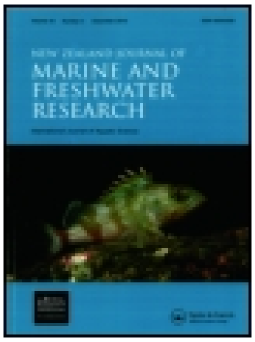


Taylor & Francis
Taylor & Francis Group

New Zealand Journal of Marine and Freshwater Research

ISSN: 0028-8330 (Print) 1175-8805 (Online) Journal homepage: http://www.tandfonline.com/loi/tnzm20

Sediments on the continental shelf and slope between Napier and castlepoint, New Zealand

K. B. Lewis

NEW ZEALAND

JOURNAL OF MARINE AND FRESHWATER RESEARCH

Department of Scientific and Industrial Research, Wellington

VOLUME 7 | SEPTEMBER 1973 | NUMBER 3

SEDIMENTS ON THE CONTINENTAL SHELF AND SLOPE BETWEEN NAPIER AND CASTLEPOINT, NEW ZEALAND

K. B. LEWIS

New Zealand Oceanographic Institute, Department of Scientific and Industrial Research, Wellington, New Zealand

(Received for publication 7 July 1971)

ABSTRACT

Sediments from the seabed off the eastern side of the North Island, New Zealand, are divided into 12 facies on the basis of grain size and mineralogy of the sand fraction. The facies are grouped into three types; modern detrital sediments, relict detrital sediments, and non-detrital sediments. The sediments are described in terms of a modified Wentworth grain-size scale and a modified Folk sediment classification.

The modern detrital sediments range from fine sand near the shore to clayey fine silt on the lower slope. At most places they are bimodal, probably because flocs and single grains are deposited together. The relict detrital sediments, which include sands and gravels, occur where deposition is slow on the inner continental shelf and near the shelf edge. Those near the shelf edge include Last Glacial sandy muds that have been winnowed and mixed with Holocene volcanic ash and glauconite. The non-detrital sediments, which contain foraminifera, volcanic ash, and glauconite, but no detrital sand, occur on anticlinal ridges on the continental slope. In places they overlie muddier sediment deposited during the last glaciation when the sources of river-borne detritus were nearer than at present and when mud was deposited more rapidly on the ridges than at present.

INTRODUCTION

The sediments on the continental shelf and slope between Napier and Castlepoint have been charted by Lewis & Gibb (1970). The following is a more detailed account of grain size and mineralogy of the sediments in relation to environment.

The study area lies offshore from the Mesozoic and Tertiary mudstones of eastern North Island and to leeward of the central North Island volcanoes (Fig. 1). A narrow, NNE trending continental shelf reaches a maximum width of 60 km off Hawke Bay. The shelf break is about 200 m deep (Pantin 1963) and the continental slope is folded into a series of anticlinal ridges and synclinal depressions paralleling the continental shelf (Houtz *et al.* 1967; Lewis 1971a). Detrital sediments are transported by southward moving coastal currents and deposited rapidly on the continental shelf and slowly on the continental slope (Lewis, in press). At places the continental slope sediments have slumped (Lewis 1971b).

Pantin (1966) divided the seabed sediments of Hawke Bay into five types which he related to the effects of waves, rivers and coastal currents. The sediments of the larger area here examined are divided into 12 facies each characteristic of a particular geographic environment. Some of the 12 facies correspond to Pantin's sediment types, others do not.

COLLECTION OF SAMPLES

About 250 sediment samples were collected by the writer with a short gravity corer (Willis 1964) and a segment of each core, between 10 mm and about 100 mm below the seabed, was retained for sediment analysis; the top was used in another study (Lewis, in press). The only satisfactory device for collecting sand was an orange-peel grab fitted with protective plates and a canvas bag to prevent sluicing of the surface sediment during recovery. A sample was taken from the upper part of each grab haul for sediment analysis.

About 50 samples collected with a cone dredge were already available in the N.Z. Oceanographic Institute collection. Those from Hawke Bay have been described by Pantin (1966). Widely spaced data in some parts of the area were usefully supplemented by about 20 brief sediment descriptions noted on the chart (N.Z. Hydrographic Branch 1956).

GRAIN-SIZE ANALYSIS

Size analyses were carried out by standard procedures (Van der Linden 1968). The coarse fraction (sand and gravel) was sieved, and the fine fraction (silt and clay) was analysed by the pipette method.

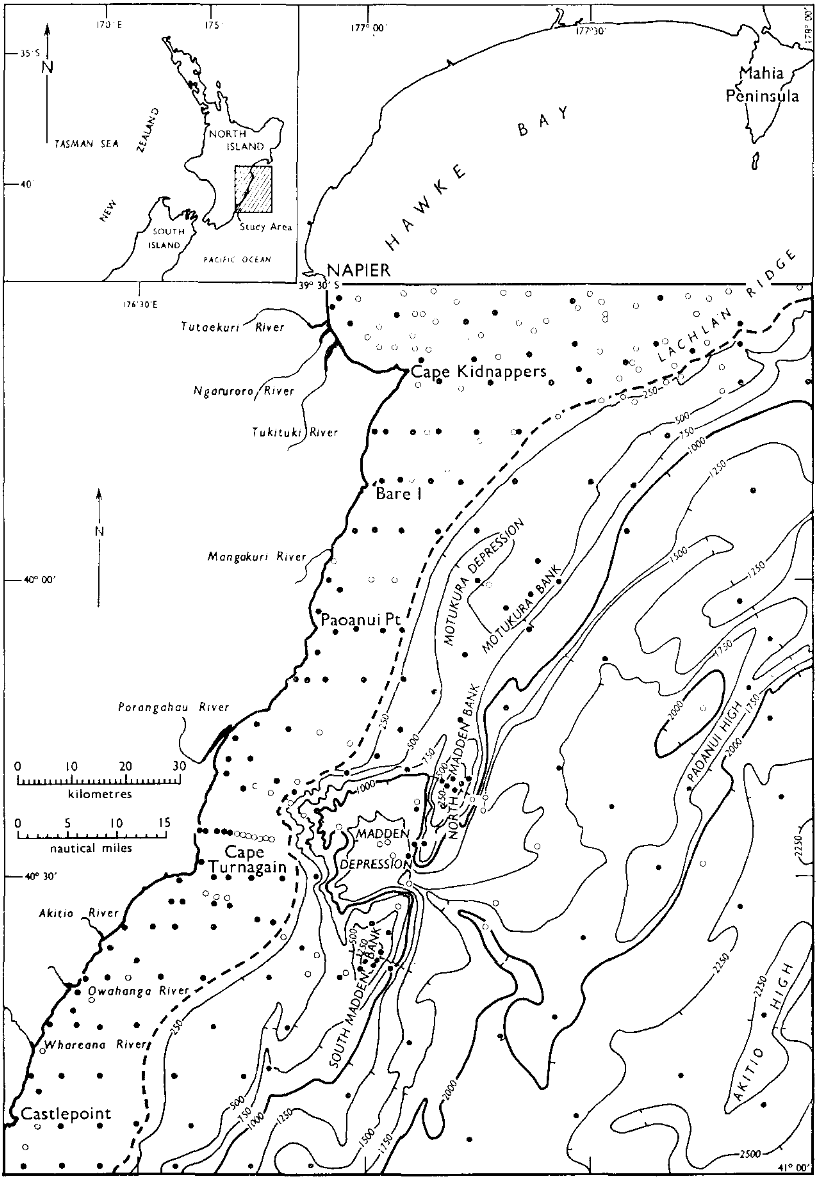


FIG. 1—Location of study area (inset) and position of sediment samples (● = analysed samples; ○ = samples for which only visual descriptions or analyses of sand fraction are available). Bathymetry in metres. Broken line marks the edge of the continental shelf at a depth of about 200 m.

The sizes of sediment grains are quoted as phi (ϕ) notations (Krumbein 1936), which represent log transformations of sizes in millimetres (McManus 1963).

Each sample was steeped for 12 h in dilute hydrogen peroxide, then was washed through a 4ϕ sieve (mesh diameter 64 μm). The coarse fraction was dried and sieved into $\frac{1}{2}$-ϕ classes (with a class interval of half a phi unit) and each class was weighed. The fine fraction was analysed into 1-ϕ classes down to a minimum size of 7ϕ (8 μm) for some samples and to 11ϕ (0.5 μm) for others. In those samples analysed to 11ϕ the cumulative curves between 7ϕ and 11ϕ are similar to curves produced by assuming an arithmetical decrease in class weights between 7ϕ and 14ϕ (Fig. 2). Therefore, in all samples the weight of the residue either finer than 7ϕ or finer than 11ϕ was apportioned into 1-ϕ classes in such a way that the class weights decreased arithmetically to 14ϕ (Fig. 2).

GRAIN-SIZE NOMENCLATURE AND SEDIMENT CLASSIFICATION

Geologists usually use the grain-size nomenclature proposed by Wentworth (1922), which is inconvenient for two reasons: the boundary between silt and clay is set unrealistically at 8ϕ (4 μm), and the nomenclature of grains coarser than sand is unnecessarily complex.

Geologists have not justified their choice of 8ϕ as the silt-clay boundary, but soil scientists have given cogent reasons for adopting 9ϕ as the silt-clay boundary (Whiteside *et al.* 1967). Indeed, since as long ago as 1936 (Shaw & Alexander 1936, Truog *et al.* 1936a and b), soil scientists have taken 9ϕ as the boundary that best separates physically and chemically reactive clays from relatively inert silts. Recently, Grim (1968, p. 2), a clay mineralogist, noted that naturally occurring clay minerals are rarely larger than 9ϕ and non-clay minerals are not usually smaller than 9–10ϕ; he concludes "There is, therefore, a fundamental reason for placing the upper limit of the clay size grade at 2 μ [9ϕ]". It seems desirable for geologists to modify their grain size nomenclature accordingly, and in the following descriptions 9ϕ is taken as the silt-clay boundary instead of Wentworth's 8ϕ.

Grains coarser than sand are described according to the simplified classification shown in Fig. 3. Wentworth's (1922) grade terms granule and cobble were restricted to inconveniently small groups of grains and are therefore abandoned. Granule is included in the pebble size-grade and cobbles are included with boulders.

The boulder-pebble boundary and the sand-silt boundary correspond closely to the practical upper and lower limits of sieving. The sand-silt boundary and the silt-clay boundary are close to the practical limits of pipette analysis. The proposed classification has five size grades, each of 5-ϕ classes, which can be divided in the same way; it is simple, logical and easy to remember and conforms to normal English usage.

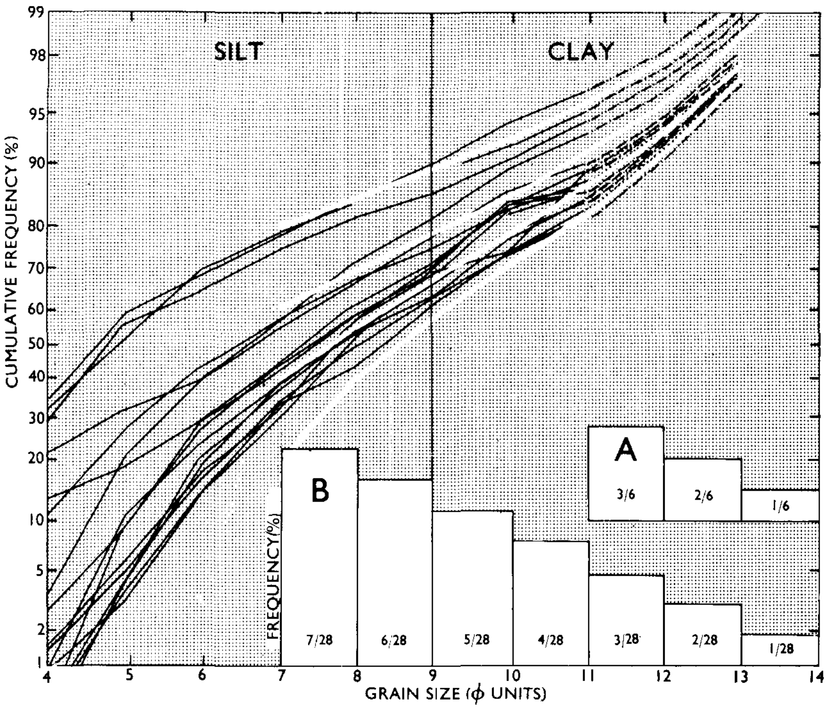


FIG. 2—Plots of cumulative frequency (% by weight finer than a given size) against grain size. Black lines are plots of 16 samples analysed to 11 ϕ, from the continental shelf and slope between Napier and Castlepoint, New Zealand. Plots are extrapolated (broken lines) by dividing residue finer than 11 ϕ into proportions shown in histogram A. White lines show extrapolations for some other samples analysed to 7 ϕ (not shown), the residue finer than 7 ϕ being divided into the proportions shown in histogram B.

It may be used to describe the size of any sedimentary particle or group of particles, e.g., a large pebble-sized brachiopod, coarse silt-sized magnetite.

Sediments are classified by using the same terms that are applied to grain-size classes. Most classifications are based on the proportions by weight of gravel, sand, silt and clay in the sediment. The widely used classification of Folk (*see* Folk 1954, 1959; Folk *et al.* 1970) is employed in this account, with slight modification to avoid use of "mud" and "muddy" as precisely defined terms (Fig. 4).

REGIONAL TRENDS

A sediment chart (Fig. 5) was constructed by contouring, at Folk's (1954) sediment class boundaries:

SIZE: metric units	SIZE: φ units	GRAIN-SIZE NOMENCLATURE: general			GRAIN-SIZE NOMENCLATURE: calcareous
		ex. l.	BOULDER	GRAVEL (G)	
2m	−11				
		v.l.	BOULDER	GRAVEL (G)	
1m	−10				
		l.	BOULDER	GRAVEL (G)	
518mm	−9				
		m.	BOULDER	GRAVEL (G)	
256mm	−8				
		s.	BOULDER	GRAVEL (G)	
128mm	−7				
		v.s.	BOULDER	GRAVEL (G)	ex. c. CALCIRUDITE (R)
64mm	−6				
		v.l.	PEBBLE	GRAVEL (G)	v.c. CALCIRUDITE (R)
32mm	−5				
		l.	PEBBLE	GRAVEL (G)	c. CALCIRUDITE (R)
16mm	−4				
		m.	PEBBLE	GRAVEL (G)	m. CALCIRUDITE (R)
8mm	−3				
		s.	PEBBLE	GRAVEL (G)	f. CALCIRUDITE (R)
4mm	−2				
		v.s.	PEBBLE	GRAVEL (G)	v.f. CALCIRUDITE (R)
2mm	−1				
		v.c.	SAND (S)		v.c. CALCARENITE (A)
1mm	0				
		c.	SAND (S)		c. CALCARENITE (A)
500µm	1				
		m.	SAND (S)		m. CALCARENITE (A)
250µm	2				
		f.	SAND (S)		f. CALCARENITE (A)
125µm	3				
		v.f.	SAND (S)		v.f. CALCARENITE (A)
63µm	4				
		v.c.	SILT (Z)	MUD (M)	v.c. CALCILUTITE (L)
31µm	5				
		c.	SILT (Z)	MUD (M)	c. CALCILUTITE (L)
16µm	6				
		m.	SILT (Z)	MUD (M)	m. CALCILUTITE (L)
8µm	7				
		f.	SILT (Z)	MUD (M)	f. CALCILUTITE (L)
4µm	8				
		v.f.	SILT (Z)	MUD (M)	v.f. CALCILUTITE (L)
2µm	9				
		v.c.	CLAY (C)	MUD (M)	ex. f. CALCILUTITE (L)
1µm	10				
		c.	CLAY (C)	MUD (M)	
488nm	11				
		m.	CLAY (C)	MUD (M)	
244nm	12				
		f.	CLAY (C)	MUD (M)	
122nm	13				
		v.f.	CLAY (C)	MUD (M)	
61nm	14				
		ex. f.	CLAY (C)	MUD (M)	

FIG. 3—Nomenclature for grains of various sizes including nomenclature for carbonate grains. (c. = coarse; m. = medium; f. = fine; l. = large; s. = small; v. = very; ex. = extremely.)

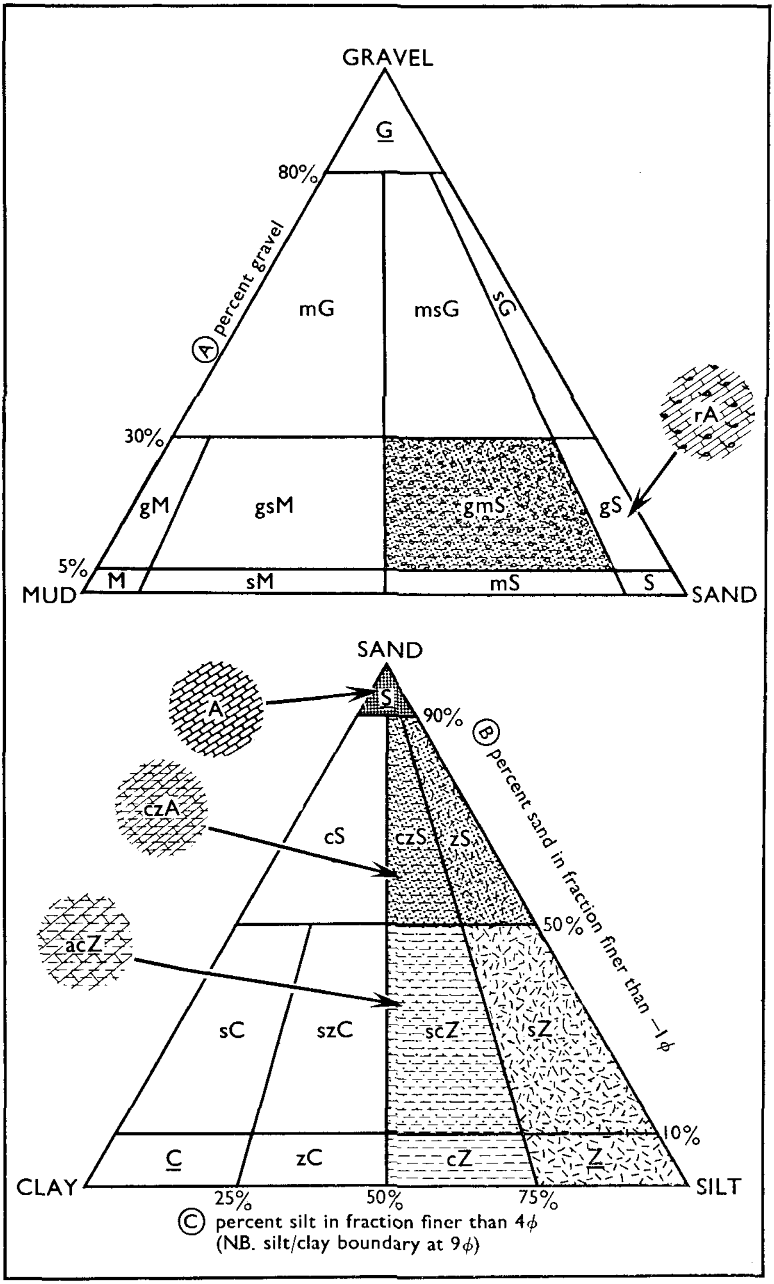


FIG. 4—Sediment classification based on the proportions of gravel (G), sand (S), silt (Z), and clay (C). Lower case letters are adjectival equivalents, e.g., g = gravelly, s = sandy. Textures represent sediments occurring in the study area, those in circles outside diagrams represent those having more than 50% calcium carbonate either in the sand fraction (A = Calcarenite, a = calcarenitic) or in the gravel fraction (r = calciruditic).

(1) the percentage of gravel,
(2) the percentage of sand in the fraction finer than -1ϕ,
(3) the percentage of silt in the mud fraction, and
(4) the percentage of calcium carbonate in the sand fraction.

The spaces between intersecting contour systems, indicated by different textures on the chart, represent the lithologies defined in Fig. 4. In general, the sediment ranges from sand near the shore to clayey silt on the outer continental shelf and continental slope. Patches of coarse sediment occur on some of the offshore ridges.

On the continental shelf the sand fraction (Fig. 6) is composed mainly of detrital grains. On the continental slope in the northern part of the area the sand fraction is mainly pumice and unworn volcanic glass. And on the continental slope in the southern part of the area the sand fraction is mainly planktonic foraminifera. Exceptions occur on the continental shelf of central Hawke Bay where volcanic ash predominates and on the offshore banks where the sand fraction includes benthonic foraminifera, comminuted shells, and coral debris.

The facies chart (Fig. 7) shows the main sediment types grouped according to grain size and mineralogy of the sand fraction. Some anomalously coarse sediments on the continental shelf and upper slope have predominantly detrital sand fractions; others on the continental slope ridges have a predominantly non-detrital sand fraction.

The percentage of clay in the sediments ranges from zero near the shore to almost 40% on the lower continental slope, but the mineralogy of the clay fraction shows no obvious trends (Fig. 8). The proportions of clay minerals in samples from the upper slope ridges were given by Seed (1968). The other samples were analysed by Dr G. G. Claridge, N.Z. Soil Bureau, DSIR, Lower Hutt, using standard X-ray diffraction techniques (Fieldes 1968). Illite, the most abundant clay mineral, constitutes 30–50% of the clay fraction, the montmorillonite content ranges from 0–40%, and chlorite and vermiculite are present in most samples. Clay-sized quartz and feldspar are present in a single sample from off the mouth of the Owahanga River, and amorphous material forms 50% of the clay fraction of a sample from the Madden Depression.

Frequency curves (Fig. 9), which describe the grain-size distribution of the whole sediment, were derived from cumulative curves by the method described by Krumbein (1934). They show that the modal grain size and the mean grain size decrease gradually offshore, that the dispersion increases offshore, and that sediments on the outer shelf and upper slope have a conspicuous tail of finer material. Most samples are bimodal, with a secondary mode of fine silt or clay size. Each frequency curve can be defined by four statistical parameters, graphic mean, inclusive graphic standard deviation, inclusive skewness, and graphic kurtosis (Folk & Ward 1957). The parameters are also derived from cumulative curves. Mean and standard deviation are

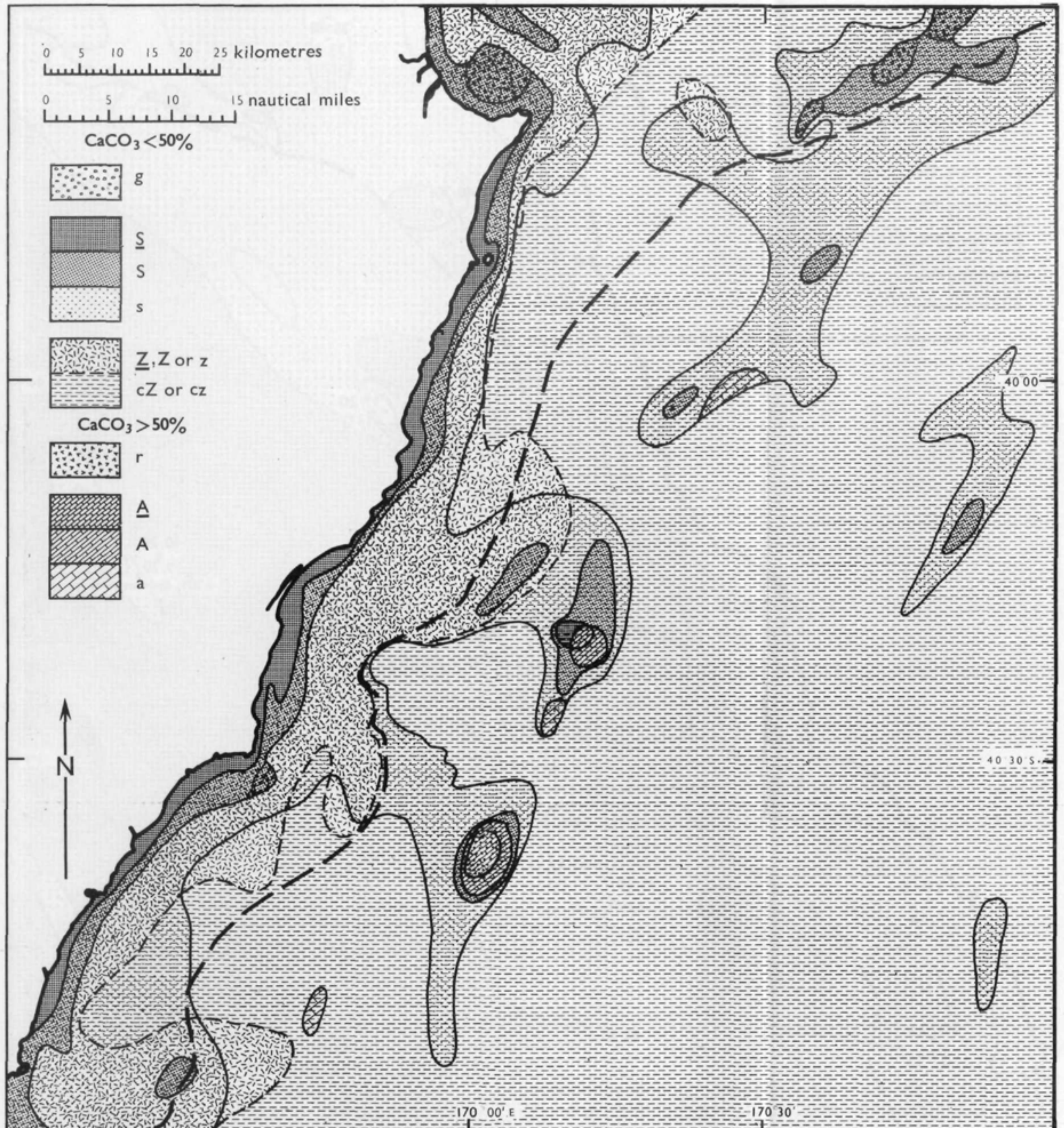


FIG. 5—Distribution of sediments on the continental shelf and slope between Napier and Castlepoint, New Zealand. Contours are at 5% gravel; 90%, 50%, and 10% sand in the $< -1\ \phi$ fraction (thin lines), and at 75% silt in the mud fraction (thin broken line). Areas between contours are textured, and overlapping textures indicate sediment type. Fractions with more than 50% carbonate are textured differently from those with less than 50% carbonate. Thick broken line is at shelf break. (g=gravelly, S̲ = > 90% sand in $< -1\ \phi$; S=50-90% sand in $< -1\ \phi$; s=sandy; Z̲, Z, or z=silt or silty, >75% silt in mud; cZ or cz=clayey silt or clayey silty, 50-75% silt in mud; r=calciruditic, A̲ = >90% calcarenite in $< -1\ \phi$; A= 50-90% calcarenite in $< -1\ \phi$; a=calcarenitic.

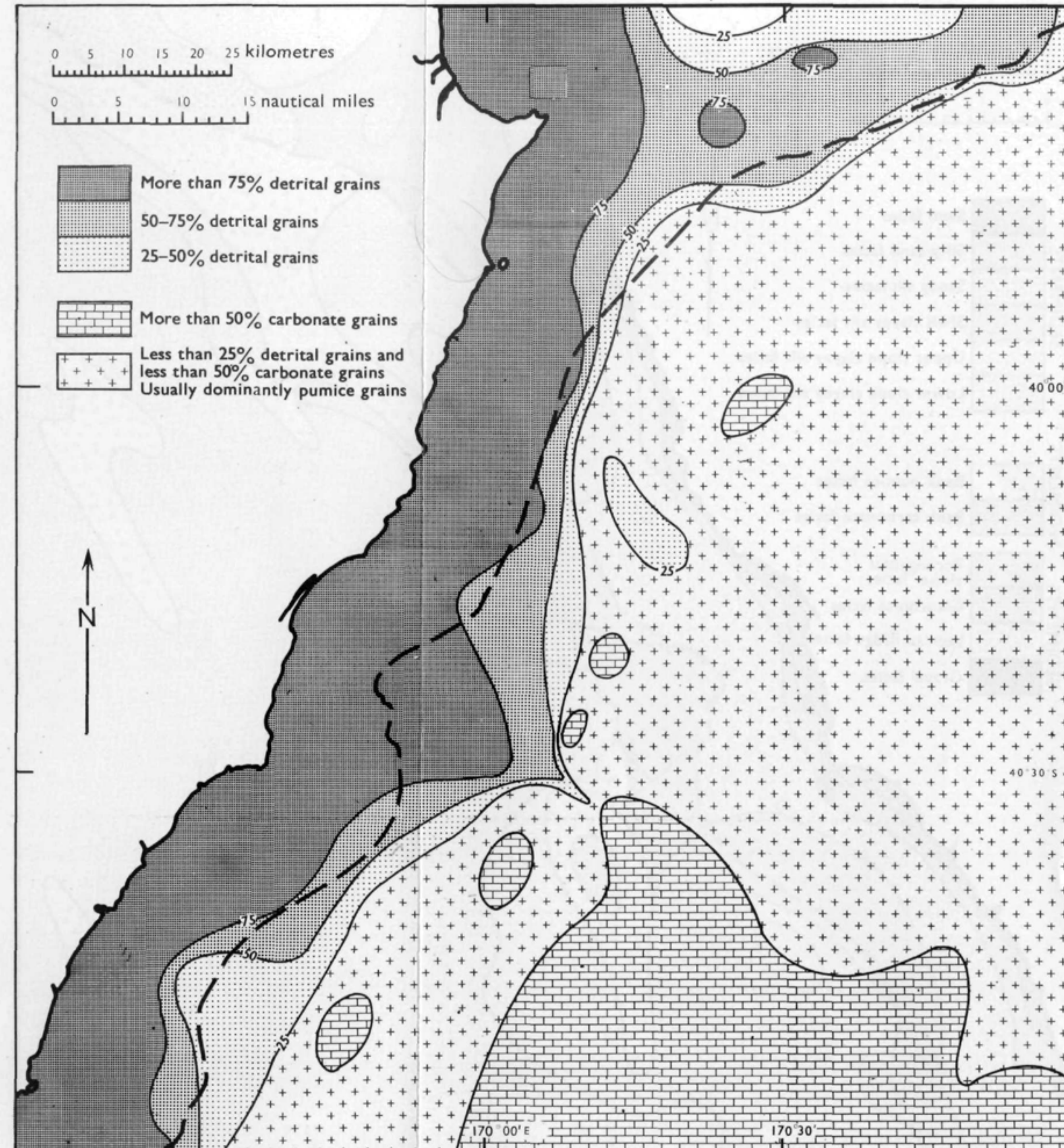


FIG. 6—Regional variation (% by weight) of sand-fraction mineralogy in sediments from the continental shelf and slope between Napier and Castlepoint, New Zealand. Data from Hawke Bay by Pantin (1966). Broken line is at shelf break.

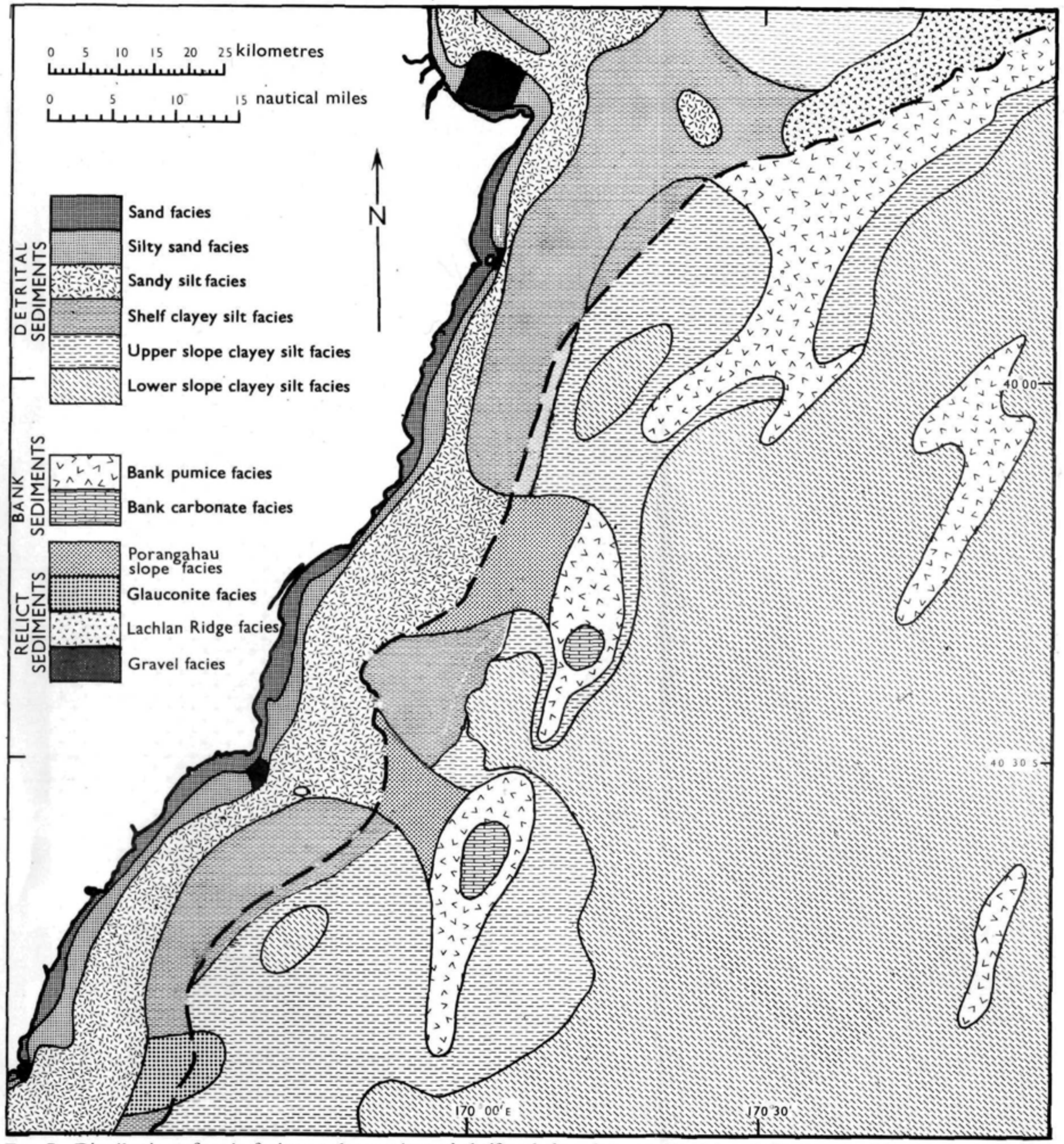


Fig. 7—Distribution of main facies on the continental shelf and slope between Napier and Castlepoint, New Zealand. Broken line is at shelf break.

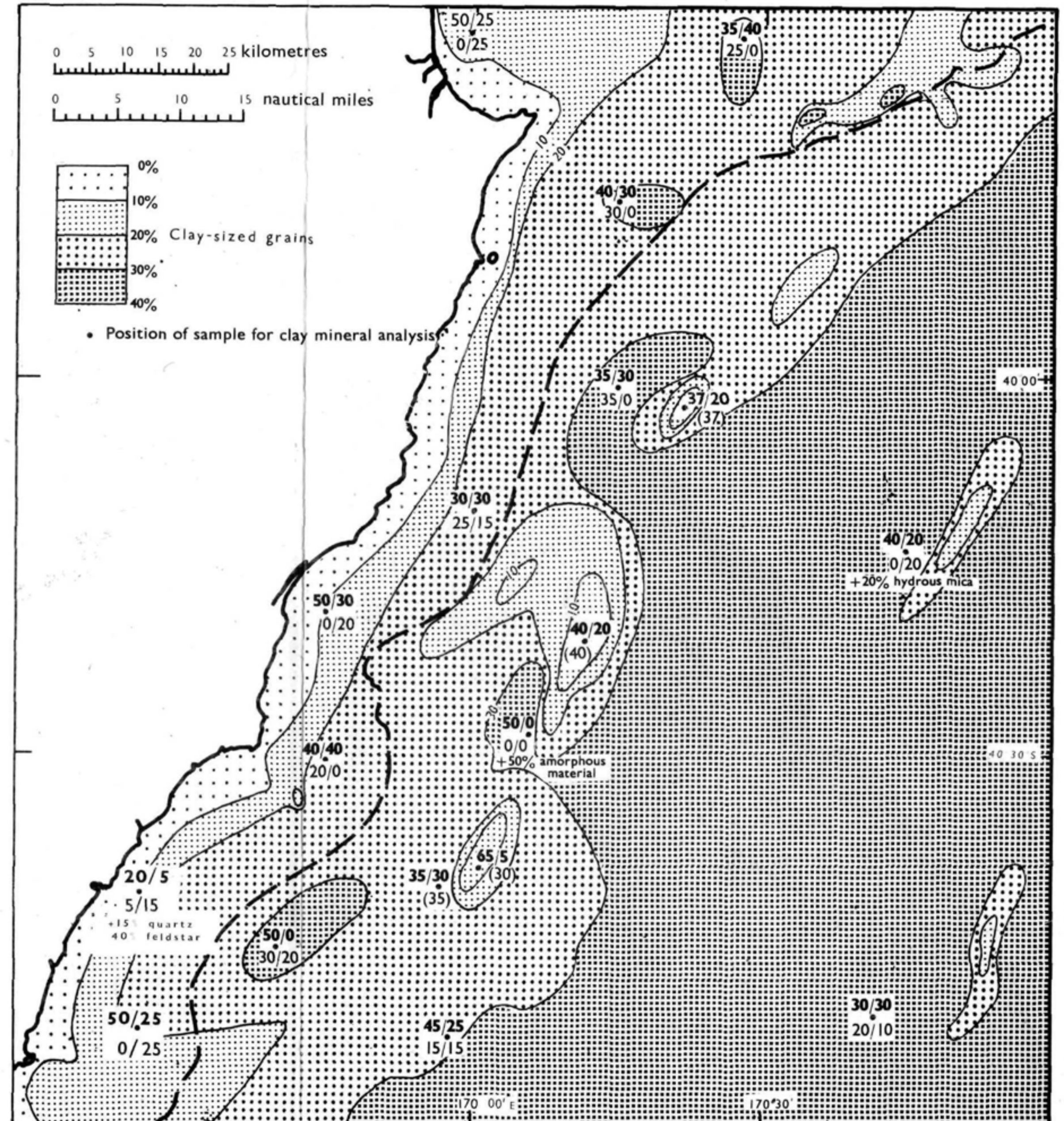


Fig. 8—Regional variation in percentage of clay-sized grains and results of 14 clay mineral analyses by G. G. Claridge, Soil Bureau, DSIR (pers. comm.) and four clay mineral analyses by Seed (1968). In bold type above each sample position is the percentage of illite (on the left) and montmorillonite (on the right); in light type below each sample position is either the percentage of chlorite and vermiculite analysed by G. G. Claridge, or (in a bracket) the combined percentage of chlorite and vermiculite analysed by Seed (1968). Broken line is at the shelf break.

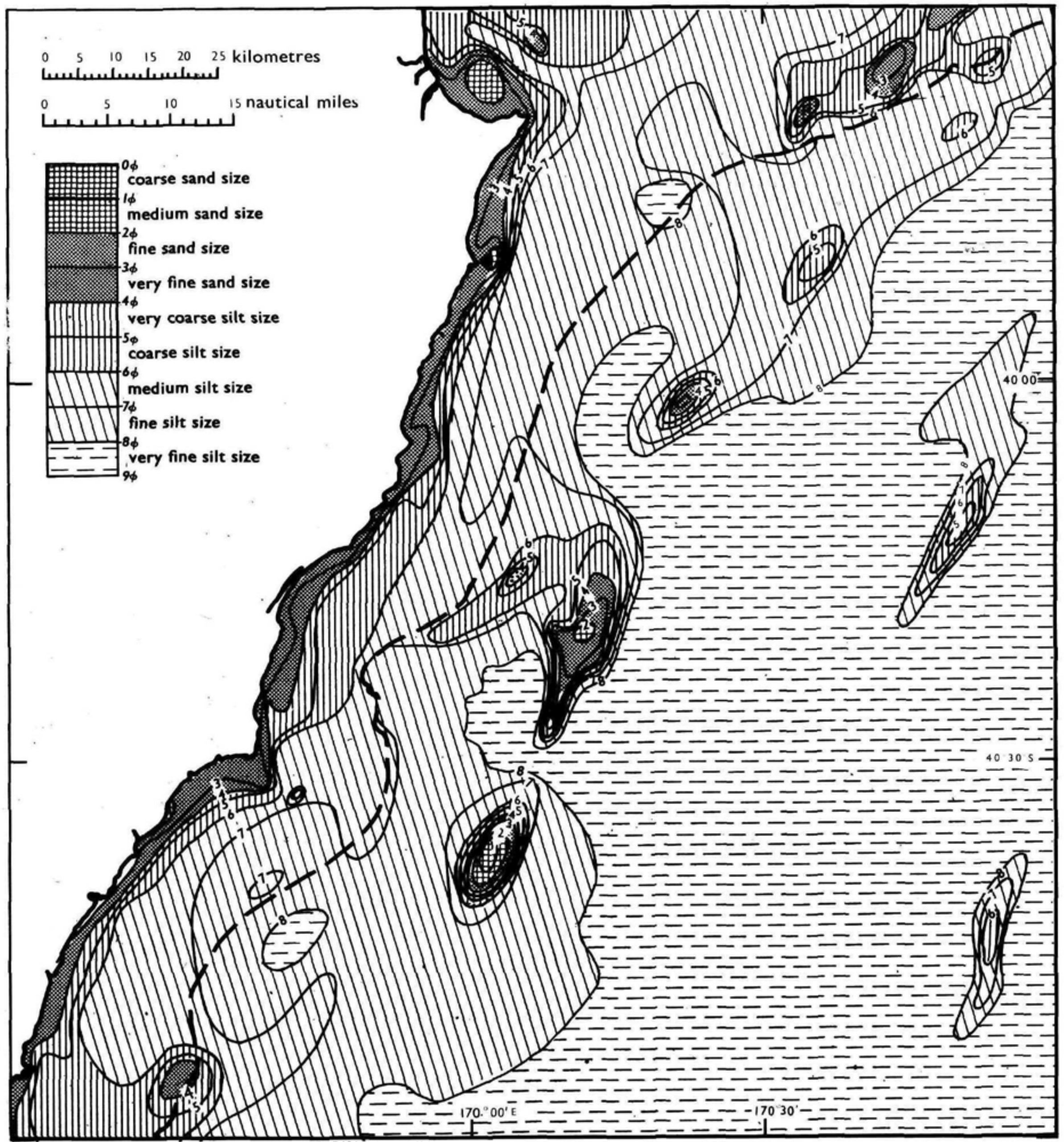


Fig. 10—Regional variation in mean grain size of sediments from the seabed between Napier and Castlepoint, New Zealand. Broken line is at shelf break.

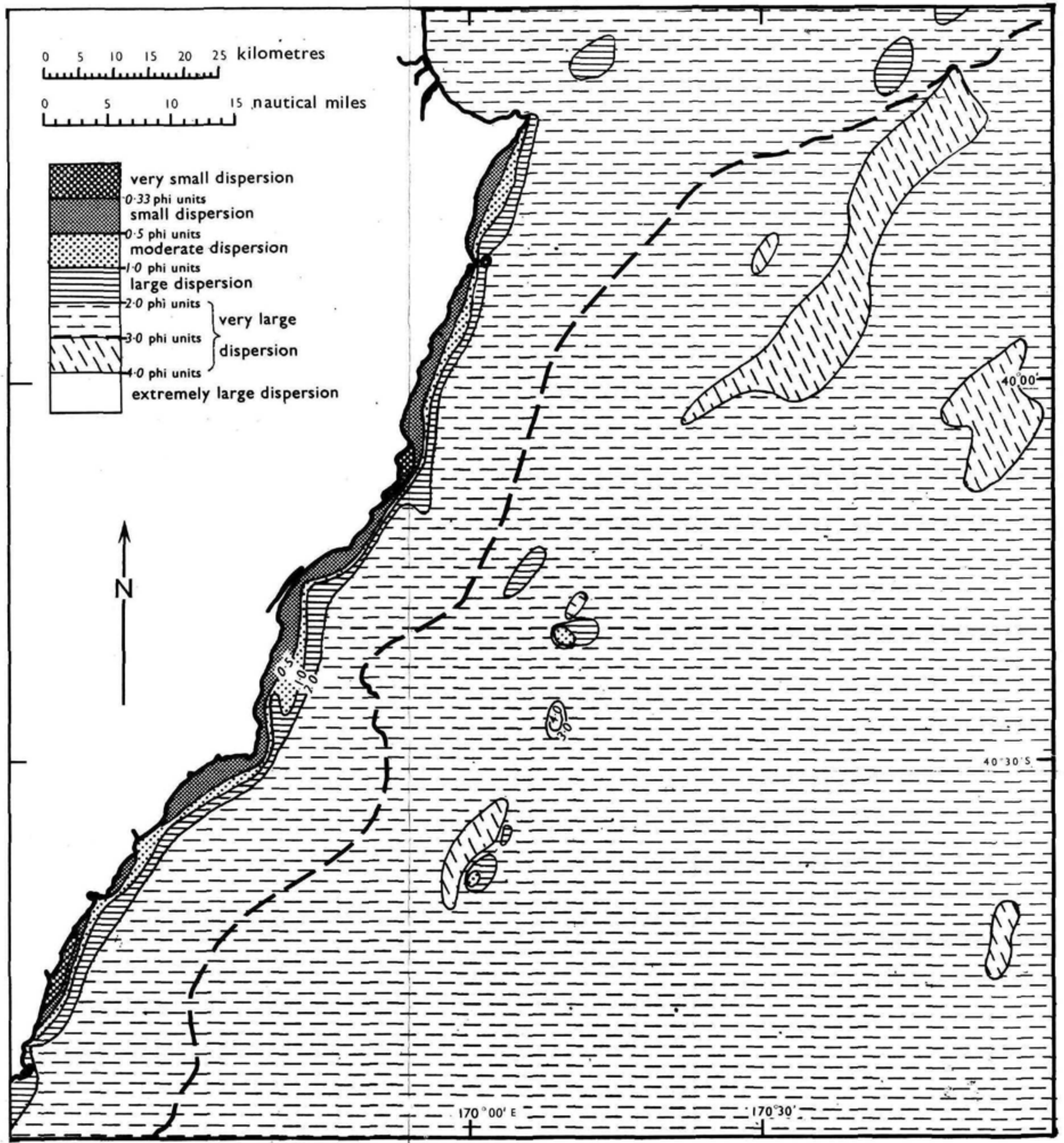


Fig. 11—Regional variation in standard deviation of sediments from the seabed between Napier and Castlepoint, New Zealand. Broken line is at shelf break.

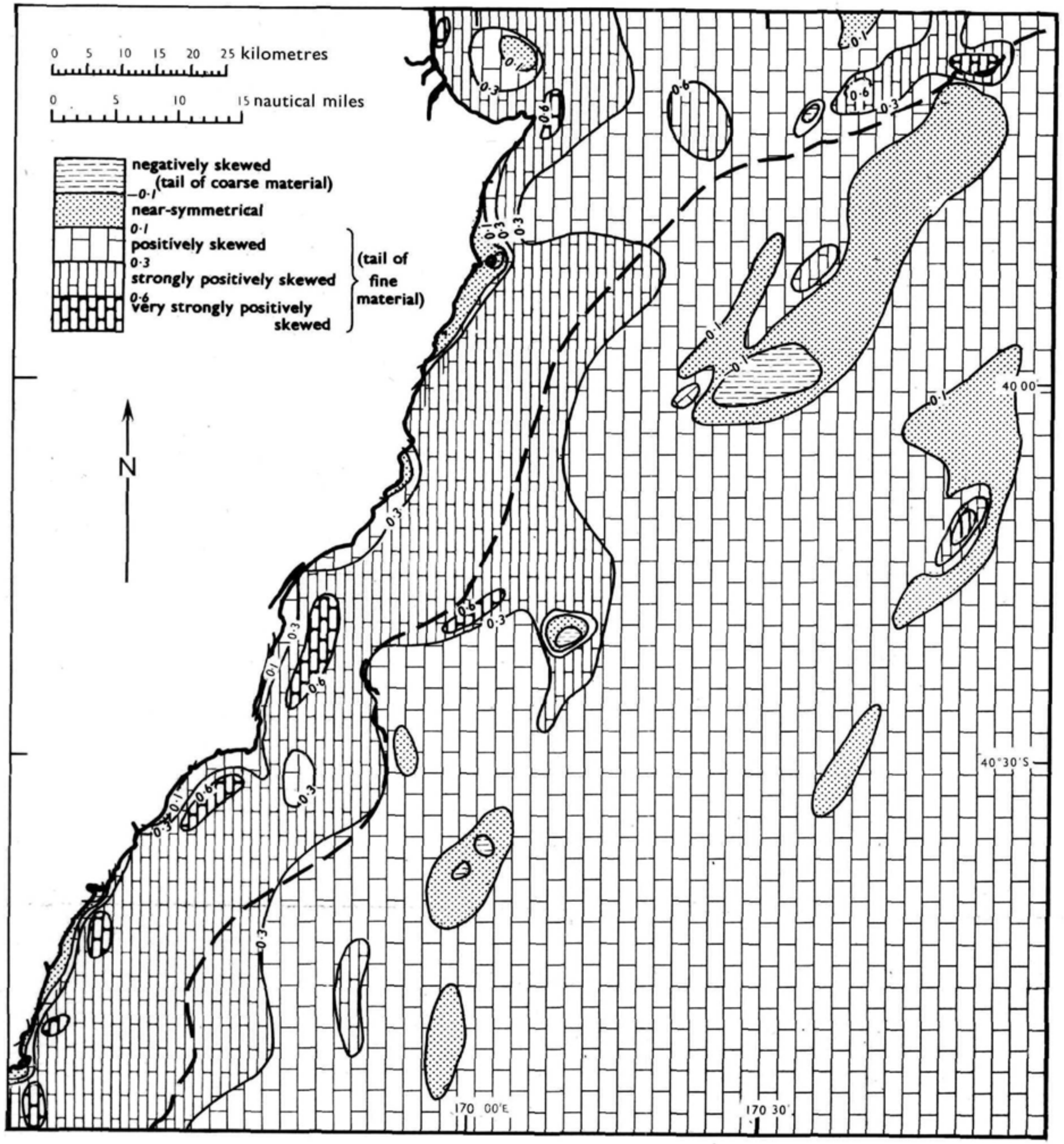


FIG. 12—Regional variation in skewness of sediments from the seabed between Napier and Castlepoint, New Zealand. Broken line is at shelf break.

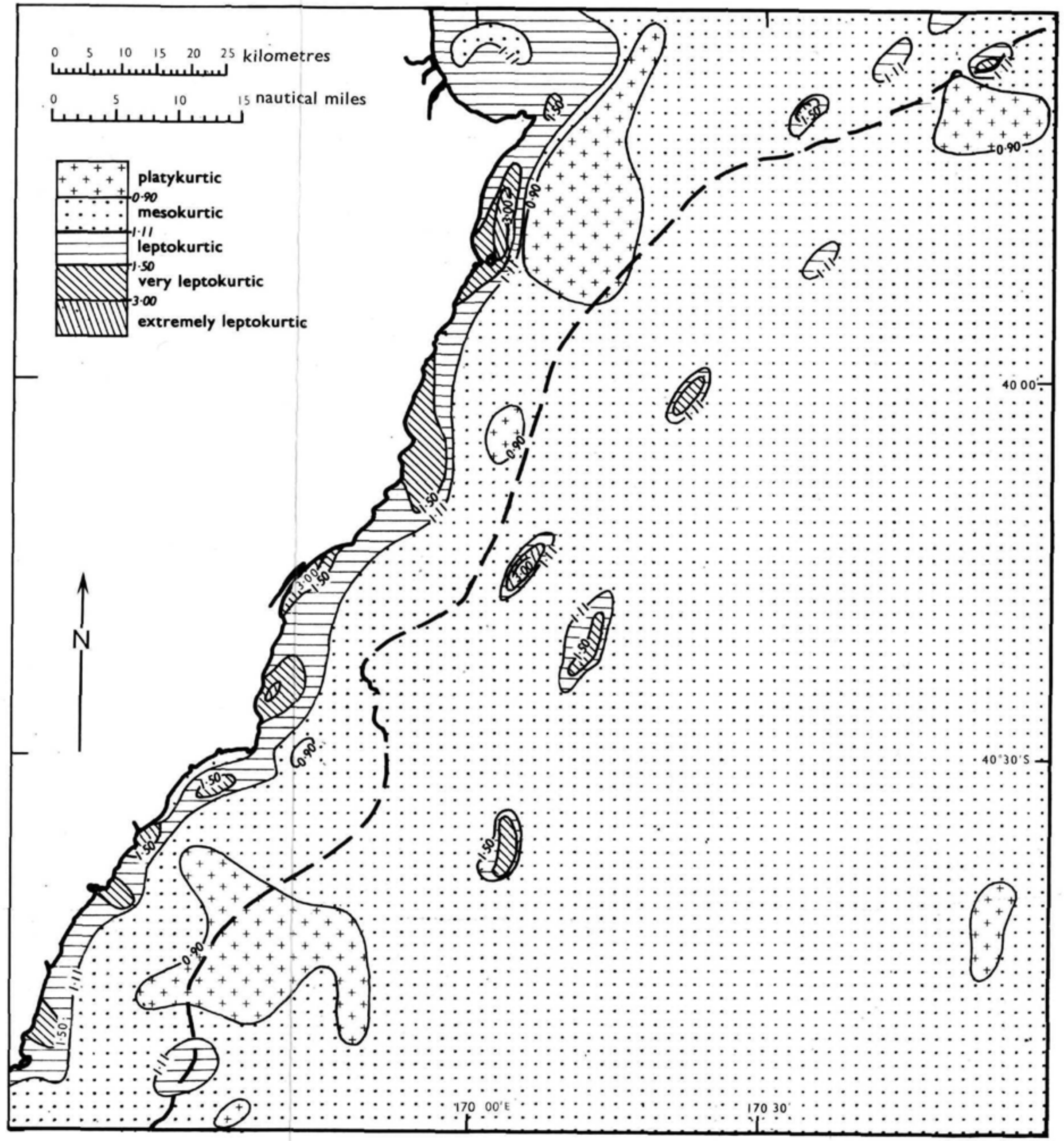


FIG. 13—Regional variation in kurtosis of sediments from the seabed between Napier and Castlepoint, New Zealand. Broken line is at shelf break.

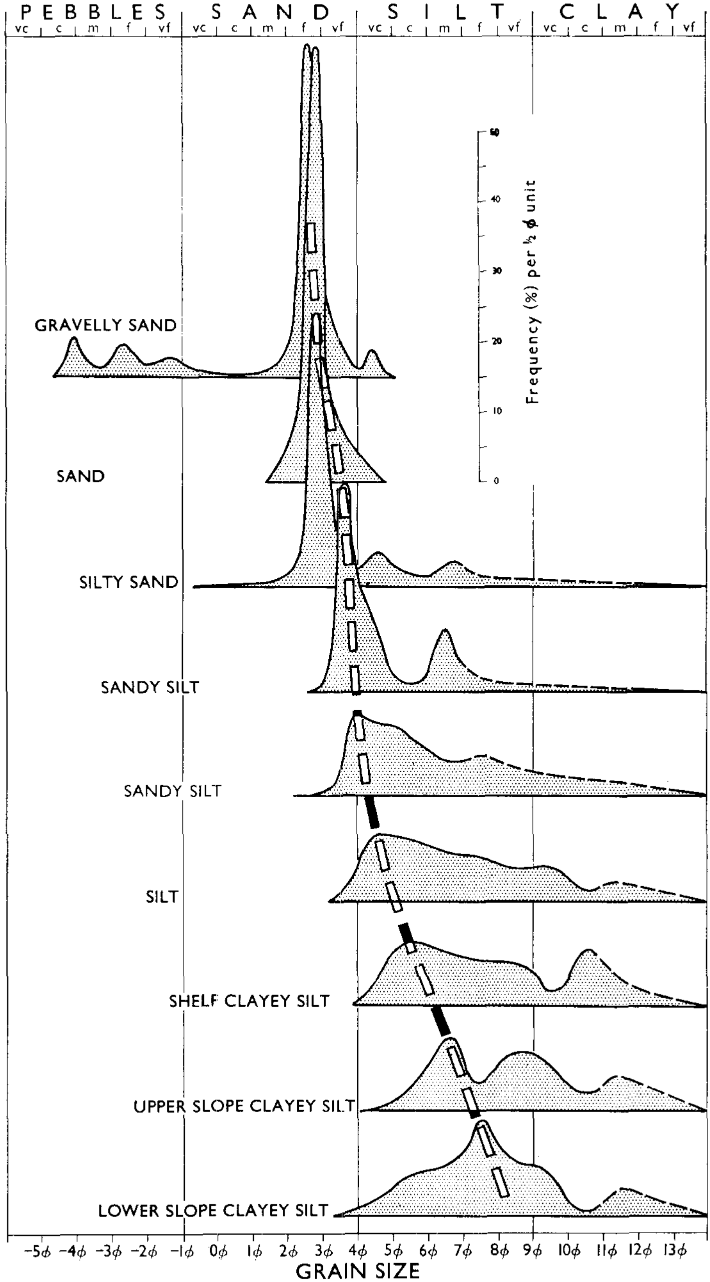


FIG. 9—Frequency curves of nine samples from the outer continental shelf and continental slope between Napier and Castlepoint, New Zealand. Fine broken lines bound the extrapolated portion of each curve. Thick broken line links the main modes.

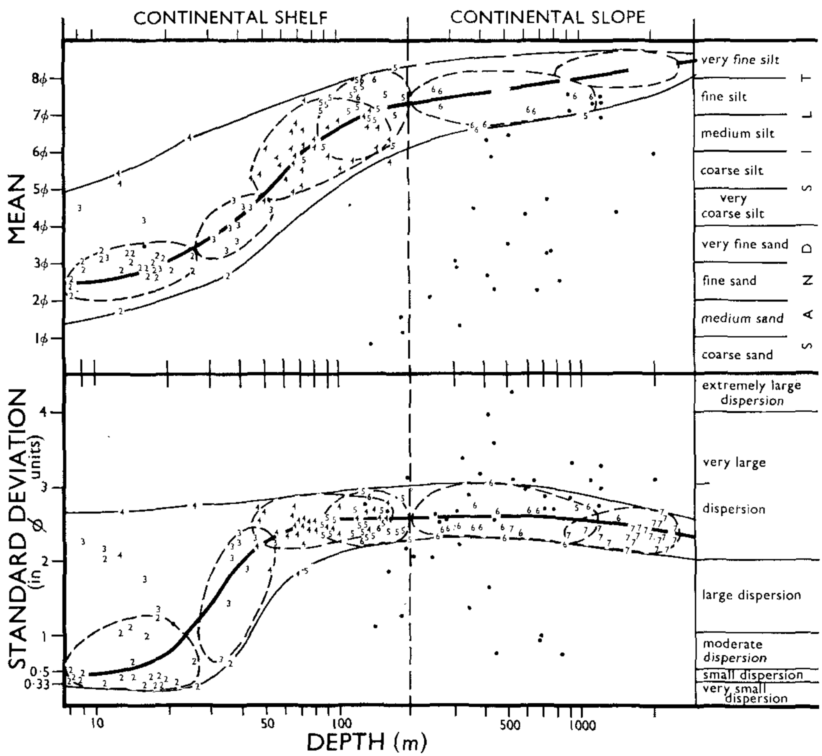
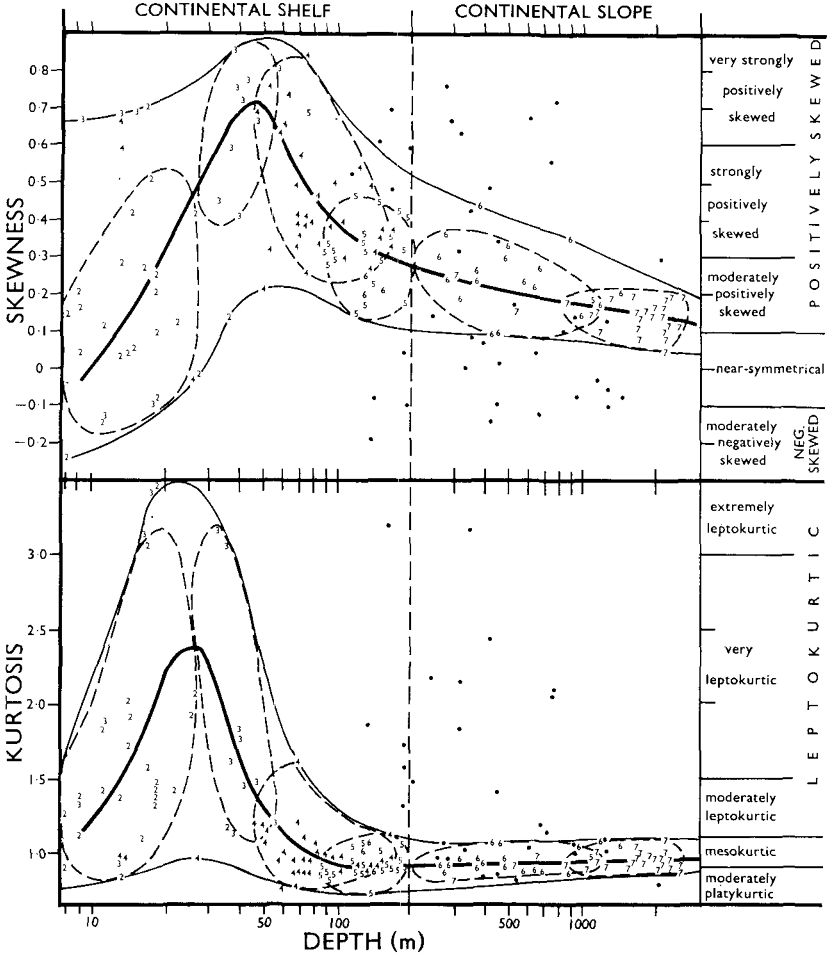


FIG. 14—(*Above & opposite*). Plots of depth from which samples were collected against grain-size parameters. 2 = sand facies, 3 = silty sand facies, 4 = sandy silt facies, 5 = shelf clayey silt facies, 6 = upper slope clayey silt facies, 7 = lower slope clayey silt facies, ● = relict and bank sediments. Plot lines (bold) are drawn through numbers by eye. Most of samples from each facies are grouped within broken lines. Vertical broken line is at 200 m, about the depth of the shelf edge.

measures, respectively, of the central size and the spread of the distribution. Skewness and kurtosis are measures of the departure from a Gaussian (normal) distribution. The parameters were computed using a linear interpolation of points on a plot of cumulative frequency against grain size in ϕ units. Each parameter shows marked changes with distance from shore (Figs. 10–13, *between pages 190 and 191*) and depth (Fig. 14).

Mean grain size decreases rapidly seawards on the continental shelf and slowly seawards on the continental slope (*see* Figs 10, 14). Sediments with the same mean grain size as sediments on the inner continental shelf occur on the crests of continental slope ridges.

Standard deviation is a measure of dispersion. It does not necessarily measure the degree to which the sediment has been sorted, and may



more accurately be said to measure the amount that the sediment has been mixed (Spencer 1963). It is debatable whether a very skewed sand with a moderate dispersion is better sorted than a near symmetrical clay with a large dispersion. Dispersion increases rapidly seawards on the inner continental shelf and has about the same value at most places to seaward of the inner continental shelf.

Skewness values are positive, indicating a tail of fine grains, at most places in the study area (*see* Figs 12, 14). Sediments are most strongly positively skewed on the middle continental shelf off some rivers. Nearly symmetrical and negatively skewed sediments are recorded only from close to the shore and from some continental slope banks.

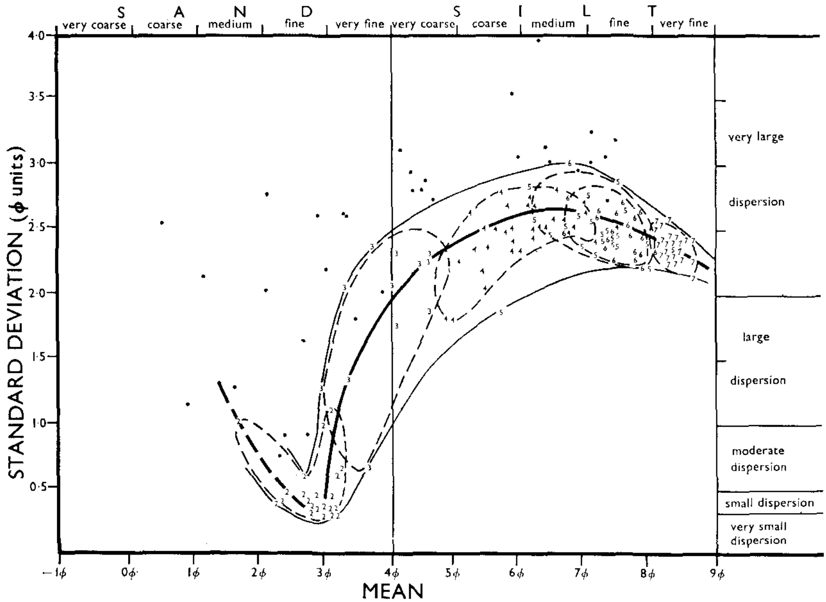
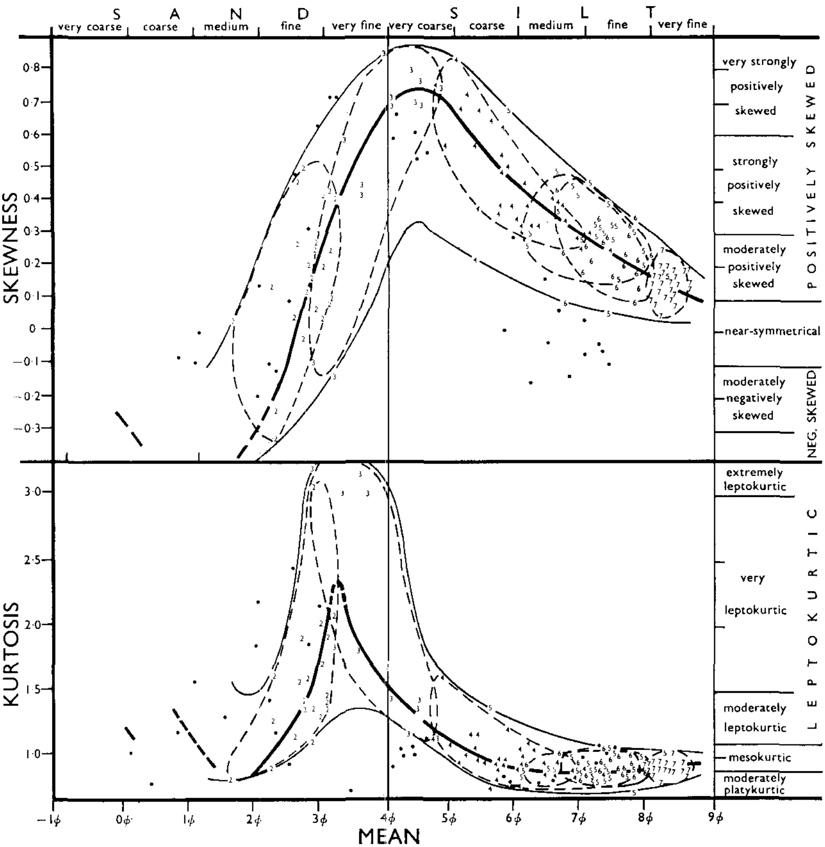


FIG. 15—Plots of mean grain size against standard deviation (*above*), skewness, and kurtosis (*opposite*) of samples from the seabed between Napier and Castlepoint, New Zealand. Vertical line is at 64 μm. 1 = gravelly sediment, 2 = sandy facies, 3 = silty sand facies, 4 = sandy silt facies, 5 = shelf clayey silt facies, 6 = upper slope clayey silt facies, 7 = lower slope clayey silt facies. Plot lines (bold) are drawn through numbers by eye; bold broken lines indicate a wide range of values for samples. Most samples from each facies are enclosed within broken lines.

Mesokurtic sediments cover most of the study area (*see* Figs 13, 14). Leptokurtic sediments, which usually have small amounts of a grain type that is either much smaller or much larger than most of the grains, occur near the coast and on the offshore ridges. Platykurtic sediments, which are usually bimodal with nearly equal proportions of two grain types, occur at some places on the middle and outer continental shelf and on some continental slope ridges.

The changes in the parameters from shore to upper continental slope are similar in many ways to the changes produced by increasing the proportion of a fine fraction in a theoretical mixture of fine and coarse fractions (Folk & Ward 1957). Near the shore, fine sand represents a coarse fraction with a grain-size distribution that is almost normal (Fig. 15). Small amounts of a fine (silt) fraction increase the dispersion of the fine sand and make it positively skewed and leptokurtic. The most leptokurtic sediments are fine sands containing about 10% of the fine fraction; the most positively skewed sediments contain about 20% of the fine fraction. The sediments with the largest dispersion are conspicuously bimodal and contain about equal proportions of



coarse and fine fractions. Plots of standard deviation and kurtosis against skewness are circular (Fig. 16), so that a three-dimensional plot of mean, standard deviation, and skewness is helical. The sediments in the study area differ from the theoretical example of Folk & Ward (1957) in that the two fractions have different dispersions and the mode of each fraction is different in different places. The mode of the coarse fraction becomes finer seawards more rapidly than the mode of the fine fraction, so that on the continental slope the modes of the coarse and the fine fractions tend to the same value, and the frequency curve becomes almost normal.

Thus, in general, detrital sediments decrease in grain size seawards, as would be expected. However, there are patches of coarse sediment that are surrounded by fine sediment. Because coarse detrital grains are not normally transported to seaward of an area where fine detrital grains are settling, the coarse sediments may be either relict and lag deposits, or non-detrital deposits. The coarse sediments on the continental shelf and on the uppermost continental slope are considered to be relict sediments because they contain a sand and gravel fraction that is mainly of detrital origin. The coarse sediments on the continental slope bank are considered to be non-detrital because they contain a sand and gravel fraction that is predominantly of non-detrital grains, such as volcanic ash, foraminiferal tests, glauconite, brachiopods, molluscs, bryozoa, and corals.

SEDIMENTARY FACIES

MODERN DETRITAL SEDIMENTS (*See* Fig. 7)

Sand Facies*

Classification: sand (fine sand).
Size grades: **gravel < 5%, sand > 90% of sand and mud,** silt 77–89% of mud.
Sand minerals: **detrital > 95%.**
Mode: 2.5–3.0 ϕ.
Parameters†: M_z 2.0–3.2ϕ, σ_I 0.3–1.1ϕ units, Sk_I −0.2 to +0.5, K_G 0.9–3.0.
To shore: inner 0 km, outer < 4 km.
Depth: inshore 0 m, offshore < 30 m.

At most places, sand-facies sediments consist of an almost normal population of fine sand size, with a small dispersion. Off most river mouths, the sand contains sufficient fine silt and clay to make it very leptokurtic. Off some river mouths a larger proportion of fine grains also makes the sand strongly positively skewed. Off the Porangahau River, sand with almost 10% mud has a large dispersion, is very strongly positively skewed, and is extremely leptokurtic.

Silty Sand Facies

Classification: silty sand (very coarse silty fine or very fine sand).
Size grades: gravel < 1%, **sand 50–90% of sand and mud,** silt 76–89% of mud.
Sand minerals: **detrital > 90%.**
Mode: 2.8–3.5 ϕ.
Parameters: M_z 3.0–4.8 ϕ, σ_I 0.7–2.4 ϕ units, Sk_I 0.4–0.9, K_G 1.2–3.1.
To shore: inner 0–4 km, outer 1–14 km.
Depth: inshore 0–40 m, offshore 10–60 m.

Silty sands are most strongly skewed and most leptokurtic near the rivers south of Cape Turnagain, 15–20 km south of the Porangahau River, and off Cape Kidnappers, which is 20 km east of the southern Hawke Bay river mouths (*see* Fig. 1). Silty sands occur at shallow depths in southern Hawke Bay, which is sheltered from southerly swells (Gibb 1962).

Sandy Silt Facies

Classification: sandy silt and sandy clayey silt (very fine sandy very coarse silt).
Size grades: gravel < 0.5%, **sand 10–50% of sand and mud,** silt 72–88% of mud.

*Data given at beginning of each facies description apply to at least 90% of samples. Data in bold type define each facies.
†After Folk & Ward (1957).

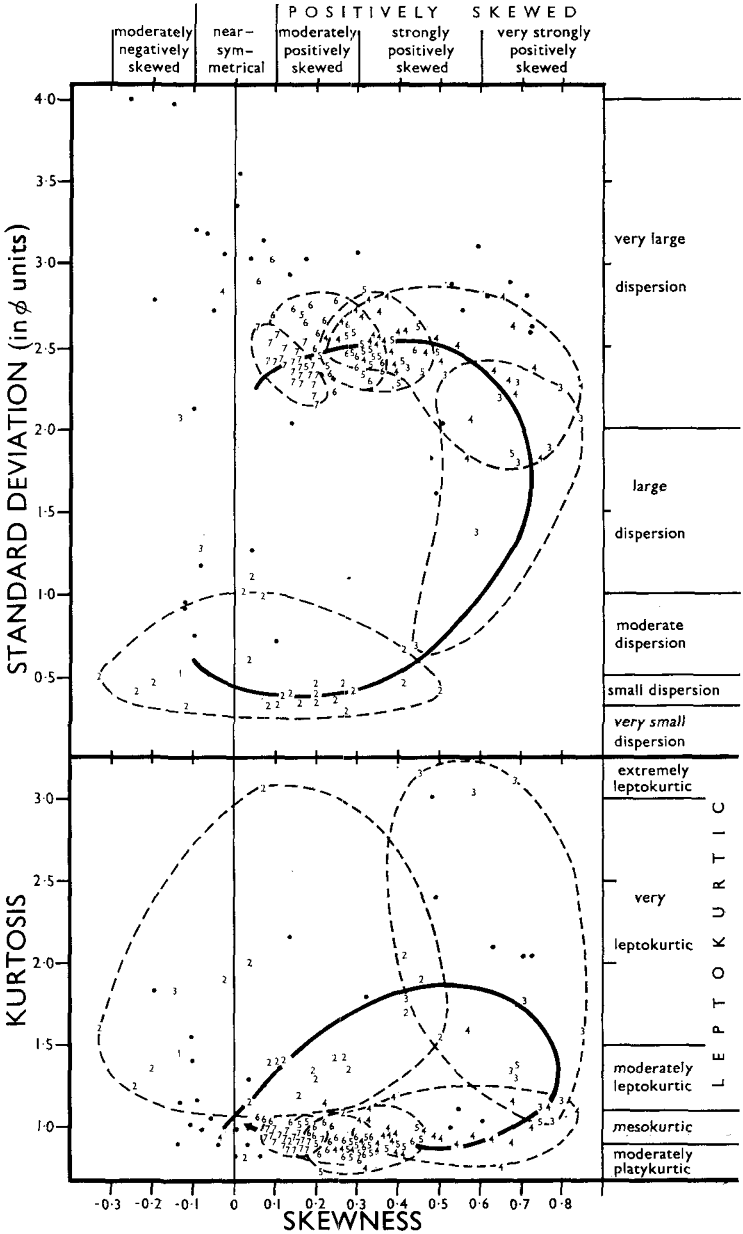


FIG. 16—Plots of skewness against standard deviation and kurtosis of samples from the seabed between Napier and Castlepoint, New Zealand. Vertical line is at zero skewness. 1 = gravelly sediment, 2 = sand facies, 3 = silty sand facies, 4 = sandy silt facies, 5 = shelf clayey silt facies, 6 = upper slope clayey silt facies, 7 = lower slope clayey silt facies, ● = relict and bank sediments. Plot lines (bold) are drawn through numbers by eye. Most samples from

Sand minerals: **detrital** $>$ **80%**, volcanic $<$ 15%, carbonate $<$ 15%.
Mode: 3.0–4.0 ϕ.
Parameters: M_z 4.7–7.4 ϕ, σ_I 1.8–2.7 ϕ units, Sk_I 0.2–0.8, K_G 0.8–1.6.
To shore: inner 3–10 km, outer 4–30 km.
Depth: inshore 13–60 m, offshore 80–200 m.

Sediments of the sandy silt facies are conspicuously bimodal, with a primary mode of very fine sand size and a secondary mode of medium or fine silt size. They have higher values for dispersion and lower values for kurtosis than most sediments to landward. Samples off the Porangahau River and off some rivers to the south of Cape Kidnappers are extremely strongly positively skewed.

Shelf Clayey-Silt Facies

Classification: silt and clayey silt (mainly clayey coarse or very coarse silt).
Size grades: **sand 0.3–10.0%,** silt 63–77% of mud.
Sand minerals: **detrital 50–85%,** volcanic 10–45%, carbonate 5–30%, glauconite $<$ 5%.
Mode: 4–6 ϕ.
Parameters: M_z 6.1–8.0 ϕ, σ_I 1.9–2.9 ϕ units, Sk_I 0.1–0.5, K_G 0.8–1.1.
To shore: inner 4–30 km, outer 18–50 km.
Depth: inshore 80–160 m, offshore 150–1100 m.

Shelf clayey silts differ from other clayey silts in having a predominance of detrital grains in the sand fraction. At some places they are bimodal, with a secondary mode of fine or very fine silt size. They are generally less strongly skewed than sediments to landward.

Upper Slope Clayey-Silt Facies

Classification: clayey silt (clayey coarse or medium silt).
Size grades: **sand 0.4–10.0%,** silt 63–73% of mud.
Sand minerals: **detrital 5–50%,** volcanic 25–85%, carbonate 20–70%, glauconite $<$ 10%.
Mode: 5–7 ϕ.
Parameters: M_z **6.7–8.0** ϕ**,** σ_I 2.3–3.1 ϕ units, Sk_I 0.1–0.4, K_G 0.9–1.1.
To shore: inner 16–35 km, outer 22–80 km.
Depth: inshore 100–300 m, offshore 700–2000 m.

Upper slope clayey silts differ from shelf clayey silts in having a predominantly non-detrital sand fraction and from lower slope clayey silts in having a mean diameter coarser than 8 ϕ. Most of the carbonate grains in the sand fraction are planktonic foraminifera.

Lower Slope Clayey-Silt Facies

Classification: clayey silt (clayey medium or fine silt).
Size grades: **sand 0.5–5%,** silt 59–65% of mud.
Sand minerals: **detrital** $<$ **10%,** volcanic 25–90%, carbonate 20–75%.
Mode: 6–8 ϕ.
Parameters: M_z **8.0–8.7** ϕ**,** σ_I 2.1–2.7 ϕ units, Sk_I 0–0.2, K_G 0.9–1.1.
To shore: inner 22–80 km, outer $>$ 120 km.
Depth: inshore 300–2000 m, offshore $>$ 2500 m.

Lower slope clayey silts differ from other clayey silts in having a mean diameter of very fine silt size, and in having lower values of dispersion and skewness than most clayey silts to landward. In the northern part of the area, the sand fraction is predominantly volcanic ash, but in the southern part of the area it is predominantly calcareous foraminifera.

RELICT DETRITAL SEDIMENTS

Gravelly Facies

Classification: gravelly muddy sand (pebbly gravelly silty fine sand).
Size grades: **gravel 5–25%,** sand 60–90% of sand and mud, silt 75–93% of mud.
Sand minerals: **detrital 95%.**
Mode: 2.5–3.5 ϕ, other modes in pebble size-grade.
Parameters: M_z 0–2 ϕ, σ_I 2.3–2.9 ϕ units, Sk_I − 0.7 to + 0.1, K_G 1.5–3.0.
To shore: inner 1–2 km, outer 4–9 km.
Depth: inshore 10–20 m, offshore 15–60 m.

Sediments of gravelly facies contain pebbles of hard rock and occur on the inner continental shelf. Some pebbles are partly encrusted with worm tubes and bryozoans.

Lachlan Ridge Facies

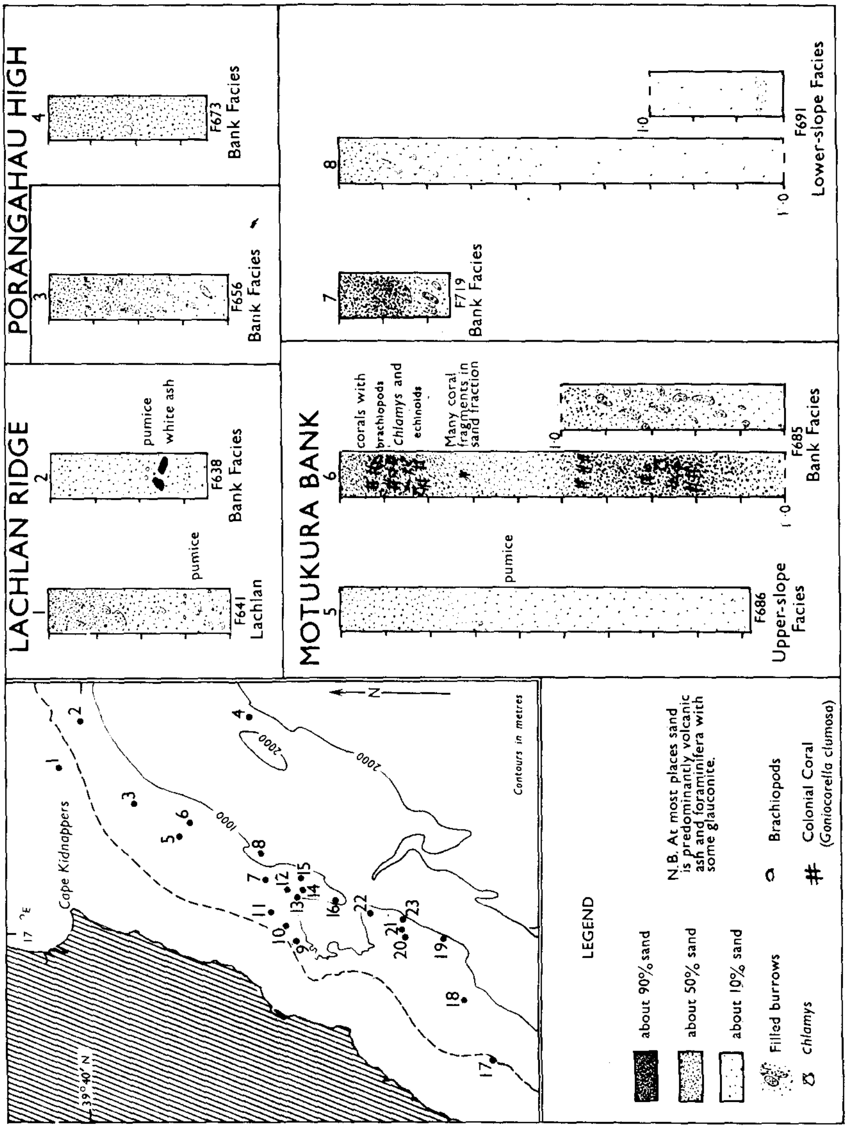
Classification: clayey silty sand, pebbly gravelly muddy sand, and calciruditic muddy sand.
Size grades: **gravel 2–15%, sand 50–85% of sand and mud,** silt 66–73% of mud.
Sand minerals: **detrital 40–75%, volcanic 12–50%,** carbonate $< 20\%$.
Mode: 1–3 ϕ.
Parameters: M_z 1–5 ϕ, σ_I 2.3–2.9 ϕ units, Sk_I − 0.2 to + 0.7, K_G 1.0–1.9.
To shore: 5–50 km.
Depth: 80–180 m.

Sediments of the Lachlan Ridge facies, which were described originally by Pantin (1966), are very variable, probably occurring in isolated patches between rocky outcrops. They have a gravel fraction of subangular pebbles and mollusc shells and a sand fraction of sand-sized mudstone fragments, terrigenous detrital grains, and volcanic ash. They occur at the Lachlan Ridge and at the Turnagain Banks on the middle continental shelf off Cape Turnagain.

The mollusc fauna at the Lachlan Ridge has been identified by Dr A. G. Beu of the N.Z. Geological Survey (pers. comm.) and includes:

BIVALVES: *Angulus edgari* Iredale, *Dosinia* (*Asa*) *lambata* (Gould), *Gari lineolata* (Gray), *Maorimactra ordinaria* (Smith), *Neilo australis* (Quoy and Gaimard), *Nucula hartvigiana* Dohrn, *Nucula nitidula* Adams, *Nucula strangei* Adams, *Poroleda lanceolata* (Hutton), *Tellinella huttoni* (Smith), *Scalpomactra scalpellum* (Reeve), *Tellinota edgari* (Iredale).
GASTROPODS: *Acteon craticulatus* Hedley, *Amalda* (*Brachyspira*) *depressa* (Sowerby), *Amalda* (*Brachyspira*) *mucronata* (Sowerby), *Amalda* (*Gracilispira*) *novaezelandiae* (Sowerby), *Antisolarium egenum* (Gould), *Austrofusus glans* (Röding), *Pervicacia tristis* (Deshayes), *Phenatoma zelandica* (Smith).
SCAPHOPODS: *Cadulus delicatulus* Suter, *Dentalium nanum* Hutton.

Many of the shells are broken and some are worn. Some are normally shallow-water forms and may have been deposited during low sea level of the Last Glacial Age. Mudstone pebbles at the Turnagain Banks have been bored and contain specimens of the boring bivalve *Pholadidea tridens* (Grey).


LACHLAN RIDGE
1
F641
Lachlan
pumice
2
F638
Bank Facies
pumice
white ash
PORANGAHAU HIGH
3
F656
Bank Facies
4
F673
Bank Facies
MOTUKURA BANK
5
F686
Upper-slope
Facies
pumice
6
F685
Bank Facies
corals with
brachiopods
Chlamys and
echinoids
Many coral
fragments in
sand fraction
7
F719
Bank Facies
8
F691
Lower-slope Facies
1·0
Cape Kidnappers
39°40′ N
N
1000
2000
Contours in metres
LEGEND
about 90% sand
about 50% sand
about 10% sand
Filled burrows
Chlamys
N.B. At most places sand is predominantly volcanic ash and foraminifera with some glauconite.
Brachiopods
Colonial Coral
(Goniocorella dumosa)

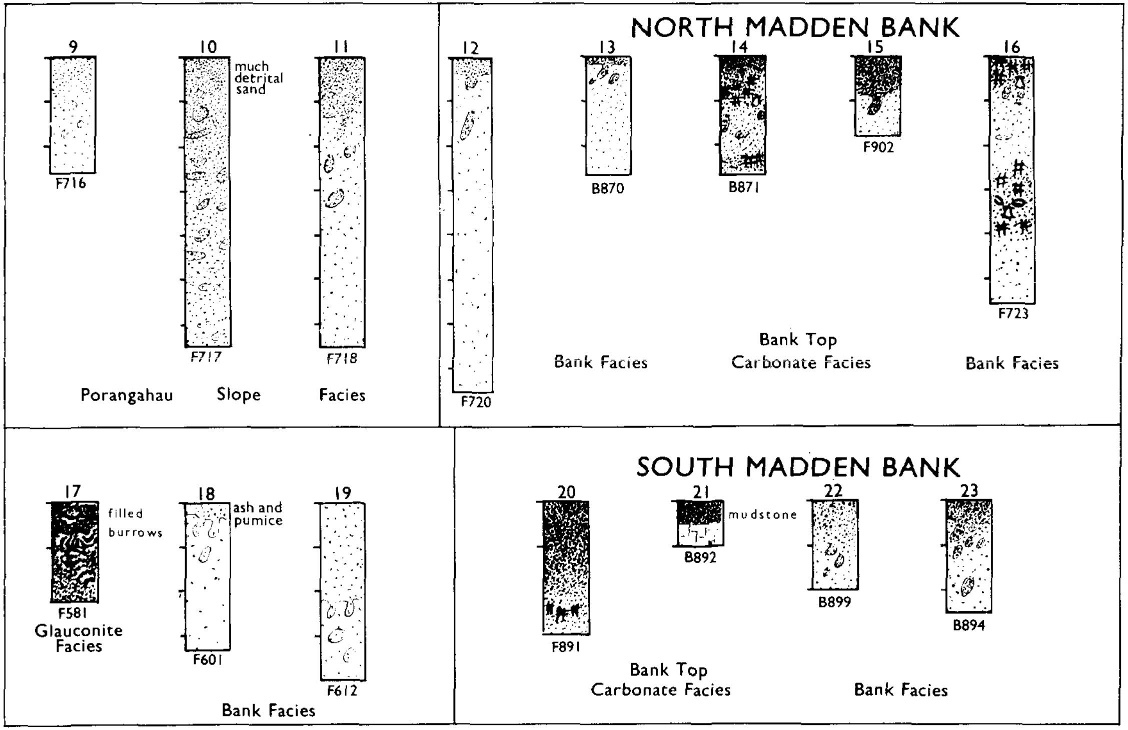


FIG. 17—Diagrammatic logs of gravity cores from areas of relict sediment and from offshore banks. Bars on cores are at 0.1 m intervals.

Porangahau Slope Facies

Classification: silty sand, sandy silt, and sandy clayey silt.
Size grades: **gravel 0.5%, sand 10–77%**, silt 67–84% of mud.
Sand minerals: **detrital 40–90%, volcanic 50%**, carbonate $< 20\%$, glauconite $< 5\%$.
Mode: 3–6 ϕ.
Parameters: M_z 3.7–7.2 ϕ, σ_I 1.3–2.8 ϕ units, Sk_I 0.1–0.8, K_G 0.9–3.2.
To shore: 18–30 km.
Depth: 200–1000 m.

Sediments of Porangahau slope facies contain no pebbles, no mudstone fragments, and few shells. They occur on the upper continental slope to the north and south of the Madden Depression. They are similar to sediments on the inner continental shelf, but contain a higher proportion of volcanic ash, foraminifera, and glauconite than most shelf sediments. Gravity cores from the area to the north of the Madden Depression (Fig. 17) show that the sediment more than 100–500 mm beneath the seabed is more muddy than the sediment at the seabed. The sediment throughout each core is extensively disturbed by burrowing organisms, and the boundary between surface sediment and underlying mud is diffuse. Porangahau slope facies is underlain by mud, but Lachlan facies is underlain by rock.

Glauconite Facies

Classification: silty sand, sandy silt.
Size grades: sand 30–65%, silt 76–83% of mud.
Sand minerals: detrital 40–75%, volcanic $< 10\%$, carbonate $< 10\%$, **glauconite 20–45%.**
Mode: 3.5–5 ϕ.
Parameters: M_z 3.8–5.8 ϕ, σ_I 2.0–2.8 ϕ units, Sk_I 0.4–0.5, K_G 1.1–1.5.
To shore: 18–30 km.
Depth: 160–250 m.

The glauconite facies occurs near the shelf break off Castlepoint. It consists of sediments that are similar to sediments on the inner continental shelf, but contains a higher proportion of glauconite.

NON-DETRITAL SEDIMENTS

Bank Facies

Classification: clayey silty **sand,** sandy **clayey silt,** calcarenitic clayey silt, and calciruditic muddy sand.
Size grade: gravel $< 12\%$ (carbonate), **sand 10–80% of sand and mud,** silt 62–73% of mud.
Sand minerals: **detrital $< 10\%$,** volcanic 30–85%, carbonate 10–60%, glauconite $< 30\%$.
Mode: 3–6 ϕ.
Parameters: M_z 2.0–7.4 ϕ, σ_I 2.0–4.3 ϕ units, Sk_I $-$ 0.2 to + 0.7, K_G 0.8–2.2.
To shore: 30–1100 km.
Depth: 200–2000 m.

Bank facies sediments occur on most banks and ridges on the continental slope. They include sediments with more than 10% sand-sized grains, but exclude the calcarenites and calcirudites that occur on the tops of some banks. At most places, the sand fraction is predominantly volcanic ash with subdominant foraminiferal tests and some glauconite.

At some places, the sand fraction includes broken molluscs and coral fragments. Bank facies sediments have a much larger dispersion than near-shore sediments of similar mean grain size.

Many cores from banks on the upper continental slope are coarse at the top and either become gradually finer downwards (Fig. 17) or show a distinct horizon below which the sediment is less sandy. The underlying less sandy sediment contains burrows filled with sandy surface sediment and colonial corals identified as *Goniocorella dumosa* (Alcock). Amongst the corals were fragments of echinoids identified by D. G. McKnight (N.Z. Oceanographic Institute) as belonging to the genera *Pseudechinus* and *Goniocidaris* (?*Petalocidaris*). Less sandy sediment with *Goniocorella* crops out on the west side of the Motukura Bank and at the southern end of the North Madden Bank. Some cores from banks on the lower continental slope become finer downwards (*see* Fig. 17, Core 4).

Bank-Top Carbonate Facies

Classification: **Calcarenite**, calciruditic calcarenite, muddy calcarenite, and muddy calcarenitic **calcirudite.**
Size grades: gravel 1–34% (carbonate), sand 55–98% of sand and mud, silt 66–78% of mud.
Sand minerals: volcanic 5–50%, carbonate 50–85%, glauconite 1–20%.
Mode: 1–4 ϕ.
Parameters: M_z 0.1–4.1 ϕ, σ_I 0.9–3.1 ϕ units, Sk_I $-$ 0.5 to + 0.7, K_G 0.8–2.2.
To shore: 34–40 km.
Depth: 160–500 m.

The bank-top carbonate facies occurs on the tops of the Madden Banks. The sand fraction consists of foraminiferal tests, shell fragments, volcanic ash, glauconite, and rare fragments of mudstone. The gravel fraction consists of brachiopods, corals, scallop shells, pteropods, and rare fragments of mudstone. Cores pass through the surface calcarenite into either calcarenitic mud or consolidated mudstone of Late Miocene or Pliocene age (Fig. 17). Dredge samples of the mudstone are riddled with burrows similar to those formed by the bivalve *Pholadidea tridens* (Gray).

The mollusc fauna from the tops of the Madden Banks has been identified by Dr A. G. Beu (pers. comm.) and includes:

BIVALVES: *Bathyarca cybaea* (Hedley), *Chlamys* (*Mimachlamys*) *gemmulata* (Reeve), *Chlamys* (*Mimachlamys*) *taiaroa* Powell, *Cosa costata* (Bernard), *Cuspidaria morelandi* Dell, *Cyclopecten aupouria* Powell, *Halirus setosa* (Hedley), *Hiatella arctica* (Linnaeus), *Limatula suteri* (Dall), *Limatula maoria* Finlay, *Monia zelandica* (Gray), *Nemocardium pulchellum* (Gray), *Pleuromeris marshalli* Marwick, *Pleuromeris zelandica* (Deshayes), *Venericardia* (*Purpurocardia*) *purpurata* (Deshayes).

GASTROPODS: *Anotoma regia* (Mestayer), ?*Antiguraleus* sp., *Asperdaphne expeditionis* Dell, *Austromitra lawsi* Finlay, *Cavolina telemus* (Linnaeus), *Clio pyramidata* (Linnaeus), *Cirsotrema zelebori* (Dunker), *Cominella* (*Eucominia*) *alertae* (Dell), *Cominella* (*Eucominia*) cf. *marlboroughensis* Powell, *Cymatona kampyla delli* Beu, *Diacria trispinosa* (Lesueur), *Emarginula striatula* (Quoy and Gaimard), *Malluvium calcareum* (Suter), *Marginella* (*Volvarinella*) *subfusula* Powell, *Microvoluta biconica* (Murdoch and Suter), *Mitrithara* sp., *Proxiuber australis* (Hutton), *Splendrillia rose-acincta* Dell, *Tanea zelandica* (Quoy and Gaimard), *Terefundus axirugosa* Dell, *Trichosirius inornatus* (Hutton). (The genera *Cavolina, Clio,* and *Diacria* are pteropods.)

SCAPHOPODS: *Dentalium* (*Fissidentalium*) *zelandicum* (Sowerby), *Dentalium* (*Laevidentalium*) *ecostatum* Kuln.

Corals from the South Madden Bank are recorded by Squires & Keyes (1967). Brachiopods were identified by Mr E. W. Dawson (N.Z. Oceanographic Institute) as *Liothyrella neozelandica* Thomson, and *Neothyris lenticularis* (Deshayes).

SEDIMENTATION : ORIGIN AND DEPOSITION

Grains of detrital origin constitute more than 90% of the sediment at most places in the study area. Most of the detrital grains are of terrigenous origin; only a few mudstone pebbles are considered to be of submarine origin. From a comparison of rates of coastal erosion and rates of offshore deposition, Lewis (in press) shows that only a few percent of the terrigenous detrital grains originate from coastal erosion, the remainder being formed by subaerial erosion and carried to the sea by rivers and wind.

When they reach the sea many of the terrigenous detrital grains pass through the breaker zone where they are sorted into three groups; gravel and coarse sand; fine sand; and mud. Much of the gravel is transported to beaches and marooned there because receding waves partly percolate into the beach material. Generally gravels migrate landward as a shore line transgresses. It may be, therefore, that gravelly sediment on the inner continental shelf represents beach deposits of drowned islands or drowned sand spits. Some angular mudstone fragments may have formed by wave destruction of *Pholadidea*-bored rocky reefs. Fine sand grains, which are easily moved and held in suspension by turbulent water, are returned by receding waves to the lower part of the beach: the interrelationship of their bed roughness velocity, threshold velocity, and settling velocity ensures that most of them remain in near-shore, high-energy environments (Inman 1949; Griffiths 1951). Mud grains are held in suspension in the breaker zone and are carried by tidal and coastal currents until they reach the offshore, low-energy environment.

Most mud is carried almost parallel to the shore by a southward flowing coastal current, but sand is moved northwards along the beaches by southerly swells (Lewis, in press). A current flows into the centre of Hawke Bay and flows out around the northern and southern sides of the bay (Ridgway 1960). The southern branch of the current picks up mud and very fine sand at the mouth of the three major rivers in southern Hawke Bay, carries it around Cape Kidnappers and deposits it on the middle continental shelf to the south. The movement of muddy water southward from Cape Kidnappers was noted as long ago as 1827 by the explorer D'Urville (Wright 1950).

It is assumed that, during constant flow conditions, a sediment-laden current deposits grains that have a normal distribution of sizes (Wentworth 1929, Krumbein 1938). A non-normal distribution is often attributed to a deficiency of some grain size in the sediment supplied to the current, or to deposition of different fractions of the sediment during different flow regimes, or to winnowing of the fines. A fourth cause, related to the difference in technique whereby current and analyst measure grain size, probably accounts for most of the non-normal grain size distributions described above. In nature grains are sorted according to their settling velocities; in the laboratory they are sorted by sieving of the coarse fraction and settling of the fine fraction after destruction of the flocs. For example, in a sediment composed of volcanic ash, detrital silt and flocs, the analyst sieves off the sand-sized volcanic ash, which forms a coarse mode or tail, and disaggregates the flocs into fine silt and clay grains, which form a fine mode or tail.

Most fine silt and clay grains aggregate to form flocs when they enter the sea. Keller and Foley (1949) found that sea water aggregated two thirds of the clay in suspension in river water to silt-sized grains. Sand, coarse silt, and large flocs settle rapidly and are deposited near the shore whereas single grains of fine silt and small flocs settle slowly and are carried far from the shore. The size of the grains that are deposited singly decreases rapidly with distance from shore, but the size of the grains that are deposited in flocs remains almost the same. Thus, the bimodal sediments on the continental shelf are composed of a coarse (fine sand and coarse silt) mode representing grains deposited singly and a fine (fine silt and clay) mode representing grains that were deposited as flocs. The sediments on the lower continental slope have an almost normal distribution of grain sizes, because the grains deposited singly are only slightly larger than the grains deposited as flocs, the flocs being composed of only a few grains.

Relict detrital grains occur in areas where Holocene deposits are thin or absent (i.e., on the innermost continental shelf and near the shelf break (Lewis, in press) and are considered to have been deposited near the end of the Last Glacial Age. At some places the coarse relict detrital grains have been concentrated by winnowing of the fines, and at all places they have been diluted by younger sand grains. The gravelly facies on the innermost shelf consists of beach pebbles mixed with younger detrital sand. The Lachlan facies, the Porangahau slope facies, and the glauconite facies, which all occur near the shelf break, consist of detrital sand and mud and younger non-detrital sand grains. The non-detrital grains are predominantly volcanic ash in the northern part of the study area and predominantly glauconite in the south. The subangular fragments of mudstone that occur in the Lachlan facies and on the South Madden Bank are probably derived from *Pholadidea*-bored Tertiary mudstone during a period of low sea level. The Porangahau Slope facies and the glauconite facies which both overlie extensively burrowed muddy sediment, were probably winnowed by burrowing organisms stirring fine silt and clay into suspension and leaving coarser grains as a lag deposit.

Non-detrital grains include volcanic ash, authigenic glauconite and organic carbonate. At most places on the continental slope the main constituents of the sand fraction are volcanic ash and tests of planktonic foraminifera. Foraminifera are the more important constituent in the southern part of the area, but are swamped by volcanic ash in the north. The ash was derived from the volcanoes of central North Island and carried to the northern part of the area by the prevailing westerly winds and by rivers that drain ash-covered hills. At most places, volcanic ash and planktonic foraminifera form an insignificant proportion of the whole sediment, but on continental slope banks they are an important or even a dominant constituent of the sediment. Relatively little mud reaches the banks, either because it is prevented from settling by currents that increase speed as they cross the banks, or because most mud in suspension is well below the surface of the sea and cannot move upslope on to the banks. The banks are a suitable environment for the growth of other types of non-detrital grains including glauconite and shells of benthonic foraminifera, brachiopods, molluscs, corals, and echinoderms. Muddy sediment that underlies non-detrital sediment on the upper continental slope was probably deposited during the Last Glacial Age when mud was carried by rivers to the middle continental shelf and was deposited rapidly on the upper continental slope.

Thus, most of the surface sediment is composed dominantly of terrigenous detrital grains. The modal grain size ranges from fine sand near the shore to medium silt on the lower continental slope, but the sediment at most places includes fine silt and clay grains from disaggregated flocs. At places where the rate of detrital deposition is low, surface sediments contain a significant proportion of either relict detrital grains or non-detrital grains. On the continental shelf and uppermost slope Last Glacial Age sediment is coarser than sediment being deposited at present, but on the continental slope banks it is finer than sediment being deposited at present.

ACKNOWLEDGMENTS

This study forms part of an investigation carried out at Victoria University, Wellington, in fulfilment of the requirements for the degree of Ph.D.

I am grateful to Professor P. Vella (Victoria University) for his constructive criticism of the manuscript, to Dr A. G. Beu (N.Z. Geological Survey) and Mr E. W. Dawson (N.Z. Oceanographic Institute) for identifications of faunas, and to Cartographic Section, DSIR, for drafting the figures.

LITERATURE CITED

FIELDES, M. 1968: Clay Mineralogy. Pp. 22–39 *in* "Soils of New Zealand". Part 2. *N.Z. Soil Bureau Bulletin 26 (Pt 2)*. 221 pp.

FOLK, R. L. 1954: Distinction between grain size and mineral composition in sedimentary rock nomenclature. *Journal of Geology 62*: 344–59.

FOLK, R. L. 1959: Practical petrographic classification of limestones. *Bulletin of the American Association of Petroleum Geologists 43*: 1–38.

FOLK, R. L., ANDREWS, P. B. and LEWIS, D. W. 1970: Detrital sedimentary rock classification and nomenclature for use in New Zealand. *N.Z. Journal of Geology and Geophysics 13 (4)*: 937–68.

FOLK, R. L. and WARD, W. C. 1957: Brazos River Bar: a study in the significance of grain size parameters. *Journal of Sedimentary Petrology 27*: 3–26.

GIBB, J. G. 1962: Wave refraction patterns in Hawke Bay. *N.Z. Journal of Geology and Geophysics 5*: 435–44.

GRIFFITHS, J. C. 1951: Size versus sorting in some Caribbean sediments. *Journal of Geology 59*: 211–43.

GRIM, R. E. 1968: "Clay Mineralogy", 2nd Edition. McGraw-Hill, New York. 596 p.

HOUTZ, R. E., EWING, J. L., EWING, M. and LONARDI, A. G. 1967: Sèismic reflection studies of the New Zealand Plateau. *Journal of Geophysical Research 72*: 4713–29.

INMAN, D. L. 1949: Sorting of sediments in the light of fluid mechanics. *Journal of Sedimentary Petrology 19*: 51–70.

KELLER, W. D. and FOLEY, R. 1949: Missouri River sediments in river water, ocean water and sodium oxalate solutions. *Journal of Sedimentary Petrology 19 (2)*: 78–81.

KRUMBEIN, W. C. 1934: Size frequency distributions of sediments. *Journal of Sedimentary Petrology 4*: 65–77.

——— 1936: Application of logarithmic moments to size frequency distributions of sediments. *Journal of Sedimentary Petrology 6*: 35–47.

——— 1938: Size-frequency distributions of sediments and the normal phi-curve. *Journal of Sedimentary Petrology 8*: 84–90.

LEWIS, K. B. 1971a: Growth rate of folds using tilting wave-planed surfaces: coast and continental shelf, Hawkes Bay, New Zealand. Pp. 225–31 *in* Collins, B. W., Fraser, R. (Eds) "Recent Crustal Movements". *Bulletin of the Royal Society of New Zealand 9*. 246 pp.

——— 1971b: Slumping on a continental slope inclined at 1° to 4°. *Sedimentology 16*: 97–110.

——— (In press): Erosion and deposition on a tilting continental shelf during Quaternary oscillations of sea level. *N.Z. Journal of Geology and Geophysics.*

LEWIS, K. B. and GIBB, J. G. 1970: Turnagain Sediments. *N.Z. Oceanographic Institute Chart, Coastal Series, 1 : 200,000.*

N.Z. HYDROGRAPHIC BRANCH 1956: Napier to Castlepoint, Chart NZ 57. Wellington.

MCMANUS, D. A. 1963: A criticism of certain usage of the Phi-notation. *Journal of Sedimentary Petrology 33*: 670–4.

PANTIN, H. M. 1963: Submarine morphology east of the North Island, New Zealand. *N.Z. Department of Scientific and Industrial Research Bulletin 149*. 43 pp.

——— 1966: Sedimentation in Hawke Bay. *N.Z. Department of Scientific and Industrial Research Bulletin 171*. 70 pp.

RIDGWAY, N. M. 1960: Surface water movements in Hawke Bay, New Zealand. *N.Z. Journal of Geology and Geophysics 3*: 253–61.

SEED, D. P. 1968: The analysis of the clay content of some glauconitic oceanic sediments. *Journal of Sedimentary Petrology 38 (1)*: 229–31.

SHAW, T. M. and ALEXANDER, L. T. 1936: A note on mechanical analysis and soils texture. *Proceedings of the Soil Science Society of America 1*: 303–4.

SPENCER, D. W. 1963: The interpretation of grain size distribution curves of clastic sediments. *Journal of Sedimentary Petrology 33*: 180–90.

SQUIRES, D. F. and KEYES, I. W. 1967: The marine fauna of New Zealand: Scleractinian corals. *N.Z. Department of Scientific and Industrial Research Bulletin 185*. 46 pp., 6 pl.

TRUOG, E., TAYLOR, J. R., PEARSON, R. W., WEEKS, M. E. and SIMONSON, R. W. 1936a: Procedures for special type of mechanical and mineralogical soil analysis. *Proceedings of the Soil Science Society of America 1*: 101–12.

TRUOG, E., TAYLOR, J. R., SIMONSON, R. W. and WEEKS, M. E. 1936b: Mechanical and mineralogical subdivision of the clay separate of soils. *Proceedings of the Soil Science Society of America 1*: 175–9.

VAN DER LINDEN, W. J. M. 1968: Textural, chemical and mineralogical analysis of marine sediments. *N.Z. Oceanographic Institute Miscellaneous Publication 39*. 37 pp.

WENTWORTH, C. K. 1922: A scale of grade and class terms for clastic sediments. *Journal of Geology 30*: 377–92.

——— 1929: Method of computing mechanical composition types of sediments. *Bulletin of the Geological Society of America 40*: 771–90.

WHITESIDE, E. P., FLACH, K. W., JAMISON, V. C., KEMPER, W. D., KNOX, E. G. and ORVEDAL, A. C. 1967: Committee Report of the particle size and distribution committee of the Soil Science Society of America: Considerations relative to a common particle size scale of earthy materials. *Proceedings of the Soil Science Society of America 31*: 579–84.

WILLIS, R. P. 1964: A new method of preparing marine sediment cores. *N.Z. Journal of Geology and Geophysics 7*: 804–10.

WRIGHT, O. 1950: "New Zealand 1826–1827 from the French of Dumont D'Urville". Wingfield Press, Wellington. 251 pp.