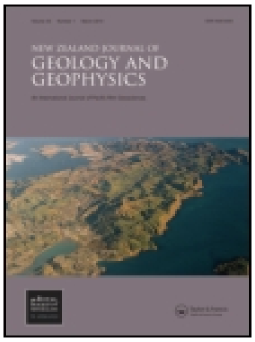

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D. I. Ross

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SURFACE MAGNETIC PERMEABILITY MEASUREMENTS ON SOME TARANAKI IRONSAND DEPOSITS

D. I. Ross

Physics Department, Victoria University of Wellington,
Wellington, New Zealand

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Abstract

Surface magnetic permeability measurements on some of the Taranaki ironsand deposits using an *in situ* permeability bridge are reported. The variation of iron ore concentration along the coast from Wanganui to Patea is discussed with particular reference to the effect of topographical features such as river mouths on the distribution. It is found that such features have a marked effect, indicating that sampling techniques may lead to erroneous values for the amount of iron ore present. It is concluded that the mechanism responsible for the concentration of the ironsands is probably a combination of sea- and wind-sorting, with the latter being the more efficient.

Introduction

In previous published investigations dealing with the New Zealand ironsands no measurements of the local distribution of titanomagnetite content have been made. Rather, a general picture has been obtained by taking relatively few samples from a considerable area and then determining the average concentration for that area by magnetic separation of the titanomagnetite from the non-magnetic residual. It was thought to be worth while to make further investigations of the ironsand deposits for two reasons. Firstly, to obtain a better estimate of the actual amount of iron ore present at any particular locality, and secondly, to determine the mechanism of concentration. It is believed that the titanomagnetite present in these sands originated in the ash showers from Mt Egmont and it is generally assumed that it has been carried to the coast by rivers and concentrated on the beaches by the action of the sea.

Apparatus

An *in situ* permeability bridge was used in the investigation, since the concentration of titanomagnetite at any point can be determined directly from the measured permeability. The relation connecting the concentration to the permeability is given by Fricke's equation (Fricke, 1924) for a binary mixture and can be put in the form:

$$\mu = \mu_0 \left\{ 1 + \frac{(x+1)\ f}{(\mu_1 + x\mu_0)/(\mu_1 - \mu_0) - f} \right\} \tag{1}$$

where μ = measured permeability of the medium
μ_1 = permeability of the magnetic grains
μ_0 = permeability of the non-magnetic grains
f = volume ratio of magnetic to non-magnetic material
x = a factor depending on the shape of the magnetic particles and on the permeability contrast of the particles making up the mixture.

It has been shown (Ross, 1961) that for the ironsands being considered $\mu_1 = 7{\cdot}10$ c.g.s. units and $x = 2{\cdot}86$ so that with these values the volume concentration of titanomagnetite may be obtained from a single permeability measurement. Fig. 1 shows a graph of equation 1 using the above values, with the experimental points also plotted. The percentage by weight of titanomagnetite present was obtained from the percentage by volume by a graph of volume percentage vs. weight percentage (Fig. 2) drawn from the results of magnetic separations of samples brought back from various regions. The separator used for this was a magnetic elutriator designed by Martin (1960). This type of separator may be adjusted to give a very pure sample of titanomagnetite with practically no loss.

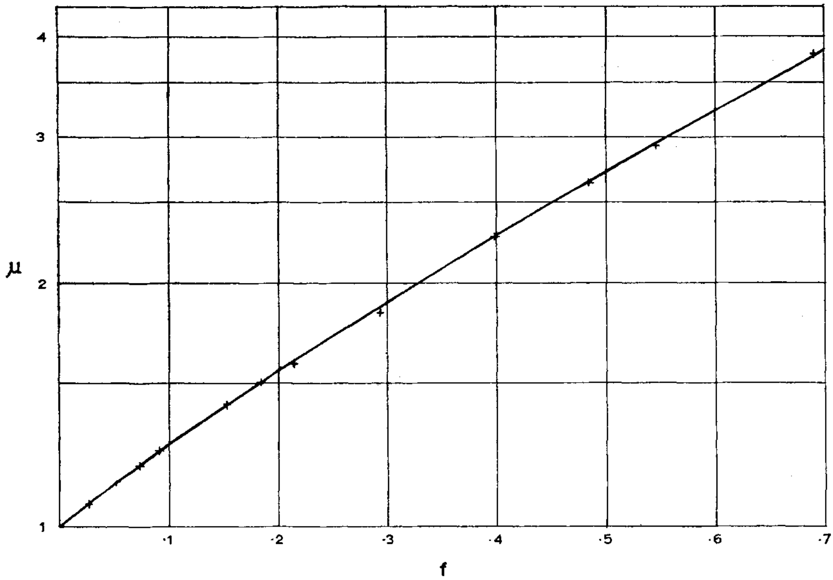

FIG. 1—Permeability of ironsands (in c.g.s. units) plotted against volume ratio. The curve is Fricke's for $x = 2{\cdot}82$ and $\mu_1 = 7{\cdot}1$.

The *in situ* permeability measuring apparatus constructed was a three-coil induction balance similar to that described by Mooney (1952). A diagram of the coil system showing dimensions is given in Fig. 3. Coils B and C are coplanar. Coil A is coaxial with coils B and C, and the axial offset (d) of coil A from the plane of coil C is variable, enabling the sensitivity of the balance to be varied. Such a system has the advantage of being relatively insensitive to small changes in surface structure.

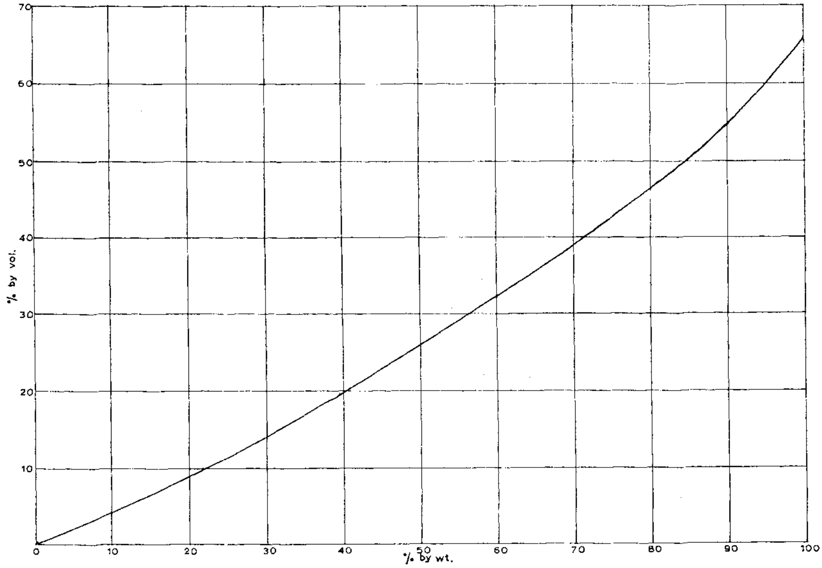

FIG. 2—Graph of volume percentage against weight percentage.

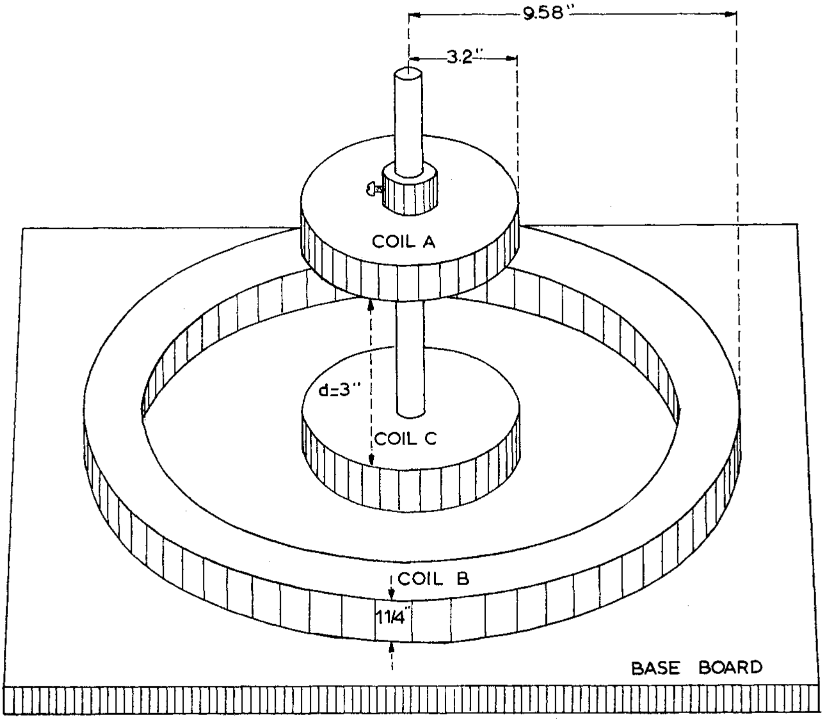

FIG. 3—Diagram of coil system.

The mutual inductance of the coil system was measured by a Carey Foster bridge (Fig. 4). A 1000 c/s oscillator of the Wein Bridge type fed the bridge and a high-gain amplifier feeding headphones was used as a detector.

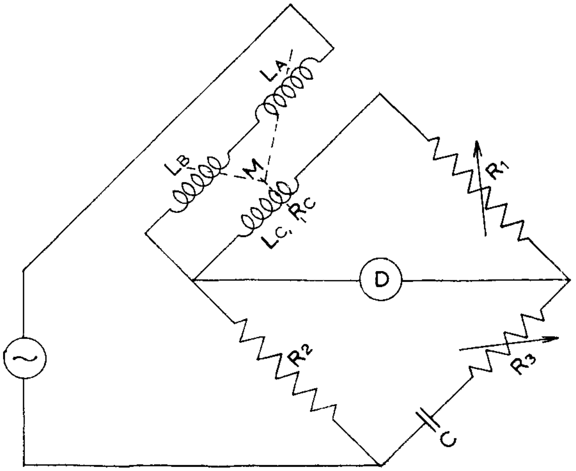

FIG. 4—Bridge circuit. L_A, L_B, and L_C are the three coils, and M is the mutual inductance of the system.

A change in permeability of the medium under the coil system is related to the change in R_3 required to rebalance the bridge by the equation:

$$\Delta R_3 = \frac{\mu - 1}{\mu + 1} \left\{ \frac{G_2 R_2 R_3/(R_2 + R_3) - G_1 R_3}{M + G_1(\mu - 1)/(\mu + 1)} \right\} \tag{2}$$

where G_1 and G_2 are geometrical constants of the coils and M is the mutual inductance of the coil system. Δ R_3 is plotted as a function of μ in Fig. 5.

It is important to realise that this equipment measures only the surface permeability of the sand. However the effective sample measured is approximately a hemisphere of radius 18 in., so that the equipment measures the average permeability of a surface sample of volume approximately 7 cu. ft.

MEASUREMENT ERRORS

Mooney has discussed the errors that may occur in this type of equipment. The main source of error noted in this investigation was small changes in calibration due to changes in the dimensions of the coil assembly and in particular in the offset of coil A. These changes occurred through mechanical shock and necessitated frequent recalibration of the equipment over a non-magnetic medium. This was done by raising the coil system 6 ft above the beach level, at which height the effect of the ironsand was negligible.

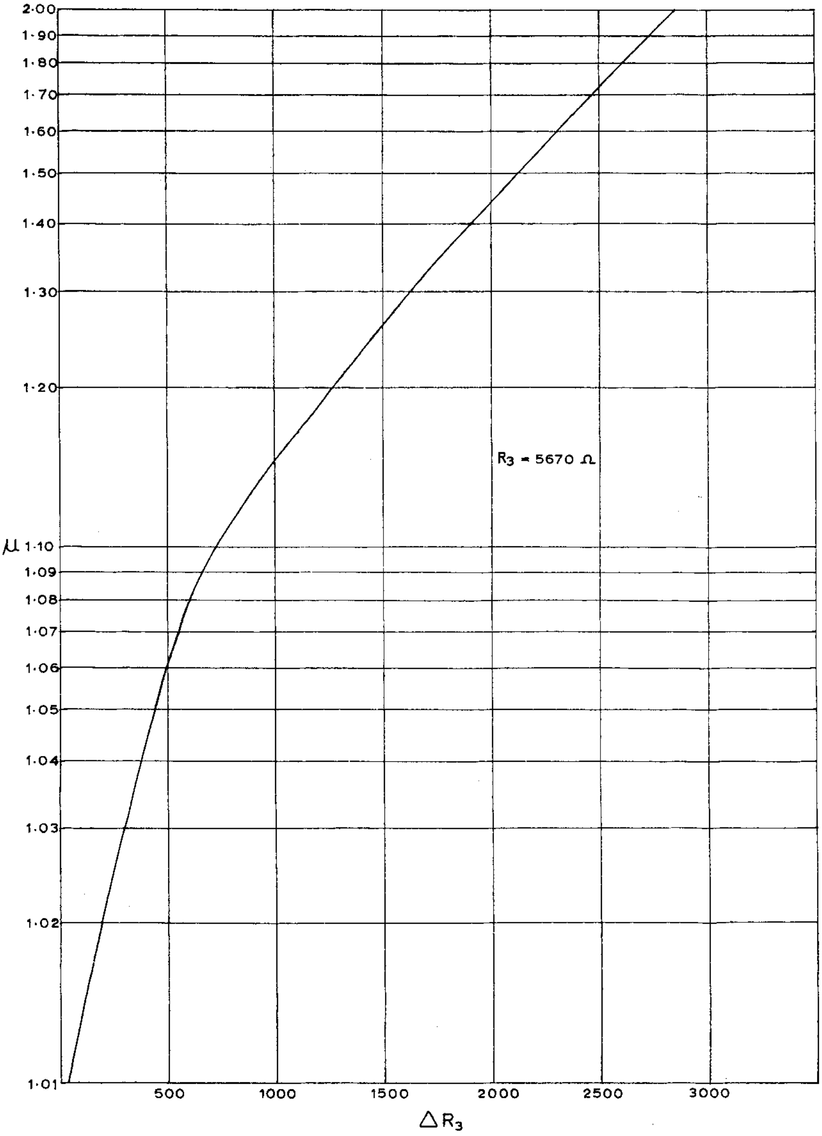

FIG. 5—Permeability of sand plotted against change in R_3.

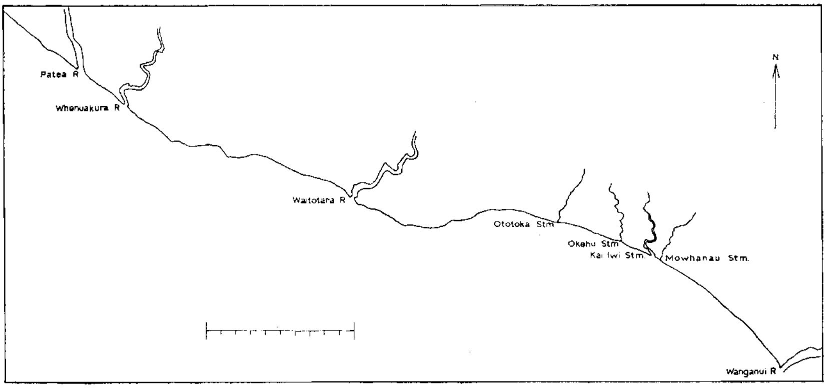

FIG. 6—Map of coastline. Each division of the scale is 1000 yd.

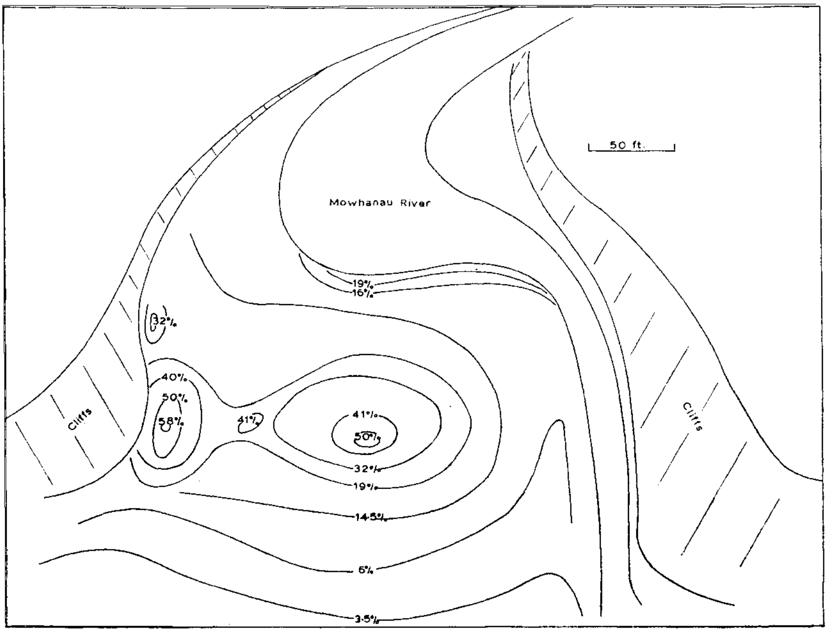

FIG. 7—Ironsand concentration contours at Mowhanau River mouth.

The relative accuracy is of the order of 2–3%, this being the order of reproducibility of results in the high permeability regions. Such accuracy would mean a relative accuracy of better than 5% in the percentage of titanomagnetite present and an absolute accuracy of the order of 6%. This absolute accuracy includes errors due to the bridge components as well as those due to variations in the coil assembly.

FIELD MEASUREMENTS

Surface permeability measurements were made in the regions around the mouths of the Mowhanau, Kai Iwi, Okehu, Whenuakura, and Patea Rivers as well as along various regions of the coast south of the Okehu River. A map of the coastline is given in Fig. 6. Contour maps of the concentration of titanomagnetite in these regions have been drawn from the measurements and are given in Figs. 7–10. Samples from the regions of greater concentration were brought back and separated in the magnetic elutriator already referred to. The concentration percentages obtained from these samples were used as a check on the permeability measurements.

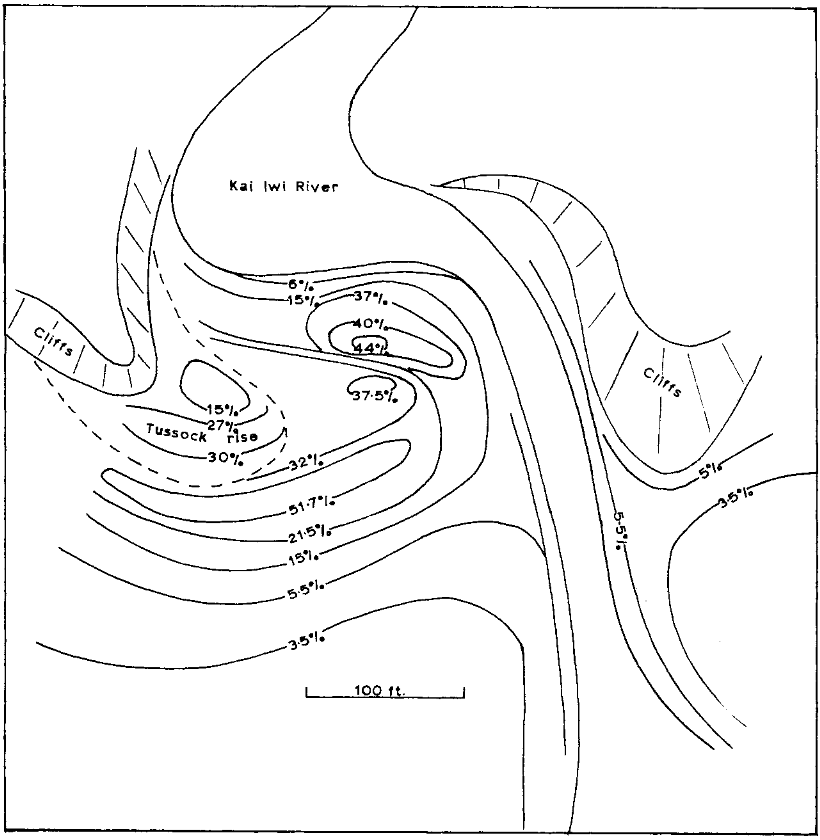

FIG. 8—Ironsand concentration contours at Kai Iwi River mouth.

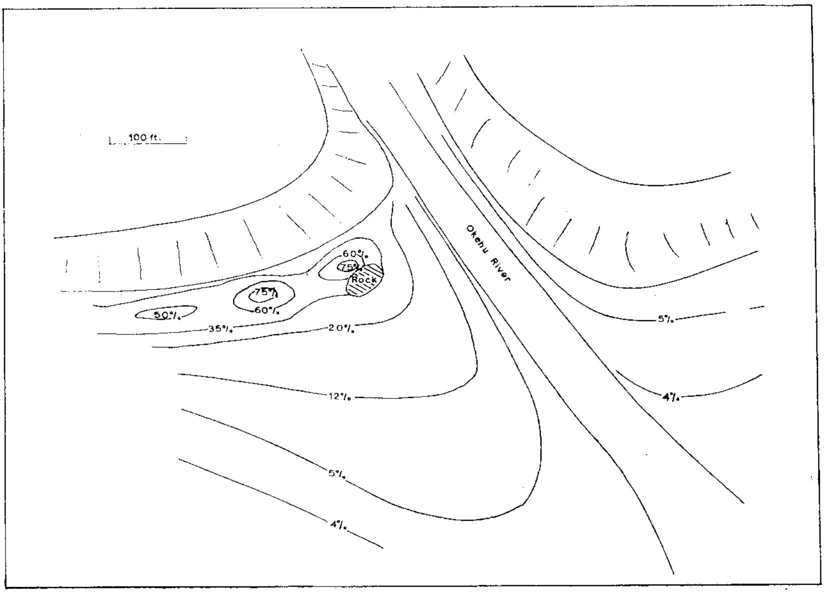

FIG. 9—Ironsand concentration contours at Okehu River mouth.

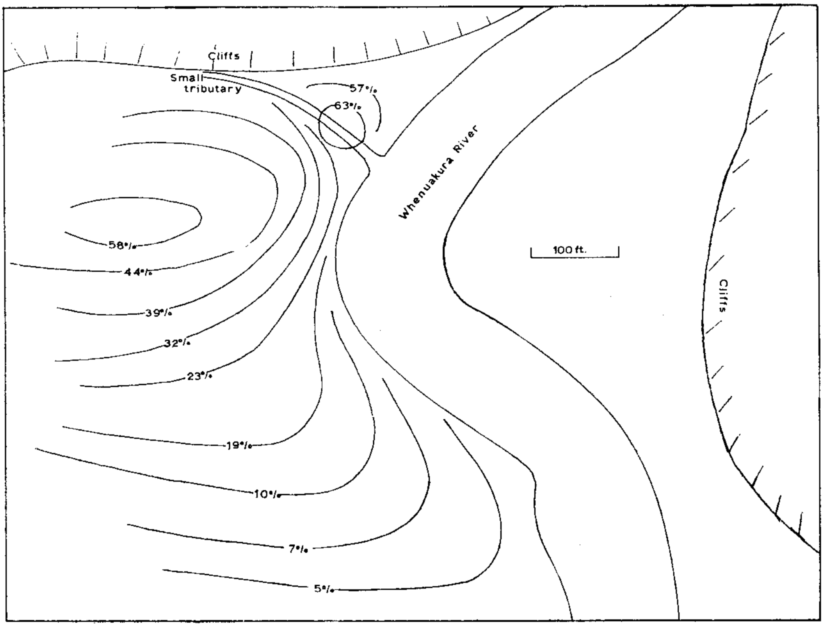

FIG. 10—Ironsand concentration contours at Whenuakura River mouth.

RESULTS

Concentration Contours along the Open Beach

It was found that below high-tide mark along the open beach the concentration contours followed very closely the tide level contours. In a number of regions south of the Okehu R. and also along the Patea beach, traverses totalling about 1 mile were made at a distance of approximately 15 ft below high-water level without any appreciable change in concentration being observed. From high-tide to low-tide level the concentration decreased from 12% to 5% by weight of titanomagnetite.

Above high-tide level there was a rapid increase in concentration to a value of 20–30% in a distance of 10–20 ft. This is very noticeable along this region of the coast, high-tide level being marked by a distinct transition from the relatively light grey of the sand below to the much darker sand above. This increase in permeability usually continued to the base of the cliffs, and in the coastal sand dunes at Patea rose to 50–60% by weight.

Concentration Contours at River Mouths

The concentration pattern at the river mouths was very similar irrespective of size of the rivers, although the degree of concentration varied. The concentration contours for the regions around the Mowhanau, Kai Iwi, Okehu, and Whenuakura Rivers are shown in Figs 7–10. At Patea the pattern is somewhat modified by the presence of the breakwater. North of the breakwater the pattern resembles that of the open beach with the sand accumulating in dunes.

The picture that emerges from these results is as follows: A very high surface concentration of 60–80% occurs about 50 ft above high-water level on the north-western side of the river. These deposits are relatively small, being 20–100 ft in diameter. In one place at the mouth of the Ototoka River, where a sample was collected but no permeability measurements were made, a concentration of 90% by weight was found. As an example of the amount of iron ore present in one of these concentrated surface deposits the amount of titanomagnetite in a 2 ft thick layer bounded by the 19% by weight contour at the Mowhanau River mouth (Fig. 7) was calculated. In this volume of sand (approximately 20,000 cu. ft) there is at least 530 tons of titanomagnetite. This is to be compared with about 80 tons in a similar volume around high-tide level or 55 tons at low-tide level. From the Mowhanau to the Ototoka River a steady increase in concentration of these local deposits was observed, but this was not continued farther north, suggesting it was dependent on the local effects of the river rather than a general trend along the coast.

DISCUSSION

An explanation of the observed results is as follows: The increase in concentration from low- to high-tide level is almost certainly due to the sorting action of the sea. A number of factors appear to influence the efficiency of this sorting action:

(1) The titanomagnetite particles are more dense than the non-magnetic sand particles (titanomagnetite 4·74 g/cm^3, sand average 2·99 g/cm^3). By itself this would mean the titanomagnetite would be concentrated near the high-water level, since particles of titanomagnetite would have a higher terminal velocity of fall in water than particles of sand of the same size. The titanomagnetite would therefore be deposited on the relatively steep slopes near high tide and the sand on the gentler slopes lower down the beach according to the normal grading pattern.

(2) The titanomagnetite particles are small ($\sim$ 0·15 mm diameter) and spherical whereas the sand particles are large ($\sim$ 0·25 mm diameter) and angular. Assuming both fractions to be spherical would mean that the terminal velocity of fall as given by Stokes's Formula would be higher for the sand particles than for the titanomagnetite. This would mean the sand would be concentrated around high-water level. However, Bagnold (1941) has shown that the diameter of the equivalent sphere for quartz sand particles is approximately 0·75 times their average diameter. Strictly, this factor of 0·75 refers to wind-blown sands but a similar factor also applies for water-carried sand. In this case the multiplying factor may be even less than 0·75 as wind-blown sand tends to be more rounded than that carried by water. The effect of this multiplying factor is to make the terminal velocity of fall for the titanomagnetite particles slightly larger than that for the sand particles. We would therefore expect the titanomagnetite to be concentrated at high-tide level, as the sand particles are more easily carried in suspension and thus swept back down the beach, although the efficiency of sorting will be lower than if both fractions were the same size.

(3) The sphericity of the titanomagnetite particles would also result in their rolling more easily than the sand particles. The effect of this would be small on beaches of slight slope but may be important in regions of higher slope.

(4) The turbulence occurring in the sea along this part of the coast means it can carry a relatively large load in suspension.

From the above considerations we would thus expect to find an increase in concentration of titanomagnetite from low- to high-tide level. This conclusion agrees with the measured concentrations. A quantitative calculation is difficult to make owing to the conflicting effects.

Transport by the sea cannot explain the observed distribution above high-water mark. From the measurements we can deduce that: (1) The mechanism in this region is far more efficient than that of sea sorting; (2) It is sensitive to the land contours.

The only mechanism possible in this region is wind transport. Since the terminal velocities of fall of the titanomagnetite and sand will be approximately the same in air the problem of the concentration of titanomagnetite in this region appears to be mainly a problem in aerodynamics. At the wind velocities occurring along the coast the angular sand grains suffer considerably more lift than do the smooth almost spherical titanomagnetite particles. Hence, with the wind blowing at an angle to the high, nearly vertical cliffs along the coast, the sand particles will tend to be carried along the coast while the titanomagnetite will be rolled up the beach, forming a maximum concentration just in front of the cliffs.

To test this process a model experiment was tried in the laboratory. A uniform mixture of sand and titanomagnetite was made up in a shallow trough with a barrier at one end to act as a cliff. A blower was used for the wind, and it was found that as the wind velocity was increased the sand particles tended to be lifted off the surface and carried away, leaving ridges of black titanomagnetite that moved slowly up the "beach" forming a region of surface concentration just in front of the barrier.

The high concentrations observed at the river mouths would appear to be due to a complex wind-current pattern in these regions. It will be observed from the diagrams that the mouths of all the rivers visited curve towards the south, entering the sea at an angle consistent with the south-eastern coastal drift in this region thus forming a funnel with a bent stem, bordered in all cases by high vertical cliffs. It seems reasonable to expect the wind currents to carry the sand and titanomagnetite into the funnel, the majority of the sand particles being blown away as along the open beach, with the titanomagnetite collecting around the centre of the funnel mouth. Since the wind-current pattern would depend on the physical dimensions of the river mouth such a mechanism would explain the consistency of the general pattern and the differences in magnitude of the pattern from mouth to mouth.

CONCLUSIONS

From the results of this preliminary *in situ* survey of the concentration of the ironsands along the beaches of South Taranaki the following points may be concluded:

(1) The permeability balance used in these measurements is a very convenient instrument for plotting the surface concentration of the New Zealand ironsand deposits.

(2) Below high-water level the concentration of iron ore in the Taranaki ironsands between Wanganui and Patea seems to be very constant along the coast at any particular level, and does not appear to increase appreciably towards New Plymouth.

(3) Above high-tide level the concentration is greatly influenced by the land contours, so that (a) on the open beach terminated by cliffs the concentration is a maximum near the cliff base, and (b) at the river mouths, the concentration is a maximum near the highest point of the spit. The actual value depends on the topography.

(4) These observations indicate that both wind- and sea-sorting operate, the former being more efficient. The mechanism, which includes conflicting effects, is deduced, and a model experiment confirms the conclusions.

(5) The measurements indicate the danger of estimating the amount of iron ore present by random sampling. Although the present measurements determine only the surface concentration, both the mechanism of concentration and observations in a 4 ft deep trench indicate that the ironsands may be appreciably concentrated only near the surface. This may be influenced by past history of the beach structure.

(6) To obtain a more complete estimate of the extent of the ironsand deposits measurements of the permeability both at the surface and at depth are required. The latter may be estimated by trenching or by measuring the spatial variations of the earth's magnetic field.

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