments of Whaingaroa Siltstone littering the beach are the result of erosion of cliffs behind the beach.



in the sediments of the harbour, and the unusually high concentration in Okete Bay is a reflection of the proximity of fairly extensive ash depsoits on the southern shore.

3.3 LIGHT MINERALS

The light mineral fraction remaining after heavy mineral separation was examined with binocular and petrographic microscopes consisted of quartz, feldspar, glass shards and rock fragments. No quantitative estimations of the composition of the light mineral fraction were made.

Quartz: Several varieties of quartz were distinguished

(1) Aungular to subrounded, anhedral to subhedral watery clear crystals are interpreted as reworked detrital grains. This was by far the most common variety of quartz present, and was found throughout the harbour.

(2) Subangular to subrounded clouded grains are probably also of reworked detrial origin.

(3) Rounded to highly rounded grains with strongly pitted surface textures. These indicative of derivation from the coastal dune sands, and are most common near the harbour entrance.

(4) Euhedral, hexagonal, bypyramidal, watery clear crystals, indicating a volcanic provenance, were present in some samples. Andesitic ashes of Howera age are the most likely sourceof this variety of quartz.

(5) Subangular to subrounded multicrystalline quartz grains occur in most samples and are probably reworked detrial

grains from Tertiary and Mesozoic rocks.

(6) Mainly anhedral, highly vacuolated grains are possibly derived from secondary quartz veins in the Mesozoic rocks.

(7) Chalcedony and chert fragments are present in some samples and are probably detrital in origin.

Feldspars: Feldspars, dominated by plagioclase were abundant in most samples, ranging from fresh watery clear cleavage flakes to worn, highly weathered, kaolinised grains. Some grains show zoning, and a few have microcline twinning,

Glass shards: Watery clear glass shards with conchoidal fractures and gas filled vacuoles are common in some samples, and are probably derived from volcanic ash.

Rock fragments: These were abundant in some samples and have been derived from a number of sources. Examination of the gravel-sized rock fragments during grain size analysis showed that pellets of Whaingaroa Siltstone are the most common rock fragments in Raglan Harbour sediments. "Greywacke" fragments are common in some samples, while fragments of Aotea Sandstone, Waitetuna Limestone, Alexandra andocites and reworked rock fragments from Mesozoic rocks are of minor importance.

The nature of light minerals in Raglan Harbour sediments reflects a multiple source, dominated by detrital grains from Tertiary and Mesozoic rocks, and also from erosion of Quarternary ash beds and from wind and water transportation of the coastal sands.

3.4 CLAY MINERALS

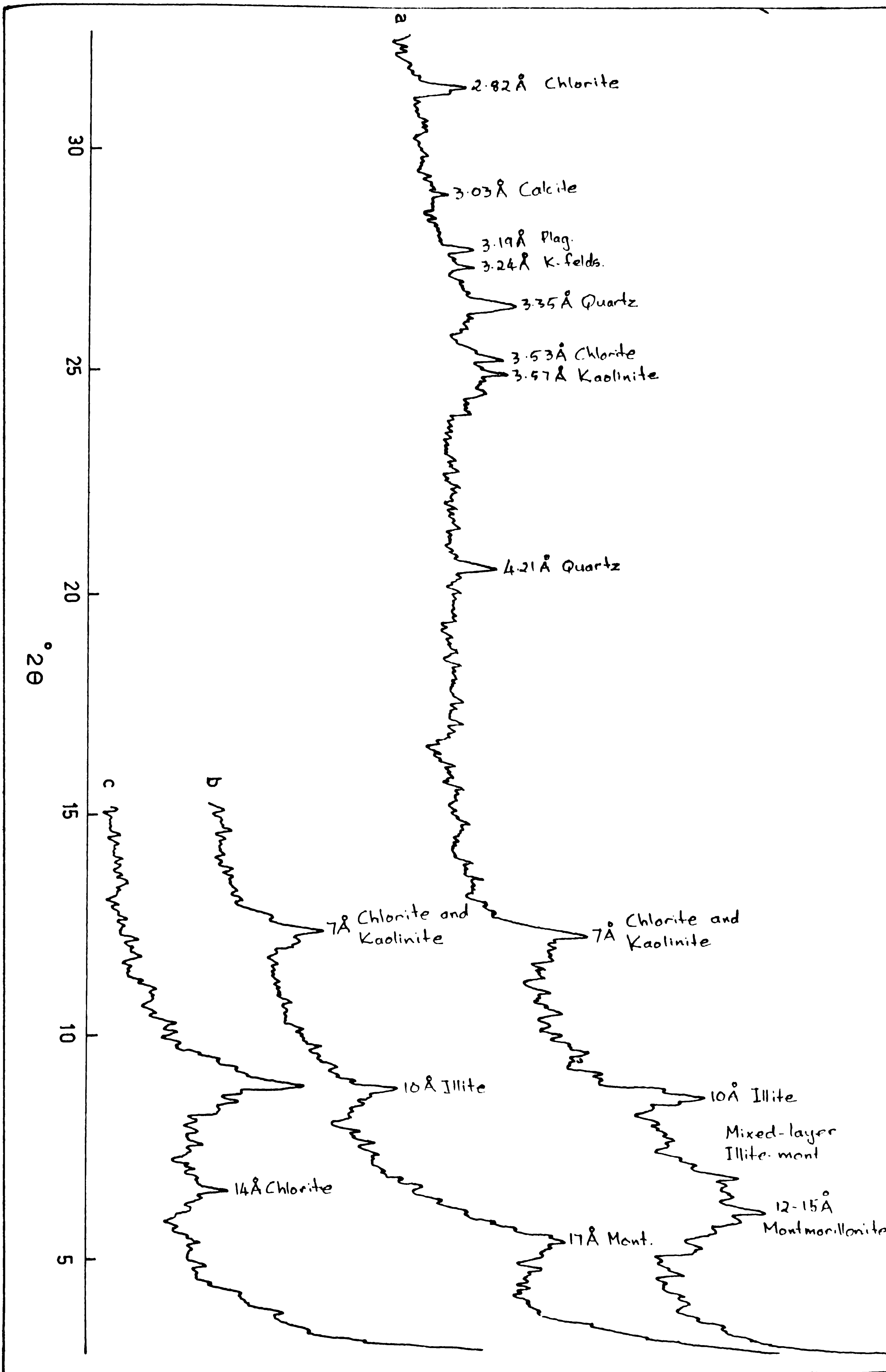
3.4.1 XRD ANALYSIS OF CLAY MINERALS

The clay mineralogy of Raglan Harbour sediments was studied by X-ray diffraction analysis of 11 samples from widely spaced locations in the harbour and from streams entering the harbour. Oriented particle mounts of the <2μ fraction were prepared by the dropper on glass slide technique. Identification of the clay minerals present was based on the position and movement of (001) reflections after X-ray analysis of air-dry, glycolated and heated (550°C) mounts (Carrol, 1970). Semiquantitative estimations of the amounts of clay minerals present were calculated using the method outlined by Weaver (1967). Representative XRD patterns for untreated, glycolated and heated samples are presented in Fig. 3.5.

The mineralogy of the <2μ fraction of all the samples analysed is dominated by the clay minerals illite, montmorillorite, mixed-layer illite-montmorillorite, kaolinite and chlorite with only minor amounts of quartz, feldspar and calcite. The clay minerals probably have relatively poor crystallinity juding by the broad and rather diffuse nature of basal reflections. However, definition of the X-ray peaks may also be affected by the presence of mixed layer clays and the method of mounting used.

X-ray diffraction patterns of the untreated mounts (Fig.3.5a) show a diffuse 12-15 A° peak, a relatively sharp A° peak, and a broad band of reflections (10.8 - 12 A°) between the two. A strong 7 A° peak indicates the presence

Fig. 3.5 Representative X-ray diffraction patterns of oriented mounts of the <2μ fraction of Raglan Harbour sediments. (a) untreated; (b) glycolated; (c) heated.



a
b
c
2.82 Å Chlorite
3.03 Å Calcite
3.19 Å Plag.
3.24 Å K-felds.
3.35 Å Quartz
3.53 Å Chlorite
3.57 Å Kaolinite
4.21 Å Quartz
7 Å Chlorite and Kaolinite
7 Å Chlorite and Kaolinite
10 Å Illite
10 Å Illite
Mixed-layer Illite-mont
12-15 Å Montmorillonite
14 Å Chlorite
17 Å Mont.
30
25
20
15
10
5
°2θ

indicates the presence of Kaolinite or chlorite or both. The distinction between the two clays in untreated samples is difficult, but if both clays are present the 3.53 A^{O} chlorite and the 3.57 A^{O} kaolonite peaks are usually slightly off-set (Weaver 1956), giving a broad or double peak. As shown in Fig 3.5a this is the case for the diffraction patterns obtained for Raglan Harbour sediments, indicating the presence of both kaolinite and chlorite.

Glycolation of the samples resulted in a shift of the 12-15 A^{O} peak to 17 A^{O} and a corresponding shift of the broad band of reflections between 10.8 and 12 A^{O}, indicating the presence of expandable clays. The 7 A^{O} and 10 A^{O} peaks were unchanged, (Fig. 3.5b), enabling identification of the latter as illite.

Heating the samples to 550^{O}C caused collapse of the expandable clay peaks to 10 A^{O} (Fig. 3.5c), showing that these are montmorillonite and mixed-layer illite-montmorillonite The 7 A^{O} is absent after heating, showing that both chlorite and kaolinite were present in the original sample, with destruction of the kaolonite and secondary chlorite peaks on heating.

Semiquantitative analysis shows the five types of clay minerals present occur in fairly constant ratios throughout the sediments of the harbour and in the stream sediments. Illite is the most abundant clay mineral present (approximately 35% in most samples). Montmorillonite

(25%) is common,and smaller amounts of mixed-layer-illite-montmorillonite (15%), chlorite (15%) and kaolinite (10%) are present in all the samples analysed.

3.4.2 ORIGIN OF THE CLAY MINERALS

Fig. 3.6 compares the relative abundances of clay minerals in Raglan Harbour sediments with those in adjacent provenance rock types.

Three principle processes are responsible for the character of sedimentary clays (Millot, 1970): detrital inheritance, transformation and neoformation.

From Fig. 3.6 it would appear that detrital inheritance is the dominant but not the sole process responsible for the clay mineralogy of the sediments in Raglan Harbour. The appreciable quantities of kaolonite and the high proportion of illite in the latter must be explained by processes other than detrital inheritance from Tertiary and Mesozoic rocks.

The Mesozoic "greywackes and argillites" of the Oparau Facies have been subject to varying degrees of weathering for a considerable period of time, and the often very deep red weathering present indicates that an advanced state of weathering and leeching has been reached. Chlorite and mica are the most readily weathered minerals in the Mesozoic rocks and degredational transformation of these produces illite, vermiculite, montmorillonite and kaolinite and a variety of their

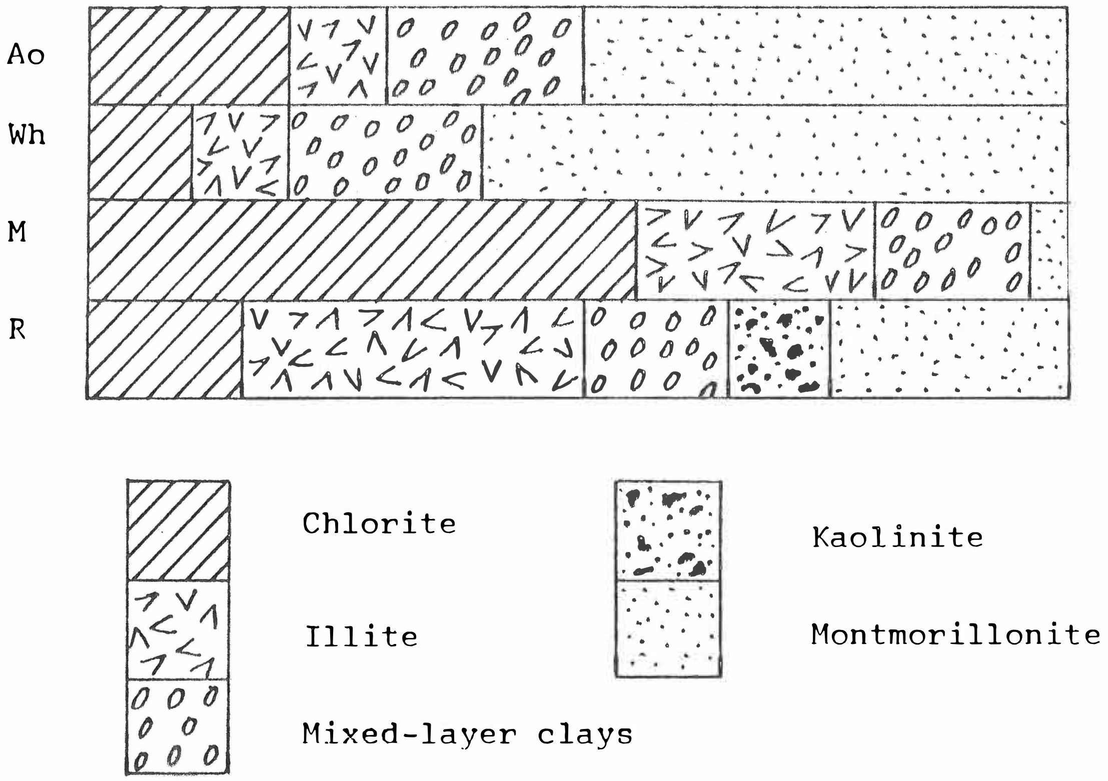


Fig. 3.6 Schematic comparison of relative abundances of clay minerals between major source rock types and Raglan Harbour sediments. Ao = Aotea Sandstone (Te Kuiti Group); Wh = Whaingaroa Siltstone (Te Kuiti Group); M = Mesozoic basement rocks; R = Raglan Harbour sediments. Clay mineralogy of source rocks from Nelson (1973).

mixed-layer assemblages (Nelson, 1973). XRD analysis of clays from soils developed on Mesozoic rocks in the Raglan district shows an abundance of Kaolinite (T. M. Hume, pers. comm. 1973), the end product of the degredational sequence. Presumably the often very thick sections of weathered rock between the parent material and the soil contain the intermediate products in the degradational sequence including illite. The volcanic ash beds of the district containing abundant micaceous minerals which weather by degradational transformation to give soils with a high proportion of kaolinite (Soil Bureau, 1968), provide a further source of terrigenous clays.

It is concluded that the chlorite, montmorillonite, mixed-layer clays and a small proportion of the illite present in the sediments of Raglan Harbour are mainly of detrital origin, and that the kaolinite and the bulk of the illite is the result of degradational transformation of micas and chlorites during soil formation. There is no evidence of neoformation of clays in Raglan Harbour.

3.5 NOTE ON SILT FRACTION

Oriented mounts of the <3μ (fine silt) and <44μ (coarse silt) size fractions, and powder mounts of the <63μ (very fine sand) fraction of a number of samples were subject to XRD analysis, and the XRD traces compared with the <2μ fraction and the total sediment analysis for the same samples.

The proportion of quartz and feldspar in the sediments was found to increase with increasing grain size within the silt-sized grade, so that the coarse silt fraction was composed almost entirely of these two minerals.

3.6 CARBONATE CONTENT

Carbonate content for all samples was determined by acetic acid (4.4M) digestion, and the results plotted as an isopleth map (Fig. 3.7). The calcium carbonate percentage obtained by this method is far higher than the calcite percentage obtained by XRD analysis (Table 3.1). Many of the samples were rich in bivalve fragments indicating that the bulk of the carbonate material in Raglan Harbour is aragonite.

The small proportion of calcite present, generally less than 5%, is probably derived mainly from erosion of the calcareous Te Kuiti Group rocks.

There is a tendency for carbonate material to be concentrated in regions of strong currents, particularly where changes in direction of tidal currents streams would be expected, and where strong ebb current streams from various arms of the harbour converge.

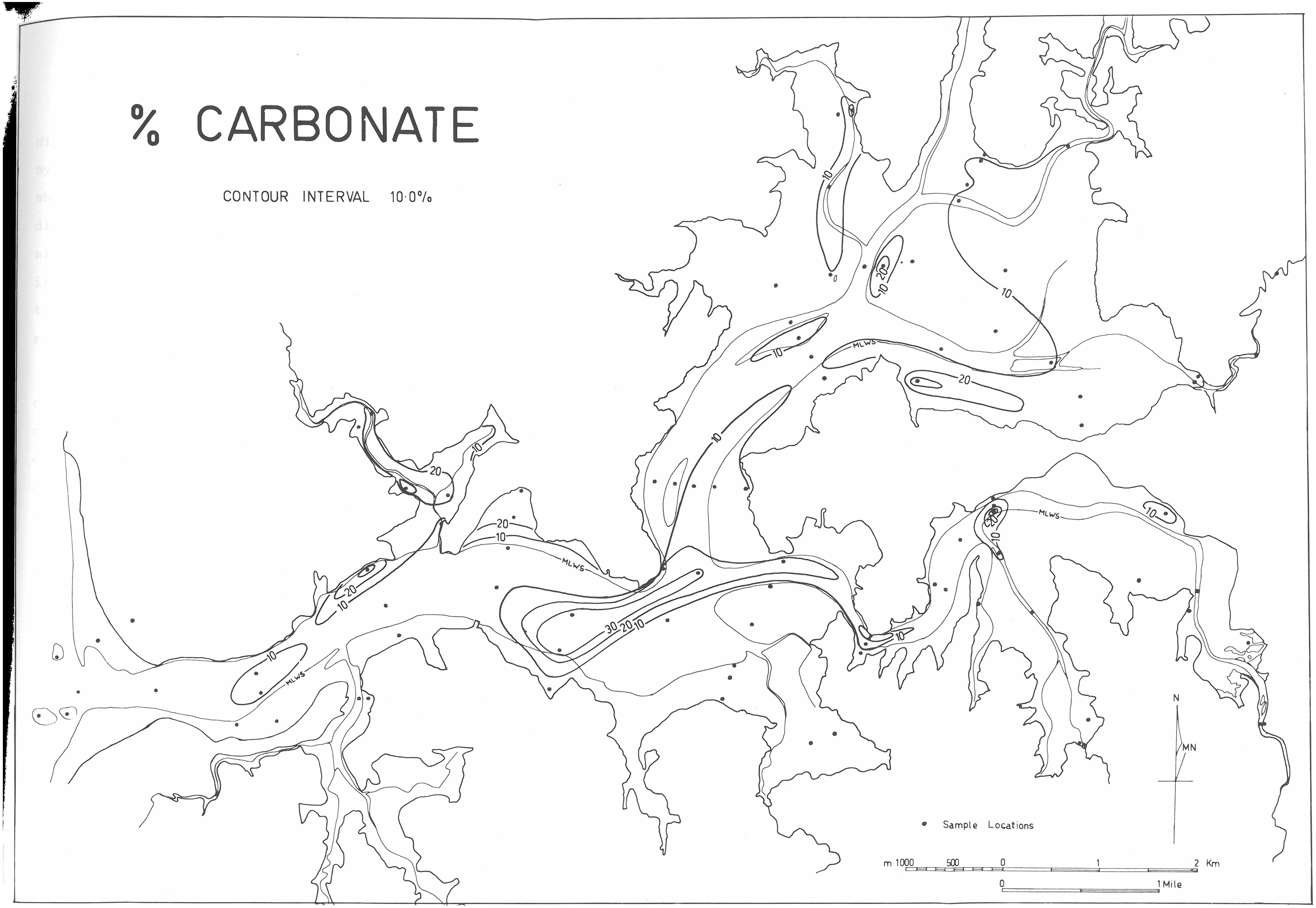


Fig. 3.7 Isopleth map of the weight percent of carbonate material in Raglan Harbour sediments.

3.7 ORGANIC MATTER

Organic content was determined by hydrogen peroxide digestion , and was suprisingly low, never exceeding 4% by weight. The isopleth map of organic content (Fig. 3.8) shows an increase from the lower harbour towards the more distal arms that is probably a function of decreasing grain size. Decay of soft bodied organisms, especially bivalves, is probably the main source of organic matter in the sediments, together with faeces zoo-& phyto-plankton and shallow water rooted vegetation.

Fine grain sediments of tidal flats usually contain over 10% organic matter (Kukal, 1971). The low organic content of Raglan Harbour sediments may be due to a supply of organic matter only slightly in excess of the supply of oxygen to the sediment-water interface, or may indicate hyperactivity of sulphate-reducing bacteria in the reducing layer immediately below the surface. The latter is partly evidenced by the pungent odour of hydrogen sulphide which characterises the fine grained sediments of the harbour.

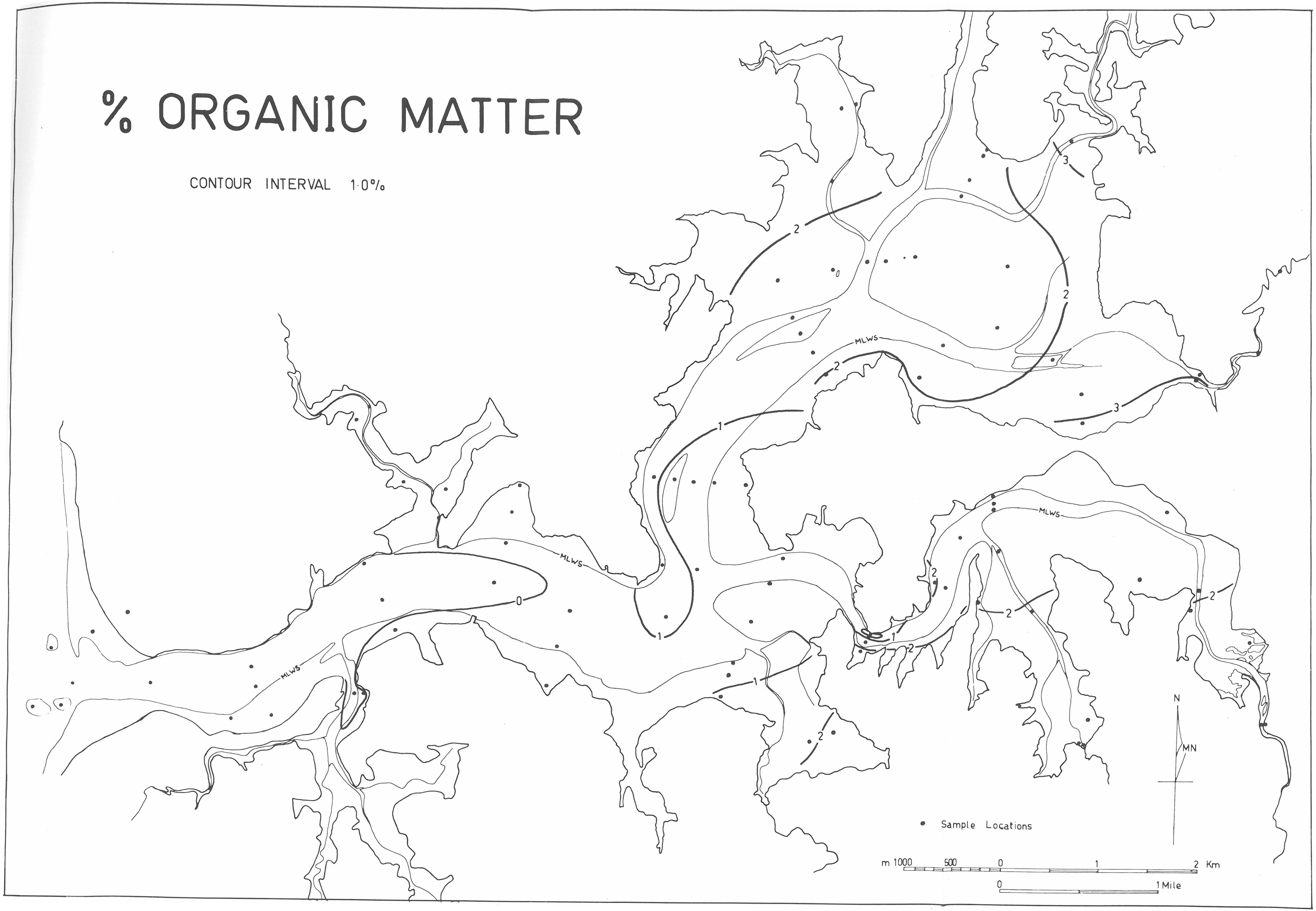


Fig. 3.8 Isopleth map of the weight percent of organic matter in Raglan Harbour sediments.

CHAPTER IV

PARAMETERS OF SEDIMENTATION

In order to explain the distribution of the characteristics of the sediments in Raglan Harbour, it is necessary to evaluate the textural and mineralogical trends shown in the preceeding two chapters in terms of the parameters which control sedimentation.

These parameters are provenance, transportation, deposition and diagenisis. A discussion of the nature and origin of Recent to Sub-recent concretions found in Raglan Harbour is included in the section on diagenisis.

4.1 PROVENANCE

The texture and mineralogy of the sediments of Raglan Harbour is indicative of complex interaction between a number of provenances.

Sediments of the lower harbour are derived almost entirely from the coastal sands. This provenance becomes less important passing further up the harbour, but continues to constitute a proportion of the sand fraction even in the most distal reaches. The heavy mineral suite throughout the harbour (Fig.3.3) is dominated by titanomagnetite and augite from the coastal sands. Material from this provenance is absent only in the restricted estuarine regions.

Most of the sand fraction, and all of the silt and clay fraction of the muddy sediments in the harbour originate from erosion of country rocks comprising the drainage basin surrounding the harbour. The most important of these source rocks are the sandstones and siltstones of the Te Kuiti Group and the Mesozoic basement rocks.

Sediment is supplied to the harbour from these source rocks in two ways: (a) as fluvial sediment load derived from erosion of the rocks and soils within the catchment draining into the harbour; and (b) from shoreline erosion within the harbour. The importance of the latter is deomonstrated by widespread marginal deposits of gravel-sized material eroded from the adjacent shoreline (Fig. 1.16) and the very extensive shore platforms around much of the harbour.

Intrabasinal sedimentation is responsible for almost all of the organic and carbonate matter in the sediments of Raglan Harbour. The latter is mainly skeletal material derived from benthonic organisms. Intrabasinal erosion below the level of permanent water saturation is not regarded as a significant provenance. In this environment mudstones are physically quite stable, and the cohesive sediment veneer over most of the intertidal shore platforms indicates that their surfaces are not subject to active erosion.

4.2. TRANSPORTATION

Variation between ebb and flood tide streams appears to be the most important factor in the movement of sediment in tidal areas (Dyer, 1971). Variation of current velocities during a tidal cycle is seldom simple. For example, a long ebb tide may have more effect on sediment movement than a short but high velocity flood tide (Dyer, 1971). Moreover differences in the strength of ebb and flood tide currents may occur at different positions in a channel. This may be partly due to the effect of Coriolis forces concentrating flows in different parts of the channel and can produce horizontal secondary current systems (Dyer, 1972). Small differences in the angular relationships between the ebb and flood tide currents will produce similar effects. The resulting multidirectional flow adds great complexity to the circular system (Wood, 1969).

It is likely that all of these factors act on the sedimentary system of Raglan Harbour. A complex bottom topography consisting of a system of meandering, curved and straight channels of different depths, flanked by tidal flats, furthercomplicates the circulation system within the harbour. An additional factor is the effect of constrictive passages connecting large open areas of the harbour, causing banking up effects of both ebb and flood tidal streams.

The relative importance of ebb and flood tide streams in Raglan Harbour cannot be accurately determined without a comprehensive suspended sediment and current velocity study. However, certain sedimentalogic factors indicate that both are important in sediment transport.

The abundance of titanomagnetite and augite throughout the harbour sediments indicates that the flood tide is able to transport sand sized material from the coast to the distal reaches of the harbour. However, an indeterminate proportion of these minerals in the sediments may be at least partially wind transported.

The development of very extensive shore platforms in Raglan Harbour has supplied enormous quantities of fine sand, silt and clay (mainly montmorillonite) to the harbour. Indications are that only a relatively small proportion of this material is incorporated into the sediments of the harbour. The fact that the sands of the lower harbour are identical texturally and mineralogically to the coastal iron-sands indicates that very little of the terrigenous sediment supplied to the harbour by hinterland erosion is removed by bed-load transport. It would appear that most of the fine sand silt supplied is deposited in the upper reaches of the harbour and that a large quantity of sediment is removed from the harbour by the ebb tide as suspended load. This concept is supported by the nature of the continental shelf sediments off Raglan Harbour, (McDougall and Brodie, 1967), which contain a high proportion of montmorillonite in their non-relict fraction (Hume, in prep.).

The maximum current velocity attained in any part of the harbour is indicated by the amount of bed-load material present in that area. Grain size distribution curves suggest that sediments of the lower harbour are entirely bed-load material, while those of some distal reaches consistentirely of material deposited from suspension. In general, the size of the bed-load population decreases up the harbour as a function of decreasing current velocity. Over most of the harbour there is more bed-load material present in the sediments of the channels than of the tidal flats indicating that the highest current velocities occur in the channels.

However, in the upper harbour, and to a lesser extent in the upper reaches of the south-east arm, the finest grained sediments are found in the channels. This apparently anomalous feature may be explained by variations of current velocities during a tidal cycle. Sediment textures in the upper harbour (Section 2.2.1) suggest that maximum current velocities are attained at stages of the tidal cycle when the tidal flats are covered with water, i.e. the end of the flood tide and the beginning of the ebb tide. At these times, currents are not confined to the channels and grain size distribution curves indicate that sediment is transported on the tidal flat areas as bed-load material. During the end of the ebb tide, and beginning of the flood tide, when water is confined to the channels, currents are weak and the sediment is transported only as suspended load. Fig. 4.1

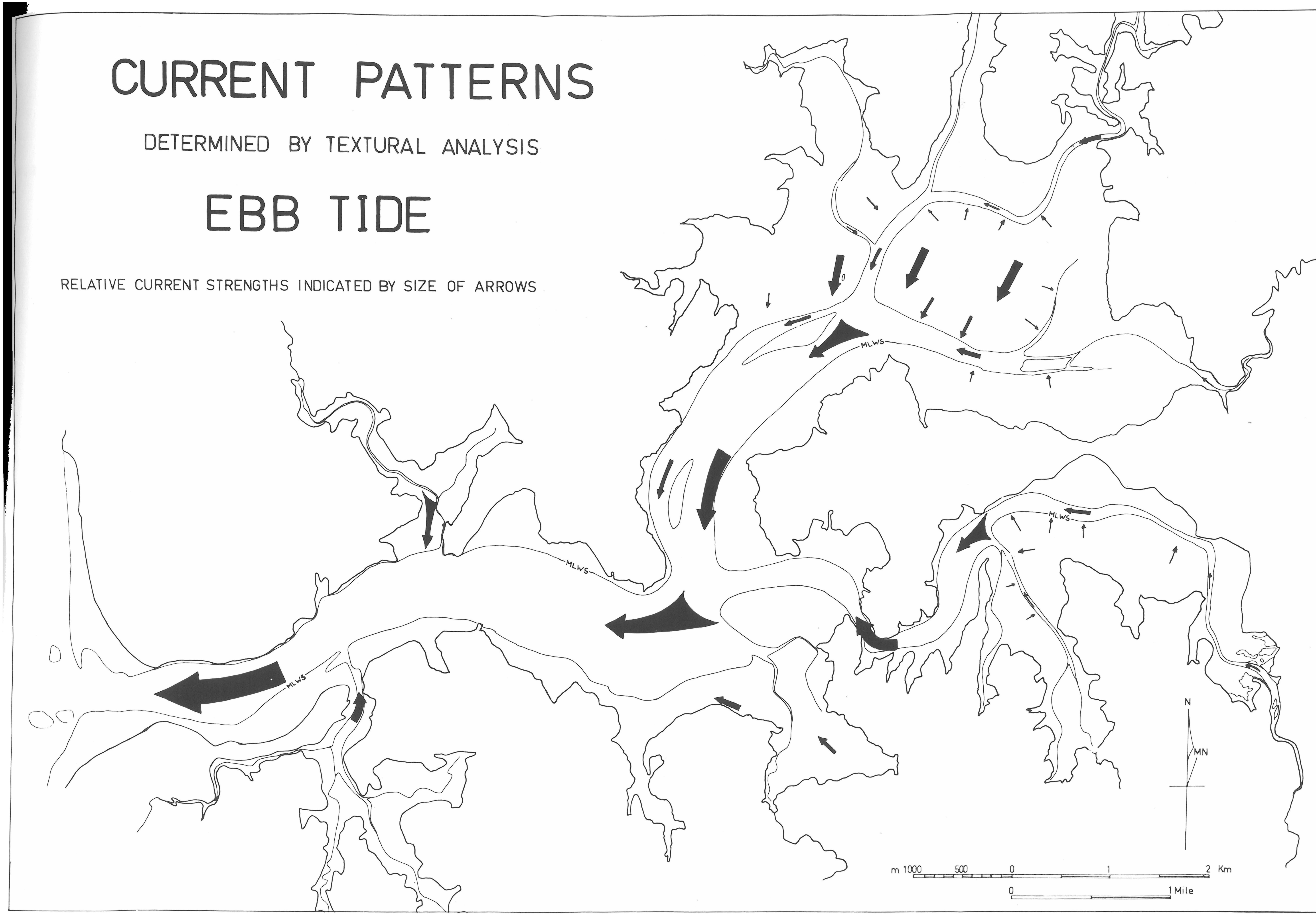


Fig. 4.1 Current patterns and relative current strengths for the ebb tide as suggested by the textural analysis of sediments of Raglan Harbour.

shows the currents patterns and relative current strengths for the ebb tide as suggested by textural analysis.

4.3 DEPOSITION

Bed-load material, consisting of traction and saltation populations (Visher, 1969) is deposited once the flow velocity near the bed falls below the deposition velocity of-grains in the load. Suspended-load is deposited once the settling velocities for the particles in suspension exceed the vertical turbulence velocity components (Allen, 1970).

Once deposited , a particle is not set in motion again unless currents acting on that particle exceed the critical erosion velocity for that particle which is generally about 50% greater than the depositional velocity (Menard, 1950).

Deposition of sediments in Raglan Harbour is probably dominantly controlled by complex variations in the velocities and directions in ebb and flood tide currents.

In many areas of the harbour , maximum current velocities probably exceed the critical erosion velocity for sand sized material, and a considerable amount of sediment re-working may occur before any particle is eventually incorporated into the bottom sediment. This would apply particularly to the harbour entrance, where sediment is likely to be in stant motion apart from a short period at slack water.

Deposition of sediments consisting mainly of bed-load material is readily explained in terms of depositional and critical erosion velocities. Small quantities of suspended material may be incorporated in sandy sediments if deposition is sufficiently rapid. However, the deposition and preservastion of muddy sediments in tidal areas is less simple.

In estuaries and tidal inlets, the deposition of suspended material is, restricted to the periods of low current velocity and slight turbulence occurring at slack water. Sedimentation of mud from suspension is appreciable only if the current velocity drops below 20cm/sec (Einstein and Krone, 1962). In Dutch tidal wäters these conditions occur for an average period of about two hours at each turn of the tide, during which time up to 0.3cm of unconsolidated mud may be deposited (Terwindt and Breusers, 1972).

Bed-load populations comprising from 2 to 50% of the muddy sediments of the tidal flats in Raglan Harbour indicates relatively high current velocities and turbulence for most of the tidal cycle.

The question arises as to why a layer of mud, deposited during a period of slack water, is preserved and not re-suspended when current velocities and turbulence increase with the turn of the tide. Furthermore, how is sand transported as bed-load incorporated into sediments consisting largely of suspension-deposited material without erosion of the latter. Three factors appear to be relavent;

(1) Critical erosion velocities for silt and clay sized particles are frequently higher than those for sands due to cohesive as well as frictional forces opposing water flow (Sundborg, 1956).

(2) Terwindt and Breusers (1972) have shown that initial consolidation of mud in the first few hours after deposition increases the critical shear velocity (U_{*c}) for the initiation of sediment movement. Mud deposited at slack water is preserved if U_{*c} is not exceeded during the following tidal cycle. The above writers also showed that a high sand content, up to a maximum of 40%, gives a more rapid initial consolidation. As a very large proportion of the muddy sediments of Raglan Harbour are deposited on tidal flats it is likely that most of the initial consolidation process occurs subaerially.

(3) Fine sand-sized material may be transported in sand-clay floccules, (Biddle and Miles, 1972), which would result in erroneous conclusions concerning sediment transport deduced from textural analysis. This may or may not be a significant factor operating in Raglan Harbour

The estuarine regions of Raglan Harbour form a distinct sedimentational environment The nature of the sediments here requires separate consideration in terms of depositional processes.

Streams entering Raglan Harbour carry a very coarse bed-load of material up to boulder size. Where streams enter the estuaries, the sudden loss of competence causes deposition of most of the bed-load material, forming very poorly sorted gravelly sediments at these points.

Floculation of clays on contact with sea water, especially of 2:1 lattice clays such as montmorrillonite, probably causes rapid deposition from suspension in the estuarine areas of the harbour. The estuarine waters appear to have sufficiently low turbulence and current velocities for deposition from suspension to occur over most of a tidal cylcle, forming sediments containing up to 98% mud. Sediments are coarser elsewhere in the harbour because sufficiently low turbulence to allow deposition from suspension occurs for only a short period during a tidal cycle.

4.4 DIAGENISIS

4.4.1 SYNDIAGENISIS

Most of the sediments of Raglan Habour show an upper oxidising layer, usually 1 or 2 cm thick, and a lower anaerobic reducing layer of undetermined thickness. This layering is most clearly defined in the fine-grained sediments of the tidal flats.

The oxidising layer is brown to light reddish-brown due to the oxidised state of the iron content. A "soupy" texture resulting from an extremely high water content is characteristic.

The reducing layer is olive grey to black from the presence of metacolloidal hydrotroillite, a black, fine-grained iron sulphide. Sulphate reducing bacteria living on decomposing organic matter in anaerobic conditions produce hydrogen sulphide which reacts with iron compounds in the sediment to form hydrotroillite (Berner, 1967). The reducing layer is more firm than the oxidising layer due to expellation of water during initial consolidation, but remains extremely plastic.

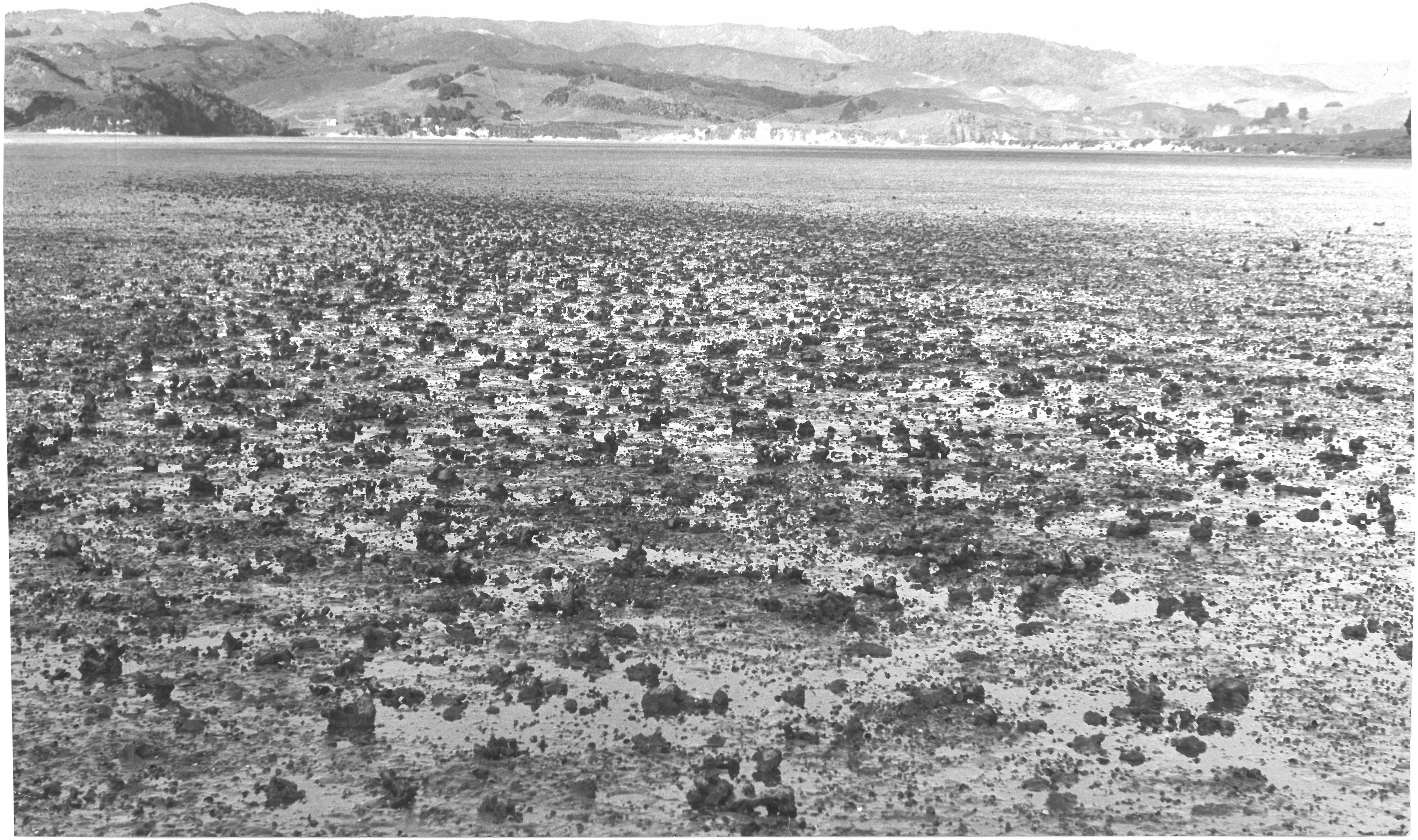
The oxidised and reduced units comprise the syndiogentic phase of Bissel (1959), with the oxidised unit corresponding to the "initial stage" and the reduced unit to the "early burial stage" of Dapples (1962).

4.4.2 CONCRETIONS

OCCURRENCE:

Concretions are found in localised areas of the south-east arm of Raglan Harbour occurring as a surficial litter

Fig. 4.2 Concretions littering a large area of tidal flat in the south-east arm.



over certain areas of the mudflats. The largest of these areas covers 2-3000 m^2 (Fig. 4.2). The concretions lie on or are partially embedded in the soft, muddy sediments of the tidal flats, amongst living and dead molluscan shell material (Fig. 4.3).

The greatest concentration of concretions was found in the proximity of an old shore platform, with a large number littered about its base (Fig. 4.4).

The shore platform is flat-topped and stands 30-40cm above the level of the surrounding tidal mud-flats. The platform consists of an extremely friable, highly weathered sandy material, and is little more than a dense mass of vertical, sediment-infilled borings, weakly cemented together, possibly by an organic mucilage (Fig. 4.5).

The concretions littering the mud flats are at the same level as the base of the platform. Removal of the small scree of erosional debris against the platform reveals concretions in soft mud immediately beneath the bored material of the platform (Fig. 4.6).

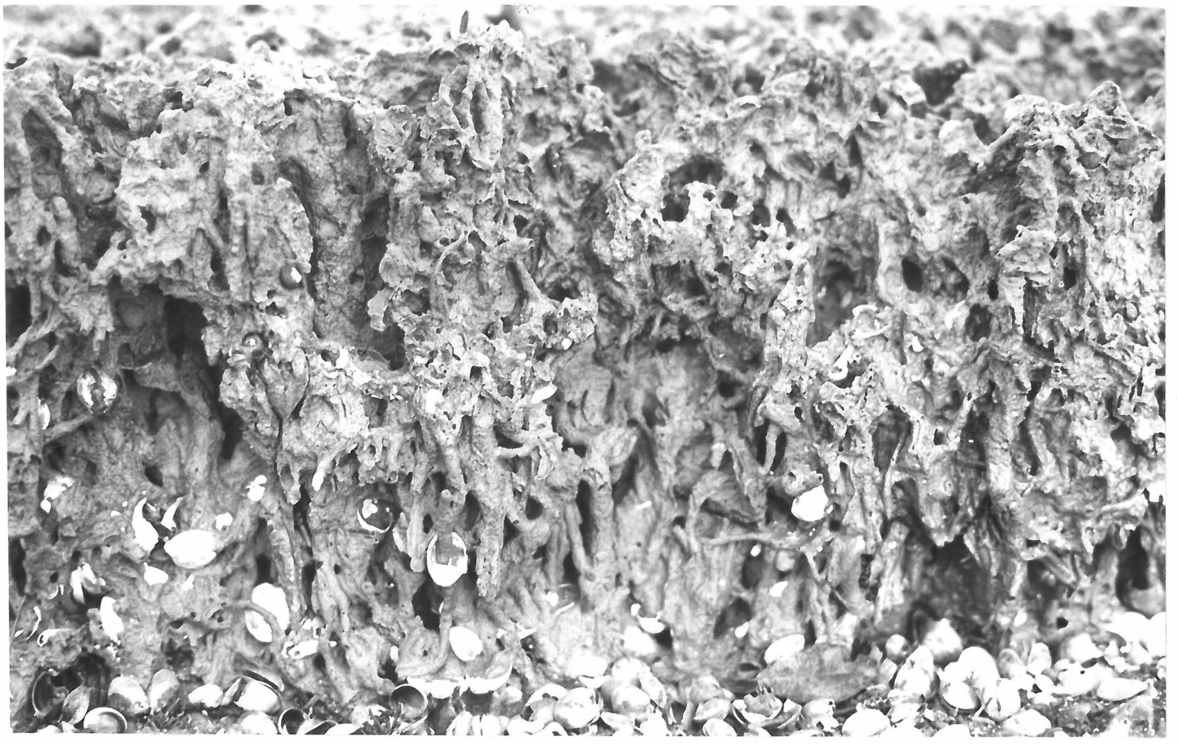
There is no evidence of any living boring organism in this shore platform and it appears to be quite "dead". It is not in equilibrium with present conditions, and the indications are that it is not of recent origin. It is obviously being eroded at an extremely rapid rate. Equally obviously it once covered those areas of the tidal flats now littered with concretions.

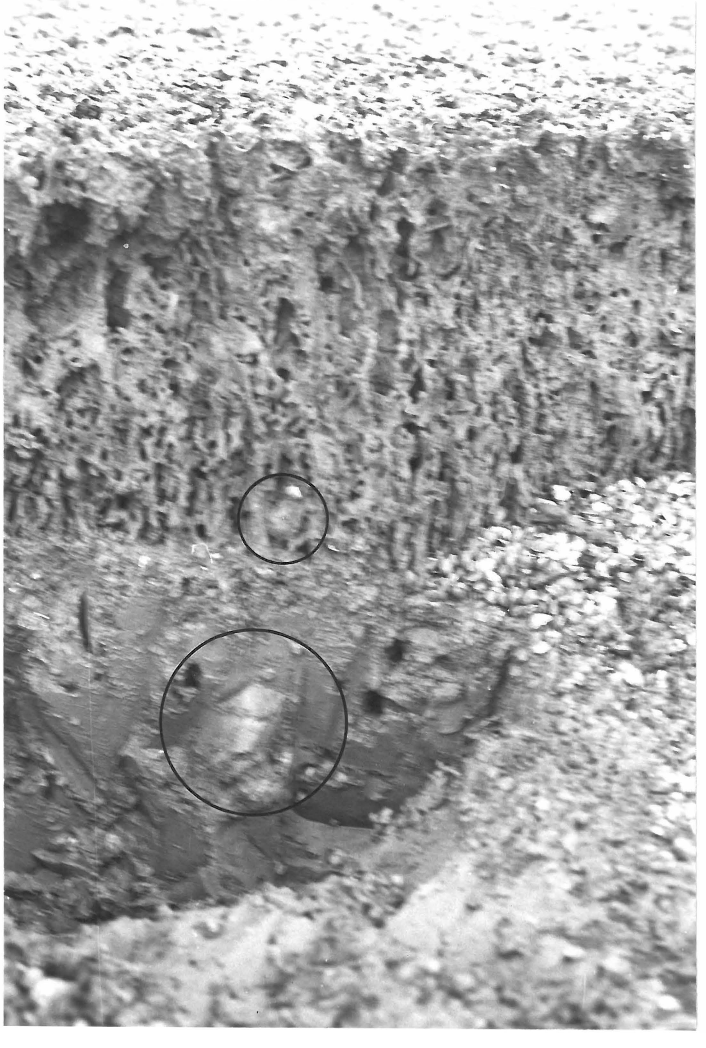
Fig. 4.3 Barnacle-encrusted concretions partially embedded in tidal-flat sediments. Average size of the concretionary masses is about 10cm across.

Fig. 4.4 Concretions littered about the base of a densely bored shore platform. Slumped blocks from the shore platform show at the centre of the photograph. The vertical margin of the platform is about 40cm high.

Fig. 4.5 Close-up view of the mass of sediment-infilled borings making up the shore platform beneath which the concretions appear to have formed. Shell material, mainly *Chione stichburyi* is of recent origin and is not incorporated in the bored material.

Fig. 4.6 Concretions (circled) embedded in the soft mud beneath the bored shore platform material. Borings extend about 45cm beneath the platform surface.





Although not all the areas of tidal flats in Raglan Harbour were examined for evidence of concretions, it is notable that the only areas in which concretions were found are adjacent to shorelines formed by sediments of the Waioneke Formation (Brothers, 1954; Kear, 1960; Chappell, 1970). The shoreplatform discussed above may be cut in the sediments, which are unconsolidated pumiceous sands and silts of Hawera age.

DESCRIPTION:

The concretions are highly variable in shape and size, ranging from simple spheres a few cm in diameter to multi-lobed masses up to 50cm across (Fig. 4.7). Shells are embedded in the concretionary material. These were identified *Chione stichburyi*, *Cyclomactra ovata*, and *Zeacumantus lutulentus*, which are members of the present day benthonic fauna of Raglan Harbour. Both valves of bivalve species are commonly present, often closed together and filled with mud (Fig. 4.8).

COMPOSITION:

In thin section, the concretionary material shows collophane and small grains of quartz and opaque materials scattered throughout non-descript micritic ground-mass.

The shell material, the mud infilling of closed bivalve shells, and the concretionary material were analysed using XRD.

Fig. 4.7 Concretions collected from the area shown in Fig. 4.2. Lens cap is 5cm in diameter.

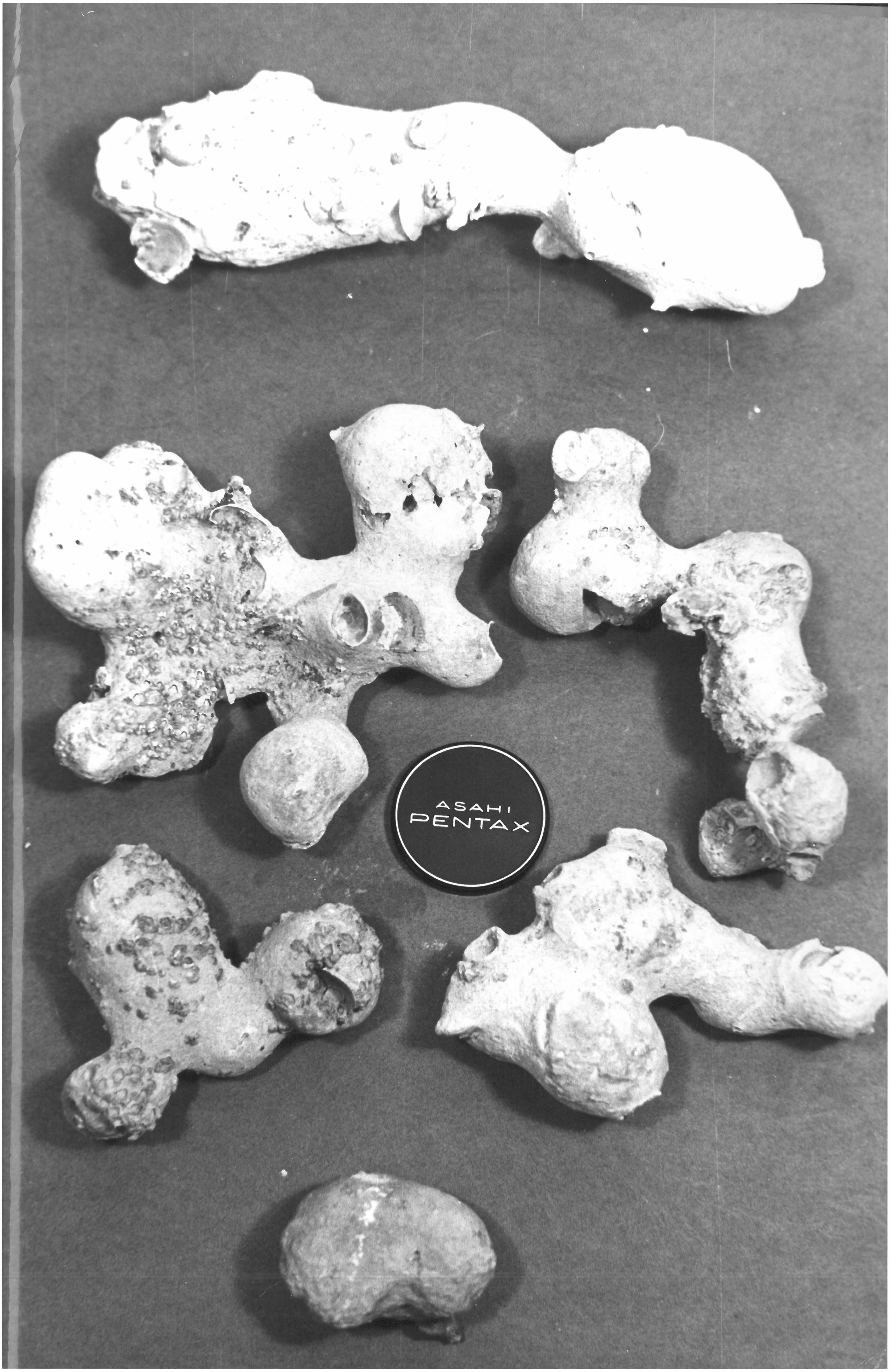
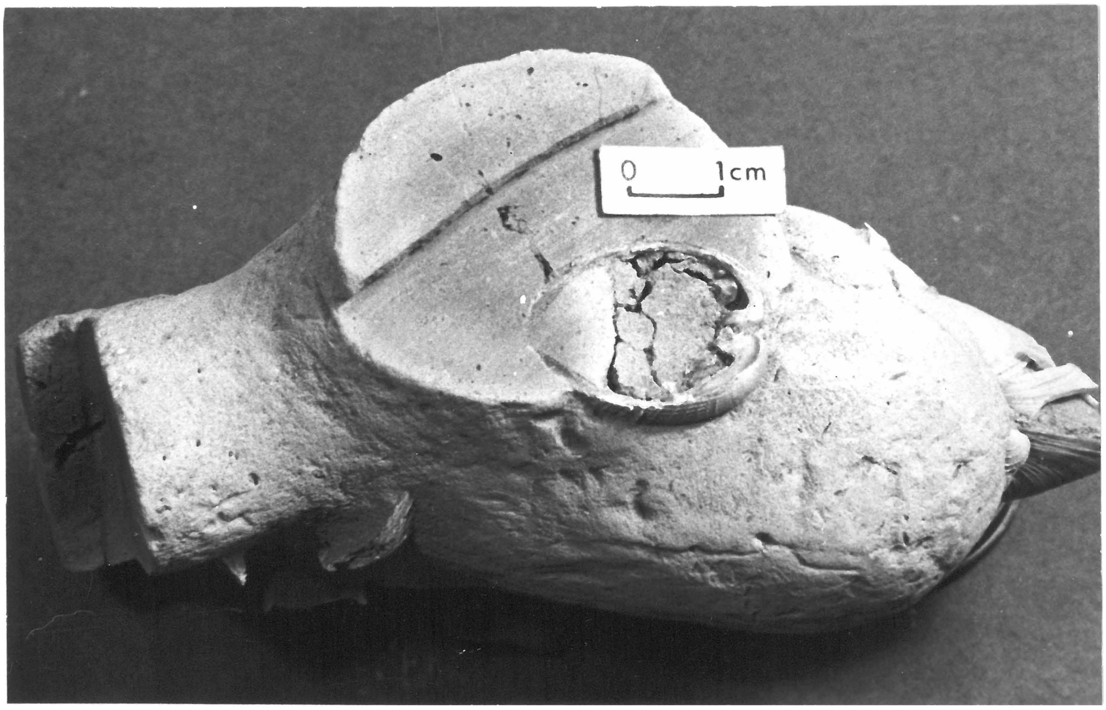

ASAHI
PENTAX

Fig. 4.8 Cross-section through a concretion in which a mud-filled *Chione stichburyi* is partially embedded. The mud infilling at the ventral end of the *Chione* is lithified and resembles the concretionary material; that at the dorsal end is soft and has cracked on drying. A mud-filled *Cyclomactra ovata* protrudes from the concretion at right.


0
1cm

The shell material was identified as pure aragonite. The mud infilling consists of quartz, feldspar and clay minerals. The latter was comprised of montmorillonite, illite. kaolinite and/or chlorite, and mixed-layer clays, together making up about 55% of the infilling material. This mineralogy is identical to that of the present tidal flat muds.

An XRD trace of the concretionary material is shown in Fig. 4.9. Semi-quantitative analysis shows that quartz (5%), calcite (15%) clay minerals (30%) and a very small amount of potash feldspar together make up about 50% of this. Relatively broad peaks at about 2.78Å and 3.41 Å are interpreted as apatite in a fairly disordered state. If any other minerals are present in the concretions, they do not give X-ray diffraction peaks.

A molybdate spot test for phosphate (Feigl, 1958) gives a positive result for concretionary material.

Preliminary interpretation of XRD, chemical and thin section analysis indicates that roughly 50% of the concretionary material consists of phosphates of the apatite group.

ORIGIN:

Concretions littering the tidal flats in the vicinity of the shore platform are not forming at the present day, as almost all of them are covered with barnacles and other forms of marine growth. However, it

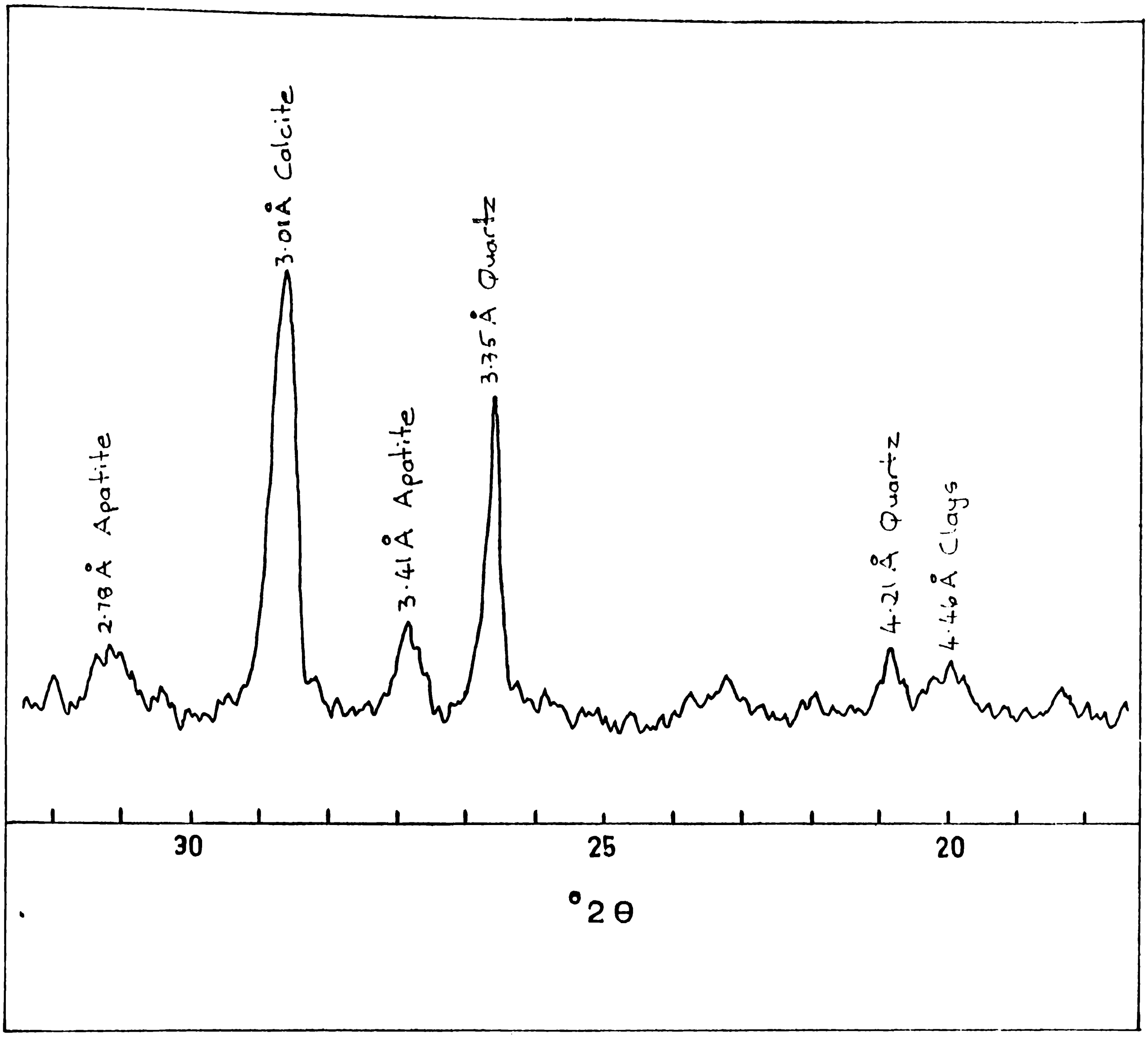


Fig. 4.9 XRD trace of concretionary material.

is possible that those in place beneath the shore platform are precipitating at present. The concretions here have no covering of marine growth or any evidence of boring, and have a gradational contact between the soft surrounding mud and the hard concretionary material. Bivalve shells partly embedded in the concretions have a soft mud infilling.

The high alkalinity required for phosphate preciptation may be provided by decay of boring organisms in the shore platform. This is partly evidenced by the occurrence of the concretions near the base of the bores. (Fig. 4.6.) The apparant lack of any living boring organisms however, would seem to indicate that those concretions that are in place are not precipitating at the present time. It is possible that concretions are forming beneath the sediment-water interface in other areas of the harbour.

Calcareous concretions of diogenetic origin and of strikingly similar appearance to those found in Raglan Harbour have been described from Quaternary shelf sediments in Cook Straight (Pantin, 1958) and from Recent sediments in Auckland Harbour (Bartrum, 1917).

Preliminary investigation of the phosphatic concretions in Raglan Harbour has produced more questions than answers. Radiocarbon dating of the shell material in the concretions and detailed study of the shore platform beneath which they appear to have formed may provide more precise information about their origin. Further work on this example of shallow water phosphate precipitation is currently being conducted by the writer.

CHAPTER V

SUMMARY AND CONCLUSIONS

Raglan Harbour is a drowned river valley system lying in a structurally depressed fault-block. The harbour covers over 30 km^2, much of which consists of extensive tidal flats dissected by relatively deep channels. Estuarine conditions are confined to the lower tidal reaches of major streams entering the harbour.

Textures and mineralogies of the surficial sediments of Raglan Harbour reflect complex interaction between supply of sediment from a number of provenances and the tidal circulation system controlling sediment transport and deposition. Energy conditions vary from the highly turbulent sand-bar environment near the harbour entrance to the very tranquil waters of the distal reaches of the harbour.

Sands in the lower harbour are progressively replaced by more muddy sediments away from the coast. Sediments in the upper harbour and the south-east arm are mainly muddy sands and sandy muds, with less abundant sandy silts and silty sands. Gravelly sediments occur throughout the harbour, and are generally products of shoreline erosion, or are lag deposits in channels. Estuarine sediments are very fine-grained muds. Muddy sediments throughout the harbour are characterised by an upper oxidising layer and a lower reducing layer.

Bulk sediment mineralogies of Raglan Harbour sediments are characterised by quartz, potash and plagioclase feldspars, clay minerals, calcite, aragonite, titanomagnetite and ferromagnesian minerals. Samples from near the harbour entrance are dominated by titanomagnetite and ferromagnesian minerals. Elsewhere in the harbour, sediments consist of mainly quartz, plagioclase felsapr, and clay minerals.

The heavy mineral suite throughout the sediments of the harbour is dominated by titanomagnetite and diopsidic augite derived from the coastal iron-sands, with less abundant hornblende and hypersthene from the same source. Epidote, biotite, leucoxene and a variety of uncommon accessary heavy minerals derived from hinterland rocks are of significant occurrence only in the more distal reaches of the harbour.

Illite, montmorillonite,mixed-layer illite-montmorillonite, kaolinite and chlorite are the main clay minerals present in Raglan Harbour sediments. Mostof these are detritally inherited from rocks in the harbour's drainage basin. Kaolinite and much of the illite have formed by degradational transformation of micas and chlorites during soil formation on the same rocks.

The sands of the lower harbour are derived by wind, wave and current action from the coastal iron-sands. This provenance becomes progressively less important passing up the harbour, but constitutes a proportion of the sand fraction even in the most distal reaches of the harbour.

Erosion of the country rocks comprising the drainage basin surrounding Raglan Harbour forms the principal sediment supply to the harbour. Comparison of the clay minderalogies and quartz-feldspar-clay and potash-plagioclase feldspar ratios between Raglan Harbour sediments and the hinterland rocks shows that the sandstones and siltstones of the Te Kuiti Group and the Mesozoic basement rocks are the most important source rocks. Sediment is supplied to the harbour from hinterland rocks as fluvial sediment load and by shoreline erosion. Intrabasinal erosion below the level of permanent water saturation is not regarded as a significant sediment source. Benthonic organisms, mainly molluscs, supply most of the carbonate material (up to 40%) and organic matter (up to 4%) present in the sediments, besides being agents of considerable sediment reworking.

Sediment transport and deposition in Raglan Harbour is primarily under the control of cyclically variable multi-directional tidal-currents, complicated by a complex bottom topography. A generalised scheme of current patterns and relative current strengths as interpreted from textural analyses as presented in Fig. 4.1. Highest current velocities are usually confined to the main channels. However, in the upper harbour, and to a lesser extent in the distal reaches of the south-east arm, the finest-grained sediments occur in the channels. Analysis of grain size distribution curves suggests that in these areas of the harbour, maximum current velocities are reached at those stages of the tide when water covers the tidal flat. Tidal currents are not fonfined to the channels, and sand-sized material is transported as bed-load over the tidal flats. At lower stages of the tide, when water is confined to the channels, currents are weak, and sediment is transported only as suspended load.

Both ebb and flood tidal currents appear to be important as sediment transporting agent. Titanomagnetite and augite derived from the coastal iron-sands occur in sediments throughout the harbour, although a certain proportion of these minerals are probably wind transported. Large quantities of sediment, supplied mainly by shoreline erosion, appear to have been from the sedimentary system of Raglan Harbour as suspended load by the ebb tide. This is partially evidenced by the nature of the non-relict fraction of the shelf sediments off Raglan Harbour.

The poor sorting of and high degree of mixing between log-normally distributed populations of grain size distribution curves indicates deposition of sediments in the harbour under highly variable energy conditions. Bed-load material is probably deposited as tidal currents cyclically decrease in velocity, with sedimentation of fines from suspension at periods of slack water. Mud deposited from suspension is preserved and not resuspended when current velocities and turbulence increase with the turn of the tide mainly as the result of initial consolidation in the first few hours after deposition. The sand content of muddy Raglan Harbour sediments probably aids rapid initial consolidation. Esuarine muds are the result of sedimentation from suspension, particularly of flocculated clays, over most of any tidal cycle.

A large proportion of the tidal flat areas of Raglan Harbour are sediment veneered shore platforms (Fig. 5.1), commonly 300-500m wide, and cut mainly in Whaingaroa Siltstone and Aotea Sandstone. These have probably been cut during the period of stable sea-level, which has existed for the last 8,000 years (Thom , et al, 1968; Shepard & Curray, 1967). The width of the shore platforms then indicates rates of erosion in the order of 0.5 to 6.0cm/year. This is extremely rapid, but not unreasonable considering the susceptibility of the Whaingaroa Siltstone and Aotea Sandstone to physical erosion, and that in certain conditions, cliffs may retreat at a maximum average rate of 91.5cm/year (King, 1972).

The present areal extent of Raglan Harbour does not represent the drowned and sediment infilled relief of a river valley system existing before the post-glacial rise of sea-level. It is likely that only the channels are traces of a now drowned drainage pattern, almost completely filled with sediment in many of the distal reaches of the harbour. The greater area of the harbour now covered by tidal flats has probably been eroded back from the channels during the period of slowly rising or stable sea level of the last 8-10,000 years (Fig. 5.2). The bulk of the eroded material has been removed from the harbour and deposited on the continental shelf.

Shore platforms in many parts of Raglan Harbour have probably reached their limits of development under present sea-level conditions. Active erosion of the shoreline appears to have practically ceased around many parts of the harbour.

Fig. 5.1 An extensive tidal flat in the upper harbour. The shoreline at the centre of the photograph is over 1-5km distant. Most of this area consists of a veneer of muddy sediment on very broad shore platforms.

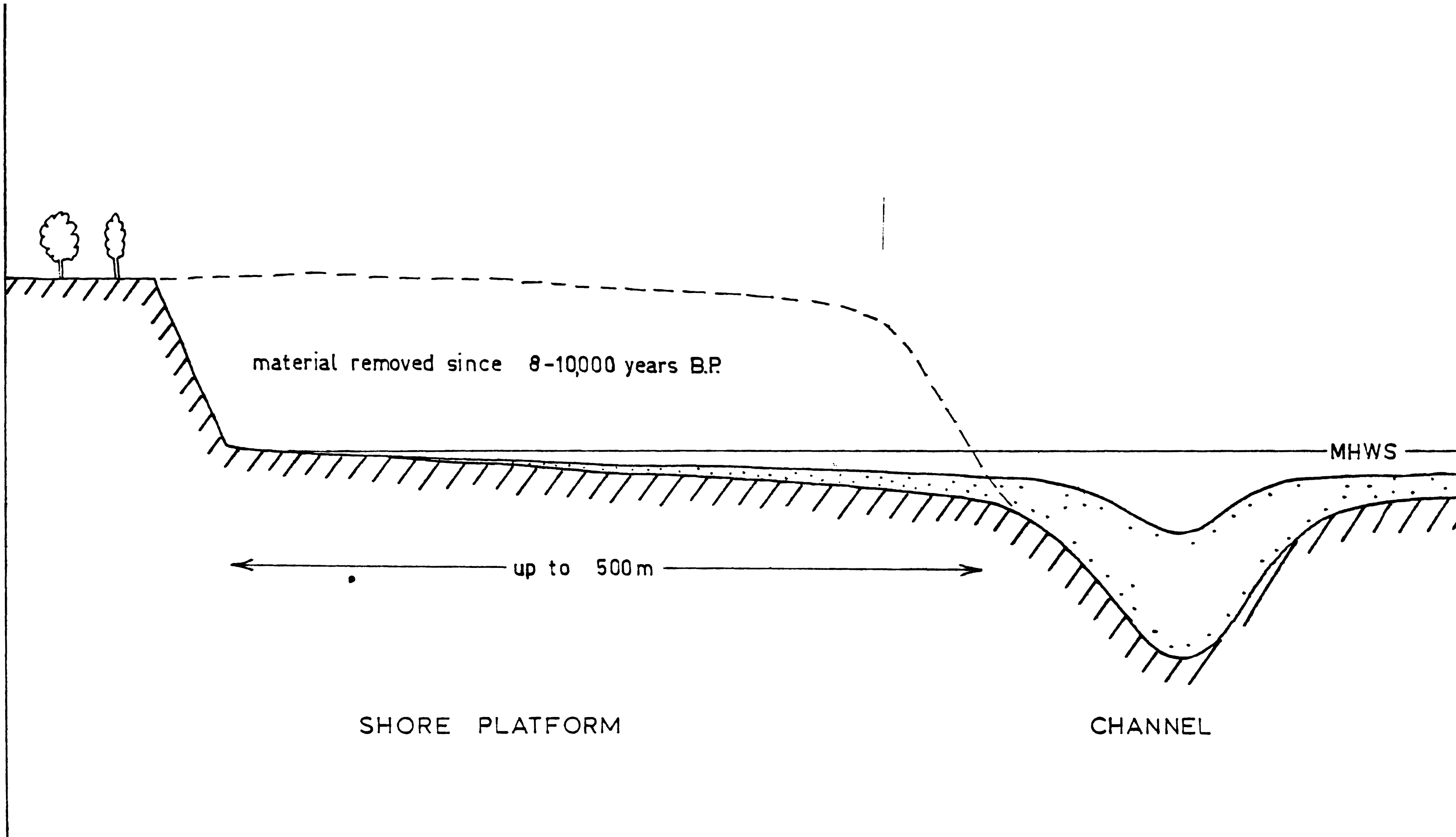


Fig. 5.2 Hypothetical cross-section of a tidal flat and a channel in Raglan Harbour. The channel represents the drowned and largely sediment infilled lower extension of the present drainage system. The tidal flat is a broad, sediment veneered shore platform, cut during the period of slowly rising or stable sea-level of the last 8-10,000 years.

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Appendix I

Conversion of sounding to a common datum

At each sample location, the depth, time and date of sampling were recorded. The measured depths were converted to absolute depths in terms of an arbitary chart datum (MHWS), by the method described below. Sample 19, collected at 1455 hrs. on 6.4.73 in 7.5 m of water is taken as a working example.

Tidal predictions were calculated for Raglan from tide tables in the N. Z. Nautical Almonac and Tide Tables (1973). Raglan is a seconday port with tidal predictions based on Port Taranaki, with a time difference of +0026 for high and low water.

	HW		LW	
	Time	Height	Time	Height
Prediction for Port Taranaki	1127	3.5m	1743	0.2m
Difference for Raglan	+0024		+0024	
Prediction for Raglan	1153		1809	

The predicted heights of Port Taranaki must be corrected to ascertain the heights of high and low water at Raglan by interpolating between the predicted heights at Port Taranaki and the mean heights of HWS, HWN, LWS and LWN at Raglan using the formula

$$D = d_2 \times d_s$$

where D is the change between predicted HW and nearest MHWS or MHWN at secondary port,

d_2 is $\frac{\text{difference between secondary MHWS and MHWN}}{\text{difference between standard MHWS and MHWN}}$,

and d_s is the difference between predicted HW and nearest MHWS or MHWN at standard port.

The values for MHWS and MHWN for standard and secondary ports were obtained from N. Z. Nautical Almanac and Tide Tables (1973),

For 6.4.73

$$D = \frac{0.6}{0.7} \times (3.5 - 3.4)$$

$$= \underline{0.1 \text{ m}}$$

This quantity is the variation from the tabulated MHWS height at Raglan corresponding to a change of 0.1 m variation of predicted HW height to the standard MHWS height. height of HW at Ragland = 3.5 - 0.1

= <u>3.4m</u>

The variation from the tabulated MLWS height at Raglan can be calculated in a similar way.

height of LW at Raglan = 0.3 + (-0.1)

= <u>0.2 m</u>

The duration and range of the tide, and the interval from HW at which the sample was taken was then calculated in order to determine the correction made to the sounding for the time of the tide at which the sample was collected.

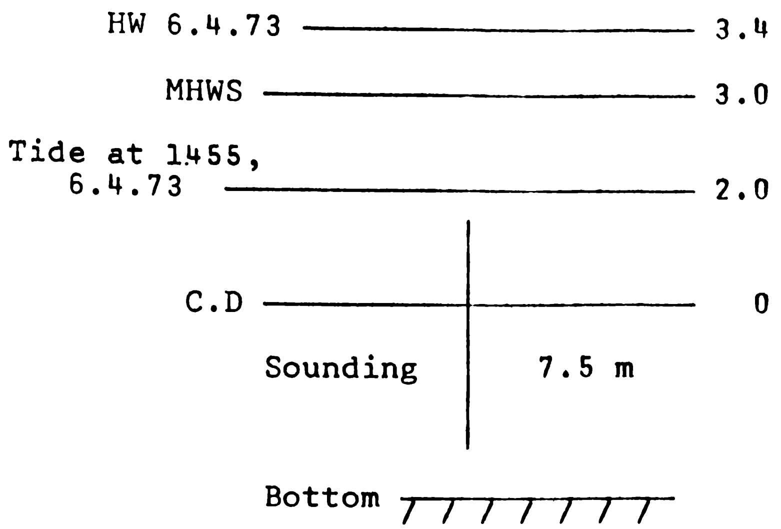
	Time		Height
LW at Raglan	1809		0.2
HW at Raglan	1153		3.4
Duration	0616	Range	3.2

HW at Raglan	1153
Given time	1455
Interval from HW	0302

This correction is calculated from the Range Table (N. Z. Nautical Almonac and Tide Table 1973) for determining the height of the tide at times between high and low water.

Height of HW at Raglan	3.4 m
Correction from Range Table	1.4 m
Height of tide at 1455	2.0 m

Tide heights are expressed as height above chart datum (C.D.) which is arbitarily defined, and is below MLWS. For Raglan, chart datum is defined as 17.15 feet below the top of the concrete decking on the main wharf (Admiralty Chart 4417). As this study involved collection of a large number of samples above C.D., it was desirable to express soundings as depth below MHWS, i.e. MHWS is zero, or C.D. for this study. This was achieved by subtracting the height of the tide at a given time from HW on the day in question and adding this figure to the sounding, or in other words, simply adding the range correction to the sounding. This gave depths in terms of the height of HW on a particular day. To bring soundings taken on different days to a common datum (MHWS), the difference between MHWS and HW on any day was added to or subtracted from the corrected sounding.



Sounding	7.5
Correction from Range Table	1.4
	8.9
Less difference between HW and MHWS	0.4
Depth below MHWS	8.5 m

The depths given in Appendix II are, however, subject to error resulting from differences in the time of high tide in different parts of the harbour, a factor which cannot be corrected for.

Appendix II

Corrected Soundings at Sample Locations

Sample No.	Depth (m)	Sample No.	Depth (m)
1	-	51	1.5
2	2.3	52	3.7
3	2.9	53	1.2
4	2.9	54	0.2
5	2.9	55	0.1
6	15.1	56	1.8
7	7.5	57	1.7
8	2.5	58	4.2
9	18.0	59	1.9
10	7.5	60	1.2
11	2.6	61	3.2
12	3.0	62	2.3
13	1.4	63	7.5
14	2.1	64	2.0
15	6.4	65	4.3
16	14.7	66	3.0
17	2.4	67	0.6
18	1.8	68	2.1
19	1.9	69	10.3
20	1.2	70	2.4
21	1.6	71	3.6
22	1.3	72	0.9
24	3.3	73	0.4
25	8.5	74	4.6
26	10.7	75	2.1
27	4.4	76	2.3
28	1.0	77	1.3
29	3.9	78	2.1
30	2.2	79	4.6
31	6.5	80	2.1
32	5.0	81	2.1
33	2.6	82	2.1
34	2.0	83	2.0
35	2.6	84	0.5
36	2.5	85	0.9
37	1.4	86	-
38	0.7	87	0.4
39	0.7	88	2.1
40	2.1	89	3.1
41	10.9	90	0
42	11.2	91	0.5
43	5.3	92	1.4
44	6.3	93	4.2
45	7.5	94	3.4
46	4.5		
47	2.6		
48	5.0		
49	6.9		
50	3.5		

Appendix III

Textural Parameters

Sample No.	Mz(ϕ)	Md(ϕ)	Mo*	σ_J	Sk_I	K_G
1	2.30	2.26	fs	0.41	+0.12	0.92
2	2.15	2.10	fs	0.34	+0.21	1.24
3	2.09	2.03	fs	0.34	+0.24	1.07
4	2.03	2.00	ms	0.39	+0.08	1.04
5	1.92	1.90	fs	0.39	+1.12	1.11
6	1.48	1.53	ms	0.38	+0.10	0.97
7	1.48	1.45	ms	0.41	+0.09	1.21
8	2.69	2.70	fs	0.44	-0.04	0.99
9	1.74	1.83	ms	0.50	+0.09	1.04
10	2.90	2.90	fs	0.40	+0.04	1.14
11	2.78	2.80	fs	0.35	-0.12	0.68
12	1.45	2.50	fs	1.01	-0.40	2.15
13	2.80	2.95	vfs	0.83	-0.39	1.05
14	3.27	3.25	vfs	0.34	+0.02	1.22
15	1.29	1.32	fs	0.46	-0.14	1.04
16	3	-	-	-	-	-
17	2	2.95	vfs	0.81	-0.35	1.68
18	2.64	2.85	vfs	1.04	-0.37	0.91
19	2.79	2.80	fs	0.78	-0.08	0.92
20	3.36	3.42	vfs	0.50	-0.18	1.25
21	2.20	2.25	fs	0.67	-0.27	1.28
22	3.02	3.40	vfs	0.86	-0.73	1.73
23	2.07	2.95	vfs	1.85	-0.68	0.97
24	3.20	3.17	vfs	0.31	+0.15	1.24
25	2.75	2.75	fs	0.37	+0.02	1.02
26	2.90	2.90	fs	0.36	-0.02	1.14
27	1.12	1.90	vfs(g)	2.25	-0.47	0.86
28	2.57	2.90	vfs	1.33	-0.48	0.93
29	3.13	3.10	vfs	0.30	-0.15	1.29
30	-1.69	-2.00	vfs(p)	0.75	+0.71	2.25
31	2.94	2.95	fs	0.39	-0.17	1.58
32	2.41	2.92	fs	1.47	-0.62	1.12
33	2.92	3.05	vfs	0.77	-0.28	1.00
34	2.38	2.70	fs	1.03	-0.78	1.68
35	2.83	3.15	vfs	0.56	-0.27	1.40
36	3.33	3.37	vfs	0.34	-0.25	1.23

* Modal grain sizes for gravel and sand fractions only are given. p = pebble; g = granite; ms = medium sand; fs = fine sand; vfs = very fine sand. Secondary modes are given in brackets.

Appendix III contd.

Sample No.	Mz(ϕ)	Md(ϕ)	Mo*	σ_J	Sk_I	K_G
37	3.14	3.14	vfs	0.43	-0.13	1.31
38	3.51	3.70	vfs	0.25	-0.49	1.48
39	2.21	2.65	vfs	1.40	+0.51	1.26
40	3.58	3.70	vfs	0.44	-0.58	1.16
41	0.07	-0.30	ms(g)	1.86	+0.30	0.73
42	0.03	-0.05	ms	1.75	+0.40	0.71
43	0.80	0.90	ms	0.75	-0.35	1.37
44	1.35	1.60	ms	1.65	-0.21	0.74
45	0.82	1.20	fs	1.66	-0.26	1.00
46	0.73	1.25	ms(g)	1.95	-0.35	0.83
47	2.28	2.35	fs	1.25	-0.21	1.20
48	2.00	2.00	fs	0.93	-0.06	1.19
49	3.25	3.45	vfs	0.72	-0.56	1.33
50	1.87	2.25	fs	1.39	-0.43	1.31
51	2.97	3.45	vfs	1.00	-0.35	0.82
52	3.43	3.70	vfs	0.63	-0.75	1.35
53	3.53	3.72	vfs	0.49	-0.74	2.06
54	-0.68	-1.00	vfs(p)	1.97	+0.24	0.77
55	1.25	1.30	fs	1.65	-0.05	0.74
56	-	-	vfs	-	-	-
57	-	-	vfs	-	-	-
58	-	-	vfs	-	-	-
59	3.26	3.35	vfs	0.60	-0.37	1.15
60	-	-	vfs	-	-	-
61	-	-	vfs	-	-	-
62	-1.25	-1.50	fs(p)	1.87	+0.17	0.85
63	3.17	3.20	vfs	0.30	-0.25	1.04
64	2.96	3.03	vfs	0.54	-0.32	1.47
65	2.86	2.90	vfs(g)	0.51	-0.22	1.11
66	0.93	1.90	fs	2.28	-0.52	1.63
67	3.06	2.95	fs	0.66	+0.23	1.48
68	3.31	3.36	vfs	0.45	-0.26	0.89
69	-	-	vfs	-	-	-
70	2.89	3.10	vfs	0.97	-0.49	1.84
71	3.36	3.37	vfs	0.44	-0.17	0.94
72	3.48	3.51	vfs	0.34	-0.25	0.87
73	2.09	2.45	vfs	1.31	-0.45	0.91
74	3.47	3.56	vfs	0.44	-0.53	1.32
75	3.02	3.37	vfs	0.76	-0.80	0.72
76	3.39	3.46	vfs	0.57	-0.46	1.54
77	3.46	3.47	vfs	0.30	-0.19	1.06
78	3.48	3.56	vfs	0.34	-0.36	0.71
79	-	-	vfs	-	-	-
80	2.35	2.50	fs	1.02	-0.21	0.83
81	2.49	2.60	vfs	1.21	-0.22	0.86
82	3.55	3.64	vfs	0.30	-0.55	0.92
83	0.77	1.10	ms	1.53	-0.27	0.86
84	-	-	vfs	-	-	-
85	-	-	vfs	-	-	-

Appendix III contd.

Sample No.	Mz(ϕ)	Md(ϕ)	Mo*	σ_J	Sk_I	K_G
86	-2.32	-2.60	fs(p)	1.69	+0.45	2.22
87	-	-	-	-	-	-
88	-1.63	-2.16	cs(p)	1.63	+0.43	0.65
89	2.25	2.46	fs	1.33	-0.33	1.00
90	-	-	vfs	-	-	-
91	2.02	2.05	ms	0.52	-0.29	1.66
92	-0.90	-1.08	cs(G)	1.28	+0.37	1.18
93	3.48	3.54	vfs	0.39	-0.45	1.33
94	-	-	vfs	-	-	-
95	-	-	vfs	-	-	-

Appendix IV

Textural Components and Classes

Sample No.	Gravel %	Sand %	Mud %	Silt %	Clay %	Textural class
1	0	100	0	0	0	S
2	0	100	0	0	0	S
3	0	100	0	0	0	S
4	0	100	0	0	0	S
5	0	100	0	0	0	S
6	0	100	0	0	0	S
7	0	100	0	0	0	S
8	0	100	0	0	0	S
9	0	100	0	0	0	S
10	0	99.93	0.07	0.07	0	S
11	0	98.20	1.80	1.80	0	S
12	5.41	94.59	0	0	0	gS
13	0	72.26	27.74	17.18	10.56	mS
14	0	52.96	47.04	32.06	14.99	zS
15	0	100	0	0	0	S
16	0	100	0	0	0	S
17	0	81.00	19.00	8.60	10.41	mS
18	0	66.39	33.61	20.54	13.07	ms
19	0	44.89	55.11	41.98	13.14	sZ
20	0	61.75	38.24	27.79	0.45	zS
21	2.45	80.45	16.89	8.05	8.85	(g)mS
22	0	46.23	53.77	45.61	8.15	sZ
23	9.91	64.85	25.24	5.17	20.07	gmS
24	0	77.29	22.71	11.05	11.66	mS
25	0	100	0	0	0	S
26	0	91.63	8.37	2.39	5.98	S
27	16.34	60.80	22.86	14.39	8.47	gmS
28	0	24.59	76.32	56.96	19.36	sZ
29	0	88.79	10.60	6.51	4.08	mS
30	57.98	15.08	26.93	13.71	13.22	mG
31	0	77.83	22.29	9.55	12.74	mS
32	3.68	52.10	44.22	21.35	22.87	(g)mS
33	0	53.25	46.65	27.61	19.03	mS
34	6.14	74.78	18.47	7.21	11.25	gmS
35	0	70.95	29.05	15.50	13.56	mS
36	0	49.26	50.74	39.49	11.25	sZ
37	0	70.01	29.99	18.08	11.91	mS
38	0	27.53	72.47	58.06	14.41	sZ
39	0	60.40	39.51	28.94	10.57	zS
40	0	13.44	86.43	54.56	23.95	sZ
41	10.46	19.82	69.97	36.79	33.18	gM
42	25.34	56.45	18.21	10.76	7.45	gmS
43	5.05	94.95	0	0	0	(g)S
44	4.53	45.97	49.24	21.81	27.43	(g)sM
45	7.22	33.47	59.31	31.15	28.16	gM
46	17.10	76.35	23.65	13.93	9.72	gmS

Appendix IV contd

Sample No.	Gravel %	Sand %	Mud%	Silt%	Clay %	Textural class
47	1.02	30.61	68.37	40.35	28.02	(g)sM
48	0	15.56	84.44	40.03	40.01	sM
49	0	10.33	89.23	48.31	40.93	sM
50	3.80	64.13	32.61	19.47	13.14	(g)mS
51	0	12.81	87.19	60.32	26.87	sZ
52	0	6.42	93.72	50.65	42.91	M
53	0	6.52	92.15	53.91	38.24	M
54	19.56	20.27	60.18	25.22	34.96	gM
55	0.58	4.66	94.26	37.12	57.13	(g)M
56	0	2.70	96.99	49.27	47.72	M
57	0	8.26	91.09	51.01	40.08	M
58	0	2.18	97.62	47.72	49.90	M
59	0	24.92	75.08	39.37	35.71	sM
60	0	19.88	78.36	42.49	35.67	sM
61	0	9.29	89.66	44.18	45.58	M
62	35.46	52.27	12.27	7.14	5.11	msG
63	0	59.95	40.05	21.73	18.31	mS
64	0	82.60	16.68	8.10	8.58	mS
65	1.67	83.11	15.22	6.24	8.98	(g)mS
66	21.42	58.94	20.20	8.39	11.81	gmS
67	0	88.97	10.09	5.10	4.99	mS
68	0	45.20	54.80	38.27	16.54	sZ
69	0	12.76	87.24	50.05	37.19	sM
70	0.29	65.32	34.38	23.33	11.05	(g)mS
71	0	27.99	72.01	43.78	28.23	sM
72	0	47.81	52.19	37.42	14.77	sZ
73	1.65	42.79	55.56	51.57	4.00	(g)sM
74	0	15.38	84.62	51.40	33.22	sM
75	0	32.12	67.88	44.76	23.12	sM
76	0	51.42	48.58	33.95	14.64	zS
77	0	73.85	26.15	14.73	11.42	mS
78	0	55.41	44.79	31.33	13.23	zS
79	0	9.30	90.70	45.12	45.58	M
80	0	27.99	72.01	30.38	41.64	sM
81	0	18.76	81.24	41.94	39.30	sM
82	0	11.27	88.73	67.40	21.33	sZ
83	7.77	43.46	48.78	33.93	14.85	gM
84	0	4.10	95.90	42.56	53.33	M
85	0	1.06	98.94	43.92	55.03	M
86	36.05	6.66	56.72	50.74	5.98	mG
87	-	-	-	-	-	-
88	47.90	27.81	24.29	16.14	8.15	msG
89	1.41	39.86	59.36	34.38	24.98	(g)mS
90	0	15.91	84.09	49.79	34.30	sM
91	6.35	90.67	3.29	-	-	gS
92	43.54	38.67	17.80	9.21	8.59	msG
93	0	39.41	60.59	37.48	23.12	mS
94	0	12.09	87.91	51.65	36.26	sM
95	0	1.81	98.19	38.52	59.67	M

Appendix V

Carborate and Organic Content

Sample No.	Carborate %	Organic %	Sample No.	Carborate %	Organic %
1	0.27	0	49	39.04	1.19
2	1.19	0	50	10.24	1.21
3	1,46	0	51	7.46	1.87
4	2.37	0	52	7.86	1.96
5	2.85	0	53	9.19	2.77
6	6.74	0	54	8.14	1.56
7	1.84	0	55	9.82	2.86
8	0.63	0	56	12.07	1.70
9	10.12	0	57	7.78	1.72
10	13.04	0	58	8.80	1.62
11	2.26	0	59	8.45	2.47
12	7.50	0	60	8.51	2.93
13	14.46	0	61	11.58	2.93
14	1.57	0.28	62	2.74	0.54
15	3.68	0	63	8.35	1.10
16	99.0	0	64	6.70	0.58
17	8.14	0	65	11.29	0.14
18	21.13	0.44	66	13.24	0.74
19	32.30	0.25	67	12.08	0.12
20	3.17	0.33	68	9.74	1.99
21	19.22	0.84	69	8.44	1.49
22	28.51	0.68	70	15.97	1.09
23	33.65	0.61	71	7.84	1.77
24	6.41	0.79	72	6.30	1.23
25	6.52	0	73	9.91	1.38
26	39.93	0.24	74	6.98	1.60
27	38.30	0.49	75	24.11	1.59
28	10.95	0.52	76	7.76	1.27
29	6.38	1.85	77	12.40	1.16
30	23.94	1.06	78	5.42	1.07
31	32.25	0.94	79	8.76	1.67
32	27.50	0.83	80	35.52	1.33
33	7.32	0.48	81	8.36	2.40
34	4.89	0.10	82	13.95	2.45
35	5.10	0.20	83	14.47	3.34
36	6.55	0	84	10.03	2.07
37	8.17	1.08	85	14.87	3.79
38	4.93	1.43	86	3.79	1.03
39	16.93	2.48	87	-	-
40	7.20	2.59	88	5.15	3.02
41	11.86	1.02	89	24.91	2.43
42	6.71	1.02	90	14.22	2.08
43	6.5	0	91	6.29	1.92
44	6.49	1.08	92	11.46	1.09
45	5.68	1.97	93	6.64	1.28
46	7.53	1.67	94	10.81	1.06
47	8.64	1.40	95	9.97	3.28
48	10.64	1.25			