

Beach Gravels and Sands.

By P. MARSHALL, M.A., D.Sc., F.G.S.

[Read before the Wellington Philosophical Society, 11th July, 1928;
Received by Editor, 15th December, 1928; issued separately,
29th August, 1929.]

PLATE 31.

CONTENTS.

	Page.
Experiments on abrasion	325
Graphic representation of results	327
Conclusions	328
Rate of fall of pebbles	330
Time required for reduction of grade	331
Application of experimental results to beaches	332
Napier beach	333
Wave action	335
Description of samples from Napier beach	337
Mohaka beach	338
Description of samples from Mohaka beach	341
Udden's classification	342
Conclusions in regard to gravel beaches	344
Effect of moving gravel on sand	345
Sand on beaches	349
Grading of sand beaches	351
Sands from exposed beaches	355
Sands from partly sheltered beaches	355
Sand of dunes	358
Sands from off shore situations	358
Sand from dredging off Napier	360
Relation between slope of beach and size of component particles	363
Conclusions in regard to sand beaches	365

PRELIMINARY.

THE series of sieves that has been used for grading the materials that are described in this paper was a standard set in which the mesh decreased from member to member in fractions of an inch. In the text the grade is always stated in decimals of a millimeter. This course has been taken for two reasons :—(1) Difficulty and expense of printing the fractions would have been considerable. (2) Actual measurement of the opening, apart from the thickness of the wire, sometimes gave a result divergent from the value of the fraction of an inch. It was considered advisable to do this despite the somewhat awkward and cumbrous decimal values of the measurement of the openings in millimeters.

The following table shows the standard sieve that corresponds with the various millimeter grades:—

50.8 mm. width of the opening of two inch sieve.	
38.1	one-and-a-half inch sieve.
25.4	one inch sieve.
19.0	three-quarter inch sieve.
12.7	half inch sieve.
6.3	quarter inch sieve.
3.4	eighth inch sieve.
2.0	tenth inch sieve.

0.84 mm.	width of the opening of	twentieth inch sieve.
0.59	.....	thirtieth inch sieve.
0.42	.....	fortieth inch sieve.
0.297	.....	fiftieth inch sieve.
0.250	.....	sixtieth inch sieve.
0.177	.....	eightieth inch sieve.
0.149	.....	hundredth inch sieve.
0.074	.....	two hundredth inch sieve.

I am greatly indebted to Mr. F. W. Furkert, C.M.G., Engineer in chief; Dr. E. Marsden, Secretary of the Department of Scientific and Industrial Research; Mr. A. E. Jull, Chairman, Captain White-Parsons, Harbourmaster, Mr. J. D. Holmes, Engineer of the Napier Harbour Board; for giving me opportunities and assistance in obtaining material for this research. Mr. V. Barak, my assistant, has been careful and unwearied in carrying out experiments. Mr. G. Harris of the Geological Survey has kindly prepared the graphs for the printer.

GRAVEL AND SAND ON BEACHES.

A paper on the wearing of gravels, published in these *Transactions*, volume 58, p. 507 et seq., gave many experimental results that had been obtained by treating graded samples of beach gravels of greywacke rock in the iron containers of a Deval machine. One of these results was stated as follows:—"It appears that the amount of abrasion actually varies almost exactly in the same proportion as the diameter of the average pebble of each grade; until a small grade 6.3—3.4 mm. is reached." In that statement the word diameter was a lapsus plumae for surface. The actual relationship is shown in the graph of this paper. (Fig. 1, curves 2, 3).

EXPERIMENTS ON ABRASION.

Further experiments have since been carried out to discover the nature of the effect of abrasion on the finer material. In the paper cited above the amount of substance lost by abrasion had been estimated by weighing all of the material, after a twenty-four hour period of movement of the machine, that was coarser than 0.07 mm. in diameter. It has now been found that in the samples of finer material the conditions of atmospheric moisture and temperature affected the weight of such a large quantity of gravel so much as to mask the effect of abrasion which might amount to two or three grams only.

The method was therefore adopted of taking a measured sample of the water after each experiment, with its suspended silt and clay, and of weighing the amount of suspended matter that was contained in it after the iron derived from the abrasion of the container had been removed by warming with hydrochloric acid.

By adopting this method it was found that the amount of matter abraded fell off very rapidly as the grade of the gravel or sand decreased, and quite uniformly so, as is shown in the graph

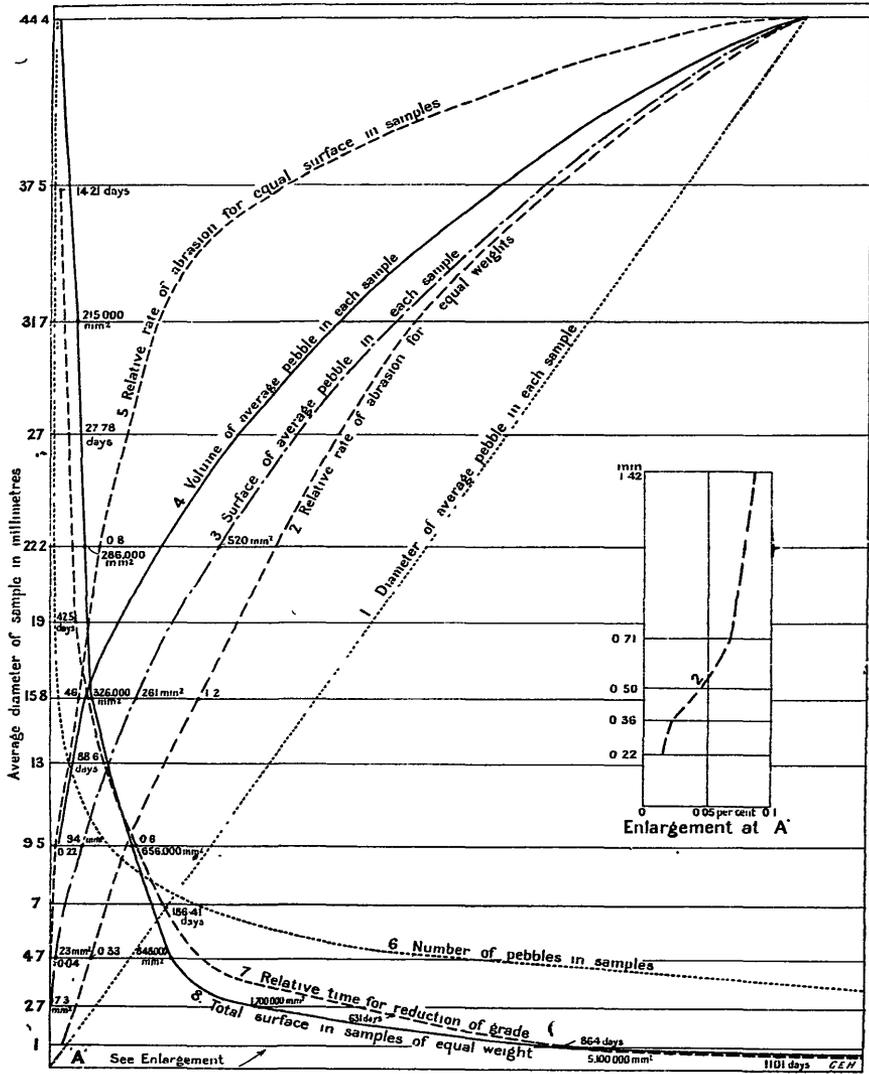


FIG. 1.

Graphs plotted to show results of abrasion of beach gravels of greywacke rock from Hawkes Bay beaches N.Z.

The values of the ordinates in curves 1—5 so calculated that the curves have the same terminal point.

Eleven samples composed of pebbles averaging 44.4, 31.7, 22.2, 15.8, 9.5, 4.7, 2.7, 0.71, 0.50, 0.36, 0.27 mm. respectively. Each sample weighed 5000 gms. and was treated for 24 hrs. in Deval machine.

Fig. 1, Curve 2. The following table (Table 1) gives the results additional to those that were published in the previous paper and in two instances replacing them.

TABLE 1.

5000 gm.	Size of grain mm.	AFTER 24 HOURS		
		Loss in gms.	Percentage loss.	Dissolved in gms.
Sample T.	6.3 — 3.4	16.58	0.332	
Sample U.	3.4 — 2.0	11.375	0.2275	
Sample V.	2.0 — 0.84	4.30	0.086	2.76
Sample W.	0.84 — 0.59	3.42	0.068	3.315
Sample X.	0.59 — 0.42	2.25	0.045	5.850
Sample Y.	0.42 — 0.29	1.092	0.022	6.925
Sample Z.	0.29 — 0.25	0.836	0.016	8.157

Samples T and U replace Samples H and L of previous paper, vol. 58, Table 5, p. 526.

Another test was made with sample T using salt water. The loss was then 16.85 gms.

There were important differences too in other respects. Thus the material that was derived from the treatment of the samples Y and Z was not particularly fine. The sand of these samples was taken from the Waihi beach and it consisted mainly of feldspar crystals not completely rounded. From this sand the action wore off minute splinters which were nearly all between .01 and .002 mm. in diameter. Actual abrasion of these fine grades appears to take place extremely slowly and within the period of experiment it actually yielded no distinguishable material.

On the other hand solution acts far more rapidly with this finer matter, and from the feldspar sand the substance that is dissolved is mainly soda with a little silica and alumina but the amount of these materials was not estimated separately. It will be remembered that Daubrée found that the material dissolved from orthoclase was mainly potash.

GRAPHIC REPRESENTATION OF RESULTS.

In order to investigate the causes of variation in the rate of abrasion graphic curves have been plotted in attempts to discover any relation between the amount of abrasion, the diameter, the surface, and the volume of the average pebble of each sample. Another curve represents the relative amount of abrasion per unit area of the pebbles of each sample. Other curves show the total number of pebbles in each sample; the total surface of the components of each sample; and the relative time that is required for the reduction of grade. (Figs. 1, 2).

The ordinates of the first five curves are so calculated that the line in each case terminates at the same point, and they thus become directly comparable. It is at once seen that the curve for the per-

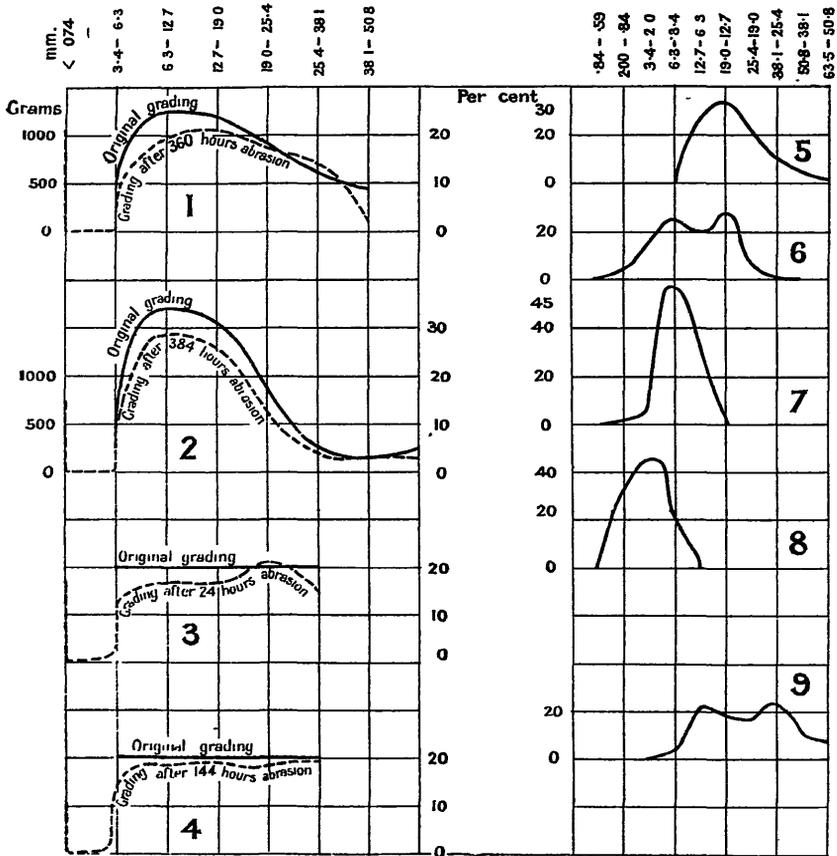


FIG. 2.

- 1.—Abrasion of greywacke gravel for 360 hours in Deval machine.
- 2.—Abrasion of second sample of beach worn greywacke gravel in Deval machine for 384 hours.
- 3.—Abrasion of hypersthene andesite gravel from the Wangaehu River in Deval machine for 24 hours. Equal quantities of five grades were taken.
- 4.—Abrasion of sample of beach worn greywacke gravel from Napier beach for 144 hours in Deval machine. Equal quantities of five grades were taken.
- 5.—Grading of gravel sample from beach at the mouth of the Tukituki River.
- 6.—Grading of sample of gravel taken from the beach at Waitangi 5 miles from the Tukituki mouth.
- 7.—Grading of a sample of gravel taken from the beach at the Bay View railway station 14 miles from the Tukituki mouth.
- 8.—Grading of sample taken from the beach at Tangoio 17 miles from the Tukituki mouth.
- 9.—Grading of sample of gravel taken from the bed of the Tukituki River at Clive Grange one mile from its mouth.

centage abrasion of the samples approaches a straight line when they consist of particles that are not greater than 31.7 mm. in diameter, and it is close to the curve that represents the surface of the average pebble in each of the samples. The other curves that have been plotted seem to indicate merely that there is little or no relation between the amount of abrasion and the other characters of the different samples. The relative weight or volume of the average pebble of a sample would naturally be expected to be definitely related to the percentage of wear; but the graphs fail to establish any relation of this nature.

There is however a close agreement between the curves for the total surface of the pebbles in a sample and that for the relative time required for the reduction of grade. In calculating the rate of change of grade the three factors that are involved are:—the amount of abrasion, the volume of the average pebble or grain, and the time. The general agreement between the curve for the time required for the reduction of grade and that for the increase in the total surface in the various experiments shows clearly that the time required for the reduction of grade varies directly (in other words, the rate of reduction of grade varies inversely) as the total surface of all the pebbles in the same weight of the various grades. That there should be a relation between these two might generally be assumed without experiment but the similarity of the curves is remarkable and suggests that this is a definite law which applies at least to those grades which have been tested and of course to all grades of intermediate size. With larger sized material the momentum acquired by fall might be so great as to cause chipping which would mask the effects of abrasion. It would seem that the characters of weight, volume and surface of the pebbles individually and collectively, each of which must influence the rate of abrasion, as well as the actual number of the pebbles, are involved in such an intricate relation that the experiments have wholly failed to reveal their separate effects.

CONCLUSIONS.

The only conclusions that have been reached are these:—

1. The combined effect is a rate of abrasion which varies in nearly the same ratio as the surface of the average pebble in a sample of approximately equal grains.

2. The relative rate of the reduction in grade varies inversely as the total surface of all the pebbles in a sample.

In all cases it is assumed in order to make the calculations possible that the pebbles are spherical. This naturally introduces some error which is far greater in the coarser samples than in the finer; for in the former many pebbles have a lenticular shape.

It is interesting to note that the material derived from the Tuki-tuki gravel by abrasion is similar in its general features to those of the papa rock from typical localities. (Table 2). This justifies the conclusion that papa rock, which is such an important constituent of the geological structure of the North Island of New Zealand, may be supposed to have been derived from the abrasion of beach

TABLE 2.

Mm.	1	2	3	4	5
— .07	0.00	0.31	0.50	14.00	7.26
0.07 — .04	31.50	24.32	29.70	26.70	17.15
0.04 — .01	24.00	26.34	33.00	22.25	31.05
0.01 — .002	26.68	23.21	30.20	36.00	34.20
.002 — .0001	19.63	20.55			
— .0001		3.38			
Colloid	1.05	0.46			

1. Abraded from Tukituki Gravel.
2. Papa Rock — Mohaka.
3. Papa Rock — Shakespeare's Cliff, Wanganui.
4. " " — Whangamomona.
5. " " — Taumarunui.

Mm.	A	B	C
— 0.250	4.52	5.06	
0.250 — 0.177	5.09	16.26	
0.177 — 0.149	5.50	38.26	0.67
0.149 — 0.079	34.64	36.20	51.10
0.079 —	47.68	4.06	42.20

- A. Grading of sand from Matawai, Poverty Bay.
- B. Sand thrown on the Breakwater, Napier.
- C. Flood deposit, Wairoa River.

gravels. It has often been supposed that this great geological formation must have been derived from the fine sediment of an extensive river system. This offered a difficult problem because there is every reason to believe that the area of New Zealand was at that time reduced to small dimensions. There was no other evidence of the existence of a large land area near New Zealand. The demonstration that this papa rock formation could have been derived by marine action on gravel shores removes a great difficulty in connection with the distribution of land in the New Zealand area throughout a large portion of Tertiary time.

RATE OF FALL OF PEBBLES.

It was thought too that the rate of fall of the pebbles in water might have a definite relation to the amount of abrasion. The rate of fall was determined by actual experiment with particles from 0.15 to 6.3 mm. diameter and for the larger particles it was calculated from Rittinger's formula $V = 2.73 \sqrt{D} (\delta - 1)$.

The following Table 3 gives the rate of fall of particles of various sizes:—

TABLE 3.

Size of pebble in mm.	Rate of fall cm. per sec.
33.1	66
25.4	52.8
12.6	37.5
6.3	26.2
3.4	22.0
2.0	16.8
0.84	11.0
0.59	6.0
0.42	4.8
0.30	3.6
0.25	2.5
0.18	2.3
0.15	1.8

No relation could be found between the rate of fall of the pebbles of the various grades and the amount of abrasion that a sample of gravel underwent. It was expected that the very small rate of fall of the finer particles would be associated with a great decline in the rate of abrasion; for during the movement of the Deval machine they would be continually suspended in the water. This, however, was not found to be the case. The evenness of the curve of abrasion seems to show that abrasion takes place as rapidly from the contact of the individual particles as it does from their contact with the sides of the cylinder.

TIME REQUIRED FOR REDUCTION OF GRADE.

By utilising the results that have been detailed above an attempt has been made to compare the relative times that would be required to reduce the size of the pebbles of one grade of gravel to that of those of the next grade.

All of the estimates that are given below are based on the experimental results that have been obtained from the use of the Deval machine. As stated previously it is not suggested that the conditions of these experiments exactly reproduce the actions that take place on a beach. In the machine the movement is continuous and the conditions of movement are almost uniform. The throw, though it is repeated every second, is small. On a beach the movement of the pebbles is very uneven and far from continuous. The throw too is often strong but in the case of each individual pebble it takes place but seldom. It remains however definite that the sliding motion and the throw which are the operating movements on a beach take place also in the machine though in a different degree.

The only previous estimate that could be found of the rate of decrease of the grade of beach materials by abrasion is that made by Sorby* and quoted by Geikie in his text book. He says "A grain

*Sorby, Pres. Address Geol. Soc. *Q.J.G.S.* 36 (1880) p. 59.

one tenth of an inch in diameter would be worn ten times as much as one a hundredth of an inch in diameter, and at least a hundred times as much as one a thousandth of an inch in diameter. Perhaps then we may conclude that a grain one tenth of an inch in diameter would be worn as much or more in drifting one mile as one a thousandth of an inch in being drifted a hundred miles. On the same principle a pebble one inch in diameter would be worn relatively more by being drifted only a few hundred yards."

Actually this statement which is based on deductive considerations greatly understates the actual condition as developed by experiments, which may be seen from the following two examples. In each of the instances mentioned a weight of 5,000 grams was taken. A sample consisting of 55 pebbles which have an average diameter of 44.4 mm. loses 299 grams by abrasion in 24 hours. A second sample with an average diameter of 4.7 mm., rather more than one tenth of the previous one, contained 56,500 pebbles and lost by abrasion in the same time 16.58 grams which is equivalent to 0.00029 grams per pebble while in the first case the loss was 5.5 grams per pebble. The amount in the second case is thus approximately one twenty thousandth part of that in the first.

In the second example one sample consisted of 212,500 pebbles with an average diameter of 2.7 mm. This sample lost by abrasion 11.375 gm. in 24 hours treatment or 0.00005 gm. per pebble. The other sample was composed of grains 0.27 mm. in diameter. The loss after the same treatment was in this case only 0.837 gm. Each grain in this sample lost exactly one ten thousandth part of the amount lost by each grain in the former sample. In this instance the amount of true abrasion may be somewhat over estimated as most of the loss was actually due to splinters that were cleaved off the grains of feldspar of which the sand was composed.

These tests show that a pebble 44.4 mm. in diameter will lose as much by abrasion during a movement of one yard as a pebble 4.7 mm. will during a movement of 20,000 yards or nearly twelve miles. As it decreased in size, however, it would, as has already been shown, have suffered from abrasion at a rate that rapidly dwindled.

The following Table 4 shows the relative rates at which gravels of various coarseness are reduced in grade, and further the time that is required for gravels of various sizes to be reduced to others of half their dimensions. It is obvious from this that coarse gravel if constantly exposed to the movement on a beach will soon be reduced in grade, while fine gravel and, in a far greater degree, sand is possessed of the most lasting properties. (The times given refer to the rate of movement in the Deval abrasion machine).

APPLICATION OF EXPERIMENTAL RESULTS TO BEACHES.

The results that were obtained from the tests conducted in the Deval machine suggested various possibilities in regard to the occurrence of graded materials on actual beaches.

TABLE 4.

Grade.		Time required to reduce to next grade.	Time required to reduce grades by 50 per cent.		
mm.	mm.	days.	mm.	mm.	days.
From 44.4	to 31.7	14.21	44.4	— 22.2	42
31.7	— 22.2	27.78	22.2	— 11.1	106
22.2	— 15.8	42.53	11.1	— 5.5	157
15.8	— 9.5	88.66	5.5	— 2.7	354
9.5	— 4.7	186.41	2.7	— 1.35	441
4.7	— 2.7	300.00	1.35	— 0.67	1200
2.7	— 1.0	631.50	0.67	— 0.33	2827
1.0	— 0.71	864.86			
0.71	— 0.50	1101.70			
0.50	— 0.36	1750.00			
0.36	— 0.27	3000.00			
		Total 8007.65			

It must, however, be evident that the application of these results should first be used in investigating the features of beaches where wave action is relatively simple, and is free from such complications as are caused by an irregular coast, or by outlying rocks, or strong tidal or coastal currents.

A beach that is fully exposed to the complete wave disturbance is clearly required and there should be sufficient constancy of wave or current action to carry the material along the beach uniformly but slowly. It is also most desirable that there should be no feed beyond the original source of supply. In order that the study may be complete the gravel must be supplied in a mixed state with coarse and fine material together and a long continuous stretch of beach is necessary in order that the final effect of the action may be observed. Finally it is most desirable that the gravel should consist of a single rock type of a uniform nature free from bedding planes.

These conditions are well satisfied in the Hawkes Bay beaches on the east side of the North Island of New Zealand. Here the tidal range is small, not more than four feet; the coastal current may amount to one knot from south to the north with the flood tide. With the ebb the water moves outward. The beach is fully exposed to the heavy ocean swell from the south and east but is protected by the Mahia Peninsula from all wave action from the north. At certain spots the beach is fed with a large supply of gravel by rivers which have steep courses. The material of the gravel is a hard and remarkably uniform greywacke rock which in the form of pebbles offers a strong resistance to fracture and shows little or no bedding. The number of pebbles that have a larger diameter than three inches is small, and there is but little material finer than 3.4 mm. diameter.

NAPIER BEACH.

The first of the two beaches that were investigated is the Napier beach (Fig. 3) which for the purposes of this paper is considered to

commence at the mouth of the Tukituki River and to extend to Tongoio a distance of 18 miles. Throughout this distance the beach

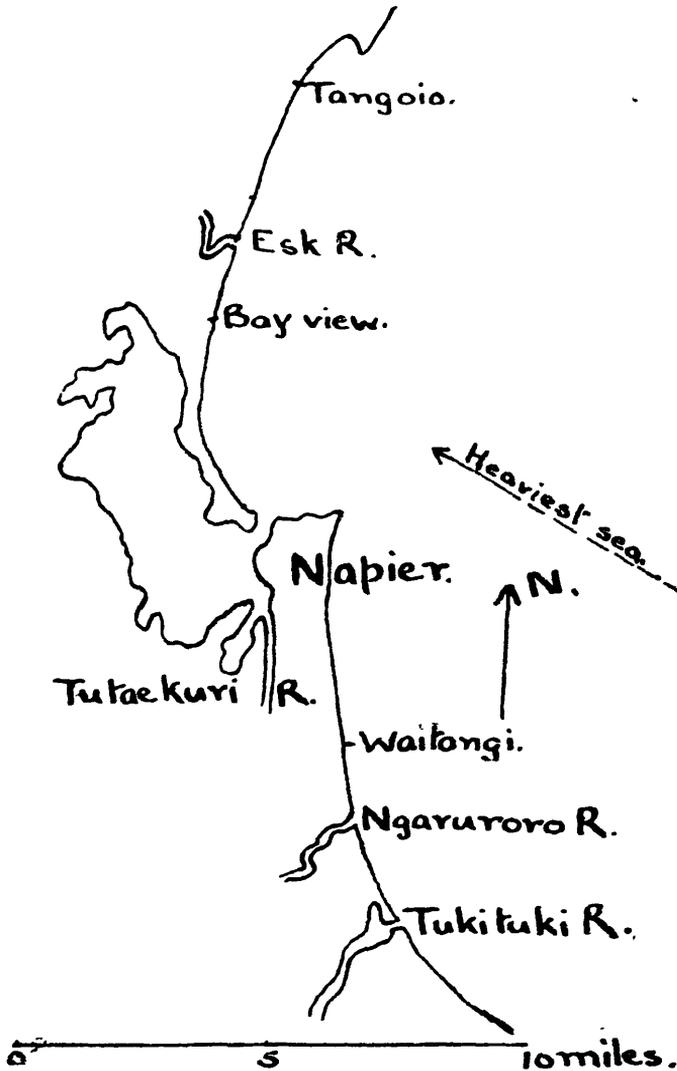


FIG. 3.—Sketch Map to show points on Napier Beach.

trends uniformly from south to north. For the greater part the beach is fed with the gravel that is supplied by the Tukituki River; but two miles from this point there is an additional feed from the Ngaruroro River, and to a far less extent from the Tutaekuri River on the north side of the Ahuriri Bluff. A negligible amount is supplied by the Esk River. At Tongoio a rocky coast succeeds the gravel beach and disturbing factors are introduced. In order to test

the changes that are caused in the gravel by wave action and sorting and by abrasion samples were taken from the following localities:—(1) A gravel bank in the bed of the Tukituki River at Clive Grange about one mile from the coast, (2) The face of the beach at the mouth of the Tukituki River, (3) Beach at Waitangi about three miles from the mouth of the Tukituki River. (Here the sample was a composite one taken from the face and the top of the beach). (4) Bay view railway station on the face of the beach 11 miles from the starting point, (5) The Tongoi beach, again from the face of the beach after 18 miles of travel.

A great deal of difficulty was experienced in taking fair samples of the gravel on the beaches; for it was found that on the beaches that are composed of the coarser materials samples of very different nature could be obtained from different parts of the beach. It was found advisable to choose some recognisable spot of such a nature that it was representative and could be readily distinguished throughout the length of the beach. Samples that were taken from such spots would give comparable results. The representative spot that was finally chosen was two feet from the point of a well developed cusp on its south side. The sample was collected from the Waitangi position before this was decided.

WAVE ACTION.

It is of course clear that the wave action is most violent on that part of a beach where the wave breaks. Here at the foot of the beach the material is coarsest, and usually a few large pebbles are seen, mixed with well sorted material. A breaking wave often suspends these pebbles momentarily and they are carried by the rush of water some distance up the face of the beach. When the wave recedes the rush of the water carries the pebble some part of the way back; for the movement of the down rushing water is assisted by the force of gravity. Each succeeding wave assists in this and though from time to time a little movement up the beach takes place, before long the pebble comes to the foot of the beach again. By its own movement and by the wash of finer material over it the pebble becomes flat sided. From time to time under specially favourable conditions of wave action in the heaviest weather, or of temporary position, one of these is so highly suspended or acquires such momentum that it is hurled up on the beach either actually beyond the reach of the water or on to the relatively flat crest of the beach. Such a pebble remains for a time at least, or even permanently beyond the range of future action on the beach. On the Hawkes Bay beaches this action quickly eliminates all of the coarsest material that is supplied by the rivers and in time nearly all of the pebbles that are not finer than three inches in diameter are thus thrown off the beach. Such pebbles as are not removed by this action are rapidly reduced by abrasion, which has already been shown to be twice as rapid with pebbles 44.4 mm. in diameter compared with those that are only a little smaller and measure 31.7 mm. in diameter.

When a pebble is carried far up on a beach to a position that it has reached in virtue of its high momentum gained from the smash

of the breaking wave it is generally not swept back to the bottom of the beach. The tongue of a wave when commencing its downward movement has at first a small velocity and this, even with the assistance of gravity, is unable to move the pebble. The volume of the water in its downward path is also much reduced as a considerable portion of its tongue has sunk into the gravel, and issues from the slope at a level that is the average water level at the moment.

At places near the point at which the beach is fed it will consist of much mixed material from coarse gravel to fine sand. The finer matter is carried up by the wave in largest quantity and much of it, because of its fineness, is carried back by the downward wash of the wave; for even the feeble velocity of the backward wash of the tongue of the wave is able to transport light material. A considerable amount of this fine material sinks into the gravel with the percolating water. Succeeding waves cause slight movement of the gravel; and the sand, that has sunk in, is submitted to the grinding action that has been shown to be so rapid in its effects. Some of the sand more or less completely ground down is carried out by the escaping water at the middle of the beach. This action will before long eliminate the sand that is supplied in large quantity to the beach in the original mixed feed.

At the same time the finer components of the gravel are being rapidly eliminated by impact. This has been shown to be a far more effective action in the Deval machine than abrasion, though less rapid than grinding. Thus the coarsest pebbles are being gradually removed by the flinging action of the heaviest seas in stormy weather; the sand is being far more rapidly destroyed by the grinding action; the smaller pebbles are being smashed by impact and supply sand which is speedily ground up; all the time pebbles of every size are being worn down by abrasion at a rate that is closely related to their individual surface area. Since impact acts much more rapidly than abrasion, and grinding more rapidly than impact, the total effect must be the production of an even-graded gravel, the maximum size of the component pebbles being determined by the extent to which elimination has proceeded and by the amount of abrasion that has taken place; in other words by its proximity to the place where the gravel is fed to the beach. The minimum size of this graded gravel will depend upon the conditions of impact. The interval between the maximum and the minimum will be greatest when the force of the sea is small, and least when the force is at its greatest for then the pebbles that are suspended by the waves strike their heaviest blows and one may be broken by another that is not many times larger than itself.

This description of the conditions on a beach is based on observations made at many times on the New Zealand beaches; on the grading and the close examination of the materials of the different grades of samples taken from beaches as described subsequently; on the results of experiments described earlier that were conducted with the Deval machine. A description and full details of the grading of the various samples that were taken from the Hawkes Bay beaches will be given on subsequent pages.

The difference in grade of the gravel on different parts of a beach has been noticed and dealt with by Vaughan Cornish.* He related the grading of the gravel to the steepness of the beach. "No stony particle of less than a certain critical size can remain permanently on a beach, but is ultimately swept out to sea. This critical size is greater on a coarse grained than on a fine grained beach for the regimen slope of the former is steeper and gravity therefore gives greater assistance to the beach work."

It is clear from this and subsequent paragraphs that Vaughan Cornish relates the features of the grading of materials on a beach to (1) the removal of fragments below a certain critical size by wave action. (2) Attrition of the larger fragments. In other words he regards the steepness of the beach as the cause of the relative coarseness.

DESCRIPTION OF SAMPLES FROM NAPIER BEACH.
(Figs. 2, 3, Table 5).

This beach is fed by the gravels of the Tukituki River and a sample that was taken from a gravel bank one mile from its mouth gave a grading that shows clearly that it is a mixed type. There are some pebbles as much as 63.5 mm. in diameter and yet there is some material as fine as one twentieth of an inch. The river has a steep slope and the greater part of the sand that it transports would not come to rest on a bank in its bed but would be carried out to sea. All of the larger pebbles in this sample are well rounded and those of the grade 12.7 — 6.3 mm. for the most part rounded, but those of the next grade 6.3 — 3.4 mm. are partly rounded though for the most part angular. Pebbles of all of the finer grades are angular.

On the beach at the mouth of the river all of the larger pebbles are more or less flattened and even those of the 12.7 — 6.3 mm. grade are in many cases worn flat. Those of the grade 6.3 — 3.4 mm. are more rounded than in the river sample. Some rounding of the grade 3.4 — 2.0 mm. is now noticeable but there is no material finer than this.

At Waitangi the flattening of the larger pebbles is much more pronounced and the rounding of the smaller is slightly more distinct.

At Bay View some 14 miles along the beach where the average grade has been reduced from about 19.0 to 4.5 mm. there is considerable change. The grade 12.7 — 6.3 mm. is now well flattened but the smaller stones in this grade are clearly losing their flattened shape. The stones larger than 12.7 mm. are completely flattened. Those of the grade 6.3 — 3.4 mm. which have been reduced from a larger flattened stone have now almost lost that shape and are mostly rounded showing a tendency to assume a shape that is nearly spherical. The material of the grade 3.4 — 2.0 mm. is clearly for the most part formed from broken pebbles and it is angular, but the angles though in some individuals sharp and fresh are usually

*Vaughan Cornish, *Geograph. Mag.* 2, 1898, p. 541 et seq.

well rounded. The form of the individuals of the next finer grade 2.0 — 0.84 mm. have an angular shape but many of the angles are rounded off and some of the pebbles are well rounded. All of the finer materials are quite angular.

TABLE 5.
GRADING OF GRAVEL FROM TUKITUKI RIVER TO TONGOIO, HAWKES
BAY.

	mm.63.0	50.8	38.1	25.4	12.7	6.3	3.4	2.0	0.84	0.59
Right Bank Tukituki River at Clive Grange . .	7.0	9.8	23.5	24.3	21.5	3.7	0.3			
Beach at mouth of Tukituki River . .		3.8	15.4	56.7	24.2	0.8				
Waitangi 5 miles			2.0	35.0	19.7	24.7	14.9	3.0	0.6	
Bay View Rly. Stn. 14 miles				2.2	31.3	57.4	6.0	3.1	0.5	
Tongoio Beach 17 miles					1.1	30.5	42.8	25.5	0.1	

At the Tongoio beach, four miles further on, the grade 3.4 — 2.0 mm. has now become the dominant one. Here the few pebbles that are larger than 6.3 mm. are well flattened but this is much more pronounced in those that approach 12.7 mm. in diameter. Flattening has now been completely lost in the grade 6.3 — 3.4 mm. and the surfaces are generally polished. The rounding of the 3.4 — 2.0 mm. grade is now almost complete and this has become the dominant grade. The grade 2.0 — 0.84 mm. contains few sharp angled grains for the majority are rounded. The small amount of material in the next and finest grade is all sharp angled.

THE MOHAKA BEACH.

(Plate 31, Figs. 4, 5, Table 6).

This extends from the mouth of the Mohaka River eastwards to Waitaniwha a distance of 35 miles. It is fed at its westward extremity with greywacke gravels that are brought down in large quantity by the Mohaka River. This is practically the only source of greywacke, though the Waihua River 6 miles eastward contributes a small amount of sand composed of volcanic minerals. The Wairoa River at 12 miles perhaps contributes a little fine material and again the Nuhaka River thirty-two miles along the beach contributes some more sand derived from crystals of volcanic minerals. All of these additions are, however, small, and they affect the beach so slightly as to be almost insignificant.

3.4 - 2.0 mm.

2.00 - 0.84 mm.

0.84 - 0.59 mm.

Mohaka.

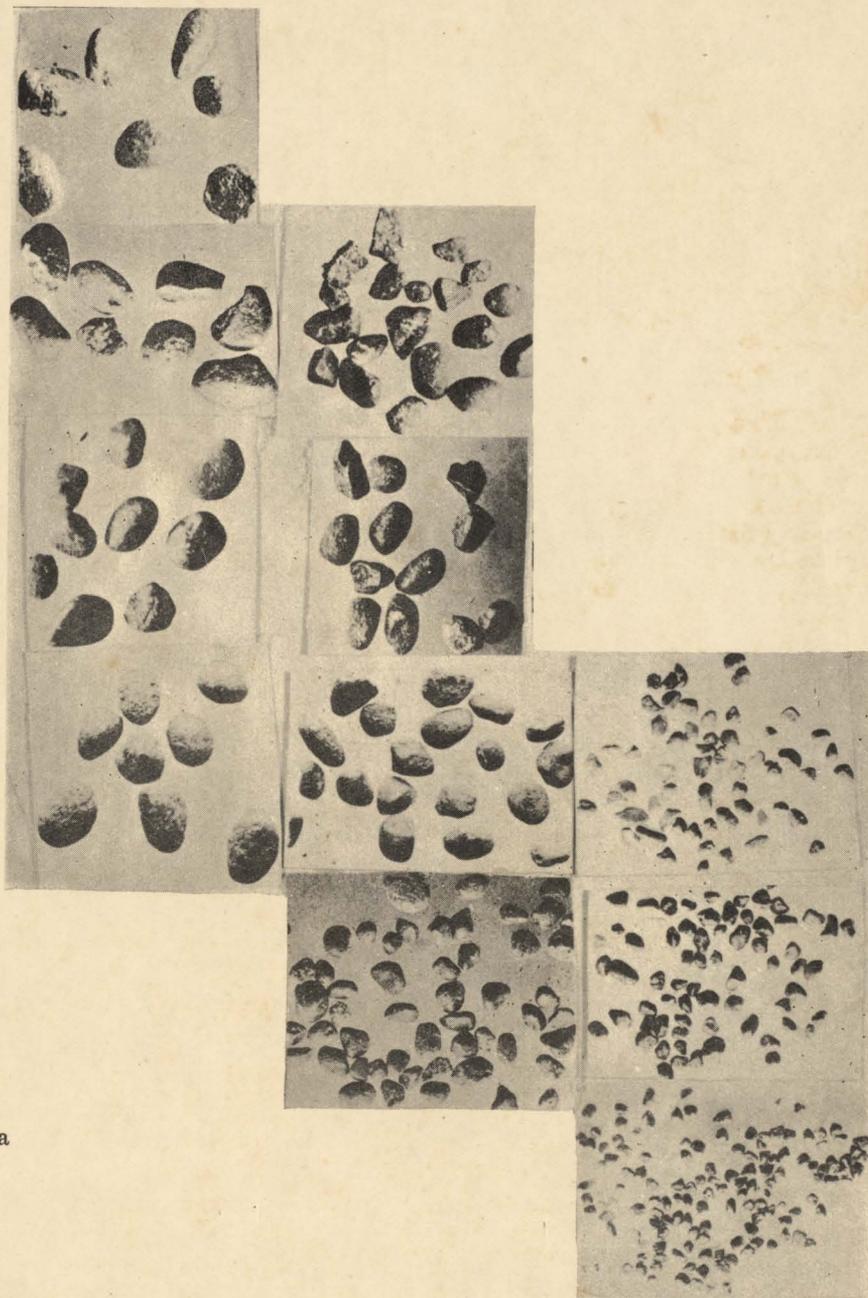
Waihua
6 miles

Wairoa
12 miles

Whakaki
24 miles

Nuhaka
32 miles

Waitaniwha
35 miles



Samples from Mohaka Beach, Hawkes Bay. $\times 2\frac{1}{2}$.

The photographs show the following points:

1. The angular form of finer grades compared with coarser grades at the same locality.
2. Gradual rounding of particles of any grade as it becomes the coarsest on the beach.
3. Different sizes of any one grade e.g. Nuhaka and Whakaki 2.00 - 0.84mm. and Nuhaka-Waitaniwha 0.84 - 0.59mm.



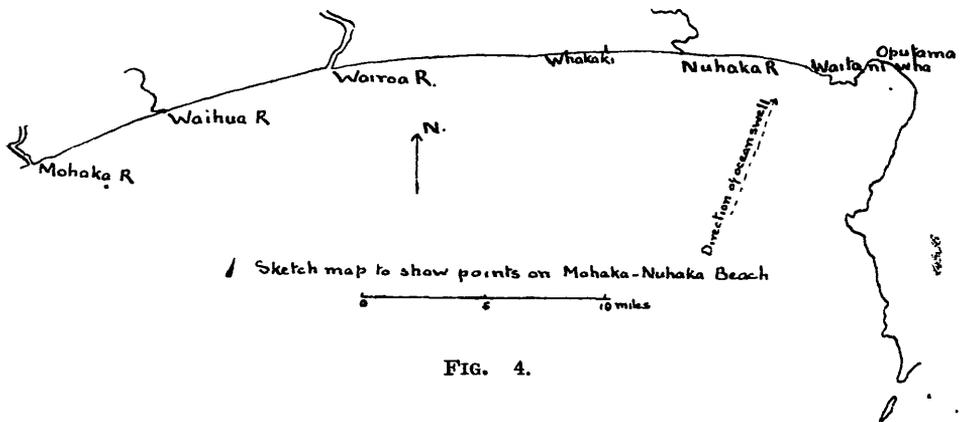


FIG. 4.

This beach throughout its length is protected from all heavy seas except from the south and south east; in particular the northerly seas are completely shut off by the projecting Mahia Peninsula. The south easterly swell, however, is particularly heavy, and is nearly always breaking on the beach. At Napier this swell is much broken down by cross seas of smaller size, but at the north easterly end of Hawkes Bay there is no such disturbing effect and the swell forms heavier breakers. The period of this swell is as much as 15 seconds and in accordance with White's table the wave length must be 1152 feet and it moves with a velocity of 76 feet per second. The waves as they reach the shore attain large dimensions and break

TABLE 6.

GRADING OF GRAVEL FROM MOHAKA RIVER TO WAITANIWHA, HAWKES BAY.

	mm.	63	50.8	38.1	25.4	12.7	6.3	3.4	2.0	0.84	0.59	0.42	0.28	0.22
Mohaka River 3 miles from mouth ...	8.72	1.42	31.20	32.19	17.70	3.92	0.66	1.32	0.66	0.66	1.12	2.96		
Mouth of Mohaka River south side ..		3.2	7.4	31.8	35.7	9.3	2.8	5.1	3.05	0.92	0.59	0.27		
Mouth of Waihua River 6 miles ..						20.2	62.5	16.9	0.4					
Mouth of Wairoa River 12 miles ...						7.5	31.0	61.2	0.4					
East end Whakaki Lagoon 24 miles ...							2.0	49.0	35.5	6.3	3.5	3.7		
Mouth of Nuhaka River 32 miles ...							1.6	23.3	54.2	12.2	5.7	3.1		
Waitaniwha 35 miles									44.5	50.6	4.5	0.		

The heavily printed figures show the points of maximum occurrence in the samples.

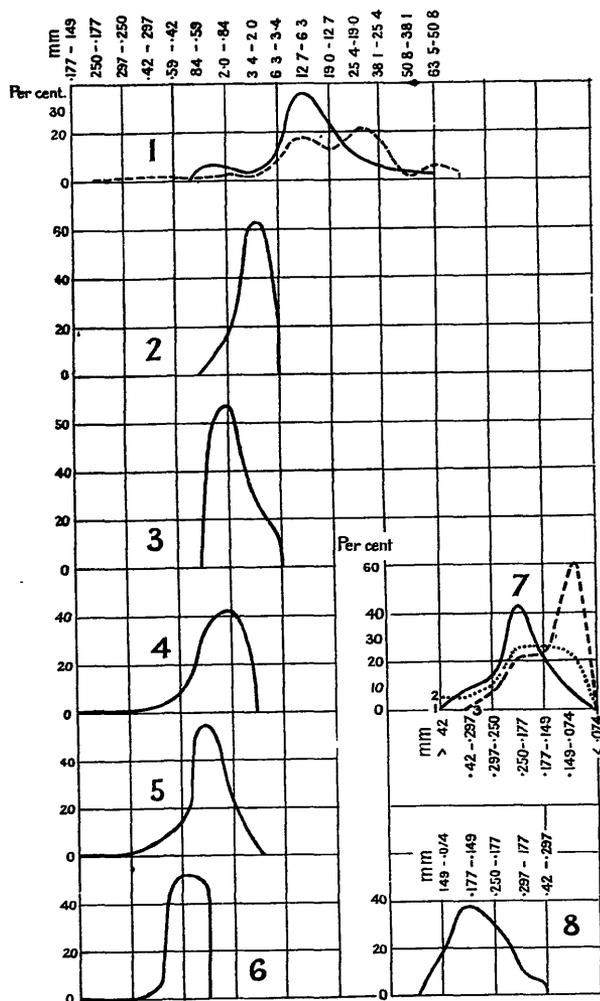


FIG. 5.

- 1.—Grading of gravel taken from the bed of the Mohaka River 3 miles from its mouth (broken line) and from the beach at its mouth (full line).
- 2.—Grading of sample of gravel taken from the beach at Waihua 6 miles from the mouth of the Mohaka River.
- 3.—Grading of gravel taken from the beach at Wairoa 12 miles from the mouth of the Mohaka River.
- 4.—Grading of a sample of gravel taken from the beach at Whakaki 24 miles from the mouth of the Mohaka River.
- 5.—Grading of a sample of gravel taken from the beach at Nuhaka 32 miles from the mouth of the Mohaka River.
- 6.—Grading of a sample taken from the beach at Waitaniwha 35 miles from the mouth of the Mohaka River.
- 7.—Grading of average beach sands:—
 1. Average of 20 samples taken from beaches that are fully exposed to wave action.
 2. Average of 15 samples of beach sands that are partly exposed to ocean wave action.
 3. Average of ten samples of sand taken from depths between 18 and 37 feet off the shore near Napier.
- 8.—Grading of a sample of sand collected on the spit between Mahia Peninsula and the mainland.

with great force. The beach is steep throughout and there are no outlying rocks to cause any disturbing features. From the Mohaka River to a point three miles beyond the Waihua mouth there are cliffs of a soft marl, the foot of which is just reached by the waves at high tide, but otherwise for the whole distance the beach is merely a gravel bank. Samples were taken in the bed of the Mohaka River three miles from its mouth; from the beach at the mouth of the Mohaka River and at the mouth of the Waihua River 6 miles distant. The other samples were from the bank at the mouth of the Wairoa River, 12 miles from the Mohaka; from Whakaki 24 miles; from the Nuhaka mouth 32 miles; and finally from Waitaniwha at a distance of 35 miles from the point of origin of the gravel, the mouth of the Mohaka River.

DESCRIPTION OF SAMPLES FROM MOHAKA BEACH.

(Fig. 5, Table 6).

The gravel from the bed of the Mohaka three miles from the mouth has a grading which closely resembles that from the bed of the Tukituki River. The different grades have the same characteristics as in that sample. In other words the coarser pebbles are well rounded, but nearly all of those that are less than 6.3 mm. in diameter are angular. The sample that was taken from the beach at Mohaka was far less sorted than that at Tukituki though it is distinctly different from the gravel of the river bed itself. Many of the larger pebbles already show some flattening while those 6.3 mm. in diameter are already partly rounded, though all smaller ones are most angular with sharp angles.

At Waihua, six miles from Mohaka, the gravel is already finer than that at Bay View on the Napier beach and indeed approaches that of Tongoio, 16 miles distant from its source. This greater speed of reduction than on the Napier beach, in comparison with apparent distance of travel, may be due to a slower movement along the beach. The flood tide probably moves more slowly here and the swell washes nearly at right angles to the beach. The gravel has much the same features as that from Tongoio. The grade 6.3 — 3.4 mm. is well worn, the larger pebbles still show a relic of the flattened form but are mostly rounded. A few freshly broken pebbles can be seen among them. The grade 3.4 — 2.0 mm. is the dominant size and has a distinctly angular appearance. No suggestion of any flattened form. A few freshly broken pebbles. The grade 2.0 — 0.84 mm. is very angular with many freshly broken pebbles but the angles are usually rounded off.

Mouth of the Wairoa River.—The few pebbles that are nearly 6.3 mm. in diameter are flattened but those near 3.4 mm. are rounded, angular form being rare. The grade 3.4 — 2.0 mm. is well rounded; there is no flattening, and angular shape is rare. The grade 2.0 — 0.84 mm. is now dominant, much more angular than the coarser grade, but angles generally well rounded; fresh angles are not common. This makes a great contrast with the same grade from Waihua. In this sample, as in that from Waihua, finer matter than that of the last grade is practically absent. In this even-graded gravel the coarsest pebbles have a diameter five times larger than the smallest.

West end of the Whakaki Lagoon.—No samples were obtained between the Wairoa River and this point, which are 12 miles apart. The grade is now considerably reduced and the grade 0.84 — 0.59 mm. has now become important. The coarsest material, which now lies in the grade 3.4 — 2.0 mm., shows a slight remnant of the flattened form, though it is clearly rapidly being removed. Most of the pebbles are well polished, especially the jasperoid shale which is the hardest constituent. The grade 2.0 — 0.84 mm. is now rounded but retains some of its angularity. The finer grade 0.84 — 0.59 mm. has a dominant angular form in 90 per cent. of the grains, but the angles are usually well rounded and the surface of the grains is polished. Sharp angles do occur though rarely. The grade 0.59 — 0.42 mm. is present to the extent of 6 per cent. All the grains are sharply angular. About 25 per cent. of this, and practically all of the material that is finer than it, consists of volcanic crystals that have been washed in from the surface covering of pumice sand which extends over this district. Here again the largest pebbles have five times the diameter of the smallest.

Mouth of the Nuhaka River, 32 miles.—The grade 2.0 — 0.84 mm. is now the coarsest, except for two per cent. of the total. It is well rounded and polished and little indication of the original shape is to be seen. The grade 0.84 — 0.59 mm. is well rounded, but the original angular form is still indicated generally. Fresh fractures are still to be seen occasionally. The finer sand, grade 0.59 — 0.42 mm., is very angular though in most cases the angles are rounded off. This material is mostly monomineralic, and 25 per cent. consists of crystals of volcanic rock that are new recruits for the beach. Grains finer than this are sharply angular, and 75 per cent. of them are derived from volcanic sand. Here the largest grains have four times the diameter of the smallest.

Waitaniwha, 35 miles.—The coarsest material is now found in grade 0.84 — 0.59 mm. The original angular form of most of the grains can still be distinguished, but the angles are rounded and are beautifully polished throughout. The grade 0.59 — 0.42 mm. is now the dominant one. The grains are markedly more angular than in the coarser grade, though fresh fractures are rarely seen and all are perfectly polished, indicating that in this fine material there is no destruction by impact and that abrasion acts very slowly. The grains of sand carried to the beach from the pumice covering of the country and of smaller size are all angular.

UDDEN'S CLASSIFICATION.

The important work of Udden* on the examination and classification of sediments does not apply with much force to these evenly graded materials. In a elastic sediment he distinguished a "chief ingredient," coarse and fine "admixture," with a derived "Law of the chief ingredient" and the "Law of the decreasing admixtures" and the "Index of sorting." The last is the ratio between the

*Udden, *Journ. Geol. Soc. America*, 25, 1914, p. 732.

quantity of the chief ingredient and that of the fine or coarse admixture, whichever happens to be the greater. These seem to be of little service here because of the inaccuracy of the methods of analysis of sediments. Thus if a sediment consists wholly of material lying between diameters of 4 and 1 with its maximum at 2 mm., with an actual variation from 3 to $1\frac{1}{2}$ mm., it would, in his method, have an index of sorting of perhaps 1 to 1. Whereas if his mechanical appliances had separated the material along the diameters 6 to 3 — $1\frac{1}{2}$ the material mentioned would all have fallen between the two latter and would have had a sorting index of 100 to 1, which would more properly represent the features of that sediment. This of course is an extreme case which might never occur in nature, and it is probable that in those instances in which the sample has a varied grading the method of classification is applicable.

In the beach samples the grading is little varied and even approaches a uniform grade. The Waitaniwha sand, for instance, which grades 44.5 per cent. 0.84 — 0.59 mm. and 50.6 per cent. 0.59 — 0.42 mm. has already a sorting index of 1 to 19. If the grading sieves had separated the sand into the 0.72 mm. and 0.36 mm. diameters the sorting index would have been far higher than this. It is not practicable to have a series of sieves that would give a true value for the sorting index in each individual case. A further complication may arise from the nature of the material on a beach. The actual value of the sorting index will obviously be different when it is used for a sand that is monomineralic from what it would be if bi- or tri-mineralic. This will be considered more fully later but it may now be said that the coarseness of sand on a beach largely depends on the specific gravity of the minerals of which it is composed.

A further difficulty is met when the samples of the same grade from different localities on the same beach are compared. If for instance samples of the 0.84 — 0.59 mm. grades from Whakaki and from Waitaniwha are compared it can at once be seen by mere inspection that the sample from Whakaki is far coarser than material of the same grade from Waitaniwha. Actually such a difference should be expected from a study of Table 6. It will be seen that the grading at Whakaki is 2.0 — 0.84 mm., 49.0, 0.84 — 0.59 mm. 35.5, 0.59 — 0.42 mm 6.3 per cent. It follows that the material at Whakaki in the 0.84 — 0.59 mm. grade must be closer to 2.0 — 0.84 mm. than to 0.59 — 0.42 mm. and that it would not extend evenly from the largest to smallest within that grade. In the Waitaniwha sample the grading is 2.0 — 0.84 mm. 0.0, 0.84 — 0.59 mm 44.5, 0.59 — 0.42 mm 50.6 per cent. Study of this relation shows that the 0.84 — 0.59 mm. grade will be far closer to 0.59 — 0.42 mm. than to 2.0 — 0.84 mm. Actually, however, the difference is greater than would be expected; for the weight of 100 grains of the former is 0.067 grams, and that of 100 grains of the latter is 0.041 grams. In other words the weight of the average grain of the 0.84 — 0.59 mm. grade at Whakaki is one-and-half times as great as one of the same grade at Waitaniwha. The diameters of the two samples would have the ratio of 1 : 1.15

in the average grain. Calculations show that the Whakaki is practically coarser than 0.71 mm. and the Waitaniwha sample is practically finer than 0.71 mm. Not only does this illustrate the errors that may arise from paying too close an attention to the grading results, but it emphasises the statements that have been made in regard to the extremely sharp grading of these beach sands and gravels. Several instances similar to this may be found in the tables that represent the gradings, and these instances are actually apparent from mere inspections of samples of the same grade from different localities.

The peculiar feature of the secondary maximum noticed by Udden (*loc. cit.*) will be noticed when discussing some features of the grinding of sand by gravel. It will only be said at this point that this feature appears to be due to abrasion or other process of reduction of grain size rather than to current sorting as suggested by Udden. It may be mentioned that a secondary maximum is to be seen in the grading of the river gravels from both the Tukituki and Mohaka Rivers (Figs. 2, 5, Tables 5, 6).

CONCLUSIONS IN REGARD TO GRAVEL BEACHES.

1. Much of the coarse material that is contributed to the beach is eliminated by wave action.

2. All sand in the original mixed feed that is finer than 5.0 mm. is quickly eliminated. Generally additions are being made to this for some distance from the point where the feeding takes place; for a river carries most of the fine matter out to sea and the wave action soon returns it to the beach where it is quickly reduced by impact and ground up.

3. There is a constant decrease of grade in the beach material in the direction of drift along the beach.

4. Pebbles that are larger than $\frac{1}{2}$ inch in diameter are worn flat on these beaches.

5. Pebbles that are smaller than $\frac{1}{2}$ inch in diameter are rounded because the wave action is sufficiently strong to suspend pebbles of this size and they do not slide along the beach. If wave action were less intense flattening would continue with pebbles of a smaller size. Since a long time and much wear is required for the round shape to supersede the flat form some remnants of the flattened shape will be found in pebbles far smaller than $\frac{1}{2}$ inch diameter.

6. Until the gravel is very fine practically all the smaller grades on a beach owe their smallness to impact, not to abrasion (in other words fragments have been chipped off them). This is proved by the general angular form of the smaller pieces. Under the conditions that obtain on Hawkes Bay beaches pebbles are able to fracture those smaller ones that have one fifth of their diameter.

7. Abrasion takes place with extreme slowness when a beach is composed of little pebbles finer than 3.4 mm. in diameter. This is proved by the highly polished surfaces of all the pebbles in beaches composed of such material.

8. The almost complete absence of grains smaller than 0.42 mm., after the destruction of that brought down by the feed, except for

a small amount that is subsequently introduced, proves that sand is not formed by beach action.

9. The remarkably even grade of the finer gravel or coarse sand on beaches is thus shown to be due to:—

- (a) Elimination of the coarsest material by wave action.
- (b) Destruction of the sand in a mixed gravel by grinding.
- (c) The action of impact which in the Hawkes Bay beaches, in consequence of the heavy surf, maintains the limits of the grades between the proportions of 5 to 1. That this is due to impact is clearly demonstrated by the fact that the finest grade in any beach sample is always angular. This bears out in a precise manner the results of experimental abrasion in the Deval machine.
- (d) Abrasion which acts far more rapidly with coarse than fine and thus with the lapse of time tends to make the difference between the coarse and the fine grade less and less.

These conclusions are opposed to those of Vaughan Cornish (loc. cit. p. 541) who ascribes the even grading to "the washing away of the particles below a certain critical size." It is clear that this explanation fails in regard to the Hawkes Bay beaches which grade with a progressive decrease throughout their length. The question of washing away of particles will be considered under the heading of "sand."

THE EFFECT OF MOVING GRAVEL ON SAND.

(Table 7, Fig. 6).

Further experiments have been made in order to investigate the nature of the grinding action of gravel on sand. In a number of these the sand that was used graded between 0.42 — 0.297 mm. The sand was removed and regraded every 15 minutes. Four different grades of gravel were used—the coarsest 25.4 — 19.0 mm. and the finest 6.3 — 3.4 mm. In the four experiments 4,500 grams of gravel and 500 grams of sand were used. Comparison of the results shows that the action is rather more rapid when the gravel has the grade 19.0 — 12.7 mm. than when it is coarser; but falls off very rapidly when the gravel is finer than this. The results are given in Table 7.

It is at once seen that the sand is rapidly attacked and the coarser grades of gravel reduce some of it to the finer grades of sand within fifteen minutes, and in an hour the amount of the finest grade is considerable. The finer gravels, however, act far less rapidly and although the sand is quickly attacked subsequent reduction of grade proceeds progressively more slowly. With the finest grade of gravel employed the action in the first fifteen minutes was considerable, but for the next three periods the further development of the action was slight. The difference between the B and C samples is particularly striking. The results have led to the opinion that actual grinding under the conditions of experiment ceases when

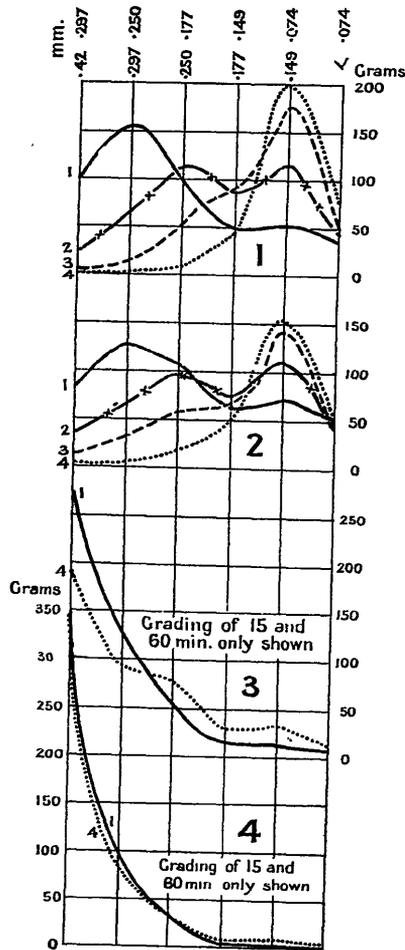


FIG. 6.

Graphs showing the rate of grinding of sand by gravels of different gradings in the Deval machine.

- 1.—4500 grams of greywacke gravel 25.4 — 19.0 mm. in diameter with 500 grams of sand 0.42 — 0.297 mm. in diameter. (1) Grading after 15 minutes' treatment in the Deval Machine; (2) After 30 minutes; (3) After 45 minutes; (4) After 60 minutes' treatment in the Deval machine.
- 2.—4500 grams of greywacke gravel 19.0 — 12.7 mm. in diameter with 500 grams of sand 0.42 — 0.297 mm. in diameter. (1), (2), (3), (4) After 15, 30, 45 and 60 minutes' treatment in the Deval machine respectively.
- 3.—4500 grams of greywacke gravel 12.7 — 6.3 mm. with sand 0.42 — 0.297 mm. diameter. (1) After 15 minutes; (2) After 60 minutes.
- 4.—4500 grams of gravel 6.3 — 3.4 mm. in diameter with sand 0.42 — 0.297 mm. in diameter. (1) After 15 minutes' treatment; (2) After 60 minutes' treatment in Deval machine.

In all cases at each regrading all matter finer than 0.074 mm. in diameter was removed.

the pebbles are smaller than $\frac{1}{2}$ inch, for their weight in water is then small and the weaker pebbles only can be ground and the whole mixture soon attains the equilibrium proportions that are proper to these materials under the particular conditions of movement. Exactly what controls the quantities of the various grades in these equilibrium proportions and apparently fixes them with considerable exactitude does not appear to have been revealed by the experiments.

TABLE 7.
GRINDING EFFECT OF GRAVEL ON SAND.

Mm.	A				B				C				D			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0.42—0.297	100.7	22.2	4.3	0.5	86.1	37.5	14.2	7.5	273.1	239.4	201.2	194.5	353.5	351.1	350.2	349.5
0.297—0.250	155.6	65.0	14.5	1.2	120.5	65.0	30.4	8.3	125.6	119.2	114.5	96.6	102.9	101.2	86.0	84.9
0.250—0.177	95.8	114.8	53.6	9.5	109.5	96.1	59.9	29.0	55.0	57.5	75.5	76.4	33.7	32.5	39.8	34.8
0.177—0.149	48.3	88.0	85.0	40.5	60.2	73.8	66.6	47.6	15.0	19.6	26.6	28.1	4.8	5.0	7.0	8.7
0.149—0.074	57.7	119.0	117.5	202.0	71.5	110.0	141.5	153.3	14.8	22.4	27.8	32.8	3.2	4.5	5.5	7.0
0.074	37.7	41.0	55.4	68.8	40.7	41.0	45.4	56.4	8.5	12.0	12.0	12.4	2.7	1.8	1.3	1.9

All quantities stated in grams.

In each case 500 gms. sand. 0.42—0.297mm. grade; 1, 2, 3, 4 after 15, 30, 45, 60 minutes' treatment respectively, 4500 grams of greywacke gravel in each case.

A—25.4—19.0 mm. B—19.0—12.7 mm. C—12.7—6.3 mm. D—6.3—3.4 mm.
Loss of weight of gravel A₄, 31.4; B₄, 22.5; C₄, 18.5; D₄, 12.7 grams.

Under natural conditions on the Waihua beach it appears that the conditions of movement cause the complete destruction of all material that is finer than 0.59 mm. though there the coarsest material is only 6.3 mm. in diameter. At Whakaki and Nuhaka however where the coarsest grade is 3.4 mm. a certain amount of finer material is present and this is maintained at Waitaniwha. This suggests that no impact or grinding action is efficient in the conditions on the east end of this beach by pebbles smaller than 3.4 mm. This is a finer grade than the smallest that acts in the Deval machine but its effectiveness here may be ascribed to the greater violence of the action on the beach.

Another feature that was roughly tested was the grinding effect of relatively smaller quantities of gravel compared with sand. In the experiment previously described it was found that 4,500 grams of gravel 25.4 — 19.0 mm. diameter in 15 minutes reduced 400 grams of sand 0.42 — 0.297 mm. out of 500 grams in grade though only 42 grams of this became finer than 0.074 mm. and in the second period of 15 minutes, 96 grams. When the same quantity of gravel acted for 15 minutes on 1,000 grams of the same sand 482 grams were reduced in grade and 46 grams of this was finer than 0.074 mm. After the next 15 minute period, 702 grams had been reduced in grade and 106 grams of this were finer than 0.074 mm. The experiment shows that the rapidity of the grinding action was relatively less when referred to the large quantity of sand present. In other words the gravel is relatively more active when the amount of sand present is not great. No further experiments were made to ascertain the conditions of this clogging effect. (Table 8).

TABLE 8.

GRINDING EFFECT OF GRAVEL ON SAND.

4500 grams of greywacke gravel 25.4 — 38.1mm.

500 grams of sand. Treated in Deval machine for hour periods.

All quantities stated in grams.

mm.	1	2	3	4	5	6	7	8	9
0.59	2.10	0.70	0.4	0.2					
0.59 — 0.42	7.60	1.10	0.1	0.1	106	7.6	0.08	0.15	0.03
0.42 — 0.297	35.90	2.4	0.1	0.05	394	22.6	1.30	0.10	0.04
0.297 — 0.250	42.70	4.5	0.2	0.02		25.7	1.65	0.08	0.02
0.250 — 0.177	139.10	21.2	1.0	0.17		50.0	3.00	0.05	0.01
0.177 — 0.149	137.00	54.7	6.0	0.4		51.5	11.50	0.34	0.01
0.149 — 0.074	82.70	180.7	91.8	19.7		109.4	64.00	19.15	1.04
0.074 — —	47.00	187.9	225.5	169.1		155.1	213.3	162.90	35.9

1. Composition of sand from Wanganui beach in first experiment. 2, 3, 4 after 1, 2, 3 hours' treatment respectively. Gravel decreased from 4500 — 4204 grams.
5. Grading of sand in second experiment. 6, 7, 8, 9 grading after 1, 2, 3 and 4 hours' treatment respectively. Gravel decreased from 4500 — 3872 grams.

- X.—Sample of greywacke gravel 25.4 — 19.0 mm. 4500 grams. Sand
0.42 — 0.297mm. 1000 grams.
- Y.—Sample of greywacke gravel 19.0 — 12.7 mm. 4500 grams. Sand
0.42 — 0.297mm. 1000 grams.
- (Material finer than 0.040 mm. was not graded).

mm.	X		Y
	15 min.	30 min.	15 min.
0.42 — 0.297	516.8	297.4	494.5
0.297 — 0.250	188.5	227.7	190.6
0.250 — 0.177	130.5	176.5	146.3
0.177 — 0.149	59.8	91.2	61.0
0.149 — 0.074	58.1	101.1	51.0
0.074 — 0.040	24.8	39.5	35.2

A sample of sand graded 0.59 — 0.42 mm. was treated with gravel of 25.4 — 38.1 mm for hour periods. The result showed that though the action was rapid the coarser sand was not attacked nearly so quickly as the finer sample though it was still well within the limit at which this action apparently commences. (Table 8; 6, 7, 8, 9).

It can generally be said that with the machine employed the grinding action of gravel commences with sand grains that are 0.84 mm. in diameter in other words when the gravel and sand have the relative diameters of 30 to 1. Gravel of 19.0 mm. diameter acts in this way on sand 0.42 mm.; that is in the same proportions as the coarser grade. Gravel of 12.7 mm. diameter does not act until the sand is 0.177 mm. in diameter, and then slowly. The experiments suggest that pebbles less than 12.7 mm. in diameter are unable to produce any grinding effect. It must be repeated that these figures apply only to greywacke rock rotated in the Deval machine.

The secondary maximum of Udden is shown conspicuously in the grading of the gravels of the Tukituki and Mohaka Rivers (Fig. 2 (5)). It appears to be developing in gravel abraded for 360 hours. It is present in the gravel of the Waitangi Beach. It seems that this feature is a function of incomplete action. On mature beaches of gravel and of sand there is no sign of it. The relatively slow rate of abrasion compared with impact would cause a secondary maximum at a grade just coarser than that effected by impact, for fine gravel abrades less slowly than coarse.

SAND ON BEACHES.

The general occurrence of sand on beaches the world over indicates clearly that this material is always being supplied to the coast in large quantity; but the frequency and permanence of sand beaches in localities far distant from any source of supply indicate as clearly that sand is being reduced in grade very slowly by wave action.

Origin of sand.—Experiments with the Deval machine showed that sand is not formed from gravel by abrasion in that machine

which somewhat closely simulates wave action (Marshall loc. cit. p. 519). When this machine was used there was no sand even after the gravel had been reduced in weight by the imitation of wave action as much as 20 per cent. It was also found that any sand originally mixed with the gravel was quickly reduced to minute dimensions by grinding action.

The examination of the Hawkes Bay beaches from Tukituki to Tongoio and from Mohaka to Waitaniwha also demonstrated this; for it was found that the beach material as a whole slowly decreases in grade and at any one place it is such that, except for a few odd larger pebbles, and an insignificant amount of fine matter, the coarsest grade has at the most five times the diameter of the smallest and that this ratio tends to decrease until at Waitaniwha the grade of coarsest is only twice that of the finest. Impact was shown to be the main cause of the evening of grade.

The actual boundary between pebbles on the one hand and of sand on the other is given by Twenhofel as a diameter of 4 mm. This is of course a wholly artificial distinction and must from the nature of the case always be so. On the other hand Hall takes 1 mm. as the diameter that separates sand from gravel. The samples from Whakahi, Nuhaka and Waitaniwha may therefore be classified as sand. However, the descriptions of them that have been given show that these finer beaches are merely the results of a process that acts uniformly and continuously from the coarsest pebble to at the least a grade of 0.42 mm. It has also been shown that the change in grade has been effected mainly by impact modified by abrasion. All of the finer matter that must be produced simultaneously by impact is ground up and removed at once. It cannot therefore be claimed that such action is the origin of most sand. In New Zealand, at least, sand is for the most part produced by the weathering action of the atmospheric agents on surface rocks.

The quartz and the other more resistant minerals are by this action separated from those minerals that are subject to destruction by weathering. The grains of these stable minerals are carried by rain water to streams and by them they are transported as sand to the coast. There is little grinding action in streams and the sand is not subject to the destruction that it suffers on a beach.

In volcanic districts much sand is derived from the beds of tuff between the lava flows. North and south of Wanganui the black sand is formed of minerals obtained in this way from the volcanic country near the volcanos Ruapehu and Ngauruhoe; and it consists largely of hypersthene, augite and magnetite. North and south of New Plymouth the sand is derived from the tuff beds that have been formed by the activity of Mt. Egmont, and there it is mainly composed of green augite, hornblende and magnetite. Throughout the greater part of the North Island, however, the beach sand is derived almost entirely from the pumice sands that have such a wide distribution over the central portion of the island. They consist mainly of crystals of feldspar (oligoclase-andesine) with 25 per cent. of quartz and always some hypersthene and sometimes hornblende. The large sand spit at Cape Farewell consists of material brought down by the Grey and Buller and smaller rivers.

It has been shown experimentally by the use of the Deval machine that sand is not formed by beach action when there is any quantity of gravel on the beach. Examination of beach materials has supported this and has shown that coarse sand is formed from gravel as the final result of abrasion after prolonged drift from the source of supply and long after all of the coarse gravel has been eliminated. At the same time it has been shown that coarse gravel abrades rather rapidly and passes into the finest material and for that reason disappears from the beach, a disappearance that is accelerated by the eliminating effect of storm waves.

Observation of the occurrence of sand beaches strongly supports these experimental results. Thus at Campbell Island which lies in the most stormy area of the South Pacific Ocean and which has suffered from a great amount of wave action there are no sand beaches except for a small stretch in North West Bay where it is derived from the Tertiary sandstones that there form the coast. There are no sand banks or gravel beaches between the projecting points of this island north or south. The same is true of Auckland Island and especially of the outlying Disappointment Island and the condition holds true also of other oceanic islands though in such localities wave and beach action have their greatest development.

The destruction of sand by gravel is well illustrated by the distribution of sand on portions of the New Zealand coast. On the east side of the southern portion of the South Island there are beaches of drifted white quartz sand within all the bays even across the volcanic mass of Otago Peninsula. These sand beaches stop abruptly at Oamaru. North of this town the coast is fronted by low gravel cliffs which provide an abundance of coarse detritus which rapidly grinds the sand into such fine grade that it floats off the beach. No drifting quartz sand is seen north of this town. On the east side of the southern portion of the North Island there is another similar example. There are white sandy beaches due to material that is supplied by the Tertiary rocks until Hawkes Bay is reached. Here the greywacke gravel of the Tukituki is encountered and white sand is not found again until Mahia is reached though all the time it is being supplied in quantity by the rivers that flow into Hawkes Bay. It is ground to so fine a state that it floats away directly it attains the beach.

GRADING OF BEACH SANDS.

It is well known that beach sands have a fairly well defined grading, though it is less precise and less sharply limited than that found in the gravels of well worn beaches. The limits of the gravel gradings are due to impact—an action that has been shown experimentally to have no value in sands; a result that would be expected since the momentum of sand grains falling in water is extremely small. On exposed beaches the sands have their maximum percentage in the grade 0.25 — 0.17 mm. This is well seen in table 9. It must be remembered that sand on a beach in the absence of gravel is remarkably long-lived and that coarser material suffers from abrasion at a relatively rapid rate. This may account for

the general absence of the coarser grades of sand on well established beaches. The absence of the finest grade of sand (less than 0.07 mm.) on the other hand is ascribed to flotation. By this it is meant that the light material that is raised by the early part of a wave does not settle before the seaward motion of the rear of the wave acting with the undertow has carried it a short distance seaward. On exposed beaches it will be seen that there is little sand finer than 0.149 mm. and on all beaches there is practically nothing finer than 0.074 mm.; though as shown in tables 12, 13 this fine material is abundant in off shore sediments at a depth of 30 feet at Napier where the actual beach at that point is a mixed gravel. (Table 1, Marshall loc. cit.).

On a rough beach flotation begins at about 0.177 mm. and most of the sand that is finer than 0.149 mm. disappears. No rigid line can from the nature of the case be drawn separating the material that will be removed by flotation and the material that will remain. Much must depend on the intensity of wave action at the moment. Evidence of this is found on comparing the grade of the beach at Lyall Bay, Wellington, before and after a heavy gale, at the same point on the beach. It is seen from Table 10 that the following changes occur:—

0.149 — 0.074 mm. decreases from 25.9 to 5 per cent.

0.177 — 0.149 mm. decreases from 31.9 to 15.6 per cent.

0.250 — 0.177 mm. increases from 17.32 to 32.56 per cent.

0.297 — 0.250 mm. increases from 4.54 to 20.10 per cent.

It follows that the more exposed a beach is, the coarser within limits is the sand that is found on it. But even on the most exposed beaches that are free from outlying rocks or projecting headlands or other obstruction that could affect pure wave action there will be some sand between 0.149 — 0.074 mm. grade.

On beaches that are partly protected the amount of this grade increases and its amount may reach a high value in sheltered beaches. The finer sand which is lost from a beach during heavy weather is not permanently lost to it if coarser than 0.149 mm. During calmer weather wave action gradually returns it to the beach.

The rate of fall of sand grains in salt water really determines the presence or absence of any grade of sand on a beach. Table 3 shows that a grain of quartz 0.177 mm. in diameter has a rate of fall in salt water of 23 mm. per second. This is almost the smallest size of quartz grains that are found on beaches fully exposed to wave attack of the South Pacific. Basing opinion on this it is thought that a falling rate of 20 mm. per second is the critical one. If the rate of fall is more rapid the grain is not suspended for a sufficient length of time to be taken further seaward by the outward movement of the reverse side of the wave combined with the undertow. If it falls less rapidly the suspension lasts long enough for removal from the beach to be effected step by step by each succeeding wave. The wave disturbance is less as soon as the beach is left behind and this will permit sand of finer and finer grade to remain unremoved as the water becomes deeper and deeper and the wave movement on the bottom becomes less and less. Illus-

TABLE 9.

GRADING OF SAND SAMPLES FROM OPEN BEACHES FULLY EXPOSED
TO OCEAN SWELL.

	mm.	0.42	0.297	0.250	0.177	0.149	0.074
1. Ocean beach Dunedin east end	57.70	30.25	7.05	3.50	0.60	0.15	0.22
2. Tomahawk beach Dunedin west end	0.50	20.20	31.70	24.50	6.80	4.00	0.20
3. Hooper's Inlet Dunedin west side	0.00	0.30	39.50	40.60	11.90	7.20	0.40
4. Hooper's Inlet Dunedin east side	10.15	43.75	16.00	20.20	5.70	2.60	0.70
5. Wickliffe Bay Dunedin south side	0.00	0.10	5.30	56.50	27.80	9.80	0.10
6. Wickliffe Bay Dunedin north side	0.20	0.30	39.60	41.30	11.50	5.45	0.20
7. Otago South Head. Dun. Lighthouse beach north end	0.15	8.80	49.70	32.20	7.80	1.60	1.00
8. Otago South Head. Dun. Lighthouse beach south end	0.40	1.00	0.40	53.60	30.70	14.00	0.40
9. Otago North Head. East of harbour mole	0.20	0.40	9.45	63.80	17.35	8.50	0.10
10. Otago North Head. 2 miles north of harbour entrance	0.00	0.50	12.60	60.95	17.30	7.30	0.15
11. Long Beach Otago	0.05	0.10	16.30	62.80	15.75	4.60	0.20
12. Paritutu Beach New Plymouth	0.22	3.30	11.30	45.90	28.10	11.10	0.05
13. Awakino Taranaki	0.00	0.10	0.88	20.90	48.54	29.00	0.06
14. Farewell Spit west end. Low tide	8.76	34.83	22.40	18.83	13.07	2.33	0.03
15. Farewell Spit west end. High tide	0.50	4.80	10.43	46.70	27.16	10.46	0.06
16. Farewell Spit 5 miles from west end. Half tide	0.40	7.23	15.50	41.80	27.00	7.80	0.07
17. Tauranga. High tide	0.27	1.62	10.10	42.30	30.90	11.99	0.30
18. Tauranga. Half tide	1.68	3.00	8.05	49.48	29.10	10.00	0.22
19. Tauranga. Low tide	2.91	9.15	17.84	39.40	23.40	6.72	0.18
20. New Plymouth. Half mile east of breakwater	0.11	2.72	17.54	37.74	23.00	17.83	0.63
AVERAGE	1.41	8.01	17.08	42.08	20.65	9.56	0.26

trations of this will be found in tables 12, 13, which give the grading of sands outside the beach limits at Napier.

It is of course apparent that the high tide line on a beach which is reached by the tongue of the waves only is subject to less extreme conditions than the line of low tide. At this level the swirl and disturbing movements are most marked for the greater portion of a tidal period, especially in localities where the rise and fall of the tide is not great, which is usually the case on the New Zealand coast, for the rise and fall is seldom more than ten feet at spring tides. These considerations naturally arouse an expectation that the sand will be coarser at the low tide level than at that of high tide. Material was collected at Lyall Bay, Tauranga and Farewell Spit to test that conclusion. The samples from Lyall Bay gave inconclusive results but that was deemed unimportant as this bay though handy for collecting is not typical as it is partly enclosed and not free to unimpeded wave action. The samples from Tauranga and from the western end of Farewell Spit however support this conclusion in a definite manner (Table 9).

If the rate of fall of sand grains really determines the grade of material that will stay on a beach it must follow that minerals that have a high specific gravity will remain on a beach when they are in smaller grains than those that have a relatively low specific gravity. Calculations show that grains of hypersthene and augite that are 0.149 mm. in diameter have a rate of fall of 20 mm. per second, and magnetite grains 0.112 mm. fall at approximately the same rate.

This conclusion was tested by examining the gradings of the sand at Awakino and at Tauranga. At Awakino the sand is almost entirely an augite (diopside) magnetite sand. It was found that 82.82 per cent. of the augite grains were coarser than 0.149 mm. and that 48.15 per cent. of the magnetite was finer than 0.149 mm. compared with 16.19 per cent. of the augite. The presence of so much magnetite in the Awakino sand is the cause of the excessive fineness that it has for a sand on an exposed beach. Striking as this result is, the separation of the minerals would probably have been far more complete if a sieve of mesh 0.162 mm. had been used. Some confusion of material also resulted from the fact that most of the grains of augite contain some small included grains of magnetite and as a consequence the separation of augite and magnetite by the magnetic method was not complete. The actual grading of the two minerals was:—

Diameter mm.	Augite	Magnetite
0.250 — 0.177	47.37	9.45
0.177 — 0.149	35.45	41.75
0.149 — 0.074	16.19	47.80
0.074		0.35

A similar result was found at Kai Iwi but the effect shows less clearly in the gradings because there is a quantity of fine quartz of local origin on this beach.

The beach sand at Tauranga consists of quartz, feldspar, hypersthene, and magnetite. When this has been graded it is most noticeable that the coarsest grade consists mainly of quartz and feldspar; the grade 0.177 — 0.149 mm. is mainly composed of hypersthene and, the grade 0.149 mm. — 0.074 mm. is mainly magnetite. In all the large number of beach sands that were graded it was found that magnetite prevails in the finest grades.

The marine sands that have been graded fall naturally into four groups:—

(1.) Those obtained from beaches that are fully exposed to the action of oceanic waves and heavy swell. (Table 9).

(2.) Samples from beaches that are partly enclosed, or sheltered from the constant or main force of the ocean swell. (Table 10).

(3.) Sand from dunes fringing the coast. (Table 11).

(4.) Samples obtained from dredging in shallow water close to the coast. (Table 12, Fig. 3).

1.—SANDS FROM EXPOSED BEACHES.

(Table 9).

In Table 9 the beaches may be considered as relatively equal in exposure. No. 1, however, was collected from a spot close to rocks which caused wave action to be most irregular. It has not been included in the average. No. 4 also was collected at a locality which was affected in the same manner but in a less degree. Both of these samples are relatively coarse. On the other hand the Awakino sample is much finer than the average. This sand has a large percentage of magnetite which owing to its high specific gravity can stay on a beach in grains much smaller than those of quartz or feldspar. The same is true of the Paritutu and Tauranga beaches but they have far less magnetite than Awakino, and the fineness is less pronounced. The samples from the south side of Wickliffe Bay, New Plymouth, half a mile east of the breakwater and No. 8 Otago are less fully exposed to the heavy seas and their slightly greater fineness may be ascribed to this. Again the samples from a low tide level are always coarser than those that are obtained from a higher level on the beach. The averaging of the totals obscures these unusual factors and gives a less true idea of the grading of a beach exposed to heavy seas than Farewell Spit or Hooper's Inlet for beaches composed of light minerals or Awakino for beaches composed of heavy minerals. Even so the average shows that there is a relative concentration of grains with a diameter between 0.250 and 0.177 mm. which forms nearly half of the total. There is but little sand that has a finer grain than 0.149 mm. and practically nothing finer than 0.074 mm.

The supposed reasons for this have already been suggested. The absence of coarser grades is ascribed to the relatively rapid abrasion of those grades; the absence of finer grades to the flotation of these grains and their removal seaward by the backwash and undertow.

2.—SANDS FROM PARTLY SHELTERED BEACHES.

(Table 10).

2. The samples that were collected on beaches that are partly protected gave very unequal results as would be expected; for

the amount of exposure to wave action is different in each case. Lyall Bay for instance is sheltered from all seas except the southerly and the form of the Bay interferes with the removal of fine sand. Here, however, comparison between the normal state of the beach (No. 3, 4, 5, 6) and its state after heavy weather (No. 7, 8) show clearly the effect of heavy wave action. On the other hand the samples from within the Otago Harbour (No. 1, 2) differ but little

TABLE 10.

GRADING OF SAND SAMPLES FROM BEACHES PARTLY ENCLOSED
AND SHELTERED.

	mm.	0·42	0·297	0·250	0·177	0·149	0·074
1. Otago Harbour south side	0·20	1·80	39·80	40·33	12·20	4·10	0·20
2. Otago Harbour sand flat	0·30	6·40	12·90	62·60	17·70	5·45	0·55
3. Lyall Bay Wellington 30 yds. from dunes	0·03	0·77	2·40	29·56	48·00	18·27	0·30
4. Lyall Bay Wellington 50 yds. from dunes	14·69	6·27	4·54	17·33	31·39	25·39	0·28
5. Lyall Bay 2 ft. below low water	5·08	2·57	6·14	23·37	34·34	27·03	0·57
6. Lyall Bay 4 ft. below low water	10·05	5·14	6·23	28·69	27·83	21·04	0·65
7. Lyall Bay 50 yds. from dunes after heavy gale 18/8/28	10·10	16·40	20·10	32·56	15·60	5·00	0·05
8. Lyall Bay 100 yds from dunes after heavy gale 18/8/28	15·60	16·50	13·10	29·30	16·05	6·50	0·04
9. Kai Iwi. Half tide	3·33	17·39	15·71	26·19	19·54	16·67	0·81
10. Kai Iwi. High tide	0·93	11·18	15·00	32·99	24·12	14·12	0·93
11. Paekakariki. Low tide	16·79	3·50	1·89	8·10	24·44	45·06	0·28
12. Paekakariki 25 yds out from low tide	5·00	2·44	1·25	10·75	35·68	44·56	0·31
13. Oputama Mahia	0·60	4·90	8·90	29·50	37·30	18·20	0·40
14. Tahunanui Nelson	1·40	2·08	1·50	14·02	43·12	37·56	0·02
15. Plimmerton	2·30	2·57	2·27	6·11	12·15	72·00	1·38
AVERAGE	5·63	6·14	10·78	26·07	26·63	24·06	0·51

from the grading of the sands in the various bays of the Otago Peninsula. Presumably there was not much shelter at the time that they were deposited. There is a great deal of fine matter in the Kai Iwi sand. This is probably derived from the fine Pliocene and Miocene sediments which stand in high cliffs on this coast and constitute the greater part of the country. At Paekakariki this fine grained quartz sand is in very large quantity. It is distinctly micaceous and it has also other characters which suggest that it has been derived from the Farewell Spit and has drifted across the straits with the prevailing westerly sea and strong flow of the ebb tide. The western part of Cook Straits has a maximum depth of 60 fathoms and the bottom is said to be covered with fine sand. If this sand had drifted down the coast from the direction of Wanganui and Wangaehu it would contain far more grains of volcanic origin. It is at any rate surprising that the percentage of the fine ingredient is so large at Paekakariki for the beach is open though the distant Cape Farewell protects it from the heavy southerly weather and Kapiti Island prevents much of the northerly seas from affecting it. A comparison of the sand from Wanganui with that from Paekakariki does not give the impression that drift along the beach has caused the development of the one from the other.

The sand at Plimmerton has the same general characters as that at Paekakariki but the beach is situated inside the Porirua inlet and is sheltered from the heavy sea waves with the consequence that the proportion of fine grained constituents is far higher than in any of the other samples. The average of these samples in table 10 gives little direct information; for the divergence of the individual samples is considerable and in many instances the features of the separate samples are entirely masked in the average. The table that gives the composition of these sands when read in the light of a knowledge of the localities from which they were obtained shows definitely that the fineness of the sand is most intimately related to the amount of exposure of the beach to waves.

TABLE 11.

GRADINGS OF SAND FROM DUNES FRINGING THE COAST.

	mm.	0.42	0.297	0.250	0.177	0.149	0.074
Otago South Head. Drift across road	0.80	2.55	51.85	31.60	9.20	3.30	0.10
Lyllall Bay	0.04	0.20	1.04	28.92	48.28	21.72	0.32
Castlecliff Wanganui	1.62	7.18	9.74	27.82	27.40	16.54	9.40
Paekakariki	5.69	12.61	0.92	20.38	29.23	31.15	0.39
AVERAGE	2.04	5.63	15.89	27.18	28.52	18.18	2.55

3.—SAND OF DUNES.

(Table 11).

3. The gradings of sand from dunes on the sea margin give rather a less definite impression of character. The samples from Lyall Bay and Paekakariki show that the sands are most definitely related to the beach sands of their neighbourhood and that the wind is able to transport all the material that has been thrown onto the beach by the waves. The average of the few samples again masks the characters of the individual sands and does not offer any definite indications of importance.

4.—SANDS FROM OFF SHORE SITUATIONS.

(Table 12).

The samples that were taken from off shore situations were all collected near Napier (Fig. 3) in depths of about 30 feet. Some were taken from the north and others from the south of the breakwater and were exposed to rather different conditions. In spite of this they show a remarkable similarity. The gap between Nos. 6 and 9 is not filled in because these spots lay directly on the line of outlet from the inner harbour where the current in ebb tide runs with the velocity of four knots and the bottom samples are much affected by this unusual condition.

TABLE 12.
GRADINGS OF SAND FROM OFF SHORE DREDGINGS.

	mm. 0·42	0·297	0 250	0·177	0·149	0·074	
Napier A 30 ft.	0·83	0·79	4 03	19·44	65·28	9·31	
Napier B 36 ft.	0 71	0·70	2 28	11·40	76·28	8·86	
Napier 1 28 ft.	0·40	0·30	4 00	18·67	9·00	6·43	
Napier 2 37 ft.	1·25	0·20	6·25	34·25	55·75	1·50	
Napier 3 35 ft.	2·00	0·10	6·00	29·05	59·50	3·00	
Napier 4 32 ft.	2·00	0·15	2 50	8·00	60·50	26·55	
Napier 5 26 ft.	0·50	0·40	1·05	5·25	87·50	5·25	
Napier 6 18 ft.	1·10	2·00	12·50	41·20	41·45	0·50	
Napier 9 24 ft.	5·40	0·75	8·33	21·60	55·83	8·75	
Napier 10 21 ft.	4·75	2·75	14·00	33·75	43·50	2·00	
AVERAGE	1·89	0·82	6·09	22·26	61·46	7·26	

A little protection is afforded by the Auckland rock to No. 4 and its extra fineness is to be explained by that fact. These samples show a remarkable general similarity and are at once distinguished from beach sands by their fine grading. Here the grade 0.149 — 0.074 mm. is predominant and in most instances there is a considerable amount of material finer than 0.074 mm. These sands are sharply graded and are quite distinct from all of the samples of beach sand by their fine nature. They vary so little that the average gives quite a good indication of their general features.

Despite what has been said about the averages of the sand from different situations the general features of the gradings are well shown by them. On exposed beaches the grading is sharp and the highest percentage is in the 0.250 — 0.177 mm. grade. In the sheltered beaches the grading is far less sharp and the maximum is in the 0.177 — 0.149 mm. size. The same is true of the sands from the marginal dunes. The off shore sands on the other hand from depths of 30 feet have a high maximum in the 0.149 — 0.074 grade.

SAND FROM DREDGING OFF NAPIER.

(Table 13).

The dredgings were collected in two series:—(1) A line extending due east from the beach at Napier. The line leaves the beach at the middle point of the municipal baths and is directed at right angles to the beach. (2) A line extending east from the outer end of the breakwater for a distance of half a mile to a depth of 10 fathoms. They were taken in a bucket which was dragged a short distance over the sea floor shortly after high tide on November 29th, 1928; but the depths given in the table were reckoned from the low water level. For forty-eight hours previous to the time at which the dredgings were made there had been an easterly swell with a lift of five feet. This is slightly higher than the average swell but there is often a moderate local sea setting on the beach from the north-east.

The gradings of the material taken in the dredgings are given in table 13. It will be seen that in the dredgings 1, 2, 3, 4, 5, there were some pebbles as well as sand. The pebbles in No. 1 were on the whole distinctly beach worn but in the other four samples the shape of the pebbles gave no indication that they had been worn on a beach. It was possible though hard to match them from the pebbles in a beach sample from the locality. They have, however, the average shape of the pebbles from the Tukituki gravels. It is clear that they are not related to the sand on the beach or on the sea floor for they are not connected with it by an increasing amount of material of intermediate grades. It is thought that these pebbles are the remnant individuals of gravel that was carried beyond the beach limits by flooded rivers and is now being gradually brought by wave action to the beach. It is most noticeable that the sand that is mixed with the gravel on the beach (Table 13 B.C.) and in the sand of the samples from shallower water that the grading has a close relation to that of sand which in experiments has been partially worn down by the grinding action of gravel (Table 7).

TABLE 13.
DREDGINGS OFF NAPIER BEACH AND BREAKWATER.

Sample No. ...	1	2	3	4	5	6	7	8	10	17	16	15	11	14	13	12
Depth ...	4½	11½	13½	15½	18½	21½	24½	28½	32	37	39	42	49½	51	56	58ft.
Distance from shore at municipal baths	30	80	130	180	230	280	330	380	30	150	300	350	440	600	700	900yds
East from north end of breakwater.																
mm.																
0.42 — 0.297	1.07	2.60	0.68	3.65	0.03	...	...	...	0.17	...	...	...	0.20	...	...	0.40
0.297 — 0.250	1.72	3.84	1.34	8.60	0.38	...	...	...	0.52	...	0.86	...	0.05	0.01	0.71	0.22
0.250 — 0.177	14.10	13.25	14.22	27.15	6.98	2.89	1.15	0.86	4.48	0.10	...	0.81	0.80	0.01	0.43	0.98
0.177 — 0.149	31.80	30.15	40.10	32.10	36.46	21.00	19.22	12.25	43.90	9.79	7.17	5.82	6.00	5.92	2.88	4.94
0.149 — 0.074	51.20	48.60	45.70	28.70	54.40	71.20	73.65	77.00	50.48	81.10	80.70	78.25	74.20	73.25	67.20	61.00
0.074	0.96	1.32	0.49	0.81	1.55	3.36	5.75	9.85	0.38	6.02	10.32	15.25	18.50	19.97	28.90	33.70

After (17) 37 ft. all grades coarser than 0.177 mm. consist of waterlogged pumice and wood fragments.

Sand amongst gravel on beach at Napier opposite Rotunda.

mm.	Clifton sand beach	Hightide	Lowtide
	A	B	C
0.42 — 0.297	20.0	6.05	1.40
0.297 — 0.250	20.9	5.32	0.44
0.250 — 0.177	33.6	23.00	14.08
0.177 — 0.149	18.7	36.30	36.44
0.149 — 0.074	5.6	29.60	46.80
0.074	0.1	0.48	0.52

In addition to the sand as graded above coarser material detailed below was present in certain samples.

Diameter in mm.	Sample B	C	1	2	3	4	5	6
25.4 — 19.0	...	...	...	...	6.31	...	6.62	...
19.0 — 12.7	...	2.43	...	0.91	0.00	...	1.08	0.05
12.7 — 6.3	...	17.17	1.27	2.94	1.10	0.50	0.62	...
6.3 — 3.4	...	37.97	1.13	2.14	0.39	1.36	...	...
3.4 — 2.0	30.62	10.06	0.40	1.54	0.05	0.21	...	...
2.0 — 0.84	45.60	5.40	0.37	2.29	0.02	0.13	...	...
0.84 — 0.59	1.43	0.18	0.20	0.71	0.01	0.23	...	...
0.59 — 0.42	0.33	0.11	0.13	0.77	...	0.45	0.08	...
Sand as graded above	19.92	24.97	98.53	88.70	92.12	97.52	91.60	99.95

The grinding of the sand would seem to take place in the upper levels of the beach where the rush of water is greatest, and sinking into the beach it carries sand with it. In the lower part of the beach the wave action is more of a pounding nature and the pore space in the gravel is permanently saturated with water. In this lower part of the beach there is no constant flow of percolating water and there is no feeding and refeeding of the gravel with sand. If the grading of this sand is compared with that of the beach at Clifton it will at once be seen that the Napier sand is much the finer. The Clifton sand comes actually from the same beach but some eight miles further south and at a point beyond the place where gravel is first supplied to the beach. This Clifton sand is actually finer than that at the low tide level on Farewell Spit and from some other localities on New Zealand sand beaches and it is reasonable to regard it as the normal grading of sand on this beach where it has not been subjected to the action of gravel grinding. On the other hand the sand that is mixed with the gravel on the beach has a grading finer than the average sample even from enclosed beaches (Tables 10, 13).

In connection with this it is important to notice the facts in regard to the actual shape of the beach materials where there are no pebbles with a diameter larger than 6.7 mm. (if such are present they are worn flat): (1) All material coarser than 3.4 mm. is well rounded. (2) That between 3.4 and 0.84 mm is mostly angular. (3) The small amount between 0.84 and 0.42 mm. is quite angular. (4) From 0.42 to 0.25 mm. it is fairly well rounded again. (5) All finer grades than 0.25 mm. consist of well rounded grains.

This condition which appears so surprising at first sight is really the normal one for beaches which have such a variety of gradings; that is those that are relatively close to the source of supply. It is at once apparent that it is precisely the condition that resulted from the experiments that were made in connection with gravel abrasion. Marshall, *loc. cit.*, pp. 520 et seq.

The rounded form of the coarser matter is due to simple abrasion. The angular form of the intermediate grades is the result of impact which has been shown to act far more rapidly than abrasion with particles of these sizes. The rounded form of the smaller sizes is caused by grinding which supersedes impact when the grains are small though the action seems to decrease rather in speed when they have been reduced to a smaller size than 0.149 mm.

It is most noticeable that the fine sand at Napier is different in form from the small amount that is found on the beaches at Nuhaka and Waitaniwha which is all angular. It has already been shown that the beach material there is too fine to effect any grinding action.

It is apparent that the quantity of material in the grades 0.84 — 0.25 mm. is extremely small. This may be taken to show that the processes of reduction in a mixed gravel are extremely rapid between these limits. This entirely agrees with the experiments that have been detailed in the previous paper. It was there shown that the processes of impact and grinding acted so rapidly that at any

one time there was a small quantity only of material of the grades mentioned though all the while material was passing rapidly from a coarser to a finer state past this intermediate size.

The gradually increasing fineness of grade as the water becomes deeper and deeper is most striking (Table 13, Nos. 5-17, but omitting No. 10 which is close to the breakwater and subject to unusual conditions of wave action for such a depth). It is at once apparent that there is a grading appropriate in its smallest details to the intensity of the wave disturbance which in its turn is directly dependent upon the depth of the water. The practical elimination of 0.250 — 0.177 mm. grade in deeper water is most marked while the grade 0.149 — 0.074 mm. at first increases uniformly until it reaches a maximum of over 80 per cent; but at that point the increase of the material finer than 0.074 is such that the coarser material has to decrease in sympathy.

It was interesting to notice that except for a few dead shells there were no organic remains at less depths than nine fathoms but in the two dredgings of greater depth there was an abundance of specimens of marine worms and of small species of *Nucula*. This seems to prove that at all depths less than nine fathoms the bottom is shifting but is stable when the depth is greater. This is somewhat surprising as it would be expected that wave action would be rather disturbing at such a depth. From the accepted formulae it would appear that with a swell five feet high and wave length of 1,000 feet there would be an oscillating movement of 0.3 feet per second on the sea floor. That the material is easily moved by water disturbance is proved by an observation made when the steamer *Port Curtis* was being anchored in seven fathoms of water. The vessel was drawing 22 feet and in order to stop her way the propeller was put at full speed astern. The movement of the water stirred up the bottom and from the water that rose to the surface a deposit was obtained that had practically the grading of the sea floor in all of its details, though 25 feet intervened between the bottom and the blade of the revolving propeller.

The finest sand from 10 fathoms is not quite as fine as the material of the thick Tertiary sandstone formation which has such a wide distribution at Lake Waikare Moana and occurs generally on the flanks of the mountain range of Hawkes Bay. The grading of this sandstone is given in Table 2, No. A. It is also very similar to the deposit left by a heavy flood on the banks of the Wairoa River. This material was derived from the Tertiary rocks which consist of fine sandstones and shales. (Table 2, C).

RELATION BETWEEN THE SLOPE OF A BEACH AND THE SIZE OF COMPONENT PARTICLES.

It is a matter of common observation that those beaches that are composed of gravel are steeper than those that are formed of sand. Actual statements of the slope of beaches are however hard to find. The only measurements made so far are of the Napier beach of fine gravel and the Cape Farewell beach of fine sand. Both are fully exposed to heavy seas. The former when measured had an average slope of $6\frac{1}{2}$ degrees, the latter of 1 degree only.

The reason of this relation does not appear to have been carefully considered. The only statement that could be discovered is that of Vaughan Cornish. He states (*loc. cit.*, p. 541) "No stony particle of less than a certain critical size can remain permanently on a beach, but is ultimately swept out to sea. This critical size is greater on a coarse than on a fine grained beach, for the regimen slope of the former is steeper and gravity therefore gives greater assistance to the backwash." In other words the steepness of a coarse beach is maintained because the finer matter is swept off it.

The experiments that have been made indicate that the coarseness of a beach is due to the feed and is maintained by the action of impact which rapidly destroys the smaller pebbles while the grinding action prevents any sand from remaining on the beach. The action of course reduces the size of those pebbles which are larger than that which allows of destruction by impact. The place of these larger pebbles must be constantly filled by new ones supplied by the feed, or the grade will decrease quickly.

Vaughan Cornish also notes that heavy seas will cause the beach to be flatter than calmer conditions for he points out the downwash becomes greater relative to the upwash.

The observations that have been made in connection with the present research have shown that the grade of the material of which a beach is composed is the most important factor in determining the slope of the beach. This is of course modified by the intensity of wave action. The stronger the wave action the flatter the beach.

The following considerations indicate that rough seas produce a flattening of the beach:—

1. A smaller proportion of the water of each wave sinks into the beach and the volume of the downwash is greater and its velocity also will be greater because friction retards the greater mass to less extent.

2. The transporting power of the backwash is greater because of the higher velocity and volume.

3. The velocity of the backwash is greater because the water has a greater distance to flow back down the beach.

4. The grade of the gravel relatively to the movement is less and it can therefore be more freely moved.

The effect of the size of the mineral particles on the grade of the beach is suggested as follows:—

1. The finer the material the less percolation into the beach and therefore the larger the volume and transporting effect of the backwash.

2. The backwash will move the beach material more easily and in greater quantity if it is finer.

3. The undertow below the level of wave action on the beach can transport very fine material some distance from the actual beach.

4. The angle of repose of fine material in water is lower than that of coarser grains. Actual tests showed that in still water the angle of repose of pebbles 3.4 — 2.0 mm. is 30 degrees, of sand 0.250 — 0.149 mm. it is 25 degrees, and a slight movement of the water makes the difference far greater.

For the reasons given it is thought that the grade of the material of which a beach is formed actually determines its slope, in conjunction with the heaviness of the wave action to which it is exposed.

CONCLUSIONS IN REGARD TO SAND BEACHES.

1. Sand on beaches is sharply graded.
2. The grading varies roughly in accordance with the exposure of the beach.
3. The grading is due to the relatively rapid abrasion of the larger grains and flotation of the smallest ones.
4. On exposed beaches the peak of the grading is 0.250—0.177 mm.
5. On sheltered beaches the grading is less sharp with its peak at 0.177—0.149 mm.
6. At a depth of about 30 feet off an exposed beach the peak is at 0.149 — 0.074 mm.
7. On the sea floor there is a complete adjustment in the absence of currents between grading and depth.
8. On rough beaches flotation becomes important when the rate of fall of the grains is 20 mm. per second.
9. The critical size for flotation of grains of quartz is 0.177 mm., augite 0.149 mm. and magnetite 0.112 mm. in diameter.
10. Grains of quartz that have a diameter between 0.177 and 0.112 mm. seem to come and go from the beach in accordance with weather conditions.
11. Grains smaller than 0.074 mm. in diameter cannot remain even on sheltered beach.
12. The slope of a beach is dependent on the grade of the materials of which it is composed being flatter for the finer material.
13. The slope is also related to the size of the waves being flatter for the heavier waves.