LABORATORY ABRASION OF GREY FLINTS, RECHARGE MATERIAL, SHINGLE-SAND AND SHINGLE-GRAVEL MIXTURES

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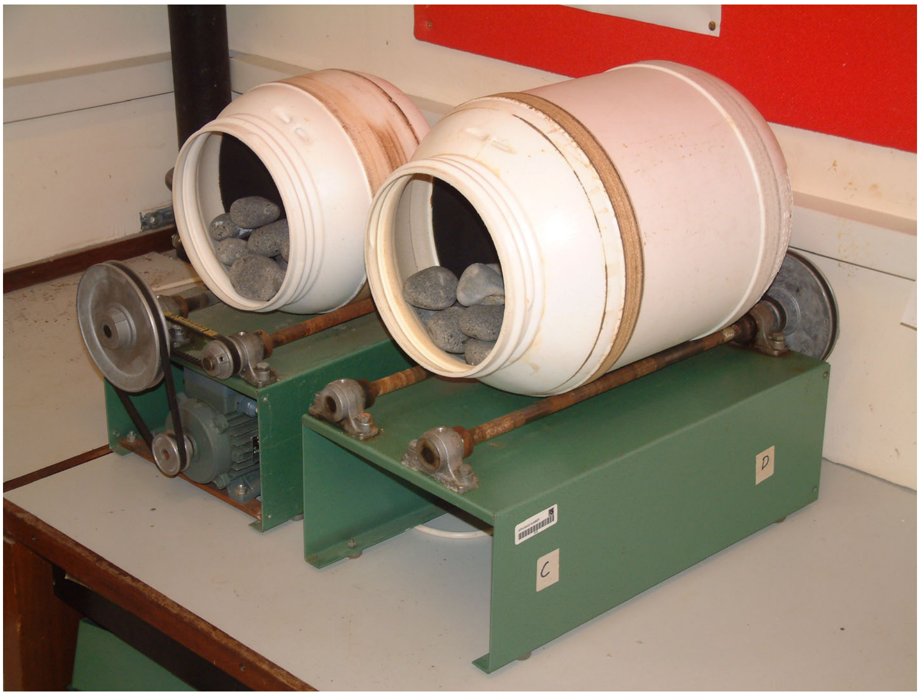


1 Aim

The aim of this work is two-fold:

- to assess the extent to which grey/black flint pebble abrasion rates are controlled by flint type, pebble weight, pebble shape and surface textural characteristics.
- to measure abrasion rates of beach recharge materials, comparing abrasion rates for sand-shingle and gravel-shingle mixtures with those of pure grey flint shingle.

2 Introduction

Pioneering laboratory abrasion experiments conducted during the Interreg II funded project BERM (Beach Erosion in the Rives Manche), provided the first published measurements of grey/black flint shingle pebble abrasion rates (Dornbusch et al., 2004). These baseline data, when combined with long term field experiments, have been used to provide estimates of beach volume losses due to *in situ* shingle pebble abrasion (Dornbusch et al., 2003; Dornbusch et al., 2002).

Now that flint shingle abrasion rates are established, the BAR project is refining these early experiments in order to investigate the key factors that control the rate of abrasion. For example, the BERM experiments showed that the abrasion rate is controlled by the weight, and therefore size, of individual pebbles (because changes in weight can be measured more accurately than changes in size, pebbles are selected according to weight and changes measured as weight changes). The experiments were conducted on pure flint shingle pebbles with no sand or gravel present in the laboratory tumbler. During Phase I of BAR these experimental results have been interrogated in order to identify key aspects that require further investigation. These include:

- Abrasion of grey flint shingle pebbles recently supplied from cliffs and shore platform in comparison to that of flint from the seabed used in beach recharge schemes.
- Abrasion of pure flint shingle pebbles from different positions on the beach and collected at different times.
- Abrasion of pure flint shingle pebbles in comparison to that of sand-shingle and gravel-shingle mixes in order to assess the impact of beach recharge materials on flint shingle beach abrasion.
- Measuring of pebble shapes to elucidate large variation in the abrasion rate of individual pebbles.

Experiments to assess the influence of the location on the beach have been carried out. These experiments were also used to compare how the new tumbling barrels performed in comparison with those used during the BERM experiments where average abrasion rates for different size ranges were established. Experiments involving flints from recharge material have so far only focussed on the size range 150-250g, which has also been used for the experiments using mixtures of shingle with sand or gravel.

Between BERM and BAR the tumbling barrels have been changed. This was necessary, because the hexagonal, rubber lines metal barrels used in BERM were difficult to close and corroded so that they required a large amount of maintenance. The new barrels are made of rubber lined plastic with one simple screw-on lid which has reduced maintenance dramatically. A choice of different barrels sizes allowed the selection of a significantly larger barrel than used for BERM. Because the inter-sample variation in the abrasion rate is high, larger numbers of pebbles in one sample will provide a more stable average abrasion rate for each sample. The increased volume of each sample also means that fewer barrels have to be tumbled thus reducing the possible influence the barrel or the tumbling apparatus may have on the abrasion rate. For the size range 150 to 250g the average number of pebbles in the BERM tumblers was 24 compared to 97 in the BAR tumblers (for the size 250 to 350g, 17 compared to 64).

3 Methodology

The methodology employed is detailed in a work protocol (2004-07-12- Protocol lab abrasion of shingle mixtures.doc). The main points to note are that pebble handling (weighing, tumbling and drying) are carried out according to a strict schedule and that the selection of samples follows clear rules. This means that the pebbles used for the tumbling experiments are always a sub-sample of the much larger sample taken from the beach. The pebbles used in individual tumbler barrels are selected according to the protocol shown in Figure 1.

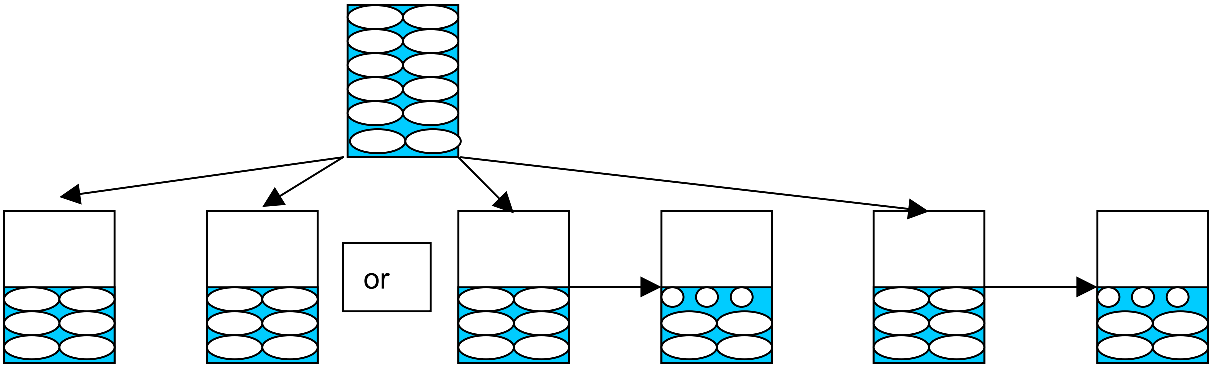


Figure 1: Schematic diagram showing how tumbling samples are created.

Initially, one tumbler barrel is filled with pebbles and the interstices filled with reconstituted seawater (for the size range 150 to 250g, this takes approximately 97 pebbles and 5.6 litres of water). The barrel contents are then evenly divided in two and placed in separate barrels that are the same size as the original (as shown on the the two left hand diagrams). For the purposes of these experiments, this state of being half full is referred to as ‘100% filled with shingle’. In experiments involving shingle mixtures (shown on the right hand), a percentage (20 or 30% of the 100%) of pebbles is removed and replaced with sand or gravel resulting in 30/70% or 20/80% mixes.

After selection, the pebbles are dried for 24 hours at 50°C and weighed to three decimal places (balance error ± 0.002g). They are than placed into the barrel together with the reconstituted seawater and left for 24 hours. During the last 2.5 hours they are tumbled at an average of 21.3 revolutions per minute. The barrel content is drained trough a sieve and the pebbles retained are again dried for 24 hours at 50°C prior to weighing. Each sample is tumbled three times so that three rates of abrasion are determined. For comparing samples, the abrasion rate for the first 2.5 hour tumbling interval is used.

4 Results

4.1 Factors influencing abrasion rates

Samples for BERM experiments were collected predominantly from the beach at Telscombe as this beach was also used for field abrasion experiments. In anticipation of the requirement for larger numbers of pebbles for the BAR experiments, the beach at Telscombe proved to be too difficult to access (long distance between beach and vehicle including steps). The beach at Newhaven provides much better access and different sources with respect to the location on the beach. The beach features a very large backshore area from which material could be easily obtained but the pebbles in this area are unlikely to have been affected by waves for a few decades and therefore may abrade differently from those on the active shore face. The BAR experiments would also necessitate that samples be collected at different times of the year because it is impossible to collect all the material that might be used over a two year period from one location during one day (not enough pebbles of the same size and shape available + storage problems at the University). It was therefore necessary to assess the influence of the position on the beach (backshore or foreshore[1]) and the season of collection on abrasion rates. Theoretically, weathering or the abrasion from people walking over the beach would have a larger impact on pebbles in the backshore area and might lead to different rates of abrasion. Equally, different wave environments in summer and winter may change the rate of abrasion under standardised laboratory conditions.

Because previous experiments involved abrasion rate measurements on beaches in France (Criel and Etretat) a comprehensive set of samples was collected from Criel which had previously shown abrasion rates comparable to those at Telscombe. However, wave climate and geology differ due the different orientation of the French coastline and lateral variation of the Chalk.

A total of twenty one barrels were tumbled for these experiments. Rounded grey flints were collected from

- the foreshore at Telscombe in August 2003
- two backshore locations at Newhaven in August 2003
- foreshore locations at Criel in December 2001 and foreshore and backshore in September 2003.

The chalk cliffs behind the beach at Telscombe consist of Newhaven Chalk (Old Nore beds are at the bottom of the cliff) and are upper Santonian to Lower Campanian in age. The chalk cliffs behind Newhaven west beach consist of both upper Newhaven Chalk and lower Culver Chalk and are Campanian in age. The chalk cliffs at Criel are middle to upper Santonian in age.

[1] Foreshore in the context of this report refers to the part of the beach that is undergoing change from waves.

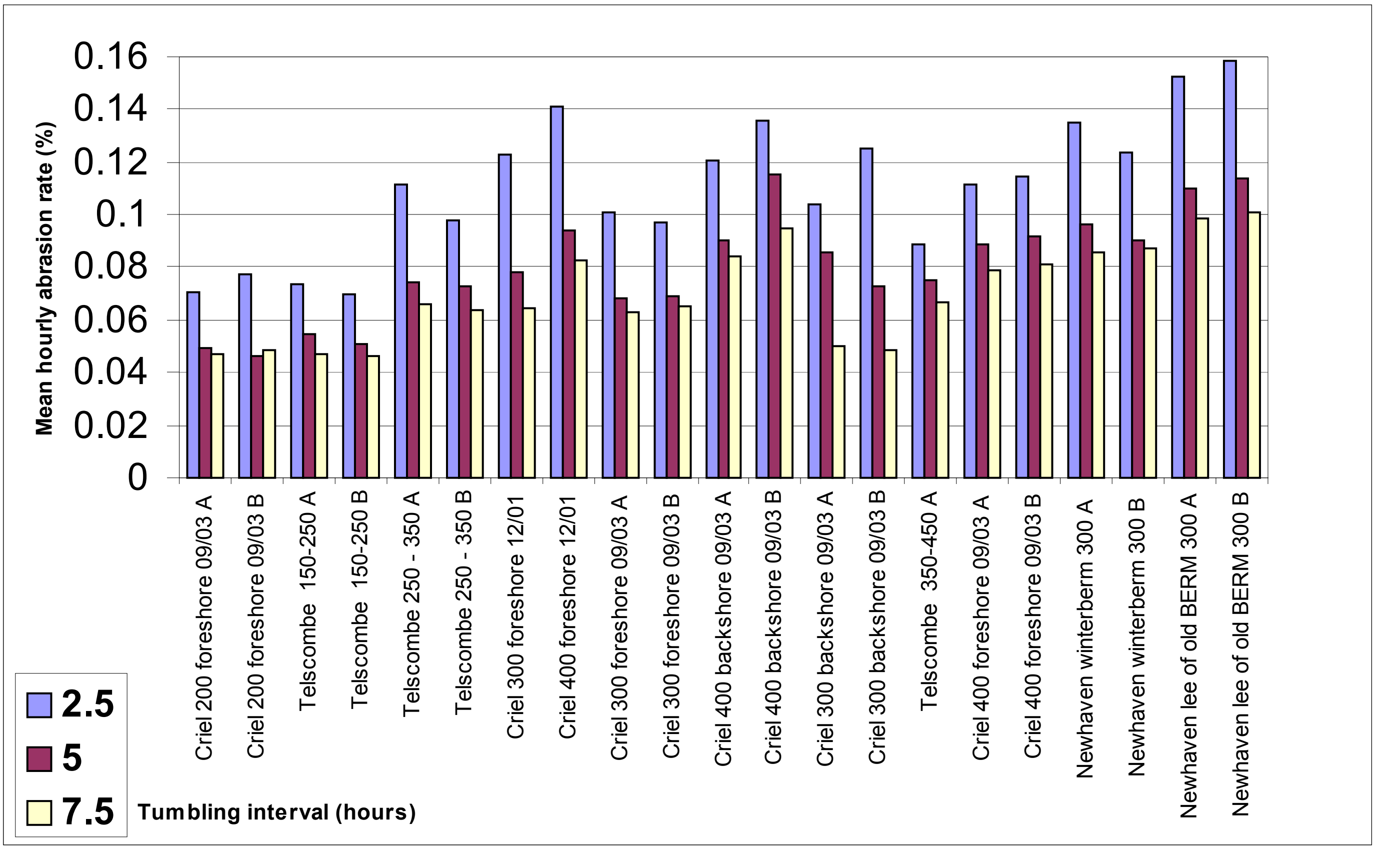


Figure 2: Abrasion rates for all samples over three tumbling intervals of 2.5 hours each.

Abrasion rates are given as the percentage weight loss per hour (Figure 2). In actual weight loss this is equivalent to values from ~0.1 g to almost 2 g per pebble, depending upon pebble size, during a 2.5 hour tumbling interval.

All samples show the decrease of the abrasion rate with time that was found in previous experiments. There is also a difference in the abrasion rate for sample pairs (A and B) that is consistent throughout the 3 tumbling intervals. Nevertheless, since the revolution rate of the tumblers is consistently different by ~1.2 revolution/minute (at a mean rate of the two tumblers of 21.3 revolutions/minute) barrels were swapped over 3 times during the 2.5 hour tumble for the last 6 samples in Figure 1. This does not seem to have changed the difference between the sample pairs (Figure 3). The difference between the paired samples appears to be randomly distributed so that factors associated with the barrels or tumblers do not seem to have any influence.

Figure 4 shows that the weight/abrasion rate relationship found in previous studies holds only partially if all samples are considered. The samples with a mean weight of 200g abrade at a consistently lower rate than the heavier ones but there does not seem to be an obvious difference in the abrasion rate between the 300 and 400g samples. However, if only samples from the same beach are analysed (Figure 4b) the relationship between size and abrasion rate shows up clearly again. This indicates that factors other than size have a significant impact on the abrasion rate.

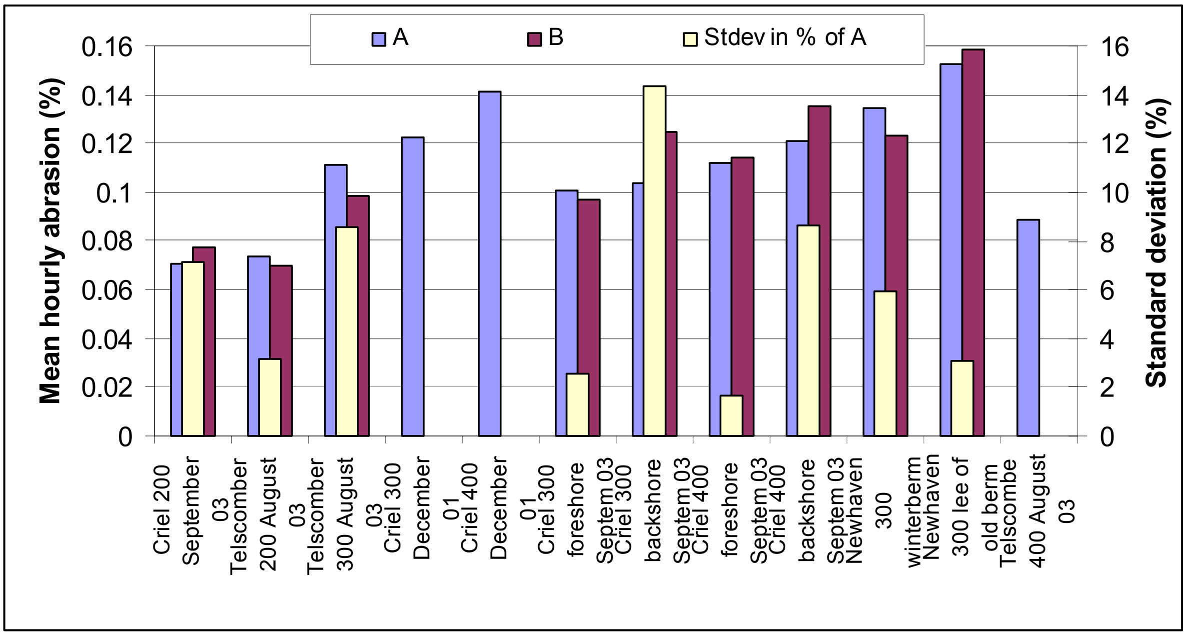
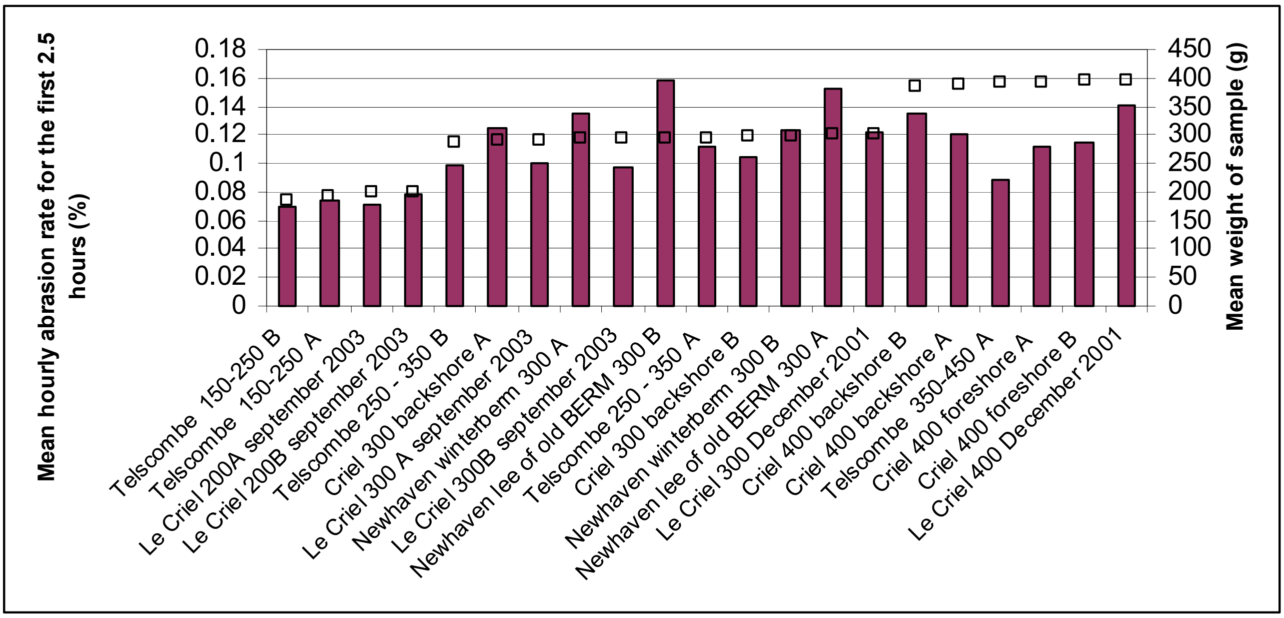


Figure 3: Abrasion rates for all samples during the first 2.5 hour interval together with the standard deviation between the paired samples in %.



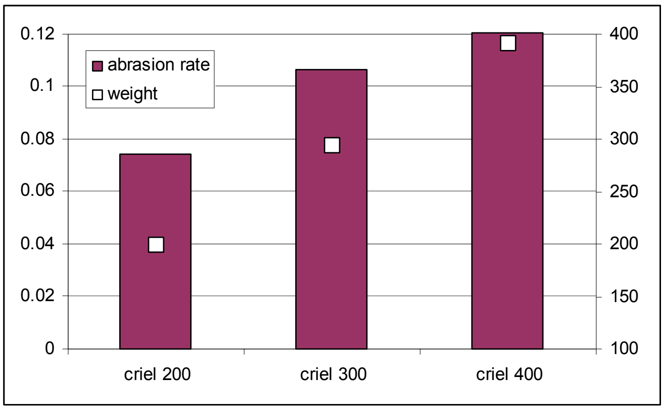
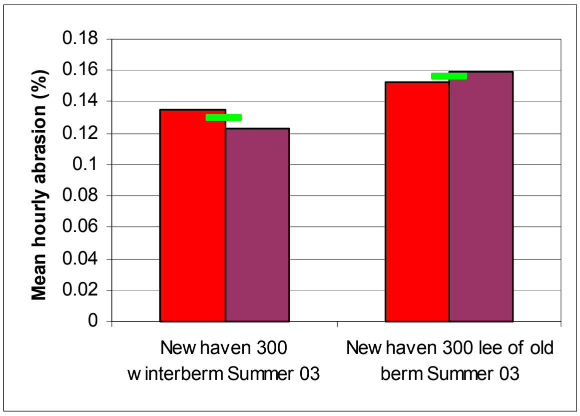


Figure 4: Comparison of the mean hourly abrasion rate for the first 2.5 hour interval (columns) and the average weight of the sample (squares). A) (above) all samples. B) (below) only samples from Criel collected September 2003 (foreshore and backshore).

4.1.1 Location

The location on the beach from which samples were collected for use in the laboratory experiments may have influenced results if the pebbles were to exhibit different surface textural characteristics. For example, pebbles on the storm berm or at the back of the beach may exhibit more brittle surfaces, or a greater development of surface chattermarks, because of the high wave energies that they have experienced in comparison to pebbles further down the beach. Alternatively, they may experience lower abrasion rates because they are less chattermarked or have lost some of the brittle surface due to the fact that they are not constantly battered, unlike pebbles in the surf zone for example. Similarly, their removal from the active surf zone may mean that they are affected by weathering processes which may also alter the surface texture possibly making it smoother. Trampling by people may also provide a gentle form of abrasion that could reduce the thickness of the brittle surface, equivalent to some time spent in the tumbler.

These differences were tested on flint pebbles collected from the beaches at Criel and Newhaven. At Newhaven samples of the same size were collected in the summer of 2003 from the position of the previous winter's storm berm and from a position landward of the last storm berm (Figure 5), i.e. from a position that has been out of the abrasion influence of the sea for several decades but which is heavily subjected to passage of people.



A) B)

Figure 5:

A) Approximate location of samples.

B) Comparison of the abrasion rate for the first 2.5 hour tumbling interval of the A and B sample (columns) and the average of the two barrels (green bars) for samples from Newhaven.

The abrasion rate for the samples from further back on the beach is 20% higher.

At Criel samples of all three weight groups were collected from the active foreshore and the flat backshore area just to the west of the eastern terminal groyne. Public access here is likely to be limited but there is no information as to whether the flat back beach area has been smoothed by bulldozers.

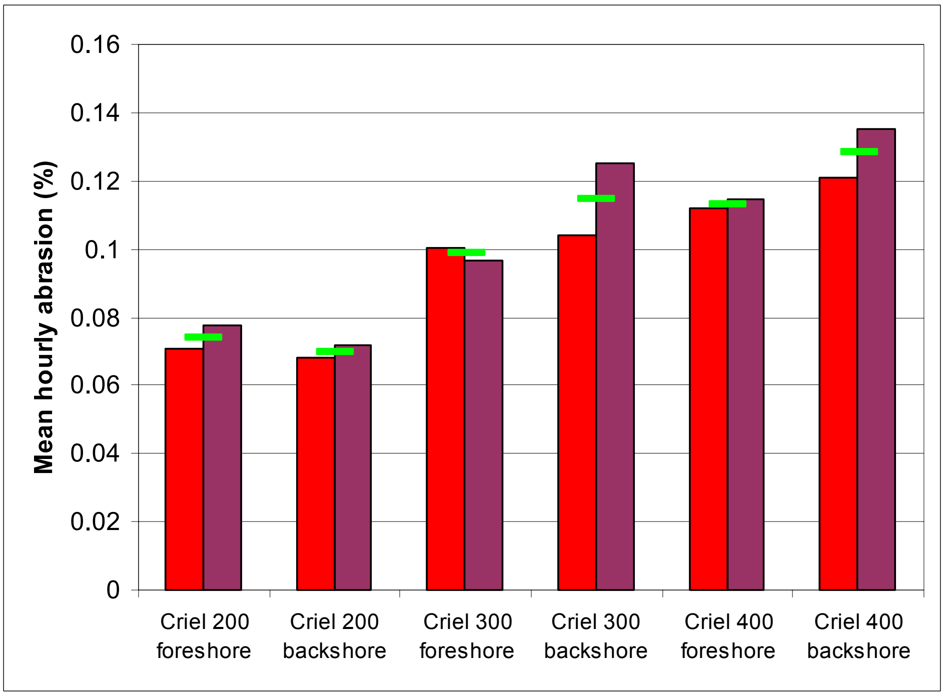


Figure 6: Comparison of the abrasion rate for the first 2.5 hour tumbling interval of the A and B sample (columns) and the average of the two barrels (green bars) for samples from Criel collected in September 2003.

The results are not consistent in that for the size classes 300 and 400g the averaged abrasion of the backshore samples is higher while for the size class 200g it is smaller (Figure 6). It would appear that location on the beach does have some influence on the abrasion rate. One explanation for this may be a link between the brittleness of the surface and the energy conditions to which they have been subject. However, this surface must have a considerable thickness as the difference in the abrasion rate persists even after the third tumbling interval (Figure 2). Also this effect seems to survive several years of subaerial exposure as is the case at Newhaven.

As a consequence of these results all experiments involving shingle mixes use shingle pebbles collected from the same source and involve two barrels filled with 100% shingle as controls.

4.1.2 Shape

Though the above comparisons show that abrasion rates can vary significantly between the average of whole samples (inter-sample variability), previous experiments have drawn attention to the fact that the abrasion of individual pebbles in one sample can vary considerably (Figure 7). The standard deviation of the individual abrasion rates (intra-sample variation) averaged over all 21 samples (see 4.1.1, Figure 2) is 24%, ranging from 16% to 55%; the maximum difference is considerably higher.

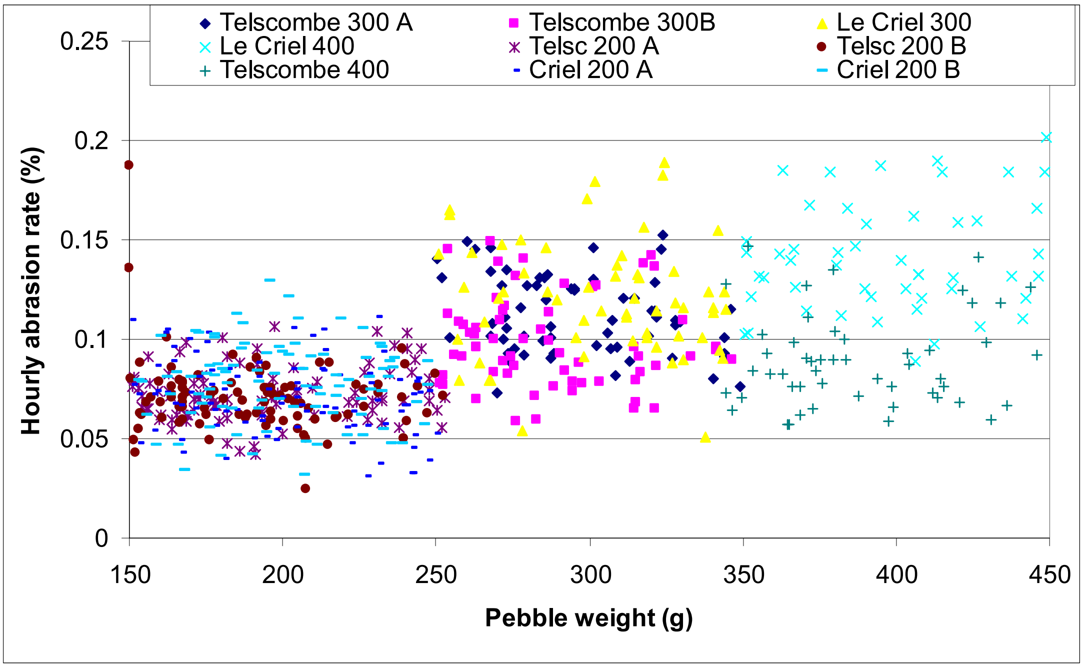


Figure 7: Abrasion rates of individual pebbles from the same sample plotted against the individual pebble weights.

To assess what might be causing this variation all three pebble axis have been measured for 227 pebbles from the paired samples of the Criel backshore samples in the size range 250 to 350 (2x64 pebbles) and 350 to 450 (49 and 50 pebbles). Correlation analysis shows the following results (Figure 8).

Pearson		ABRA-SION	WEIGHT	A	B	C	b/a	c/b	c/a	KRUMBEIN	zing number
Correla-tion	ABRASION	1.000	.267	.022	.253	.133	.162	-.053	.075	.126	.060
	WEIGHT	.267	1.000	.363	.654	.472	.213	-.050	.133	.188	-.029
	A	.022	.363	1.000	-.069	-.341	-.699	-.247	-.744	-.809	.297
	B	.253	.654	-.069	1.000	.198	.751	-.529	.165	.468	.238
	C	.133	.472	-.341	.198	1.000	.360	.719	.872	.722	-.599
	b/a	.162	.213	-.699	.751	.360	1.000	-.218	.611	.868	-.026
	c/b	-.053	-.050	-.247	-.529	.719	-.218	1.000	.632	.291	-.655
	c/a	.075	.133	-.744	.165	.872	.611	.632	1.000	.922	-.570
	KRUMBEIN	.126	.188	-.809	.468	.722	.868	.291	.922	1.000	-.380
	zing number	.060	-.029	.297	.238	-.599	-.026	-.655	-.570	-.380	1.000

Figure 8: Correlation analysis for 227 pebbles of two different size classes.

The highest correlation exists between the abrasion rate and the pebbles' weight. However, plotting both against each other does not show a convincing correlation (Figure 9). None of the pebble shape factors has any significant correlation with the abrasion rate. This holds also true when the analysis is carried out for individual barrels. It is probable that factors other than shape, such as flint geological and surface textural properties, have significant influences on the rate of abrasion.

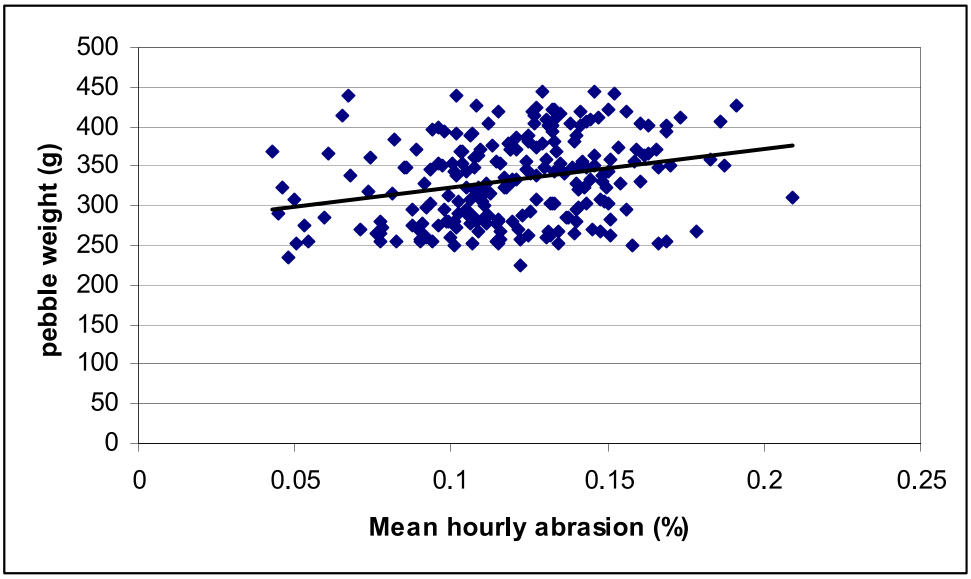


Figure 9: Scatter plot of individual pebble weights and abrasion rates together with a linear regression curve.

4.1.3 Season

Seasonal changes in wave climate may change the abrasion rate for samples collected from the same position on the beach. Alternatively, longshore transport can lead to a different population of beach material being in the same position at different sample times. The comparison between samples collected from the foreshore at Criel in December 2001 and September 2003 seem to indicate that the earlier samples abrade at a higher rate (Figure 10).

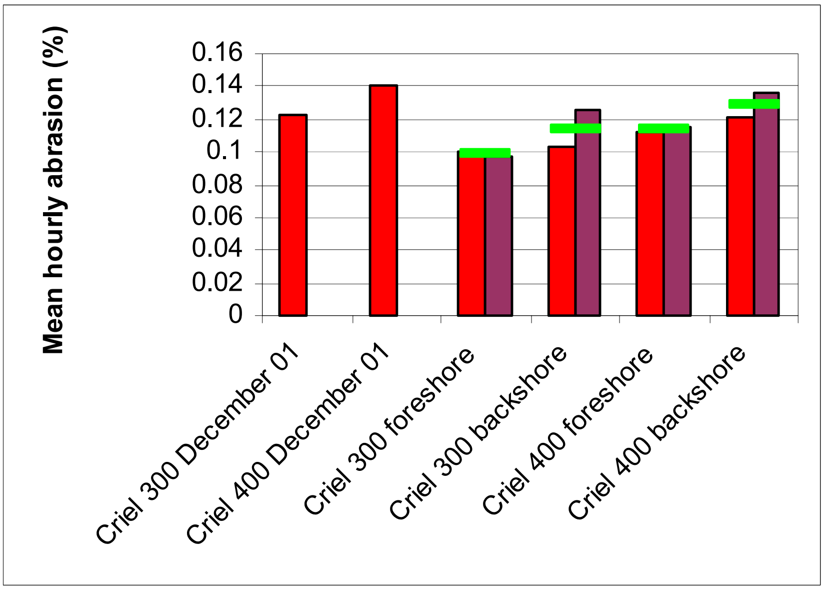


Figure 10: Comparison of the abrasion rate for the first 2.5 hour tumbling interval of the A and B samples (columns, only one sample each for December 2001) and the average of the two barrels (green bars) for samples from Criel collected in December 2001 and September 2003.

4.1.4 Discussion

The present data show that the abrasion rate of whole samples depends on the average weight of the sample (thus confirming previous results) and the location from which it was collected, i.e. which beach + location on that beach. Samples taken from the same position on a beach but at different times also seem to differ in their abrasion rates possibly due to differences in the wave energy experienced by the pebbles prior to collection or by the fact that a different population was sampled (longshore transport may replace one type of shingle with another).

It is therefore essential, that the experiments to compare pure shingle with shingle and sand/gravel mixes use shingle collected from one population.

The large variations in the abrasion rate of individual pebbles within one sample still eludes an explanation as factors like weight or shape show only weak correlations with the abrasion rate and in combination do not increase the predictability of the abrasion rate.

4.2 Abrasion of recharge material

Recharge material was collected in July 2004 from the Sovereign Harbour end of Pevensey Bay. It was originally dredged from the Hastings Bank. From the mix of shingle, gravel and sand in the recharge material, only pebbles in the size range of 150-250g were selected to match the size and shape of the grey flint used in previous experiments. Altogether four samples (barrels) of the recharge material have been tumbled.

Comparing the abrasion rates with those of the same sized material from both Criel and Telscombe (Figure 11) shows that the abrasion rate for the first 2.5 hours is very similar (averages for Criel = 0.072, Telscombe = 0.071, recharge = 0.075). However, the rate at 7.5 hours appears to be slightly lower than that for Telscombe. Although the highest rate for one sample comes from the recharge material, so does the lowest. It therefore appears, from this preliminary experiment, that the difference in abrasion rate of similar sized pebbles of geologically recent dark grey flints and those extracted from the sea bed for the use of beach recharge is very small. More detailed experiments will be conducted to further investigate this preliminary finding.

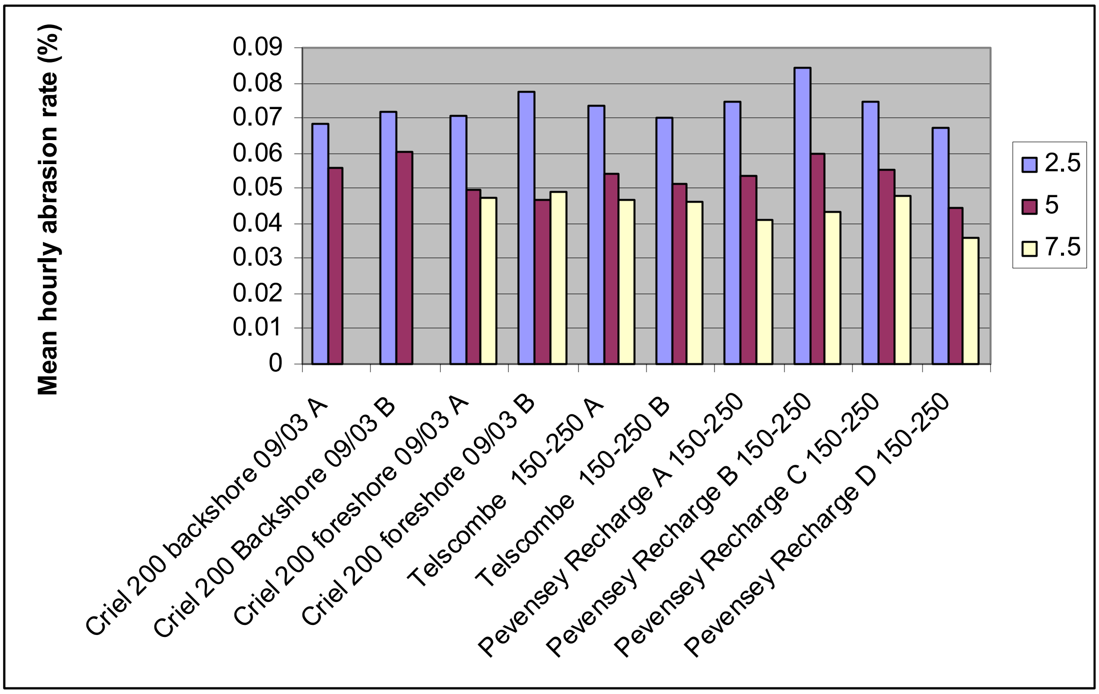


Figure 11: Comparison of mean hourly abrasion rates of grey and recharge flints of the same size.

4.3 Abrasion of shingle-sand mixtures

To assess the influence of sand on the abrasion of grey flint shingle six samples (barrels) were prepared. The sand and gravel used in the experiments were sieved from the recharge material collected from Pevensey Bay. The grey flint shingle pebbles used were from Newhaven. In all barrels the water content remained the same but the amount of shingle and the admixture was changed. Two samples (100%a and 100%b in Figure 12) were control samples where the barrel was filled in the same way as the standard procedure, i.e. half the barrel was filled with shingle and the interstitial space filled with water. Sample 80%c contained only 80% of the shingle of the control samples and 60%f only 60 %. These reduced fillings were used to establish the effect a reduced shingle load on its own has on the abrasion rate and as such to confirm or contrast preliminary results from BERM experiments. If for example a reduction in the shingle load only would lead to a reduction in the abrasion rate a reduction in the abrasion rate by replacing shingle with sand would be more difficult to be attributed to the influence of the sand. Samples D and E contained 80% flint shingle as sample C but also 20% of sand (0.5 to 2mm). The amount of 20% sand was selected as this a common amount of sand within beaches along the BAR coast, as has been found by the project’s analysis of beach sediment.

Results are shown in Figure 12. The main findings are that a reduction of the shingle load (comparison of C and F with A and B) is associated with an increase in the abrasion rate (supporting preliminary results obtained during the BERM project), and that the addition of sand reduces the abrasion rate significantly (>50%). The presence of sand seems also to halt abrasion rates at a low level much earlier (after 5 hours) than for samples with shingle only. In the case of the latter, the decline in abrasion rate continues for many more hours whilst for the former it seems to remain relatively constant from the second tumbling interval onwards.

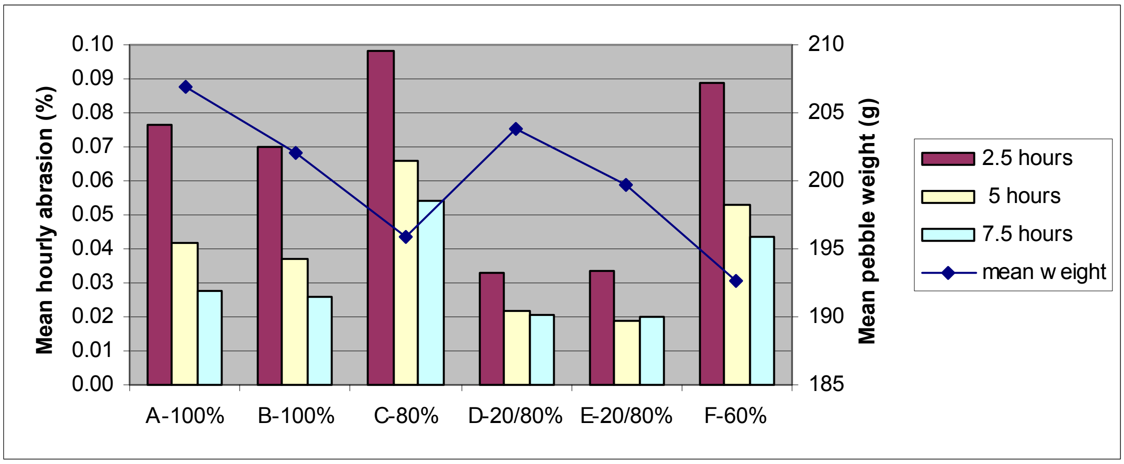


Figure 12: Mean hourly abrasion rates and average sample weights for grey flints from Newhaven. Labels on the x-axis reflect the composition of the sample with 100% indicating that all the sample was flint, 80% and 60% that 80 and 60% of the sample were flint and 20/80 that 80% was flint shingle and 20% was sand (0.5 – 2 mm).

4.4 Abrasion of shingle-gravel mixtures

The influence of gravel was investigated using six samples (barrels) of flint shingle from Newhaven with a weight range of 150 to 250g. Barrels A and B are the control with 100% shingle, barrels C and D contain 30% gravel (4 – 8 mm) and 70% shingle and barrels E and F 20% gravel and 80% shingle (Figure 13).

The addition 20 and 30% gravel reflects the range of gravel found within beaches along the BAR coast, as has been found by the project's analysis of beach sediment.

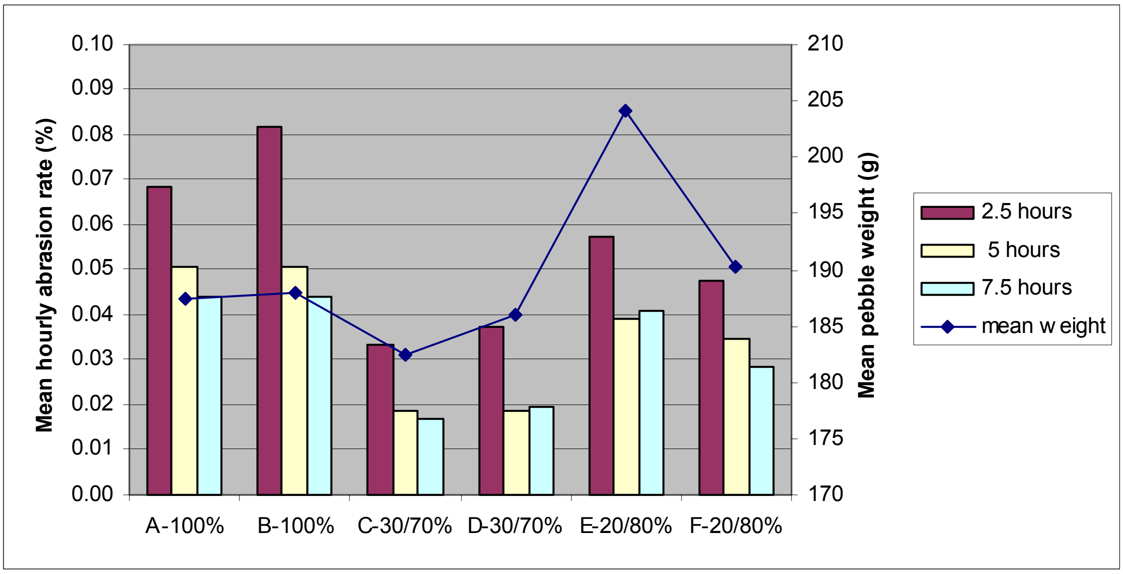


Figure 13: Mean hourly abrasion rates and average sample weights for shingle and shingle-gravel mixes.

The results are very similar to those from the shingle-sand mixture experiment. The addition of gravel reduces the abrasion rate of flint shingle significantly. The addition of 20% gravel leads to a 30% reduction in the abrasion rate and the addition of 30% to a reduction of 50%. Similar to the results for sand, the difference in the abrasion rate for the mixtures between the second an third tumbling interval seems to be much smaller than for the pure shingle samples.

4.4 Discussion

The results of the laboratory abrasion experiments carried out in BAR phase I appear to provide good news for the coastal manager. Firstly, flint pebbles from recharge material appear to abrade at similar rates to those of grey flint pebbles and secondly, tumbling grey flint pebbles in more ‘beach-like’ mixes with sand and gravel records lower abrasion rates. It is therefore likely that field rates of abrasion are lower than those measured only flint shingle in the laboratory.

However, little knowledge exists of the material mix on the beach foreshore that is regularly moved by wave action. Although the bulk beach usually contains ~20-30% sand and similar amounts of gravel, the surface layer is often highly sorted so that sand is absent and it is composed of pebbles of a narrow size range. Whether this sorting takes place and is maintained whilst the waves move over the beach or whether it is only produced by the last waves during the receding tide is largely unknown. It is possible, therefore, that the field abrasion rates might be somewhere between that of pure shingle and sand-shingle mixes in the laboratory.

The mechanism that leads to the reduction of the abrasion rate by adding smaller particles is at the moment unknown. It could be due to either a ‘ball-bearing’ effect of the smaller particles or by actually restricting the movement of the pebbles by forming a matrix between them. This could only be clarified by observing pebble movement inside the barrels during tumbling.

5 Outlook for BAR phase II

Experiments using smaller amounts of sand or gravel need to be carried out to find out at which point (at which percentage of sand / gravel) abrasion rate slows down, eg samples could be run with 5 and 10% sand /gravel content.

These experiments should be combined with observations of the processes inside the barrels that will help in understating the mechanism through which the reduction in the abrasion rate is achieved.

To measure the abrasion rate under even more realistic conditions shingle needs to be tumbled with a combined mixture of sand and grave to assess the combined influence of a more complex mixture.

The preliminary experiments conducted during BAR Phase I have identified two areas that require further examination:

Investigating the influence of sediment mixtures over a wider range mixing ratios

Experiments using lower amounts of sand or gravel need to be carried out to investigate the point at which (i.e. the percentage of sand / gravel) abrasion rate slows down, e.g. samples could be run with 5 and 10% sand /gravel content. Equally, some experiments should be run with higher amounts to assess the full range of environmental conditions. These experiments should be combined with observations of the processes inside the barrels that will help in understating the mechanism through which the reduction in the abrasion rate is achieved.

To measure the abrasion rate under even more realistic conditions shingle needs to be tumbled with a combined mixture of both sand and gravel to assess the combined influence of a more complex mixture.

Investigating the factors that influence the abrasion rate of individual pebbles

The influence of flint shingle pebble surface textural characteristics on abrasion rates requires further investigation. For instance, it is unclear at the moment whether the abrasion rates measured are due to a gradual wearing away of the chattermarked surface or whether, under high energy surf zone conditions, the chattermarked surface is constantly re-forming.

The geochemistry of flint shingle pebbles requires further investigation, particularly in relation to how it affects pebble hardness and the development of surface textural characteristics such as chattermarks.

6 References

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This report is partly based on the following reviews, protocols and reports:

2003-11-14-Report_Laboratory abrasion 01.doc

2004-01-06-Report_Laboratory abrasion 02- shape.doc

2004-07-12-Protocol_Laboratory abrasion of shingle mixtures.doc

2004-09-21-Report_Laboratory abrasion 03-sand mixtures.doc