The Wearing of Beach Gravels.

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IN text books on Geology, the work of Daubree on the abrasion of gravels is still extensively quoted, though his work was done in 1879. In his experiments he generally employed angular fragments of rock, though occasionally rounded pebbles were used. He stated that the principal product of the action was mud, though a notable quantity of sand was also produced:—

> "Le principal produit de l'action mutuelle des fragments de roche solide qui s'usent dans le sein des eaux n'est pas du sable comme on l'a souvent prétendu, mais du limon.
>
> "Outre le limon, il se produit encore dans la trituration des roches quartzeuses du sable proprement dit . . . . . leur diamètre n'atteint pas un quart de millimètre. (*Etudes Synthétiques de Géologie experimentale*, vol. 1, p. 251 *et seq.* Daubrée, Paris, 1879.)

Wentworth more recently studied the effect of abrasion on the shape of pebbles and, in particular, estimated the rate at which they became rounded. The latest author, Barrell, has emphasized the fact that practically no sand is produced by this action, but he does not describe any detailed experiments in support of the statement.

The experiments described in this paper were made with natural well-worn shingle from the beach at Napier, New Zealand. This beach is exposed to the prevailing ocean swell from the south-east and the gravel is constantly moved along the beach. The material of the gravel is a hard greywacke rock which is extremely uniform in nature and composition. In each test the gravel was carefully graded in order to find how the materials of different sizes were affected by the treatment. The average resistance of greywacke rock is indicated by its response to the standard tests for roadmaking materials. In these standard tests, its toughness varies from 20 to 30, the French co-efficient 10 to 15 and the hardness 19.

In making his tests Daubrée used a rotating cylinder to produce a sliding movement for the materials employed. There was also provision for a fall of about 6 inches every half revolution. The movement amounted to 160 feet per minute. Wentworth used rotation only, and the pebbles travelled 150 feet per minute. The experiments recorded in this paper were conducted with a Deval Machine. The iron cyclinders in which the charges of gravel (always 5,000gm. in weight) were enclosed are 34 cm. long and 20 cm. diameter and inclined at an angle of 30 degrees to a horizontal axis of revolution. They were rotated at an average rate of 38 revolutions per minute, and with each charge of gravel two litres of fresh water were added. The pebbles had a fall of several inches every half revolution or 76 times per minute, and slid for a distance of about 65 feet every minute. This gives a motion which approximates to one mile per hour. It is thought that this is generally similar to the movement of pebbles on a beach, though on the New Zealand beaches ocean waves reach the strand to the number of 10 to 15 per minute. The movement due to each wave is far greater than that in the Deval Machine, and the pebbles are moved over the floor of the same greywacke material instead of that of an iron cylinder.

The greywacke rock is rather fine grained. The component grains are only occasionally as large as 0.4 mm. in diameter. The average is probably about 0.2 mm. After the pebbles had been treated in the Deval Machine, it was found that the component sand grains of the greywacke were worn on the surface but were seldom knocked out of the parent rock.

Daubrée states that when rounded pebbles of granite were used in his experiments the loss amounted to 0.25 to 1.0% for 15 miles of travel; equivalent to 0.4 to 1.6% of loss for 24 miles of travel.

The greywacke used in the present experiments lost about 1.6% in 24 hours. Daubrée did not grade the materials he used and gives no quantitative statements of his results.

Abrasion.

The first tests were made with two typical samples from the Napier beach, each 5000gm. in weight and before treatment they were divided into the following grades:—

2″ to 1½″	50.8 to 38.1 mm.
1½″ to 1″	38.1 to 25.4 mm.
1″ to ¾″	25.4 to 19.0 mm.
¾″ to ½″	19.0 to 12.7 mm.
½″ to ¼″	12.7 to 6.3 mm.
¼″ to ⅛″	6.3 to 3.4 mm.

After the samples had been treated for 24 hours, they were washed, regraded, and the weight of the material of each grade was recorded. This in the case of sample A was repeated 15 times. After the first period the loss was found to be 193.5 gm. This loss consisted of fine grained material which floated off when the gravels were washed. An examination of the floated substance showed that it contained only 0.01% of substance coarser than 0.07 mm. in diameter. When the weights of the different grades of the sample were scrutinized, it was found that one-third of the loss (67 gm.) was derived from the grade of material finer than ¼″ (6.3 mm). Contrary to expectations, no sand was formed. The material graded between one-tenth and one-twentieth of an inch (2.0 to 1.18 mm) weighed only 11.2 gm. In order to test this still further in the grading subsequent to 48 hours, the finer material was separated into the following grades:—

1/8″ to 1/10″	3.4 to 2.0 mm.
1/10″ to 1/20″	2.0 to 1.18 mm.

Sample A—Table 1.

After 168 hours, the weight of material smaller than one-twentieth inch (1.18 mm.) was also estimated. The conditions of the experiment were not extremely exact, for it was difficult to wash the material quite cleanly from the cylinder, and the method of separation of grains by sifting always causes some inaccuracy. It is, however, probable that on the average the results of sifting are fairly accordant. At any rate it was found that even in the small quantities of finely graded material the results were remarkably consistent. The more noticeable points were these:—

The total material finer than ¼ inch (6.3 mm.) was always small. In Sample A the original amount was 8.82%. On treatment this was reduced rather rapidly, and in 144 hours amounted to 7% only. Thereafter the percentage remained practically constant, and this appears to be the percentage of this grade stable or proper to this particular gravel under the condition of movement in the experiment. In this paper it is termed "the equilibrium proportion."

The second point was that the percentage of material finer than one-eighth inch (3.4 mm.) was practically constant at 0.035%, even when the percentage lost varied around 1.5 in 24 hours, the word "loss" always referring to the material finer than 0.07 mm. in diameter. Table 1 shows that this loss is about 75 gm. or 1.6% of the total weight in every 24 hours. The coarser material underwent relatively little change, though the tendency of grade ½ to ¼ inch (6.3 to 3.4 mm) was to increase, but the actual amount was no more than an increase from 25.75% to 26.9% after 360 miles of travel. The change that the table shows in the coarsest grade was large, owing to a slight reduction in the size of some of the fragments which allowed them to pass through the holes in the sieve which had previously been too small.

The stability of the proportions of the different grades is remarkable, and suggests that the conditions of movement in the experiments closely approach those that prevail on an actual beach. At the close of the test after 360 hours 21.4% of the weight of the gravel had been lost or converted into material finer than 0.04 mm, yet this considerable amount of loss had not been associated with any but the slightest amount of change in the grading of the gravel apart from the decided loss in the amount of the finest grade from 8.82 to 6.9%.

Sample B—Table 2. The gravel used in this sample had somewhat different percentages from those of Sample A in the various grades of the constituents of the gravel. It came, however, from the same beach, and is composed entirely of the same greywacke rock. The most noticeable difference is a smaller quantity of ¼ to 1-10th inch (6.4 to 2 mm) which amounted to 170.7 gm. or 3.4% in place of 8.8% in Sample A. There was also a larger quantity of ½ to ¼ inch (12.7 to 6.33 mm). The test periods employed were 48 hours. There were the same general results. No sand was produced, but the main product of the action was 2% of material finer than 0.04 mm for every 48 hours. There was a striking difference of a special nature, when this sample was compared with

Sample A Table 1. This is seen in the changes of the proportion of the grade ¼ to 1/10th inch (6.4 to 2.0 mm). Originally this weighed 170.7 gm. or 3.41%. The amount and percentage constantly increased and finally after 360 hours of treatment it amounted to 221 gm. or 5.2%, and was still increasing. It is clear that the equilibrium proportion for this constituent of Sample B had not been reached. In Sample A the equilibrium proportion for the ¼ to ⅛ inch (6.3 to 3.4 mm) material is approximately 7% of the total weight, and it is probable that the relative coarseness of this sample may require a higher percentage of the finer graded material than in Sample B before the equilibrium proportion is reached. In Sample B also there seems to have been a slight excess of the constituent 1 to ¾ inch, the percentage of which decreased from 18.4 to 16.1 in 384 hours.

Sample O—Table 4. In order to test the tendency of a sample of gravel to change its grading under the action of abrasion during the periods employed, experiments were made with a sample consisting of equal quantities of 5 grades between 1½ inches (38.1 mm) to ⅛ inch (3.4 mm). The sample was treated for six periods of 24 hours each and was dried, graded, and weighed after each period. It was found that the quantity and proportion of the grading between ¼ and ⅛ inches (6.3 to 3.4 mm) constantly decreased at the rate of 0.5% every 24 hours. The other grades showed no important change during the four periods. Of the fine material produced by the abrasive action on this sample 21.4 gm of the grade ¼ to ⅛ inch (6.3 to 3.4 mm) was produced in 24 hours, and after 144 hours' treatment the quantity of this grade amounted to 34.7 gm., or 0.78% of the total in place of 0.44%. The small amount of increase in this constituent in the last three periods of the treatment showed that the amount of this grade had practically reached its equilibrium proportion in 144 hours. The material of one-tenth to one-twentieth inches grade (2 to 1.18 mm) reached its equilibrium proportion (.025%) at the end of the second period of 24 hours. The material between one-twentieth and one-twohundredth inches (1.18 and 0.07 mm), a wide range, attained its minute equilibrium proportion of 0.00092% at the end of 24 hours. The finest material between 0.04 mm and 0.0004 mm amounted to about 90 gm. or 1.9% in each of the 24 hour periods. This experiment emphasises the fact that when a sample is not graded in proportions appropriate to its dominant nature and to the conditions of abrasion, the wearing action at once tends to rectify those incongruities that exist.

Sample K—Table 5. In order to test still further the rate of abrasion and the adjustment of the grade of materials to the conditions of movement in the periods of treatment, another type of sample was used. (See Table 5). It consisted of 2500 gm. of gravel 1½ to 2 inches (38.1 to 50.8 mm) and 2500 gm. of gravel ½ to ¼ inch (12.7 to 6.3 mm). The loss in this case was very high, especially in the finer material, in which it amounted to nearly 10% in 24 hours. The grading of material between ¼ and ⅛ inch (6.3 to 3.4 mm) had clearly made a good start. As in all cases, the material between one-twentieth and one-twohundredths inches

(1.18 to 0.07 mm) was almost negligible while the silt and clay amounted to 234 gms. The result in these respects merely emphasises that obtained from the treatment of Sample A and Sample O. It was very noticeable that the loss of the finer grade ½ to ¼ inch (12.7 to 6.3 mm) was 15 times as rapid as when material of this grade was used by itself. Sample C, Table 5. In other words, 2500 gm. of this grade lost 234 gm. compared with the loss of 30 gm. from 5000 gm. when this grade was used by itself for the same period. In addition another 181 gm. were reduced to a finer grade than ¼ inch (6.3 mm) which was the finest material at the beginning of the experiment. The loss of the coarser material 2-1½ inches, however, was slightly less than when used by itself; for 2500 gm. lost 2.3% in Sample K whereas in Sample F, Table 5, 5000 gm. used by itself lost 6% in 24 hours.

In Sample A it was seen that the amount of fine gravel material, grade ¼ to ⅛ inch (6.3 to 3.4 mm), decreased at a rate far more rapid than that of all the grades of coarser gravel. In order to decide whether this variation was an important action, tests were made of a sample of each separate grade. Samples, F, E, G, D, C, H, L, Table 5. The results showed that the gravels of coarser grades abraded far more rapidly than those of finer grade. So far as the experiments went 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 ¼ to ⅛ inch (6.3 to 3.4 mm) is reached. Using this fine material it was found that the rate of abrasion diminishes far less than the amount equivalent to the reduction in size of the average pebble. When a still smaller size ¼ to 1/10th inch (6.4 to 2.0 mm) is tested it is found that the amount of abrasion actually increases in a decided manner. The probable explanation of this will be given later under the heading "Impact."

In one typical instance an estimation was made of the grade of the materials finer than 0.07 mm. Sample G, Table 5 was employed and the result showed that clay was the most important constituent with particles smaller than 0.002 mm diameter, and fine silt with a diameter between 0.01 and 0.002 mm was also present in large quantities, but there was not much material coarser than this. The smallest particles had a diameter of 0.0004 mm. This result gives a total of 86.48 gm. whereas only 72 gm. were lost from the sample. The difference is ascribed to iron worn from the cylinder and to water absorbed from the air by the fine clay. The proportion of water absorbed or combined by the clay was found to amount to 10%.

The effect of this treatment on the shape of the pebbles was not very pronounced. Actually it was found that the pebbles became distinctly rounder and the flat pebbles from the beach were clearly wearing on their edges. The change of form was not great, but it points to the conclusion that the movement of the pebbles during the experiment involved a greater amount of throw, and a relatively smaller amount of sliding, than under natural conditions on a beach.

The results of these tests on abrasion may be generally summarized as follows:—

(1) The effect of the wearing of gravel under this imitation of beach conditions follows laws that define the proportion of the different grades of coarseness most precisely, though these cannot be given a quantitative expression without a far more extensive series of experiments.
(2) Under the conditions employed the rate of the wear of the beach gravel subjected to experiment amounts in 24 hours to a value between 1 and 2% for every 24 miles of movement in the machine.
(3) Practically no fine or coarse sand is formed by the action, though in the experiments the two samples of gravel A and B were reduced in weight by a total amount of 1841.2 gm.
(4) The material developed by the abrasion consists of extremely fine-grained material lying almost entirely between the limits of 0.07 mm to 0.0004 mm.
(5) With prolonged treatment the different grades of the gravel were reduced to certain definite proportions which remain constant. These are here termed the equilibrium proportions.
(6) If any component grade is present in greater or less amount than its equilibrium proportion, it is decreased or increased rather quickly as the action proceeds.
(7) When a sample is examined, it is found that there is practically no intermediate stage in the product of wearing between fine gravel (one-twentieth inch 1.18 mm) on the one hand, and silt 0.01 mm in diameter on the other. Nine-tenths of the material developed is fine silt and clay.
(8) If the gravel originally contained much fine pebble—between $\frac{1}{8}$ and $\frac{1}{4}$ inches (3.4 and 6.3 mm), say 8% or more, wearing under the conditions employed actually produces a coarser sample of gravel, paradoxical as the statement may sound.
(9) There is a slow tendency to produce a gravel of more uniform grade of intermediate sizes.
(10) The shape of the pebbles under the conditions employed tends to become more rounded.
(11) Noticeable fracture of pebbles takes place to a most limited extent.

Impact.

Consideration of the results of the wear of Sample A and Sample O showed that the loss of the finer constituents $\frac{1}{4}$ to $\frac{1}{8}$ inch 6.3 to 3.4 mm) could not reasonably be ascribed to abrasion since there was no corresponding increase in the quantity of the grades finer than $\frac{1}{8}$ inch (3.4 mm). In fact after the experiments had been continued for 48 hours the percentages of these in Sample A showed no increase, though the decrease in the quantity of $\frac{1}{4}$ inch to $\frac{1}{8}$ inch grade (6.3 to 3.4 mm) continued to be important.

It seemed that impact or the crushing of the smaller pebbles by the larger ones was the only other cause that could account for the continued loss of the grade between ¼ and ⅛ inch (6.3 to 3.4 mm). In discussing this action of crushing of the smaller pebbles the coarse gravel which does the crushing is called "the impactor" and the finer gavel which is crushed by the action is termed "the impactee" for the purposes of this paper.

In order to test this idea experiments were made with a sample consisting of 4500 gm. of gravel between ¾ and 1½ inches (19 to 38 mm) with 500 gm. of fine gravel one-twentieth to one-eight inches (1.18 to 3.4 mm). Sample N, Table 6. When this was treated for 24 hours it was found that hardly any of the finer grade or impactee one-twentieth to one eight inch (1.18 to 3.4 mm) remained. No satisfactory conclusion as to the rate of the action could be derived from this experiment and it was therefore begun anew, but the sample was dried, graded and weighed after each hour's run, and after each hour all material finer than 0.04 mm was discarded. The early results (each of the first three periods of one hour) showed a rapid loss of the impactee but of this loss which amounted to 93.3 gm. in the first hour and 48 gm. in the third only about 7% graded between 1.18 and 0.07 mm and only 2% in the wide interval between 0.59 mm and 0.149 mm. In other words 93% of the loss was composed of material finer than 0.07 mm.

It was suggested that the silt and clay, or the material below 0.04 mm, was derived from abrasion of the impactee; and though this seemed highly improbable, it was decided to settle the doubt by an actual counting of the pebbles of which the impactee was composed. An equivalent sample of the original material was taken, and it was found that the 500 gm. contained 28,965 pebbles, this number being derived from counting the pebbles in a small sample taken from the 500 gm. After four periods of hourly run, a fresh sampling showed that this number had been reduced to 16,040 pebbles. It was remarkable that the average weight of the individual pebbles was slightly greater than at the beginning of the experiment. This proved conclusively that the loss was not due to mere abrasion but to the destruction of the smaller pebbles in the sample by impact, and showed that the action was selective in its nature, and that the larger pebbles on the average survived. The tests of this sample were continued for a total of 15 one hour periods, and the results obtained in the earlier periods were maintained in all detail throughout. At the end of 15 hours 379 gm. of impactee (⅛ to 1/10 inches—3.4 to 2.0 mm) had been reduced to 44.5 gm. and the number of pebbles from 28,965 to 1,868. The average weight of the pebbles in this grade after 15 hours was finally 0.0238 gm. and at the beginning of the first hour 0.022 gm. At the end of the same period 121 gm. of gravel 1/10 to 1/20 inches—2.0 to 1.18 mm) had been reduced to 19.6 gm. while the average weight was changed from 0.011 gm. to 0.0076 gm. The whole of the grading for the 15 different hour periods is given in Table 6. This Table shows some irregularities in the numbers of the pebbles, but this must be ascribed to unsatisfactory sampling. After the ninth hour-period of test, sampling was abandoned and the whole of each batch of pebbles was counted.

The feature previously noticed that a small amount of material only graded between one-twentieth and one-twohundredth inches (1.18 to 0.0074 mm) was maintained throughout the tests. Not only is this the case, but the quantity in each grade maintained its proportion with minute and persistent regularity, in each of the 15 hour periods. A peculiar feature in the table is the slightly higher weight graded between one-sixtieth and one-seventieth inch (0.250 to 0.210 mm) than in the grades respectively finer and coarser than this. This seemed incongruous, and the openings in the sieves employed were therefore measured and it was found that the one-seventieth inch sieve had an opening of 0.192 mm instead of the standard 0.210 mm. In consequence of this, much of the material that should have passed through this sieve and have been retained on one-eightieth inch (0.177 mm) was actually retained on one-seventieth. In all the tables given, the actual openings of the sieves that were employed are stated in millimetres. The values suggested in fractions of inches are not exact.

The results of all the gradings and weighings throughout the tests of Sample N are remarkably accordant, and indicate that in spite of the rough nature of the apparatus employed the errors were reduced to a minimum.

Further tests were made in attempts to find a relative measure for the rate of the action due to impact. Sample K Table 5 which has been referred to previously under "Abrasion" shows clearly that impact has been commenced by the action of an impactor 1½ to 2 inches grade (38.1 to 50.8 mm) on an impactee as coarse as ½ to ¼ inch (12.7 to 6.3 mm) which was treated for 24 hours. In this case the loss of 234 gm. during the period of treatment is relatively low, and shows that the action of impact on such a coarse grade of material is slight with the amount of fall obtained during the movement of the apparatus.

Sample P Table 3 shows how much more rapid this action became when the same impactor was used with a finer impactee ¼ to ⅛ inch (6.3 to 3.4 mm). The loss amounted to 105.4 gm. in one hour, but of this 25 gm. was coarser than 0.59 mm and 59 gm. was finer than 0.07 mm. The loss in this case was not quite so great as in Sample N, where both the impactor and the impactee were of a finer grade. In this sample the number of pebbles in the impactee were reduced in one hour from 5,270 to 3,510, while the average weight of these small pebbles rose from 0.97 to 1.12 gm. This result was emphasized by giving another hour's treatment, and it was found that the grades of material between ⅛ and 1/30 inch (3.4 to 0.5 mm) decreased slightly in weight in accord with the decrease in weight of the whole quantity of impactee, but remained practically constant when compared with the values after the first hour's treatment. In other words the quantities of the grades 1/8th to 1/10th inch (3.4 to 2.0 mm) and 1/10th to 1/20th inch (2.0 to 1.18 mm) and 1/20th to 1/30th inch (0.59 to 0.42 mm) had already attained their equilibrium proportions for the particular sample at the end of one hour. It is clear that in this sample impact caused the destruction of pebbles $\frac{1}{8}$ inch in diameter and perhaps rather larger than this. The increase in the weight of the average pebble of the impactee after an hour's treatment shows that impact was markedly selective.

It is probable that impact accounts for the loss in Sample H Table 5 which is distinctly higher than that of Sample C and of Sample L Table 5. Only a small amount of impact, however, could result from the movement of such a fine-grained impactor, under the conditions of experiment.

Further tests were undertaken in order to obtain more exact ideas as to the rapidity and the limits of the effect of impact.

Sample Q Table 3 consisting of 4500 gm. $\frac{3}{4}$ to 1 inch (19.0 to 25.4 mm) and 500 gm of $\frac{1}{8}$ to 1/10 inch (3.4 to 2.0 mm) was treated. After rotation for one hour the 500 gm. were reduced to 462.5 gm., a loss of 37.5 gm. but 23.32 gm. of this was not finer than 1.18 mm. It is therefore clear that this impactor which averaged $\frac{7}{8}$ inches in diameter (23.8 mm) was far less effective than an impactor of an average $1\frac{1}{4}$ inch (31.7 mm) Sample S. In other words, a decrease in the diameter of the impactor by 24% decreased the effect of the action in the ratio of 130 : 37.

Another sample, R Table 3, consisted of 4500 gms. of $\frac{3}{4}$ to 1 inch (19.0 to 25.4mm.) with 500 gms. 1/10th to 1/20th (2.0 to 1.18mm). Comparison with Sample Q shows that the average size of the impactee was reduced from 9/80th of an inch to 6/80ths while impactor of the same grade was used. In this case the effect of impact was increased in the ratio of 37 : 54.

The following tabulation gives a rough idea of the changes in the effect of impact when the grade of the impactor and the impactee are varied:—

ONE HOUR TREATMENT.

Impactor	Impactee	Weight of Material due to Impact Finer than	
		(1·18 mm 1/20″)	(0·59mm. 1/30″)
Av. Size $\frac{14}{8}$″ 47·6 mm.	$\frac{15}{80}$′ 5·1 mm.	82·9 gm.	72 gm
,, $\frac{10}{8}$″ 34·0 mm.	$\frac{9}{80}$″ 3·0 mm.	73·1 gm.	68 gm.
,, $\frac{7}{8}$″ 23·8 mm	$\frac{9}{80}$″ 3·0 mm.	14·0 gm.	13 gm.
,, $\frac{7}{8}$″ 23·8 mm.	$\frac{6}{80}$″ 2·0 mm	54·0 gm	48 gm.

From these figures we get the rough indication that if the average diameter of the impactor varies from 7 to 10 the effect of impact varies from 1 to 5. If the size of the impactee varies from 6 to 9 the effect falls from 4 to 1. These figures obviously apply only to the particular conditions of movement used in the experiments and to the material employed. They indicate the importance of the action of impact in the destruction of gravel on a beach and show the rapidity with which it tends to eliminate the finer material in a mixed gravel. On the other hand, experiments on the abrasion of fine material of a uniform grade as shown in Table 5 Sample C, H and L indicate that in the absence of coarse material the destructive effect of the movement is small.

This greywacke rock under the conditions employed suffers little from impact if the diameter of the impactee is 1/10th or more of the diameter of the impactor. If the impactor is coarse, the impactee will be attacked even when relatively larger. The effect, however, is great when the relative diameter of the impactee falls to 1/15th of the other. As has been stated previously the presence of material of intermediate grades tends to protect the impactee from the action of the impactor in a very marked degree.

Impact has been shown to be a most important action in connection with the wearing of gravel, and in general acts rapidly in reducing the percentage of the fine constituents. There is, however, a definite limit to its action. Thus if Sample A Table 1 is studied, it is at once seen that when the constituent grade ¼ to ⅛ inch (6.3 to 3.4 mm) has been reduced to 7%, approximately, of the weight of the sample, it remains constant at that amount; in other words, the effect of impact is no longer noticeable. In Sample B the amount of this constituent constantly increased from 3.4% to 5.2%. Here impact failed to prevent an increase in the percentage of this constituent. In sample O where the impactee was at first 20% there was a contant decrease to 15.7%. In Sample N the loss of this constituent during the second hour was 14.5% and in the fifteenth hour 10%.

These results are remarkably accordant, and show that when the percentage of impactee is less than the proportion of equilibrium for the particular sample, the effect of impact is no longer apparent, and in general the rapidity of the action of impact depends upon the excess of the impactee above the equilibrium proportion.

Another point is noticeable. In a mixed gravel such as Sample A, a higher percentage of impactee actually amounting to 7% is required for the equilibrium proportion than in Sample N which has no material of grades between 1 inch and ⅛ inch (25.4 to 3.4 mm). The equilibrium proportion here is less than 1.3%. This supports the conclusion that material of intermediate grade protects the impactee from the effect of impact, but experiments were not carried far enough to determine the nature and amount of its protection.

The following notes were made in regard to the nature of the materials, in Sample N (Table 6), of the minute quantities of the sands graded from 1/30th inch to 1/200th inch (0.59-0.07 mm). In the coarser grades quartz was not predominant; but in those finer than 1/60 inch (0.24 mm) it attained 80-90 per cent. At 1/100th inch (0.14 mm) muscovite became noticeable, and was prominent at 1/200 inch (0.074 mm) though it could hardly be discovered in the rock.

Grinding.

Further inspection of the wearing of Samples A, B and N. all showed a feature in common, that when action had taken place on gravels variously graded, whether it lasted for one hour or for 24, or 48 there was always a minute proportion only of material between 1/30th and 1/100th inch (0.59 and 0.149 mm) while the amount between 1/20th and 1/200th inch (1.18 and 0.07 mm) was unimportant. This was the case even in those instances when one and a half grams and more were being reduced from the condition of fine gravel, to that of silt and clay every minute.

It is clear that the first effect of impact, must be mainly the production of grains of material between 1/20th and 1/200th inches; yet at any one time, the amount of material of this size in all of the samples, was found to be negligible. The suggestion is clearly that material of this grade was destroyed, almost directly it was formed, by some action which operated with great rapidity. Further experiments were made in order to ascertain the actual rate at which the fine gravel and sand were changed into silt and clay. A sample was first employed, consisting of 4,500 gm. 1½ to 1 inch, (38.1 to 25.4 mm), and 500 gm. of quartz-sand from Otago, which graded as follows:—

		mm. mm.	gm.
Sieve	20-40	1.18-0.42	7.3
	1/40-1/50	0.42-0.28	18.5
	1/50-1/60	0.28-0.24	37.2
	1/60-1/70	0.24-0.19	120.3
	1/70-1/80	0.19-0.17	32.5
	1/80-1/100	0.17-0.14	178.6
	1/100-1/200	0.14-0.07	94.8
	Passed 200		9.8

After this sample had been treated in the Deval Machine for 24 hours, 0.01 gm. of sand only were retained on the 200 inch sieve; while the material between 0.07 and 0.04 mm weighed 10 gm., that between 0.04 and 0.01 weighed 116 gm., and the material finer than 0.01 mm weighed 374 gm. It was clear from this experiment that the grinding action of the tube mill type was so rapid that shorter intervals of time were required for experiment. A sample was therefore employed consisting of the gravel used previously, with 500 gm. of quartz-sand, graded from 1/60th to 1/70th (0.25 to 0.19 mm) and treated for one hour. It then graded as is shown in Table 7 Sample J (2). All of the sand was lowered in grade, and the greater part was reduced to extremely fine dimensions. It was treated for another half-hour, and was then practically all in a finer state than 0.07 mm. During the first hour, the gravel lost 14.6 gm., and in the second half-hour, 9 gm.; altogether a loss of 0.52% in 1½ hours. The result shows that gravels of this type, weighing 4,500 gm., will in 1½ hours grind 500 gm. of sand into a fine condition, for all but 26 gm., were finer than 0.07 mm. The grinding action is, therefore, far more rapid than abrasion or the effect of impact. When pebbles, 1 inch to 1½ inches (2.54 to 3.81 cm) are used, the grinding action begins with fragments of sand 1/30th inch, or 0.59 mm in diameter, and the grinding action continues until material is reduced to the state of silt and clay.

In all the experiments previously described greywacke rock was used. One additional experiment has been made with andesite pebbles collected near the mouth of the Wangaehu River (Table 8). These were graded in the same manner as Sample O, but the loss after 24 hours' treatment amounted to 816 gm. in place of 95 gm. from greywacke rock. Sample O Table 4. The andesite rock was slightly vesicular but the pebbles represented sound material, for they had travelled more than 100 miles down the river-valley from their source. In this experiment, by far the greatest amount of loss was from the material between ¼ and ⅛ inch (6.3 to 3.4 mm), for the 1,000 gms. of this grade were reduced to 515 in the 24 hours. Although the effect of impact was so much more rapid and the coarser products of its action between ⅛ inch and 1/20th (3.4 to 1.18 mm), that is, fine pebbles were in relatively large amount, the rest of the material, down to a grade of 0.04 mm was little larger than in a greywacke rock which lost only 95 gm. in 24 hours. The result clearly shows that notwithstanding the rapid rate of reduction of the finer pebbles by impact, the action of grinding was able to reduce the material supplied by impact as rapidly as it was provided.

Summary.

The experiments detailed in this paper show that the reduction of gravel under the conditions of movement employed is due to three actions which are considered to be distinct-termed respectively—"Abrasion," "Impact," and "Grinding."

"Abrasion" is the mere effect of pebble rubbing against pebble.

"Impact" is the effect of definite blows of relatively large pebbles on others relatively small.

"Grinding" is the crushing of small grains by the continued contact and pressure of pebbles of relatively large size.

1. Abrasion is by far the slowest of these actions, and its amount varies from 6% of loss in 24 hours with coarse material (3.81 to 5.08 cm), to 0.6% with fine material (0.63 to 0.34 cm).

2. Impact acts far more rapidly than abrasion, but only when the impactor has ten times or more the diameter of the impactee. It may then cause a loss of 10% to 16% of the impactee in one hour, when the proportion of impactor and impactee are 9 : 1. At the same time, this action increases the rate of wear of the impactor, though much of this wear may be due to the subsequent grinding of the small fragments due to impact. In Sample N Table 6 the loss of the impactor is 0.2% per hour, or 4.8% in 24 hours, in place of 2.9% in 24 hours, when such gravel is used by itself. In this sample the materials would lose 2.8% in 24 hours, if used separately, but when they are treated together, impact causes the effect to increase 16 times.

3. Grinding is by far the most rapid action under the conditions of experiment. In the test that was made, the loss was 523 gm. in 1½ hours. If sand were continuously supplied, the loss

would be at the rate of 8,368 gm. in 24 hours. Calculations show that if 12,500 gm. of gravel and sand were used, under such conditions, the silt and clay that would be produced would amount to 66.5% in 24 hours.

It follows that loss by abrasion of beach pebbles, formed of uniform hard greywacke, amounts to 1.5% in 24 hours. The movement during the experiment being roughly equivalent to 24 miles of travel. Impact may produce waste sixteen times as rapidly as abrasion, while grinding, acts 2½ times as rapidly as impact.

It is clear from the above (1) that when gravel from ¾ of an inch upwards is moving on a beach, the fine gravel, 1/10th of an inch and less must soon be eliminated. (2) Sand cannot live on a beach where wave action keeps gravel in movement.

It is hoped to consider the nature of the materials on some typical beaches in New Zealand, in the light of these results that have been obtained from experiment. The preliminary statement can now be made, that gradings of gravel samples taken from definite spots on beaches where gravel has travelled 5 to 50 miles, show results that are in clear accord with those obtained by experiment.

It must once more be emphasized that the experiments described in this paper apply with one exception to rock of a single type only, and to one set of conditions only. There would obviously be great differences from the results described in this paper if different material was employed and if the conditions varied in relation to velocity of movement, diameter of cylinder, inclination of cylinder, proportions of charges, amount of water used, soluble substances in the water. It is thought, however, that the experiments are sufficiently varied to justify the conclusion that such differences would be variations in degree, not in kind.

Mr. B. Elphick, B.Sc., London, my assistant, has conducted the experiments with great care and understanding, and has made many valuable suggestions.

GS.

SAMPLE A.

TABLE 1.

Abrasion test of 5000 grams of gravel from Napier, weighed and graded every twenty-four hours.

Grades. Inches.	Mm.	Original.	%	24 hrs.	%	48 hrs.	%	72 hrs.	%	96 hrs.	%	120 hrs.	%	144 hrs.	%
1/20 -	1.18 -	Not separated		Not separated		Not separated		Not separated		Not separated		Not separated		Not separated	
1/10 - 1/20	2.0 - 1.18					6.3		4.3		3.9		3.2		3.0	
1/8 - 1/10	3.4 - 2.0			11.2	7.8	21.3	7.7	18.2	7.5	14.7	7.3	12.5	7.1	13.0	7.0
¼ - ⅛	6.3 - 3.4	441	8.82	363.8		336.2		325.3		316.5		306.2		294.0	
½ - ¼	12.7 - 6.3	1287	25.75	1226.0	25.5	1211	25.7	1188	25.6	1169	25.6	1154	25.6	1130	25.5
¾ - ½	19.0 - 12.7	1257	25.14	1249.3	26.0	1217	25.8	1235	26.6	1190	26.1	1175	26.1	1169	26.4
1 - ¾	25.4 - 19.0	914	18.28	904.8	18.3	899	19.1	872	18.8	887	19.2	867	19.2	842	19.1
1½ - 1	38.1 - 25.4	636	12.72	672.7	13.9	650	14.0	622	13.4	652	14.3	710	15.8	704	15.6
2 - 1½	50.0 - 38.1	461	9.22	375.2	7.8	372	7.9	369	7.9	333	7.3	268	5.9	266	5.9
	Total weight	4996		4803		4712.8		4633.8		4565.6		4495.9		4421	
	Loss			193.5		90.2		77		68		70		74.8	
	Percentage Loss			3.88		1.88		1.64		1.47		1.53		1.69	
	Total Loss			193.5		283.7		360.7		428.7		498.7		573.5	
	Total Percentage Loss			3.88		5.7		7.2		8.6		9.8		10.5	

TABLE 1—*continued.*

Abrasion test of 5000 grams of gravel from Napier, weighed and graded every twenty-four hours.

168 hrs.	%	192 hrs.	%	216 hrs.	%	240 hrs.	%	9 hrs. in 3 periods.	24 hrs. saltwater.	%	312 hrs.	%	336 hrs.	%	360 hrs.	%
0.2	7.1	0.13	7.2	0.2	7.1	0.28	7.1	0.14	0.10	6.95	0.15	7.1	0.10	7.1	0.10	6.9
2.0		2.4		2.1		2.0		1.65	1.55		1.85		1.6		1.5	
11.5		11.1		10.7		9.5		9.5	10.05		11.1		10.2		8.0	
300		295.7		289.7		283.0		281.1	272.5		276.3		270.1		262.2	
1111	25.4	1089	25.3	1063	25.1	1033	24.9	1027.5	1022.8	25.0	997.7	24.7	987.7	24.4	964.6	24.5
1161	26.8	1139	26.4	1125	26.5	1099.5	26.5	1088.5	1079.6	26.4	1060.1	26.4	1057.4	26.5	1060.7	26.9
817	18.5	817	18.9	798.2	18.8	798	19.2	800.7	790.9	19.3	785.3	19.4	748.7	18.9	746.5	18.96
699	16.0	722	16.8	717.5	16.9	689.4	16.6	687.5	684.8	16.7	724.8	17.9	739.1	18.5	715.0	18.3
264	6.0	234	5.5	231.4	5.4	227.7	5.5	226.8	225.7	5.5	179.3	4.2	177.8	4.4	176.8	4.4
4365.7		4310.33		4237.8		4142.38		4123.39	4088.00		4036.60		3983.7		3934.8	
55.25		55.47		72.53		95.42		—	35.39		51.40		42.9		48.9	
1.24		1.27		1.68		2.25		—	0.71		1.24		1.06		1.25	
630.8		686.7		758.5		854.12		872.61	908.0		959.4		1016.3		1061.2	
12.7		13.8		15.1		17.1		—	18.1		19.2		20.3		1.25	

SAMPLE B.

TABLE 2.

Abrasion test of 5000 grams of gravel from Napier, weighed and graded every forty-eight hours.

Grades. Inches.	Mm.	Original	%	48 hrs.	%	96 hrs.	%	144 hrs.	%	192 hrs.	%
1/20 -	1.18 -					0.3		0.7		0.4	
1/10 - 1/20	2.0 - 1.18			1.3	3.9	1.5	4.1	1.3	4.3	1.3	4.4
¼ - 1/10	6.3 - 2.0	170.7	3.41	185.6		197.5		200.3		202	
½ - ¼	12.7 - 6.3	1691.3	33.83	1661.3	34.0	1603	33.4	1575	33.5	1537	33.4
¾ - ½	19.0 - 12.7	1590.4	31.81	1550.5	31.8	1531	31.9	1491	31.8	1479	32.2
1 - ¾	25.4 - 19.0	920.4	18.41	862.9	17.7	846	17.6	818	17.4	775.7	16.9
1½ - 1	38.1 - 25.4	236.9	4.74	234.6	4.8	266	5.5	263	5.6	261.2	5.7
2 - 1½	50.8 - 38.1	159.7	3.19	240.9	5.0	205	4.1	202	4.3	198.4	4.3
2½ - 2	63.0 - 50.8	230.6	4.61	143.3	2.9	142	3.0	141	3.0	140	3.0
Total Weight	- - -	5000		4880.3		4792.3		4692.3		4593	
Loss				119.7		88		100		99.3	
Percentage loss				2.39		1.9		2.1		2.1	
Total loss				119.7		207.7		307.7		407	
Total percentage loss				2.39		4.1		6.1		8.1	

TABLE 2—*continued.*

Abrasion test of 5000 grams of gravel from Napier, weighed and graded every forty-eight hours.

Grades. Inches.	Grades. Mm.	240 hrs.	%	288 hrs.	%	336 hrs.	%	384 hrs.	%
1/20 -	1.18 -	0.1 -		0.13 -		0.12 -		0.10 -	
1/10 - 1/20	2.0 - 1.18	1.1 -	4.7	2.3 -	4.7	1.3 -	5.0	1.20 -	5.2
¼ - 1/10	6 3 - 2.0	209.7 -		204.9 -		212.6 -		221.0 -	
½ - ¼	12.7 - 6.3	1481.4 -	33.1	1468.4 -	33.4	1439.8 -	33.4	1405 -	33.3
¾ - ½	19.0 - 12.7	1407.5 -	31.5	1402.2 -	31.8	1373.7 -	31.95	1340 -	31.7
1 - ¾	25.4 - 19.0	779.4 -	17.4	724.0 -	16.5	703.3 -	16.3	680.5 -	16.1
1½ - 1	38.1 - 25.4	258.4 -	5.7	256.4 -	5.9	254.5 -	5.9	252.3 -	5.9
2 - 1½	50.8 - 38.1	194.3 -	4.3	191.3 -	4.3	188.6 -	4.3	185.5 -	4.4
2½ - 2	63.0 - 50.8	138.6 -	3.1	137.5 -	3.1	136.5 -	3.15	135.2 -	3.2
Total Weight - - -		4470.5		4387.13		4310.42		4220.8	
Loss		122.5		83.37		76.71		89.62	
Percentage loss		2.67		1.86		1.75		2.07	
Total loss		529.5		612.87		689.58		779.20	
Total percentage loss		10.59		12.25		13.79		15.58	

GS.

Table 3.

Napier Shingle.

Sample	Wt Gm.	Grading Inches	Loss of Weight of Gravel in One Hour
P	4,500 500	$1\frac{1}{2}$ – 2 $\frac{1}{8}$ – $\frac{1}{4}$	22 gm.
Q	4,500 500	$\frac{3}{4}$ – 1 $\frac{1}{8}$ – $\frac{1}{10}$	5 gm.
R	4,500 500	$\frac{3}{4}$ – 1 $\frac{1}{10}$ – $\frac{1}{20}$	6 gm.
S	4,500 500	$1\frac{1}{2}$ – 1 $\frac{1}{8}$ – $\frac{1}{10}$	7 gm.

GRADES		SAMPLE "P"		SAMPLE "Q"	SAMPLE "R"	SAMPLE "S"	
Mm.	Inches	1st hr. Wt. Gm.	2nd hr. Wt. Gm.	1 hr. Wt. Gm.	1 hr. Wt. Gm.	1st hr. Wt. Gm.	2nd hr. Wt. Gm.
6·3 - 3·4	$\frac{1}{4}$ - $\frac{1}{8}$	394·6	353·6				
3·4 - 2·0	$\frac{1}{8}$ - $\frac{1}{10}$	22·1	19·63	462·5	...	369·8	298·3
2·0 - 1·8	$\frac{1}{10}$ - $\frac{1}{20}$	11·0	9·37	23·32	446	57·1	60·7
0·84 - 0·59	$\frac{1}{20}$ - $\frac{1}{30}$	1·85	1·48	0·68	6·88	3·35	3·65
0·59 - 0·42	$\frac{1}{30}$ - $\frac{1}{40}$	0·58	0·45	0·11			
0·42 - 0·30	$\frac{1}{40}$ - $\frac{1}{50}$	0·56	0·45	0·08	2·35	2·33	2·05
0·30 - 0·25	$\frac{1}{50}$ - $\frac{1}{60}$	0·37	0·27				
0·25 - 0·18	$\frac{1}{60}$ - $\frac{1}{80}$	0·66	0·55	0·27			
0·18 - 0·15	$\frac{1}{80}$ - $\frac{1}{100}$	0·98	0·97		0·37	0·81	0·61
0·15 - 0·07	$\frac{1}{100}$ - $\frac{1}{200}$	7·12	5·78	0·30	2·12	4·12	4·05
0·07 - 0·04	...	25·15	24·34	1·92	11·53	22·67	24·72
0·04 - 0·01	...	25·85	34·65	4·28	14·74	18·63	35·35

TABLE 4

SAMPLE O.

NAPIER SHINGLE.

Even graded sample from 1½ inches - ⅛inch 38.1 - 3.4m.m.

M.M.	Inches.	Original.	24 hrs.	48 hrs.	72 hrs.	96 hrs.	120 hrs.	144 hrs.
0.84 - 0.04	1/20 - 1/200	0.00	0.45	0.45	0.39	0.46	0.35	0.45
2.0 - 0.84	1/10 - 1/20	0.00	4.9	6.0	6.1	6.8	5.6	6.05
3.4 - 2.0	⅛ - 1/10	0.00	21.4	26.0	29.63	32.45	34.4	34.7
6.3 - 3.4	¼ - ⅛	1000.00	931.0	872.3	821.5	775.9	742.6	707.7
12.7 - 6.3	½ - ¼	1000	996.7	986.7	976	953.3	948.5	930.7
19.0 - 12.7	¾ - ½	1000	1019.6	986.9	971	968.45	959.6	953.6
25.4 - 19.0	1 - ¾	1000	941.2	950.4	935	928.5	916.8	899.8
38.1 - 25.4	1½ - 1	1000	993.5	987.9	981	976.0	959.1	953.4
		5000	4905	4813.65	4720.62	4641.86	4566.95	4486.40
	Loss - - -	- - -	95	92.65	93.03	78.76	75.91	80.55
	Percentage Loss	- - -	1.9	1.9	1.9	1.7	1.6	1.8

GS.

TABLE 5.

ABRASION OF NAPIER SHINGLE.

24 hour runs.

	Inches	Mm.	After 24 hrs.	
				%
Sample F 5000 gms.	2 - 1½	50.8 - 38.1	Loss 299 gm.	6.0
Sample E 5000 gms.	1½ - 1	38.1 . 25.4	Loss 144 gm.	2.9
*Sample G 5000 gms.	1 - ¾	25.4 - 19.0	Loss 91	1.8
Sample D 5000 gms.	¾ - ½	19.0 - 12.7	Loss 61	1.2
Sample C 5000 gms.	½ - ¼	12.7 - 6.3	— 30	0.6
Sample H 5000 gms.	¼ - 1/10	6.3 - 2.0	— 40	0.8
Sample L 5000 gms.	¼ - ⅛	6.3 - 3.4	— 28	0.56
Sample K Original			After 24 hours	
2500	1½ - 2	38.1 - 50.8	Loss 58 gm.	2.3
2500	½ - ¼	12.7 - 6.3	Loss 234	9.4
	1/20 -	0.18 -	Wt. gm. 0.85	7.2
	1/10 - 1/20	2.0 - 0.8	3.2	
	⅛ - 1/10	3.4 - 2.0	8.5	
	¼ - ⅛	6.3 - 3.4	168.5	

* Note on Sample G:

Repeat for 24 hours gave a loss of 72 gms.

> .074	.01 gm.
.074 - .04	0.17 gm.
.04 - .01	7.4 gm.
.01 - .002	32.1
< .002	46.8

Smallest particle formed .0004 mm.

The excess of 14.48 gms. is due to absorptiou of water and to the addition of iron dust from the apparatus.

TABLE 6.

Abrasion Tests. Napier Beach Shingle. Sample N.

4500 gm. ¾″ - 1½″ (3931 gm. 1″ - 1½″, 569 gm. ¾″ - 1″) 500 gm. 1/20″ - 1/8″ (379 gm. 1/10″ - 1/8″, 121 gm. 1/20″ - 1/10″).

Mm.	Inches.	Original.			Abrasion 1 hr.			Abrasion 2 hrs.			Abrasion 3 hrs.		
25.4 - 38.1	1 - 1½	4500 gm.			4491 gm.		Loss 9 gm.	4482 gm.		Loss 9 gm.	4469 gm.		Loss 13 gm.
19.0 - 25.4	¾ - 1												
		No. of Pebbles	Wt. gm.	%	Wt. gm.	%		Wt. gm.	%		Wt. gm.	%	
2.00 - 3.4	1/10 - ⅛	17550 .022 gm.	379	75.8	324.6	72	54.4	268.9	69	55.7	231.6	68	37.3
1.18 - 2 00	1/20 - 1/10	11415 .011	121	24 2	92 1	20.4	28 9	87.4	22.4	4.7	76.7	22.7	10.7
0.59 - 1.18	1/30 - 1/20				4.2	0.93		3.8	0.97		3.4	1.0	
0.42 - 0.59	1/40 - 1/30				1.0			0.75			0.6		
0.28 - 0 42	1/50 - 1/40				0.8			0.55			0.4		
0 25 - 0.28	1/60 - 1/50				0.5			0.3			0.2		
0.19 - 0.25	1/70 - 1/60				0.52	0.83		0 4	0 73		0.3	0.60	
0.17 - 0.19	1/80 - 1/70				0.2			0.2			0.1		
0.14 - 0.17	1/100- 1/80				0 7			0.65			0.4		
0.07 - 0.14	1/200- 1/100				4.0	0.89		3.5	0.89		2.45	0.73	
0.04 - 0.07					22.1	4.9		24.8	6.3		21.8	6.4	
0.01 - 0.04		Not used	in		22.8			31.5			25.6		
- 0.01		subseq	uent c	harge	26.8			27.98			27.8		

TABLE 6—*continued.*

Mm	Inches.	Abrasion 4 hrs.				Abrasion 5 hrs.				Abrasion 6 hrs.			
25.4 - 38.1	1 - 1½	4463 gm.	Loss 6			4457 gm.	Loss 6			4449 gm.	Loss 8		
19.0 - 25.4	¾ - 1												
		Wt. gm.	%		No. of Pebbles.	Wt. gm.	%		No. of Pebbles	Wt. gm.	%		No. of Pebbles
2.00 - 3.4	1/10 - ⅛	201 8	69.7	29.8	8530 .024 g.	171.9	68	29.9	7456 .023 g.	154	69.4	17.9	6442 .0238 g.
1.18 - 2.00	1/20 - 1/10	63.1	21.8	13.6	7510 .008 g.	59.9	23.8	3.2	10150 .0059 g.	53	23.9	6.9	6321 .0084 g.
0.59 - 1.18	1/30 - 1/20	2.95	1.0			2.3	0.9			2.03	0.91		
0.42 - 0.59	1/40 - 1/30	0.55	0.62			0.4	0.54			0.35	0 52		
0.28 - 0.42	1/50 - 1/40	0.35				0.3				0.27			
0.25 - 0.28	1/60 - 1/50	0.20				0.18				0.13			
0.19 - 0.25	1/70 - 1/60	0.25				0.17				0.15			
0.17 - 0.19	1/80 - 1/70	0.15				0.10				0.05			
0.14 - 0.17	1/100- 1/80	0.30				0.30				0.21			
0.07 - 0.14	1/200- 1/100	1.70	0.6			1.20	0.5			1.23	0.55		
0.04 - 0.07		19.0	6.6			15.5	6.1			10.52	4.7		
0.01 - 0.04		20.25				21.6				15 59			
- 0.01		26.00				16 6				13.65			

GS.

TABLE 6—*continued.*

Mm.	Inches.	Abrasion 7 hrs.				Abrasion 9 hrs. (2 hr. period)				Abrasion 10 hrs.			
25.4 - 38.1	1 - 1½	4443 gm.		Loss 6		4426.3 gm.		Loss 17		4418.5 gm.		Loss 8	
19.0 - 25.4	¾ - 1												
		Wt. gm.	%		No. of Pebbles.	Wt. gm.	%		No. of Pebbles.	Wt. gm.	%		No. of Pebbles
2.00 - 3.4	1/10 - ⅛	140.29	71.5	13 71	6738 .0208	104.4	69.8	35.89	4435 .0235	93.98	70.3	10.57	4000 23.325
1.18 - 2.00	1/20 - 1/10	44.05	22.5	8.95	7437 .0089	35.0	23.4	9.05	4923 .0071	31.50	23.4	4.5	3840 .0082
0.59 - 1.18	1/20 - 1/20	1.70	0.87			1 435	0.96			1.12	0.84		
0.42 - 0.59	1/30 - 1/20	0.22				0.264				0.195			
0.28 - 0.42	1/40 - 1/30	0.18				0.165				0.100			
0.25 - 0.28	1/50 - 1/40	0.09	0.44			0.072	0.47			0.052	0.36		
0.19 - 0.25	1/60 - 1/50	0.10				0.084				0.059			
0.17 - 0.19	1/70 - 1/60	0.04				0.014				0.010			
0.14 - 0.17	1/80 - 1/70	0.13				0.115				0.070			
0.07 - 0.14	1/100- 1/80	0.85	0.43			0.809	0.54			0.520	0.39		
0.04 - 0.07	1/200- 1/100	8.12	4.1			7.209	4.9			5.93	4.4		
0.01 - 0.04		14.62				24.94				9.48			
- 0.01		13.80				21.26				15.80			

TABLE 6—*continued.*

Mm.	Inches.	Abrasion 11 hrs. (1 hr. without water)				Abrasion 12 hrs.				Abrasion 13 hrs.			
25.4 - 38.1	1 - 1½	4421 gm.*	Loss			4411 gm.	Loss			4403 gm.	Loss 8		
19.0 - 25.4	¾ - 1												
		Wt. gm.	%		No. of Pebbles.	Wt. gm.	%		No. of Pebbles (and wt.)	Wt. gm.	%		No. and wt. of Pebb'es.
2.00 - 3.4	1/10 - 1/8	65.1	68.5	28.08	2770 .0235	59.83	70.1	5.27	2495 .024	53.4	72.4	6 4	2240 .0238
1.18 - 2.00	1/20 - 1/10	18.8	19.5	12.70	3631 .0052	19.50	22.8	+0.7	2849 .0069	15.95	21.6	3.6	2205 0072
0.59 - 0.18	1/30 - 1/20	1.357	1.43			0.82	0.86			0.50	0.68		
0.42 - 0.59	1/40 - 1/30	0.305				0.11							
0.28 - 0.42	1/50 - 1/40	0.250				0.07							
0.25 - 0.28	1/60 - 1/50	0.277	2.02			0 06	0.42			0.34	0.46		
0.19 . 0 25	1/70 - 1/60	0.435				0.045							
0.17 - 0.19	1/80 - 1/70	0.127				0.015							
0.14 - 0 17	1/100- 1/80	0.530				0.065							
0.07 - 0.14	1/200- 1/100	1.900	2.00			0.39	0.45			0.49	0.66		
0.04 - 0.07		5.500	5.8			4.43	5.20			2 89	3.92		
0.01 - 0.04		6.68				9.04				7.90			
- 0.01		32.0	*Adherent fine matter			9.646				11.66			

TABLE 6—*continued.*

Mm.	Inches.	Abrasion 14 hrs.				Abrasion 15 hrs.					
25.4 - 38.1	1 - 1½	4397 gm.		Loss 6		4391 gm.		Loss 6		Total Loss 109	% 2.18
19.0 - 25.4	¾ - 1										
		Wt. gm.	%		No. and Wt. of Pebbles.	Wt. gm.	%		No. and Wt. of Pebbles.		
2.00 - 3.4	1/10 - 1/8	48.0	73.0	6.4	2002 .024	44.5	75.7	3.5	1868 .0238	334.5	88.5
1.18 - 2.00	1/20 - 1/10	14.22	21.7	1.73	1850 .0071	11.53	19.6	2 69	1507 .0076	109 46	90 8
0.59 - 1.18	1/30 - 1/20	0.52	0.78			0.33	0.56				
0.42 - 0 59	1/40 - 1/30										
0.28 - 0.42	1/50 - 1/40										
0.25 - 0.28	1/60 - 1/50	0.34	0.52			0.16	0.25				
0.19 - 0.25	1/70 - 1/60										
0.17 - 0.19	1/80 - 1/70										
0.14 - 0 17	1/100- 1/80										
0.07 - 0.14	1/200- 1/100	0.29	0.43			0.23	0.39				
0.04 - 0 07		2.33	3.52			2.20	3.75				
0.01 - 0.04		4 89				5.09					
- 0 01		3.17				1.66					

GS.

Table 7.

Sample J_2 Napier Shingle.

4500 grm. 1 in. - 1½ in. (2.54 - 3.81 mm.)
500 grm. quartz-sand from Dunedin graded 1/60 in. - 1/70 in. (0.245 - 0.192 mm.)

Treated for one hour.

Gravel 4485.4 gm. Loss 14.6 or 2.9 %

Inches	Mm.	Weight
Sand 1/40 - 1/80	0.42 - 0.18	0.4 gm.
1/80 - 1/100	0.18 - 0.15	4.0
1/100 - 1/200	0.15 - 0.07	142.0
	0.07 - 0.04	211.0
	0.04 - -	143.0

Treated for an additional half-hour with exception of material finer than 0.04 mm.
Gravel 4476 gm. Loss 9.4 gm.

Inches.	Mm.	Weight
Sand - 1/100	- - 0.15	0.07
1/100 - 1/200	0.15 - 0.07	26.0
	0.07 - 0.04	241.0
	0.04 - 0.01	55.3
	0.01 - .	34.0

Table 8.

Sample of Wangaehu gravel (Andesite).

Mm.	Inches	Original	After 24 hrs.
38.1 - 25.4	1½ - 1	1000	777.5
25.4 - 19.0	1 - ¾	1000	1066
19.0 - 12.7	¾ - ½	1000	864.5
12.7 - 6.3	½ - ¼	1000	878
6.3 - 3.4	¼ - ⅛	1000	515
3.4 - 2.0	⅛ - 1/10		59.66
2.0 - 1.18	1/10 - 1/20		14.98
1.18 - 0.59	1/20 - 1/30		1.50
0.59 - 0.42	1/30 - 1/40		0.38
0.42 - 0.28	1/40 - 1/50		0.27
0.28 - 0.25	1/50 - 1/60		0.18
0.25 - 0.19	1/60 - 1/80		0.27
0.19 - 0.17	1/80 - 1/100		0.37
0.17 - 0.07	1/100 - 1/200		0.97
0.07 - 0.04	1/200 - -		4.16
0.04 - -			816.6