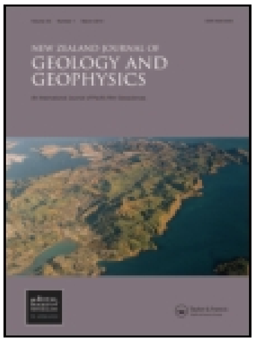

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PETROGRAPHIC STUDIES OF IRONSANDS AND ASSOCIATED SEDIMENTS NEAR HAWERA, SOUTH TARANAKI

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ABSTRACT

Studies of ironsands near Hawera included detailed examinations of the mechanical and mineralogical properties of present-day beach deposits and dune sands. Mineral assemblages of sands from the Rapanui Formation and heavy mineral suites from the underlying Waipipi Formation were also investigated. Whereas minerals of granitic–metamorphic origin characterised the Waipipi Formation, minerals of recent volcanic (andesitic) origin were predominant in the bedded deposits of the Rapanui Formation and in recently formed ironsands.

Measurements of the abundance of the principal ferromagnesian minerals in andesitic sands near Hawera indicate that they were ultimately derived from augite andesites and augite-hornblende andesites from Mt Egmont. The complete absence of andesitic minerals in the Waipipi Formation clearly shows that either activity along the Egmont volcanic line had not yet begun or, if it had, the products of these eruptions had not been incorporated into the sedimentary record before the end of of the Waipipian.

INTRODUCTION

Sands enriched in the mineral titanomagnetite are generally referred to as ironsands, and in Taranaki the term Taranaki ironsand has been applied to such deposits. Although fairly concentrated deposits have been formed, at Waitara for example, reserves north of the Waitara River, e.g., Lake Taharoa and Kawhia are now known (Fyfe and Nicholson, 1949) to greatly exceed those along the Taranaki coast. Since these have been shown by Martin (1955) to contain titanomagnetite of the same composition as the Taranaki deposits the term Taranaki ironsand could usefully be extended to them as well.

As a preliminary survey of the sands along the coast near Hawera revealed no significant concentration of ironsand the present studies have been concerned primarily with:

(1) Measurements of the bulk textural properties of ironsands of the beaches and dunes near Hawera;

(2) Determination of the mineralogical composition of these sands and of their inferred source beds in the Hawera Series.

Most geologists think that the ironsands in Taranaki have been derived from andesitic debris and ash beds of the Hawera Series, and that Mt Egmont

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and the adjacent volcanic centres of Kaitake and Pouakai have been the major contributors. Since the most likely source of material in the Hawera Series (Rapanui Formation) at Hawera is Mt Egmont itself, a further objective in petrographic studies of the ironsands was to estimate abundance of the principal ferromagnesian minerals. If these minerals, notably the pyroxenes, amphiboles, and olivines, were deposited in roughly the same proportions as in Mt Egmont andesites, then measurements of their relative abundance in the ironsands should furnish additional data on the trends of petrographic variation in Mt Egmont andesites (Gow, 1965).

PREVIOUS STUDIES

Ironsands in the Hawera district appear to have first been referred to by Thomson (1917), who noted the abundance of dark ferriferous minerals in loose sands exposed in the cliffs near the Zig Zag at Hawera. Dune sands resting unconformably on the Hawera Series were considered by Thomson to have been derived *in situ* by wind action. According to Thomson it was this "second sorting by wind action" that had produced the concentration of titanomagnetite. Results of ironsand studies at Patea by Hutton (1940) confirmed Thomson's view. Hutton (1945) also studied beach and dune sands at Fitzroy, New Plymouth, and Finch (1948), carried out similar studies at Wanganui. Fleming (1946) discussed the occurrence of ironsands west of Wanganui, and Beck (1947) has made quantitative estimates of ore reserves at Waitara. More recently, Ross (1963) has investigated the relative roles of wind and wave action on ironsand concentration on beaches between Wanganui and Patea.

OCCURRENCE OF IRONSANDS AT HAWERA

Ironsands occur in several types of deposit. The principal modes of occurrence are: (1) beach sands; (2) beach dunes; (3) fixed dunes resting unconformably on the Hawera Series; (4) loosely consolidated sands at various horizons in the Rapanui Formation.

(1) The ore content of beach sands varies considerably from place to place and diminishes rapidly down the beach. Ironsand concentrates form at the cliff foot in sheltered bays; drifts up to 4 ft thick were observed. Apart from the formation of these very localised beach placers no extensive deposition of ironsand has occurred on beaches near Hawera.

(2) Both the Waingongoro and Kapuni Streams follow deeply entrenched meanders near the coast and in recent times have suffered diversion near their mouths. Dunes formed from sand blown up from the beaches have partly filled the abandoned meanders of both streams, and, at Kapuni for example, a small lake has been impounded by advancing sands. Near the mouth of the Waingongoro Stream at Ohawe Beach the sea is rapidly encroaching on the dune area.

(3) Dune sands of an earlier cycle cap a coastal bench (Rapanui Terrace) 200 ft above present sea level. These sands were deposited unconformably

on the Hawera Series, and small dune complexes have developed near the Hawera golf links and at the Zig Zag near Waihi Beach.

(4) Volcanic sands are widespread in the Rapanui Formation near Hawera. These contain local concentrations of ironsand, which have in places been transformed to hardpans by percolating waters. However, these deposits are never sufficiently concentrated to be of economic importance.

GRADING ANALYSES

Field samples weighing up to 500 gm were washed thoroughly in water to remove salt, dried, and then split by hand-quartering to about 100 gm for mechanical analysis. Locations of the samples are shown in Fig. 1. Samples were graded on a nest of U.S. Standard Sieves attached to a Ro-tap vibrator and results of these mechanical analyses are presented in Figs. 2–4. Cumulative curves were constructed to determine the median grain diameters and sorting coefficients of the samples, and these data are tabulated below.

TABLE 1—Median Grain Diameters and Sorting Coefficient of Samples

	Beach Dunes			Dune Complex	
Samples	Median Diam. (mm)	Sorting Coeff.	Samples	Median Diam. (mm)	Sorting Coeff.
A1	0·235	1·35	B1	0·245	1·35
A2	0·200	1·35	B2	0·220	1·35
A3	0·230	1·35	B3	0·190	1·30

	Beach Sands			Beach Placers	
Samples	Median Diam. (mm)	Sorting Coeff.	Samples	Median Diam. (mm)	Sorting Coeff.
*C1	0·135	1·15			
C2	0·180	1·25	D1	0·200	1·20
C3	0·240	1·35	D2	0·175	1·20
C4	0·180	1·25	D3	0·200	1·20
C5	0·235	1·25			
C6	0·310	1·50			

*Also a beach placer.

All sands, regardless of type, are well graded. Beach placer deposits are the best sorted and are somewhat finer grained than other sands. In all samples except one, the majority of grains were retained on sieves of mesh diameter $\frac{1}{4}$ mm and $\frac{1}{8}$ mm. These results agree with observations made by Finch (1947) on ironsands near Wanganui, but not with results obtained by Hutton (1940) at Patea. However, it should be noted that beach sands at Patea are really beach placers. Since grains of titanomagnetite are generally restricted to the finer grades in source rocks, the beach placers at Patea tend to be both finer grained and more perfectly sorted than nearby dune sands of more varied mineralogical composition. Sample C1 (Fig. 4) compares

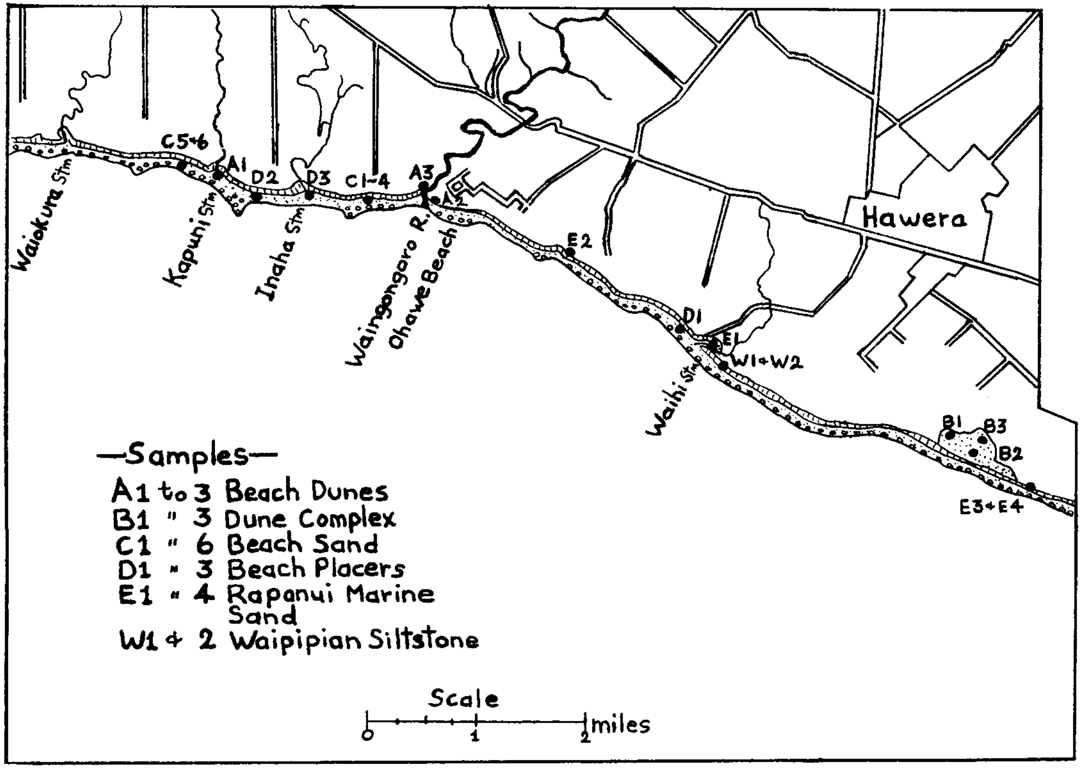

FIG. 1—Map of coastal area near Hawera showing locations of sand samples.

very closely with beach sand from Patea, and it contained a much higher percentage of titanomagnetite in the $\frac{1}{16}$ mm sieve than other samples. Estimates of ore content were obtained by grain count and are shown as cross-hatched areas in the histograms of mechanical analyses. Although not strictly comparable to weight percentages, the grain counts do give some idea of ore distribution in the various types of sand. These results show clearly the tendency of titanomagnetite to concentrate in the finer grades. As noted earlier, no concentrating of ironsand as found at Patea and Waitara has occurred on beaches near Hawera.

OHAWE BEACH STUDY

In order to study changes in texture and mineralogical composition on a typical South Taranaki beach a series of samples (C1–C4) was collected from Ohawe beach approximately half a mile from the mouth of the Waingongoro Stream. A fairly extensive beach is exposed at low tide, and the samples were collected at points 5, 20, 40, and 80 yards respectively, from the base of the cliffs seaward. These beach sands are derived almost entirely from loosely consolidated sediments of the Hawera Series exposed in cliffs up to 150 ft high. Results of the mechanical analyses of this group of samples are shown in Fig. 2. Variations in mineral composition within the grade sizes of each sample and from one sample to another are presented in Fig. 5.

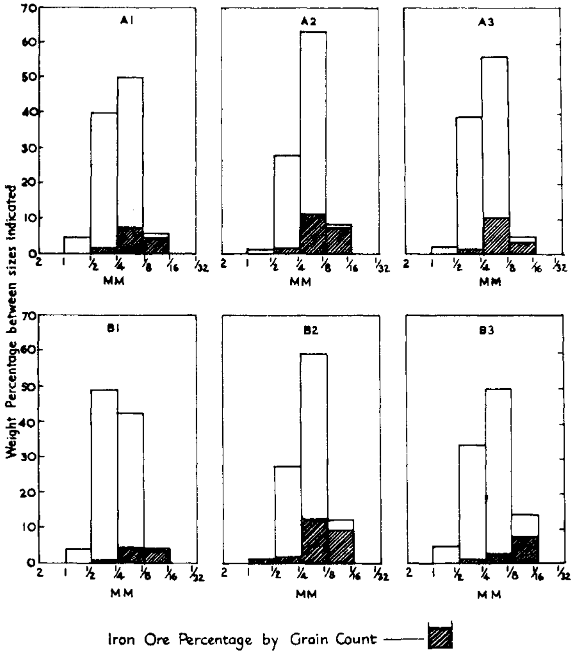

FIG. 2—Grading analyses of dune sands.

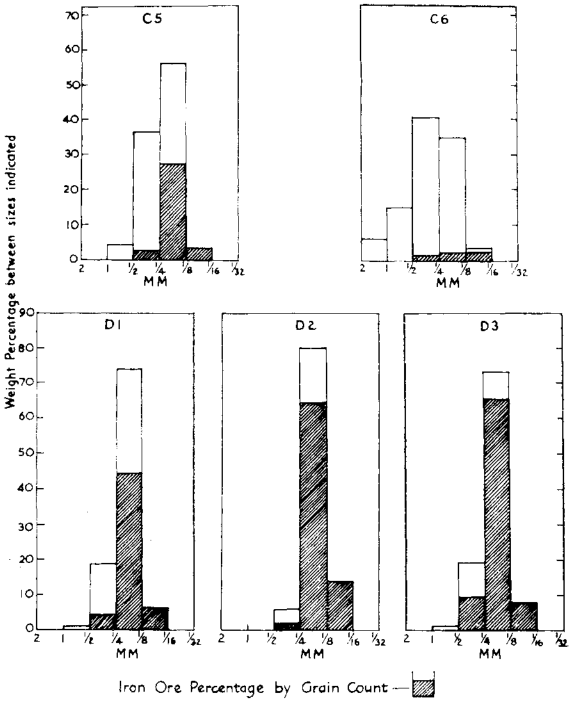

FIG. 3—Grading analyses of beach placers and a beach sand.

Sample C1 with its high content of titanomagnetite is the finest grained and best sorted of the series, but the quantity of titanomagetite then falls off very rapidly with increasing distance down-beach. Augite is the predominant mineral in C2. In C3 augite and hornblende and light minerals are present in about equal amounts. C4 is slightly better sorted than C3, but it contains very little titanomagnetite and is composed chiefly of angular fragments of plagioclase feldspar, volcanic glass, and shell material. These marked changes in mineral composition from one sample to another can be attributed to very selective transportation of minerals in the direction of wave travel. Wave action has sorted particles according to their size, shape, and specific gravity. From the variations shown in Fig. 5 it appears that specific gravity has exerted the greatest control over the size distribution and mineral composition on various parts of the beach.

The thickness of sand also decreased progressively in the down-beach direction, C1, for example, was obtained from a 4 ft layer of sand which graded into a fine-grained gravel of undetermined thickness. At C4 the layer of sand had reduced to less than 1 ft thick. The beach beyond C4 was composed of an admixture of andesitic gravel and boulders.

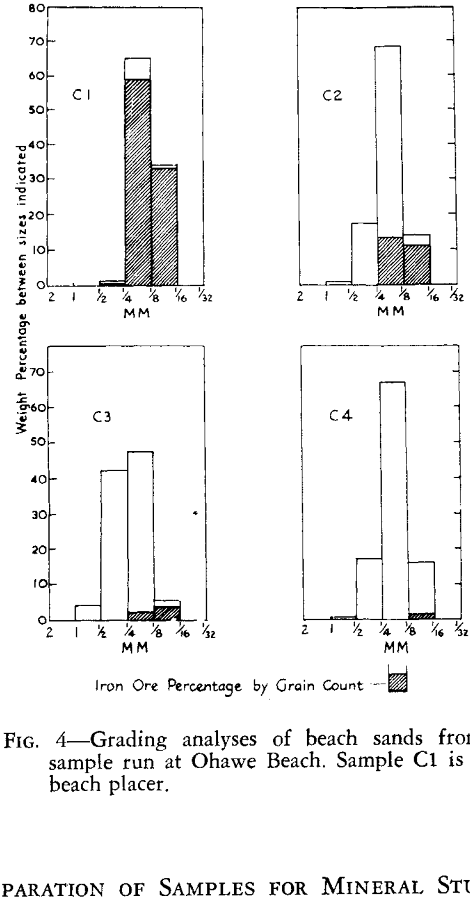

FIG. 4—Grading analyses of beach sands from sample run at Ohawe Beach. Sample C1 is a beach placer.

PREPARATION OF SAMPLES FOR MINERAL STUDIES

The researches of Hawkes and Smyth (1931), Rubey (1933), Russell (1936), and others show clearly that mineral frequencies vary with grade size, so that several screenings from the same sample should be studied if representative results are to be obtained. A very high percentage of grains was retained on the $\frac{1}{8}$ mm mesh of most samples and in addition to preparation of slides from this screening, the $\frac{1}{4}$ mm and $\frac{1}{16}$ mm grade sizes were examined. Heavy liquid separations with bromoform were used for samples from the base of the Hawera Series with their small percentages of heavy minerals. The rarest minerals were isolated by electromagnetic separation of the heavy residues.

Sand grains were mounted in Canada balsam and identified under the microscope. A systematic grain count of a number of representative slides was then made to estimate mineral abundance. At least 100 non-opaque grains per slide were used for grain counts. Up to 500 grains were counted in some slides and the average count per slide totalled 300 grains.

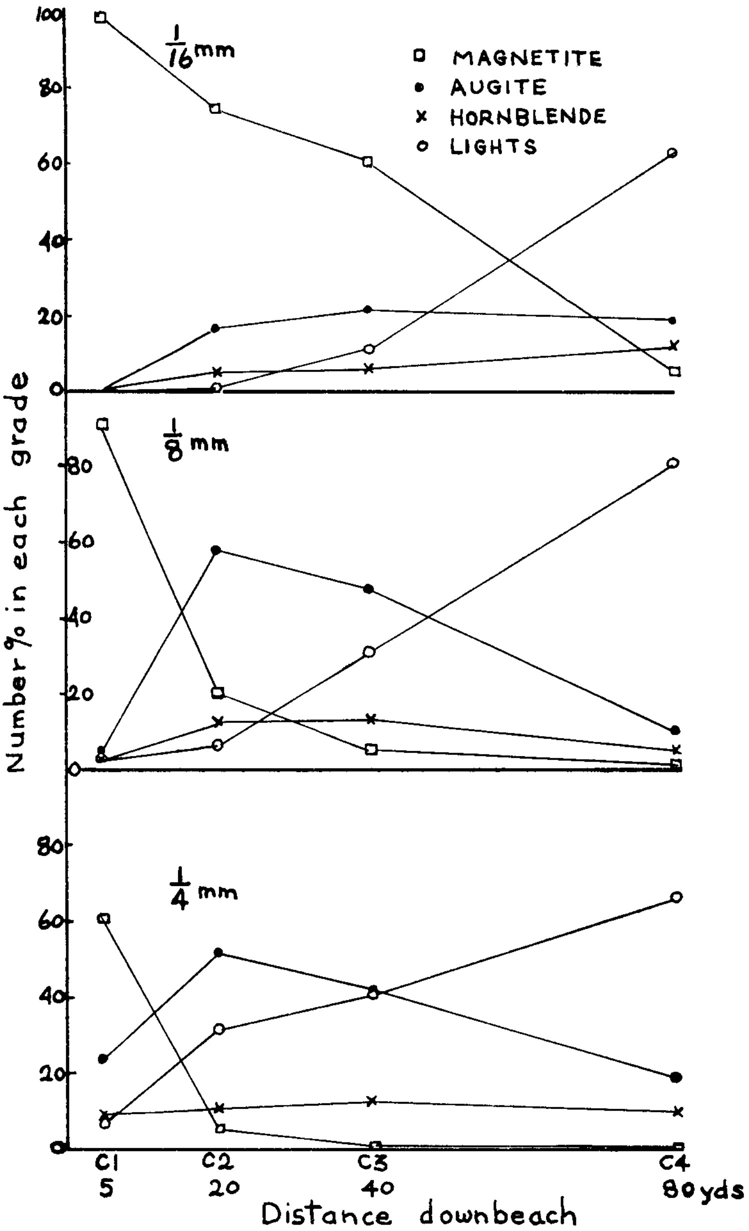

FIG. 5—Variation with location on the beach of mineral abundance in the various size grades of sand samples from Ohawe Beach.

MINERALOGY OF THE IRONSANDS

Titanomagnetite, diopsidic augite, green-brown hornblende, red-brown hornblende, and plagioclase feldspar are the most characteristic minerals of beach and dune sands. Hypersthene and olivine occur more sparingly, and garnet, zircon, apatite, quartz, and muscovite are usually confined to the finest screenings. Quartz and muscovite are occasionally found in the coarser fractions.

Titanomagnetite

Titanomagnetite is found in all grade but it is normally concentrated in the finer screening. Grains are distinctively blue-black in reflected light and strongly magnetic. Subrounded grains occur commonly in the coarser grade sizes. Most of these larger grains have pitted surfaces. Angular grains predominate in the finer grades and well formed octahedral crystals were observed occasionally. Granules of magnetite occur frequently in fragments of glossy mesostasis in grains of augite they constitute the commonest type of inclusion. They occur much less frequently in hornblende, hypersthene, and olivine. More detailed studies of titanomagnetite were not attempted. The chemical aspects have already been treated adequately by Wylie (1937) and Martin (1955), and more recently Wright (1964) has published new data on the optical, magnetic, and X-ray properties of titanomagnetite in New Zealand ironsands.

Augite

Diopsidic augite is the dominant mineral of the beach and dune sands (beach placers excepted). It was readily identified by its light grass-green colour; pale but distinctive yellow-green pleochroism was observed in many grains. Subrounded euhedral grains are especially common in the coarser fractions, but the number of anhedral forms increases rapidly with decreasing grain size. The finest screenings contained abundant prismatic tabular cleavage flakes and crystal fragments. Inclusions of iron ore are common. Prismatic inclusions included plagioclase and apatite.

$Z \wedge C$ 45°
$2V$ 60° (+ve)

Hypersthene

Hypersthene was observed in all gradings. Most of the grains show prismatic outlines sometimes modified by rounding. Colour varies from pale green to salmon pink and most hypersthene grains are pleochroic in these tints. Inclusions of opaque matter are much less prevalent than for diopsidic augite, and may be absent altogether. Colourless euhedral inclusions were also observed in some grains.

X = Pink
Y = Yellow
Z = Green
$2V$ 70° (−ve)

Amphiboles

Amphiboles were present in all samples. Three varieties were distinguished:
(1) Green-brown hornblende
(2) Red-brown hornblende (lamprobolite).
(3) Blue-green hornblende.

Green-brown hornblende

This is prevalent, but never exceeds augite in any of the samples. It is characterised by the intensity and quality of its pleochroism. However, some grains possessed such a deep body colour that they appeared quite opaque when examined in ordinary light under the microscope. Prismatic grains with well developed cleavages are typical. Green-brown hornblendes generally contain much fewer opaque inclusions than augite.

X = Light brown $Z \wedge C$ = 15°–20°
Y = Brown $2V$ 80° (−ve)
Z = Green

Red-brown hornblende

This is much rarer than the green-brown variety, but it is more common than hypersthene. Colour, pleochroism, and shape are distinctive. Grains vary from a pale golden brown to deep red, and the majority are translucent. Grains usually have squarish outlines, though prismatic elongate forms were observed. Well rounded grains are rare. Inclusions are very rare.

X = Yellow-brown Z = Deep red
Y = Red-brown $Z \wedge C$ = 5°–10°

Blue-green hornblende

This is exceptionally rare and was identified in one or two samples only. Prismatic outlines are typical. This variety differs from the other two in possessing very much weaker pleochroism.

X = Blue-green Z = Green
Y = Green-yellow $Z \wedge C$ = 15°–20°

Olivine

Grains of olivine are found in all fractions but they occur more commonly in the coarser grades ($\frac{1}{4}$ mm and $\frac{1}{8}$ mm). Well rounded olivines with scaly and pitted surfaces are typical, but conchoidally fractured grains were noted. Cleavage was observed in two or three grains only. Most olivines are colourless, but a cream-yellow tinge was noted in some, and most grains have a silky lustre. Inclusions are rare, but small opaque granules and euhedral crystals of high refractive index, were observed. The identification of olivine in the sands at Hawera is particularly interesting as Hutton (1940, 1945) apparently failed to recognise this mineral in ironsands at Patea and New Plymouth.

Garnet

Garnet occurs more abundantly than either zircon or apatite. Well rounded grains and chips are common, but garnets with recognisable crystal outlines are rare. Though colourless garnets were observed, most grains show a pinkish tinge. Several yellow grains were also noted. Both anisotropic and opaque inclusions were observed, the former generally as small birefringent "spots".

Zircon

Rounded grains occur, but euhedral zircon with pyramidal terminations are more typical. Though pinkish zircons were observed, most were colourless. Opaque as well as colourless inclusions were noted, but the latter predominate, and are sometimes aligned parallel to the vertical axes of zircon crystals.

Apatite

Apatite is much rarer than zircon, and occurs either as rounded grains, or as fragments of larger crystals.

Epidote

This mineral is a rare constituent of the ironsands and occurs as subangular to subrounded grains. Most epidotes are yellowish green and pleochroic, but there are occasional colourless clinozoisitic grain. "Compass needle" interference figures were observed for several grains. Inclusions are rare.

Mica

Muscovite and biotite are of minor occurrence in all samples. Muscovite is more prevalent than biotite, and cleavage plates up to 1 mm in diameter were noted. These furnish ideally centred interference figures with moderate optic axial angles (40°, −ve). Two varieties of biotite were recognised: a brownish type, and a much rarer greenish variety. Grains often exhibited a bleached appearance. The optic axial angle of the brown biotite is very small (5°–10°, −ve). There were granular inclusions of iron ore in several grains of muscovite, but pleochroic halos were seen in brown biotite only.

Monazite

Several well rounded grains of high relief and pale yellow colour were noted. Birefringence was high and one grain furnished a +ve biaxial figure with small optic axial angle.

Sphene

Rare grains of a semi-opaque nature with high refractive index were identified as sphene.

Tourmaline

Tourmaline occurs as rare grains of high relief. These grains were confined to the finest screenings, and were pale blue and faintly dichroic. A single grain from sample C3 appeared to be slightly biaxial.

"Light" Minerals

Plagioclase, glassy mesostasis, and andesitic glass constitute the bulk of the "lights". They occur in all grade sizes, but show a preference for the coarser screenings. Decrease in grain size is usually accompanied by increasing angularity.

Plagioclase

All plagioclase grains examined were characterised by a refractive index greater than Canada balsam. Both normal and oscillatory zoning were observed. In several zoned grains of the coarser fractions thin mantles with refractive indices lower than Canada balsam were recognised suggesting late addition of alkali-rich feldspar. Multiple twinning on the Albite and Albite-Carlsbad laws are common, and extinction angles of symmetrically illuminated twinned grains show a range of composition from andesine to labradorite. Surfaces of grains were frequently clouded with decomposition products. Rod-shaped and prismatic inclusions, opaque granules, and bubbles were all observed.

Glass

Glass occurs as pale brownish grains of irregular habit.

Glassy Mesostasis

Subangular to irregular grains are typical. Grains containing small crystals of feldspar are common, and opaque granules are usually abundant.

Shelly Material

Shell fragments were recognised in some sands of low ore content, especially in the coarser grades. Grains were well rounded regardless of size, and usually show traces of ribbing and striation. Calcareous tests of foraminifera were noted in some samples.

Quartz

Minor amounts of quartz were recognised in all grade sizes. Irregular to shapeless grains devoid of inclusions are typical.

MINERALOGY OF THE HAWERA SERIES

As is the case with present-day sands, volcanic constituents comprise the most important single source of minerals in the bedded sands of the Hawera Series (Rapanui Formation). An examinaton of several slides from the Rapanui Marine Sand showed that the opaque minerals, pyroxenes, and amphiboles are identical in composition to corresponding minerals in present-day beach and dune sands. Magnetite, diopsidic augite, common hornblende, and lamprobolite are predominant among the heavy minerals. Plagioclase, glassy, mesostasis, and argillaceous aggregates constitute the bulk of the lighter grains. Minor minerals include hypersthene, olivine, garnet, epidote muscovite, biotite, zircon, and quartz. Results of measurements of mineral abundance in Rapanui Marine Sand are included in Table 2 and Fig. 8.

MINERALOGY OF WAITOTARAN SILTSTONE

Because of the persistent occurrence of a number of non-volcanic minerals in the Rapanui Marine Sand and present-day ironsands heavy mineral assemblages of the Waitotaran Siltstone (Waipipi Formation) that underlies the Rapanui Formation at Hawera were examined. The samples, collected from Waihi Beach, were crushed in a mortar and the $\frac{1}{16}$ mm grade size and finer screenings retained for heavy mineral separation. The heavy fractions constitued less than 0·5% by weight of the samples. The most important constituents were opaque minerals, muscovite and biotite, amphiboles, epidote, garnet, and zircon.

Opaque Minerals

Opaque minerals dominate the heavy residue. Separation with a strong magnet showed that most of these grains were magnetite. Irregular outlines are typical, but rounded grains were noted. Rare opaque detritals with brownish lustre in reflected light were identified as ilmenite but leucoxene rims were not observed on any of these grains.

Mica

Muscovite and two varieties of biotite were recognised.

Muscovite

Muscovite occurs typically as colourless laminated platy grains of low relief, 1·0 mm and more in diameter.

Biotite

Two varieties of biotite were recognised, namely brown biotite and green biotite. Brown biotite is prevalent, and frequently contains inclusions of iron ore and opaque dust. Green biotite resembled brown biotite in most of its properties but pleochroic halos were observed in brown biotite only.

Amphiboles

Amphiboles are important members of the Waitotaran heavy residues. Three distinct varieties were recorded, namely greenish brown and bluish green hornblende, and a much rarer species, actinolite. Green-brown hornblende is more abundant than the blue-green variety, and both types show distinctive pleochroism. Most grains were elongate-prismatic with marked longitudinal cleavage. Needle-like inclusions of high refractive index were observed in some blue-green hornblendes. Pale yellow-green prismatic grains with fibrous cleavage were identified as actinolite. Several extinction angles were measured and these ranged around 16°.

Epidotes

Epidotes, ranging from lemon coloured pleochroic varieties to colourless clinozoisitic types occur fairly commonly in the heavy residues. Tabular to sharply anhedral grains were noted. Moderately high relief and large optical axial angles are typical of most grains, but variations in colour, pleochroism, and birefringence indicate some range in composition. Inclusions are rare in the yellow epidotes, but some colourless grains contained numerous opaque granules. Rare colourless grains of fairly high relief were identified as zoisite. These grains exhibited inky blue interference tints under crossed nicols and sometimes yielded interference figures with moderate 2V (30–40° +ve).

Garnet

Garnet is a common constituent. Conchoidally fractured grains predominate but subrounded garnets are not uncommon. Most garnets have a pinkish tinge, but colourless grains were noted. Opaque inclusions are common, and brown stains were sometimes observed on surfaces of grains.

Zircon

Both colourless and pale pink zircons were observed and, unlike garnet, most zircon grains still retain prismatic outlines. A distinctly purplish tinge was noted in some zircons and these grains are perhaps comparable with the variety of zircon known as hyacinth. Apatite and sphene are of minor importance. Rare minerals included chlorite, monazite, tourmaline, and rutile.

MINERAL PROVENANCE

The present-day beach deposits appear to be derived substantially from the erosion of the Rapanui Formation, which in turn was derived from andesitic rocks from along the Egmont Volcanic Lines. Heavy mineral assemblages are dominated by diopsidic augite, green hornblende, and magnetite. Lamprobolite, hypersthene, and olivine occur much less frequently but are found in all samples. Mt Egmont has probably been the principal source of detritus. Direct deposition from volcanic ash and the erosion of andesitic lavas have contributed to the sediments of the Rapanui Formation.

At Hawera the Rapanui Formation was deposited unconformably on arenaceous siltstone of the Waipipi Formation. Mineralogical studies of the beds on both sides of this unconformity show that it not only represents a hiatus in time, but also separates beds with radically different heavy mineral suites.

Whereas the Rapanui Formation at Hawera is composed substantially of andesitic debris, all the major heavy minerals of the Waipipi Formation, with the exception of epidote, are common accessories of crystalline acid igneous rocks. These include magnetite, garnet, zircon, muscovite, biotite, and hornblende. Epidote is generally confined to high-rank metamorphic rocks. Muscovite is also an important constituent of a variety of metamorphic rocks and biotite is often found in low-rank metamorphics. Of the rarer minerals, chlorite was probably derived from low-rank metamorphic rocks, and monazite, apatite, and sphene are associated commonly with granitic and pegmatitic rocks.

Although granitic pebbles are abundant in Jurassic conglomerates at Kawhia, actual outcrops of granitic-metamorphic rocks have never been observed in the North Island of New Zealand. However, acid igneous and high-rank metamorphic rocks are extensively developed in North-west Nelson, and even as early as 1920 Marshall and Murdoch had attributed the widespread occurrence of micas in Waitotaran siltstones in Wanganui and Taranaki to sources in North-west Nelson. It is possible that the granitic-metamorphic rocks of the Nelson district may have extended much further northward in past geological times, but whether the Waipipi Formation at Hawera was formed directly from such sources or was derived from pre-existing sediments, e.g., the Taranaki Series, is difficult to determine.

The initiation of widespread volcanic activity in Taranaki definitely post-dates the deposition at Hawera of the Waipipi Formation because the latter contains no andesitic minerals. However, the abundance of andesitic detritus in sands and conglomerates at the base of the Hawera Series clearly indicates that the Taranaki volcanoes must have been in existence for some time before the deposition of the Rapanui Formation at Hawera.

Just when volcanism began in Taranaki is difficult to determine. Grant-Taylor (1964) believes activity along the Egmont Volcanic Line did not begin until Hawera time, with eruptions occurring first at Kaitaki and culminating with Mt Egmont, where activity has continued into very recent times. On the other hand the widespread occurrence of pebbles of hornblende andesite in Nukumaruan beds near Wanganui might indicate that volcanoes in Taranaki have been active since the Nukumaruan (Steiner, 1953). Unfortunately the initiation of activity along the Egmont Volcanic Line cannot be resolved more accurately at Hawera because both Nukumaruan and Castlecliffian beds are absent from the geological record.

ABUNDANCES OF FERROMAGNESIAN MINERALS

A systematic grade count of a number of samples was made to obtain some general idea of the overall abundance and size-grade distribution of the minerals in andesitic sands near Hawera. Results of these analyses are presented graphically in Figs. 6 to 8. Magnetite was purposely excluded from the grain counts of beach sands and dunes (Figs. 6 and 7) to facilitate more rapid counting. In Fig. 8 titanomagnetite has been included in the grain count to give some idea of its concentration at various levels in the Rapanui Marine Sand. Of the four samples of Rapanui Marine Sand examined, E2 was taken from a layer of concentrated ironsand and E1 came from a magnetite-poor zone. Samples E3 and E4 were obtained from two separate layers containing an average concentration of ironsand.

Almost without exception diopsidic augite was the most prevalent ferromagnesian mineral in all size grades of the samples examined. Common green-brown hornblende was the next most abundant ferromagnesian mineral, followed in order of decreasing abundance by lamprobolite, hypersthene, and olivine.

In terms of their overall physical properties augite, common hornblende, lamprobolite, hypersthene, and olivine can be considered similar. In andesitic sands such as those near Hawera these five minerals would tend to be deposited together, so that their relative abundances in these sands should tend also to reflect approximately the relative order of abundance of the principal types of andesite erupted from Mt Egmont.

Hornblende is perhaps more readily cleavable than the other four minerals, and this could affect its distribution in the sands. However, since these minerals have not travelled any great distance from their source (the sands under consideration are all less than 25 miles from the crater of Mt Egmont) the effects of differential abrasion are probably quite small. Russell (1939) failed to observe any appreciable change in the proportion of hornblende or pyroxene in river sands transported more than 1,100 miles down the Mississippi. Russell's conclusion that differential abrasion results in negligible losses of minerals, even after prolonged transport, has been confirmed, according to Pettijohn (1957), by Van Andel in his study of sands along the Rhine.

Intrastratal solution, given enough time, could cause changes in mineralogical composition. Of the minerals under consideration only olivine is likely to have been affected in this way. However, none of the olivines examined in the various slides showed any signs of deep pitting or etching. This seems to indicate that losses by intrastratal solution have been minimal too.

It is very doubtful if volcanic sources other than Mt Egmont and associated centres have contributed to andesitic sands near Hawera. Very considerable quantities of ash have been erupted from a number of sources in the centre of the North Island, but this material appears to be distributed almost entirely to the east and south-east of the eruptive centres. Little, if any, of this ash appears to have been deposited in the immediate vicinity of Hawera.

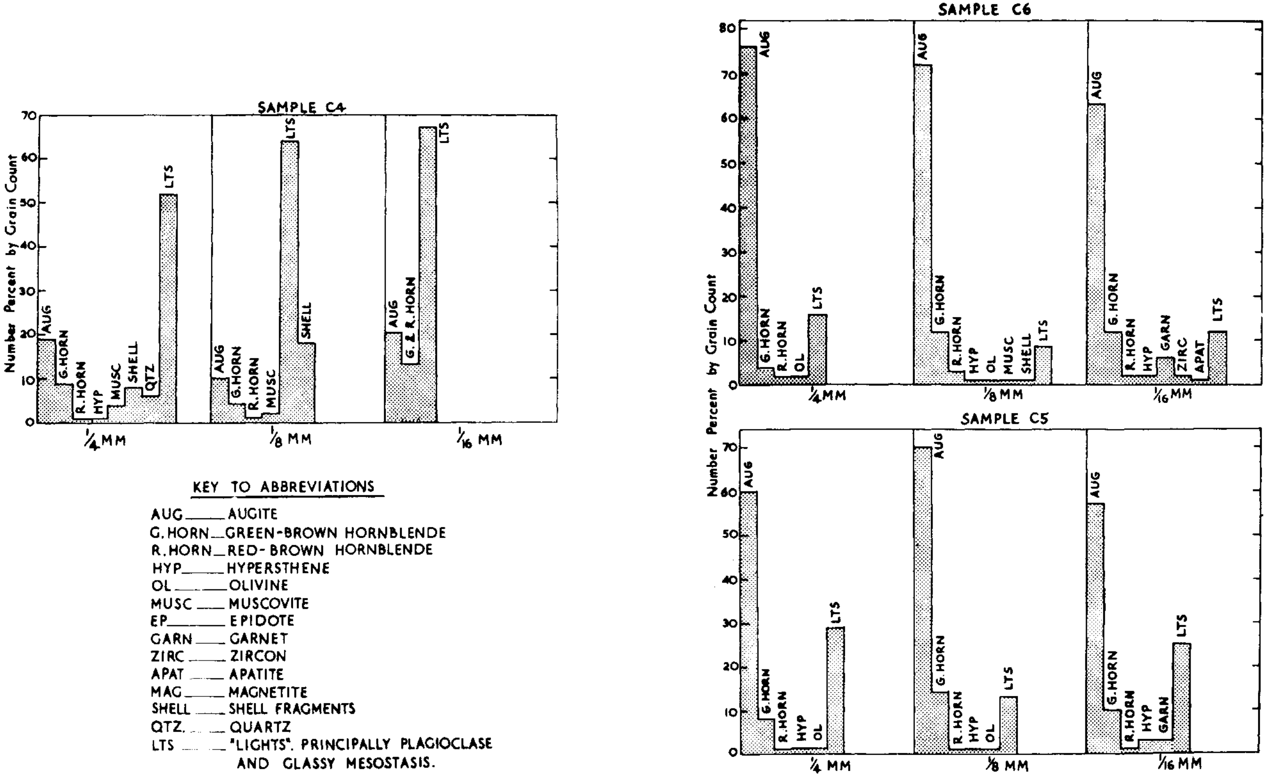

FIG. 6—Variations in mineral abundance in the different size grades of three beach sands.

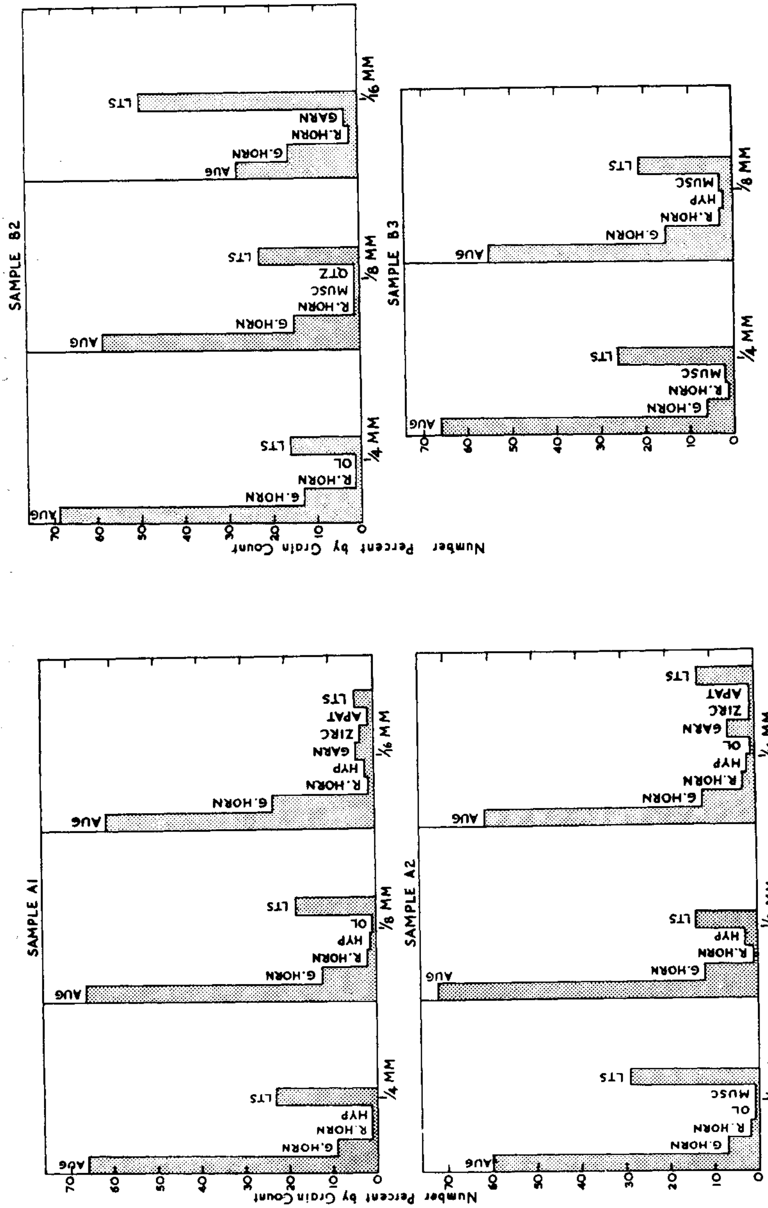

FIG. 7—Variations in mineral abundance in the different size grades of sands from beach dunes (*left*) and dune complex (*right*).

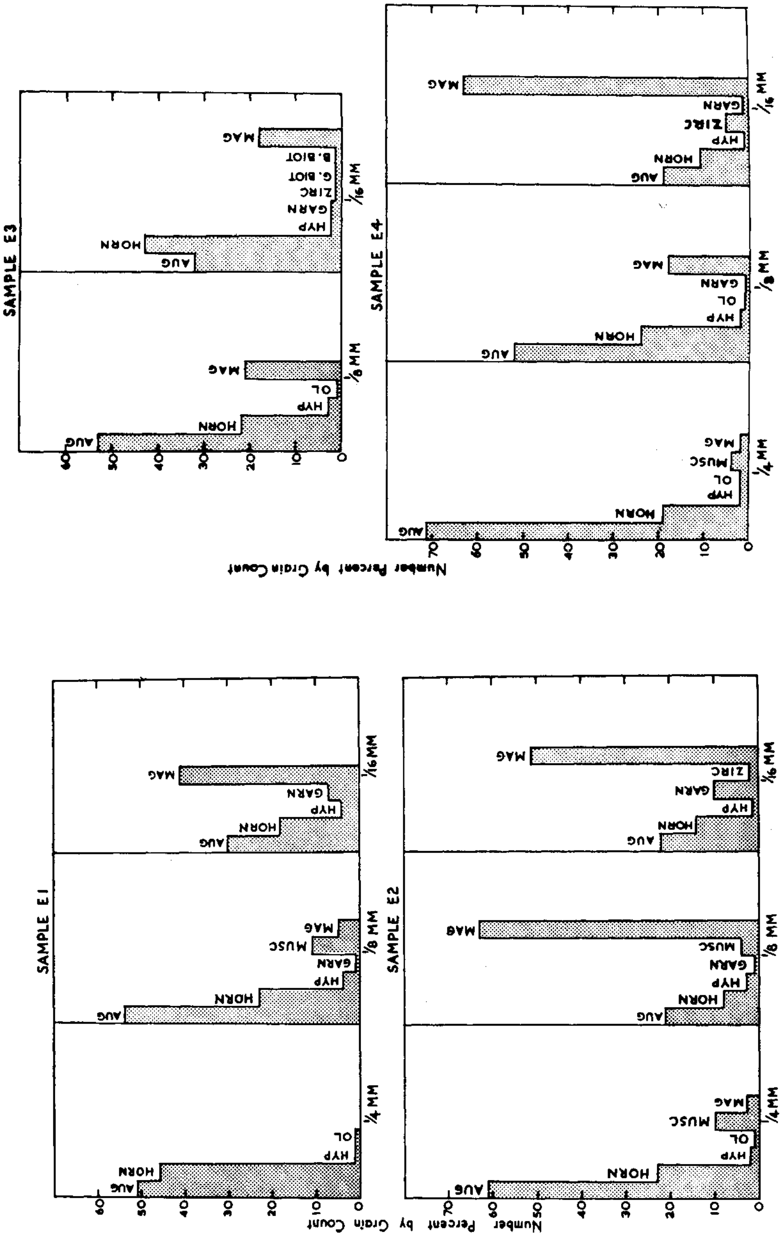

FIG. 8—Variations in mineral abundance in the different size grades of sands from the Rapanui Formation near Hawera.

The histograms of abundance (Figs. 6 to 8) show that the proportions of ferromagnesian minerals do not differ too greatly within the different size grades of each sample. To examine further these variations, the modal grade was selected for measurements of mineral frequency, and the resulting ratios of abundance are listed in Table 2; all ratios are referred to common green hornblende taken as unity.

TABLE 2—Relative Abundance of Minerals in Sand Samples

Sample	Augite	Green Hornblende	Red Hornblende	Hypersthene	Olivine
A1	5·1	1·0	0·15	0·15	0·08
A2	6·1	1·0	0·08	0·25	—
B2	3·9	1·0	0·13	—	—
B3	3·7	1·0	0·20	0·13	—
C2	5·1	1·0	0·15	0·15	0·07
C3	4·2	1·0	0·16	0·08	—
C4	2·5	1·0	0·25	—	—
C5	5·0	1·0	0·07	0·07	0·07
C6	6·0	1·0	0·25	0·08	0·08
E1	2·3	1·0*		0·17	—
E2	2·6	1·0*		0·37	—
E3	2·5	1·0*		0·14	0·05
E4	2·2	1·0*		0·08	0·04

A and B, Dune Sands;
C, Beach Sands;
E, Rapanui Marine Sand.

*total hornblende.

These results show that diopsidic augite is between two and six times as abundant as common green hornblende. Though augite was only two or three times as prevalent as hornblende in the Rapanui Marine Sand, it is between four and six times as abundant as hornblende in present-day beach sands. This seems to indicate that some enrichment in augite does take place during reworking of sediments. Common green hornblende is much more abundant than the oxidised red-brown variety, lamprobolite. In general, lamprobolite is less than $\frac{1}{6}$ as prevalent as green hornblende, or less than $\frac{1}{25}$ as abundant as augite. Hypersthene is slightly less abundant than lamprobolite and olivine appears to be the least abundant of the ferromagnesian minerals. The average percentage proportions of these five minerals, based on measurements of the modal size grade, were as follows: Augite 76%; common hornblende 18%; lamprobolite 3%; hypersthene 2%; olivine 1%.

Thus it appears that augite andesites and augite hornblende andesites are the principal rock types erupted from Mt Egmont. The proportion of hornblende-bearing andesites containing the oxidised form, lamprobolite, is apparently quite small. The relatively low percentage of hypersthene seems to indicate a lack of hypersthene andesites on Mt Egmont. This tends to confirm abundant petrographic evidence of the andesites themselves (Gow, 1965) that this paucity of orthorhombic pyroxene, coupled with a relative abundance of hornblende, distinguishes Mt Egmont andesites from those of Tongariro National Park volcanoes.

Although olivine does not appear to be as abundant as hypersthene in beach and dune sands near Hawera it was, interestingly enough, found to be much more abundant than hypersthene in andesites from Mt Egmont. This might indicate either that some intrastratal solution of olivine has occurred or that hypersthene has been introduced from other sources.

CONCLUSIONS

At Hawera concentrated ironsand is confined to small drifts near high tide mark. These are found only in a few sheltered bays along the South Taranaki coastline, and they are not economically significant. There are no real diagnostic differences in sorting, grade size, and mineralogical composition between beach sands and dune sands. The exceptional fineness and degree of sorting of beach placers can be attributed to the limited size of titanomagnetite available in the andesitic source rocks. Most sands from along the coast at Hawera are both fine grained and well sorted with median diameters of around 0·2 mm and sorting coefficients (Trask) of around 1·3.

In beaches the sand is very selectively sorted in the direction of wave travel. Size, shape, and mineralogical composition are all affected. In particular, density differences between minerals appear to have controlled considerably the composition of sands on different parts of a beach. The order of deposition of the principal minerals from the top to the bottom of the beach was titanomagnetite, augite, hornblende, and light minerals.

Diopsidic augite is the dominant ferromagnesian mineral of present-day beach and dune sands. It is between four and six times as abundant as common green hornblende and it is more than 25 times as prevalent as red-brown hornblende (lamprobolite). Hypersthene and olivine occur in somewhat lesser amounts than lamprobolite. The bulk of these minerals has been derived from the erosion of the Rapanui Formation exposed in sea cliffs up to 200 ft high near Hawera. Some contribution is also made by streams draining the slopes of Mt Egmont.

Augite was found to be only two to three times as abundant as green hornblende in the Rapanui Marine Sand, indicating that some enrichment of augite has occurred during reworking of these sands on present-day beaches.

The relative proportions of the principal ferromagnesian minerals in andesitic sands near Hawera indicate that they were ultimately derived from augite andesites and augite-hornblende andesites from Mt Egmont. The persistent occurrence of olivine probably attests to periodic eruptions of basaltic andesites from Mt Egmont. Hypersthene andesites, so typical of the Tongariro National Park volcanic rocks, are apparently of very minor importance on Mt Egmont.

The complete absence of andesitic minerals ni the Waipipi Formation near

Hawera clearly indicates that either the Taranaki volcanoes had not yet erupted or, if they had, the products of these eruptions had not been incorporated into the sedimentary record before the end of the Waipipian.

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