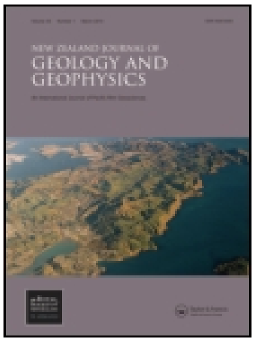

New Zealand Journal of Geology and Geophysics

ISSN: 0028-8306 (Print) 1175-8791 (Online) Journal homepage: http://www.tandfonline.com/loi/tnzg20

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To cite this article: PAUL F. Hamill & PETER F. Ballance (1985) Heavy mineral rich beach sands of the Waitakere coast, Auckland, New Zealand, New Zealand Journal of Geology and Geophysics, 28:3, 503-511, DOI: 10.1080/00288306.1985.10421203

To link to this article: http://dx.doi.org/10.1080/00288306.1985.10421203

New Zealand Journal of Geology and Geophysics, 1985, Vol. 28: 503–511
0028–8306/85/2803–0503$2.50/0

Heavy mineral rich beach sands of the Waitakere coast, Auckland, New Zealand

PAUL F. HAMILL*
PETER F. BALLANCE
Department of Geology
University of Auckland
Private Bag
Auckland, New Zealand

Abstract Heavy mineral rich beach sands of the Tasman Sea coast of the Waitakere Ranges, west of Auckland City, include major minerals plagioclase, augite, titanomagnetite, and quartz, with minor ilmenite, hypersthene, hornblende, biotite, and potassium feldspar, and accessory zircon and apatite. Major sources for the sands are Taupo Volcanic Zone rhyolitic volcanics, delivered via the Waikato River, and Taranaki andesitic volcanics, via the longshore drift. Longshore trends from south to north include a slight fining, a reduction in rock fragments, an increase in heavy mineral content, and a tendency for the feldspar/quartz ratio to decline. Ilmenite is a significant component; it is derived from the Taupo Volcanic Zone (not from the Waitakere Ranges as previous authors have suggested), and it increases in quantity from south to north. However, it does not replace titanomagnetite.

The Taupo Volcanic Zone could have supplied all of the ironsand on the west coast north of the Waikato River mouth. Longshore trends and distribution of ironsand and other minerals on the continental shelf all strongly suggest a net northwards littoral drift of sand, which would be expected from the prevailing south–southwesterly wave approach. Possible contributions of sand from relict continental shelf accumulations, and from a large igneous body which underlies the continental shelf, cannot be evaluated.

Keywords beaches; sand; Waitakere Ranges; heavy minerals; grain size; littoral drift; longshore currents; Taupo Volcanic Zone; sediments; iron-rich composition

INTRODUCTION

Beach and dune sands rich in volcanic-derived heavy minerals, especially titanomagnetite ("ironsand"), are prominent along the west coast of the North Island of New Zealand between Cape Egmont and the Kaipara Harbour entrance (Kaipara Heads) (Williams 1974) (Fig. 1). Offshore, however, ironsand is concentrated in two distinct nearshore strips, one extending northwards for about 100 km from Cape Egmont, and one extending northwards for about 75 km from the mouth of the Waikato River (Waikato Heads) (McDougall 1961; Carter 1980) (Fig. 1). The two strips are separated by about 100 km of continental shelf with low concentrations of ironsand in surface sediments. From coastal ironsands between Waikato Heads and Kaipara Heads, adjacent to the northern offshore strip, Nicholson & Fyfe (1958) and Wright (1964) recorded ilmenite in addition to titanomagnetite. The ilmenite reached concentrations as high as 16.9% in a sample from Manukau Harbour entrance. Williams (1974) stated that ilmenite tends to replace titanomagnetite as the principal iron mineral northwards from Waikato Heads. Kear (1979) speculated that the ilmenite might be locally derived from the basic lavas of the Waitakere Group (Fig. 1).

The present study (Hamill 1979) describes the grain size and mineralogy of beach sands along the Waitakere coast, west of Auckland City (Fig. 1). It was designed to: (1) establish any longshore trends in mineralogy and grain size; (2) investigate the source of the titanomagnetite and ilmenite, and other heavy minerals; (3) consider the possible role of the offshore ironsand concentration (Carter 1980) and the large offshore magnetic igneous body (Hatherton et al. 1979) in supplying heavy minerals to the beach system; and (4) draw conclusions about the results of coastal processes.

Previous work includes Schofield (1970, 1975), whose West Auckland Sand Facies and Egmont-Kaipara Sand System include the study area. Yock (1973) studied Pleistocene and Recent sands immediately north of the study area, from Muriwai to Kaipara Heads, and Barter (1976) studied similar deposits south of the study area, from Waikato Heads to the Manukau Harbour entrance. Within the study area, Delgrosso (1971) made textural studies of Piha and Te Henga Beaches, and Williams (1977) described the growth of Whatipu

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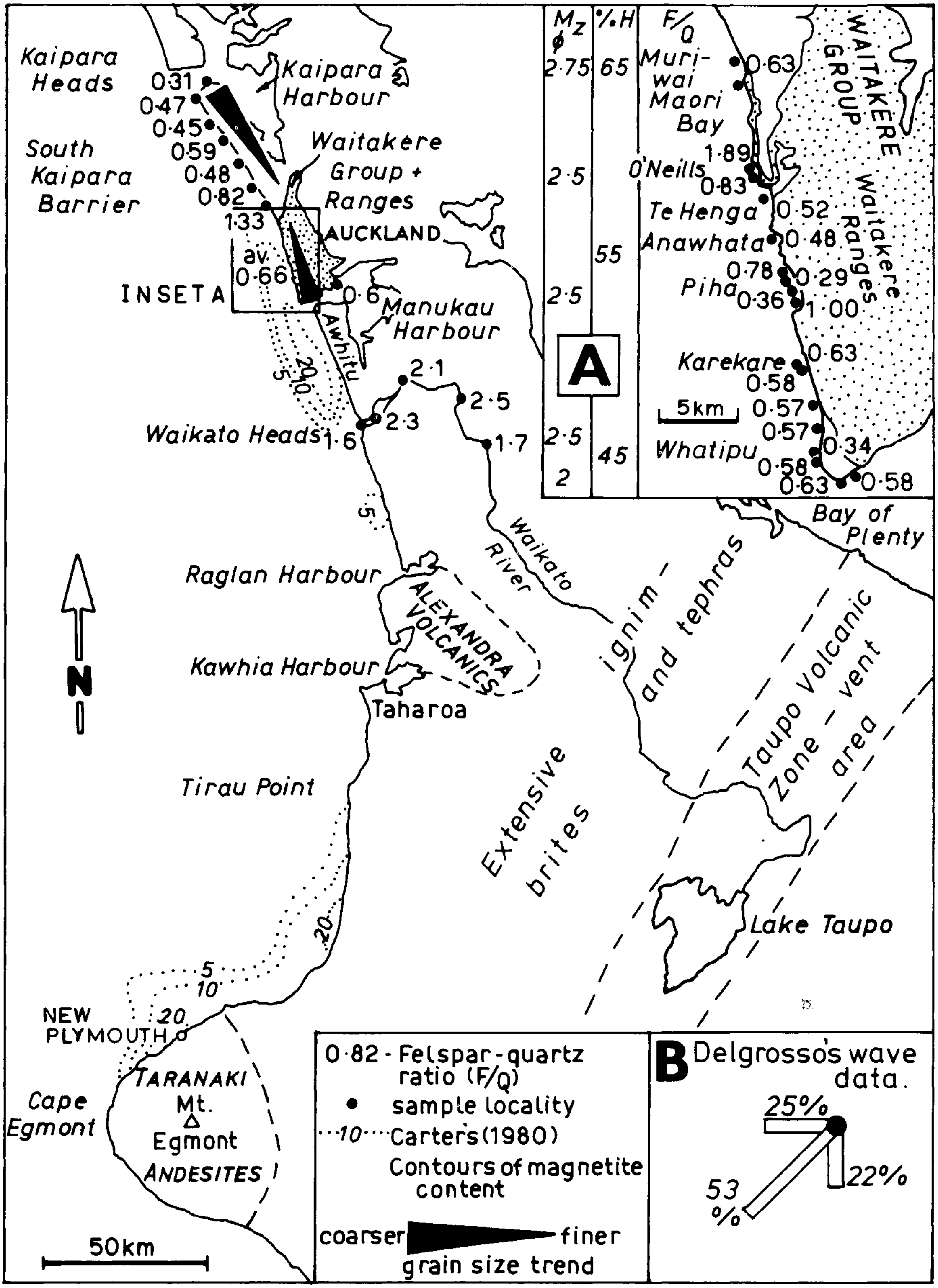
*Present Address: Ashton Mining Ltd, 20th floor, 444 Queen Street, Brisbane 4000, Australia.

Received 10 June 1983, accepted 28 May 1985


Kaipara Heads
Kaipara Harbour
South Kaipara Barrier
0·31
0·47
0·45
0·59
0·48
0·82
1·33
av. 0·66
INSET A
Waitakere Group + Ranges
AUCKLAND
0·6
Manukau Harbour
Awhitu
5
10
20
2·1
2·5
2·3
1·7
Waikato Heads
1·6
Raglan Harbour
Kawhia Harbour
ALEXANDRA VOLCANICS
Taharoa
Waikato River
ignim- and tephras
Extensive brites
Taupo Volcanic Zone - vent area
Lake Taupo
Bay of Plenty
Tirau Point
NEW PLYMOUTH
Cape Egmont
TARANAKI Mt. Egmont ANDESITES
50km
N
M_z φ
%H
F/Q
2·75
65
2·5
55
2·5
2·5
45
2
A
Muri-wai
Maori Bay
O'Neills
Te Henga
Anawhata
Piha
Karekare
Whatipu
5km
WAITAKERE GROUP
Waitakere Ranges
0·63
1·89
0·83
0·52
0·48
0·78
0·29
0·36
1·00
0·63
0·58
0·57
0·57
0·34
0·58
0·63
0·58
0·82 - Felspar-quartz ratio (F/Q)
● sample locality
··10···Carter's (1980) Contours of magnetite content
coarser finer grain size trend
B Delgrosso's wave data.
25%
22%
53 %

Beach. The adjacent Waitakere Ranges, comprising Early–Mid Miocene basic volcanic rocks, were described by Hayward (1976, 1983) and Wright & Black (1981).

SAMPLING AND ANALYSIS

Forty-two samples were taken along the 25 km stretch of coast. Each beach was sampled by means of channel samples taken from holes dug to the water table, approximately midway between high and low tide levels. The intention was to obtain representative reference samples of the sand at regular intervals, free of the extreme concentration effects which lead to very high local percentage of heavy minerals at high-tide level (west coast "blacksands"), and free of variations caused by short-term changes in weather and wave climate. No record was kept of weather and wave conditions during the sampling period. Eighteen of the 42 samples were reference samples; their locations are shown in Fig. 1 (inset A). The remainder were samples of individual laminae, taken at various levels in the beachsand, and at many points between high and low tide marks. The latter were selected to sample a full range of concentrations of heavy and light minerals.

Sieving was carried out at ¼ϕ intervals from 1.68 mm (0.75ϕ) to 0.063 mm (4ϕ). Size data were computer analysed into histograms, frequency curves, and individual statistical parameters of Folk (1974). Heavy mineral separation was carried out in tetrabromoethane (specific gravity = 2.95) and the weight percentage of the heavy and light fractions was calculated. The light fraction was mounted and ground into thin sections, and the heavy fraction was mounted into polished thin sections. Both transmitted and reflected light microscopic examination were used. Grain counting using the Line Method (Galehouse 1971) was carried out to determine the frequencies of the individual mineral species present. Two hundred grains per slide were counted.

Samples used in the study are held in the University of Auckland Petrology Collection, numbers AU21522–21563.

TRENDS IN GRAIN SIZE AND MINERAL PERCENTAGES

Four grain-size parameters were computed (Folk 1974): graphic mean (M_z), inclusive graphic standard deviation (SD), inclusive graphic skewness (SK_I), and graphic kurtosis (K_g). Distance (D) was measured from an arbitrary point, fixed at Muriwai Beach (NZMS 260, sheet Q11, grid co-ordinates 375852). Table 1 shows a summary of the ranges of the statistical data for all samples. Using data only from the reference samples, M_z plotted against D shows an overall northwards fining trend (Fig. 2); however, if the two extreme coarse samples at

Table 1 Range of all grain-size parameters and percentage of heavy minerals for all samples.

Parameter	All samples
Mean	3.22 ϕ - 1.72 ϕ
Sorting	0.26 ϕ - 0.57 ϕ
Skewness	−0.28 - +0.21
Kurtosis	0.82 - 1.29
% heavy minerals	3% 99%

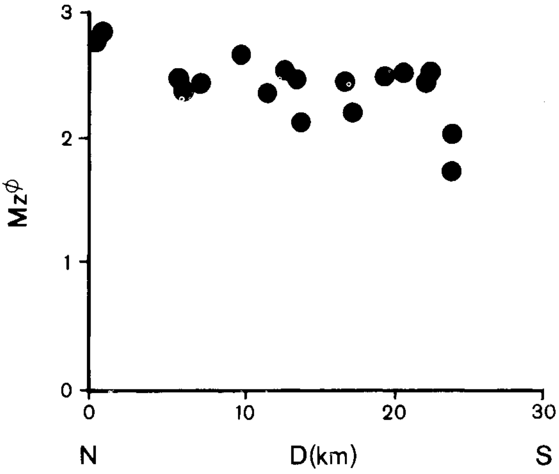


Fig. 2 Mean grain size (M_z) of reference samples plotted against distance from Muriwai (D).

Fig. 1 *(opposite)* Locality map showing major sources for coastal sands; offshore concentrations of magnetite from Carter (1980); feldspar/quartz ratios (F/Q) outside the present study area from Schofield (1970); grain-size trends from this study and Schofield (1970); *Inset A* shows the present study area, location of reference samples, F/Q ratios, average $M_z\phi$ and % heavy mineral values. *Inset B* shows the proportions of wave approach directions at Piha recorded by Delgrosso (1971).

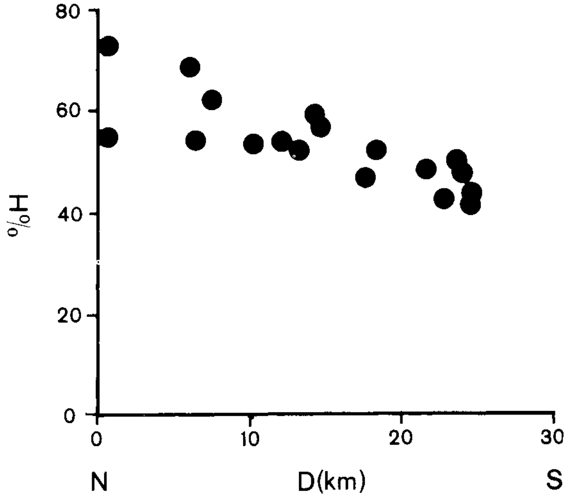


Fig. 3 Percentage of heavy minerals (%H) in reference samples plotted against D.

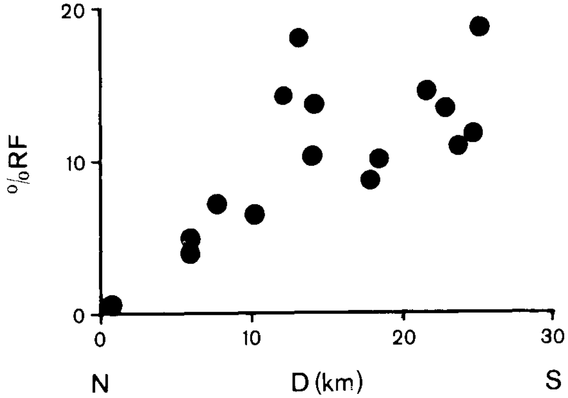


Fig. 4 Percentage of rock fragments (%RF) in reference samples plotted against D.

Table 2 Mineral composition of sands in this study (all samples) and in the area immediately to the north (Yock 1973).

Mineral	Yock (1973)	This study
Actinolite	Noted	N/O
Augite	0.3–83%	1–32%
Hornblende	0.3–41%	0– 9%
Hypersthene	0.3– 8%	0– 9%
Microcline	0.3– 1%	Undifferentiated feldspar
Orthoclase	0.3–25%	2–25%
Plagioclase	8 –46%	
Quartz	33 –56%	2–36%
Apatite	Noted	Noted
Biotite	0.3– 6%	0–17%
Chrysotile	Noted	N/O
Epidote	0.3– 1%	N/O
Garnet	Noted	0– 2%
Glauconite	0.3– 1%	0– 1%
Monazite	0.3– 4%	N/O
Sphene	Noted	N/O
Tourmaline	Noted	N/O
Xenotime	Noted	
Zircon	0.3– 7%	0– 3%
Rock fragments	10 –50%	0–21%
Titanomagnetite	1 –95%	0–40%
Ilmenite	Noted	0–15%
Spinel	Noted	Noted
Sulphides	Noted	Noted
Gold	Noted	N/O
Rutile	Noted	N/O
Hematite	Noted	0– 6%

N/O = not observed.

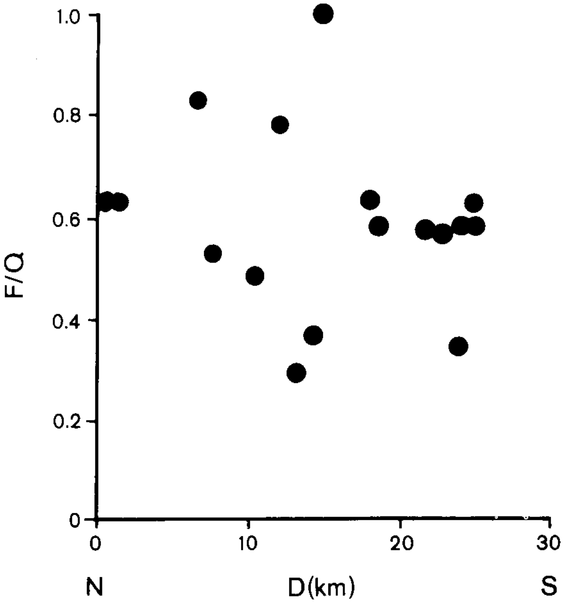


Fig. 5 Feldspar/quartz ratios (F/Q) in reference samples plotted against D. A value of 1.89 at 6.1 km is omitted from the graph.

the southern end and the two extreme fine samples at the northern end are removed, there is no trend. Percentage of total heavy minerals (%H) shows a clear northwards increase from 45% to 60% (Fig. 3).

Percentage of rock fragments (%RF) shows a clear overall northwards decrease from 15% to 0% (Fig. 4). The data points are scattered and can be interpreted as indicating two northwards-decreasing sectors separated at 15 km. The feldspar/quartz ratio (F/Q) shows a very wide scatter and no overall trend within the study area (Fig. 5).

Rock fragments are less resistant to abrasion than quartz and many other crystals. Their northwards decrease suggests a net northerly movement of sand, as does the northwards fining and northwards increase in heavy mineral concentration.

MINERALOGY

The dominant light mineral species (Table 2) are quartz and feldspar. Minor constituents are rock fragments and calcite. The dominant heavy mineral species are titanomagnetite and augite, minor constituents being ilmenite, hornblende, biotite, and hypersthene. Accessory minerals are hematite, zircon, and garnet. Rare constituents include limonite, apatite, and xenotime.

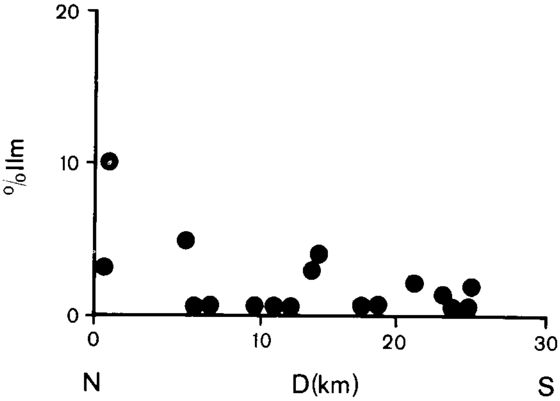


Fig. 6 Ilmenite content (%Ilm) against D. The data show a northwards increase in the samples that contain ilmenite.

Table 2 compares our sands with those of Yock (1973) to the north. Titanomagnetite values are similar in both studies. Yock (1973) recorded no specific values for ilmenite or hematite, describing them only as oxidation lamellae within titanomagnetite. We observed such oxidation lamellae in a base of titanomagnetite, as well as discrete, homogeneous grains of ilmenite and hematite. The latter were counted specifically; the former were counted as titanomagnetite.

Titanomagnetite and ilmenite

Ilmenite content increases from south to north, but many samples lack ilmenite altogether (Fig. 6). By contrast, titanomagnetite content shows tremendous scatter and little indication of a trend (Fig. 7). Titanomagnetite was plotted against ilmenite to test the inverse relationship suggested by Williams (1974); there is a wide scatter but with a tendency for ilmenite to increase as titanomagnetite increases (Fig. 8). It would appear that the two minerals are from the same source and are responding to the same processes of transport and sorting.

In sands with high contents of heavy minerals, the percentage of both titanomagnetite and ilmenite varies widely. Titanomagnetite is confined to size classes finer than 0.31 mm (1.70ϕ), and appears to diminish below 0.125 mm (3.00ϕ); this fact would be significant in planning industrial extraction of ironsand.

PROVENANCE

On the basis of mineral composition, ease of access to the west coast, and volumes of material able to be contributed, three volcanic terrains are thought

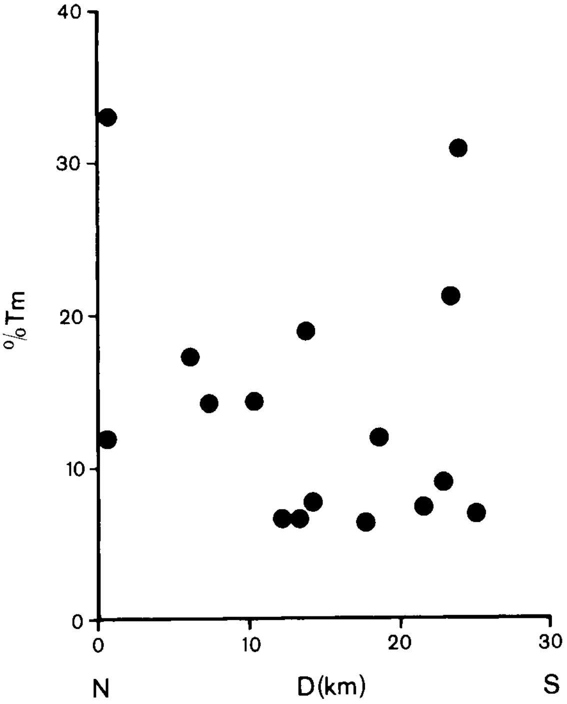


Fig. 7 Titanomagnetite content (%Tm) against D for all samples. The scatter is large.

to contribute the bulk of the sand to Waitakere beaches. They are the Early–Mid Miocene Waitakere Group of basalts to basaltic andesites (Wright & Black 1981) forming the adjacent Waitakere Ranges (Fig. 1; Hayward 1983); the late Neogene andesites of Taranaki (Fig. 1; Gow 1967, 1968); and the Quaternary rhyolites and rhyolitic ignimbrites of the Taupo Volcanic Zone (Ewart 1967; Rutherford 1976), whose detrital products are delivered to the west coast by the Waikato River (Hume et al. 1975; Aziz 1981).

The characteristic mineralogy of the three sources and of the Waitakere beach sands is listed in Table 3. With the exception of augite and hypersthene, the Taupo source and the beach sands show a one-to-one correspondence in major and minor mineral phases, suggesting that the Taupo source is dominant. The augite may have originated either in Taranaki or the Waitakere Group. The red-brown and green-brown hornblendes are closer to Taranaki sources (Gow 1968) than to Taupo hornblendes which are typically green (Rutherford 1976). Thus, a significant contribution from Taranaki is indicated.

The Taupo- and Taranaki-derived minerals may have been stored in temporary repositories en route, for example, Waikato River alluvium (Hinuera Formation, Hume et al. 1975; Aziz 1981). Many minor source terrains may have contributed

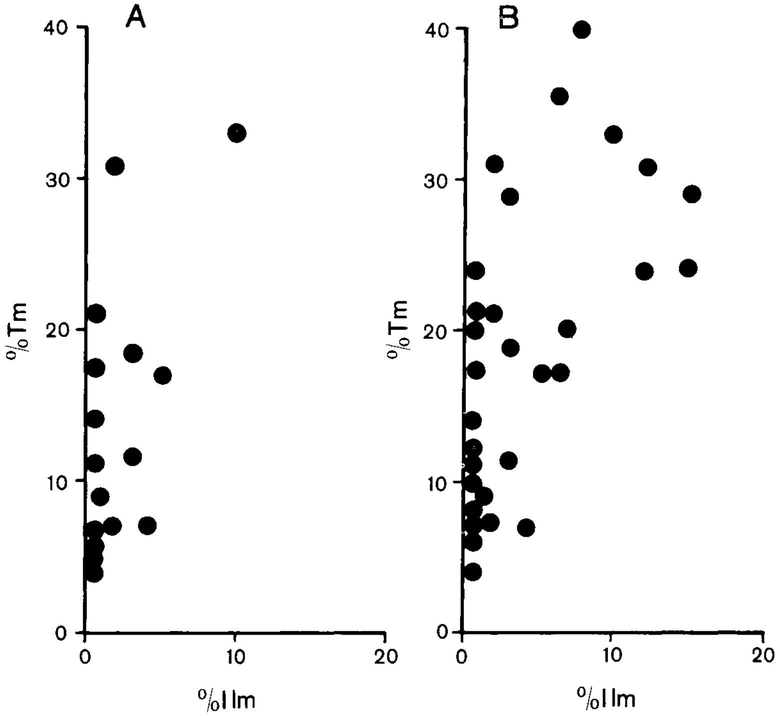


Fig. 8 Titanomagnetite content against ilmenite. **A** reference samples. **B** all samples.

Table 3 Phenocryst mineralogy of the three main possible source terrains compared with the Waitakere beach sands. Data from Wright & Black (1981), Gow (1967, 1968), Ewart (1967), Rutherford (1976), Hume et al. (1975), and Aziz (1981).

Waitakere Group	Taranaki	Taupo Volcanic Zone & Waikato River	Waitakere Beach sands
Major			
Plagioclase	Plagioclase Augite Hornblende	Plagioclase Quartz Titanomagnetite Hypersthene	Plagioclase Augite Quartz Titanomagnetite
Minor			
Augite Olivine Hypersthene	Titanomagnetite Olivine	Hornblende Potassium feldspar Augite Epidote Biotite Ilmenite	Hypersthene Potassium feldspar Hornblende Biotite Ilmenite
Rare/accessory			
	Hypersthene Biotite Ilmenite	Zircon Apatite Actinolite Muscovite Hematite	Zircon Apatite

material (e.g., glauconite; Table 2), perhaps from Paleogene sedimentary rocks south of Waikato River.

Grain shape

Most grains are subrounded. Original crystal shapes could be detected in a small percentage of the grains of all the common mineral species. The proportion of euhedral crystals is similarly small in Waikato River sands derived from the Taupo Volcanic Zone (Hume et al. 1975; Aziz 1981), indicating that most grains on the beaches are probably first-cycle detritus. The implications of this fact, and of the mineralogy in general, are that there is a net northerly transport of sand along the beaches.

SOURCE OF WEST COAST IRONSAND

There is particular interest in the ironsand component of North Island west coast beaches because of its economic importance. Traditionally it has been regarded as deriving from Taranaki andesites (e.g., Williams 1974; Kear 1979). This is because of: (1) its symmetrical distribution north and south of Cape Egmont (Fig. 1); (2) Brodie's (1960) drift card experiments which indicated coastal surface currents diverging to the north and south of Cape Egmont; and (3) the lack of significant ironsand concentrations in Bay of Plenty coastal sands which are derived largely from Taupo rhyolitic sources.

However, Lawton (1979) suggested that Taupo sources could have supplied magnetite to the west coast. Aziz (1981) calculated that the Waikato River could in fact have supplied all of the known ironsand reserves of the coast north of Cape Egmont in the past 0.25–1.8 million years, given: (1) Lawton's (1979) estimate of more than 1 × 10^9 t of ironsand at the major Taharoa, Waikato Heads, and Raglan dune deposits, leading to Aziz's guess of 2 × 10^9 t as an approximation to total ironsand in the coastal system; (2) present-day bedload movement in the lower Waikato River of approximately 220 000 t/year (Finley 1974); (3) an average content of opaque minerals in Waikato River sands of between 0.5% (Hume et al. 1975) and 3.8% (Aziz 1981); and (4) the beginning of rhyolitic volcanism in the Taupo Volcanic Zone at 1–1.5 million years ago (Seward 1974).

Ewart (1967) noted a "striking similarity" between the textural types he observed in titanomagnetites of Taupo pumice formations and those described by Wright (1964) from west coast ironsands.

Ilmenite occurs in appreciable amounts only north of the Waikato River mouth (Nicholson & Fyfe 1958; Wright 1964), and the only known significant source for it is the Taupo Volcanic Zone (Table 3). It does not occur in Waitakere Group rocks as Kear (1979) suggested (Hamill 1979; Wright & Black 1981). This distribution suggests a Taupo source, distributed by the Waikato River. However, Aziz (1981) recorded ilmenite only as a rare constituent in Waikato River sands; this is difficult to understand.

Additional evidence favouring a Taupo rhyolitic source for some west coast ironsand may be provided by Carter's (1980) northern offshore concentration of magnetic ironsand (Fig. 1) which begins abruptly at the mouth of Waikato River and extends northwards to just north of this study area. It and the observed distribution of ilmenite northwards from Huriwai Beach, about 10 km south of the Waikato River mouth (Nicholson & Fyfe 1958; Wright 1964; H. W. Kobe pers. comm), together with quartz and potassium feldspar, suggest that there is a net northwards movement of Waikato River-derived sand. Thus, the ironsand found north of the Waikato River mouth is probably derived from the rhyolitic volcanic rocks of the Taupo Volcanic Zone.

FELDSPAR/QUARTZ RATIOS

Quartz is more resistant to abrasion than feldspar (Blatt et al. 1980) and hence longshore reduction of the feldspar/quartz ratio (F/Q) can be inferred to indicate the direction of net littoral sediment drift (e.g., Healy 1978). Schofield (1970) recorded F/Q for Waikato River sands and for beach sands at Waikato Heads and north of the study area. Our data (Fig. 1, inset A, and Fig. 5) fill part of the gap in Schofield's coverage. There is a sharp drop in the ratio between Waikato River and the adjacent beach (Fig. 1), implying either an immediate removal of feldspar in the more energetic littoral environment, or a dilution of river sand by quartz-rich coastal sand moving northwards. From Waikato Heads northwards to Kaipara Heads there is an overall reduction in F/Q, but there are several reversals in the downwards trend. We interpret this, as Schofield (1970) did, to mean that there is a net northwards littoral drift of sand; however, the highly erratic variation in ratios shown in Fig. 5 suggests that there is much local mixing and perhaps dilution with locally derived feldspar-rich sand.

COASTAL SEDIMENT MOVEMENT

Coastal sediments record the long-term average result of near-coastal water movements; as summarised by Carter (1980) and Heath (1981, 1982), these movements contain many independent elements and are very complex. Near to shore, however, wave-induced longshore drift tends to dominate. We interpret the trends in Waitakere beach sands—slight northwards fining, northwards decrease in rock fragments, northwards increase in heavy mineral content, tendency for a northwards decrease in F/Q—and the observed distribution of ironsand and Taupo-derived minerals, to indicate a clear net northwards drift of littoral sediment. This drift apparently persists at least as far north as Kaipara Heads (Schofield 1970) and is consistent with the prevalence of wind waves from the southwesterly direction (Delgrosso 1971; Pickrill & Mitchell 1979; Heath 1982) (Fig. 1).

POSSIBLE INFLUENCE OF OFFSHORE SAND SOURCES

Two offshore sources may be important in supplying sand to Waitakere beaches. Carter's (1980) northern offshore concentration of magnetic ironsand (Fig. 1) may be acting as a temporary storehouse of Waikato-delivered sand which accumulated during lowered Pleistocene sea level. Carter considered it to represent relict littoral accumulations which are mobilised by storm-induced water movements and are approaching equilibrium with the modern hydraulic regime. Thus, it could be supplying sand to the modern beaches, but we have no means of testing that supposition.

The other possible source is represented by the large positive magnetic and gravity anomalies which occur on the continental shelf west of the Waitakere beaches. Hatherton et al. (1979) considered that they indicate a very large volcanic body, of basic–intermediate composition, and of probable Tertiary age. Again, such a body would represent a possible source of sand of the mineralogy observed on Waitakere beaches, but there is no way of testing the supposition.

ACKNOWLEDGMENTS

We thank Dr H. W. Kobe and Dr P. M. Black (University of Auckland) for assistance with mineral identifications, and Dr Kobe for unpublished information on the distribution of ilmenite. Dr Kobe, Dr M. R. Gregory (University of Auckland), and Dr T. R. Healy (Waikato University) reviewed a draft of the paper. Dr P. Hosking and Mr G. MacGregor assisted with statistical analysis and computer programmes. P. F. Hamill gratefully acknowledges the help of his parents during his student days.

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