Life expectancy of shingle beaches: measuring in situ abrasion

Authors: Dornbusch, U., Williams, R.B.G., Moses, C., and Robinson, D.A.

Source: Journal of Coastal Research, 36(sp1) : 249-255

Published By: Coastal Education and Research Foundation

URL: https://doi.org/10.2112/1551-5036-36.sp1.249

Journal of Coastal Research	SI 36	249-255	(ICS 2002 Proceedings)	Northern Ireland	ISSN 0749-0208

Life expectancy of shingle beaches: measuring in situ abrasion

U. Dornbusch, R.B.G. Williams, C. Moses, D.A. Robinson

Geography Laboratory, School of Chemistry, Physics and Environmental Science,
University of Sussex, Falmer, Brighton, BN1 9QJ, United Kingdom.

ABSTRACT

In situ abrasion of shingle beach material is a neglected area of study in coastal geomorphology, with reduction in beach volumes normally attributed to longshore and offshore drift. Results from field abrasion experiments conducted on flint shingle beaches on the East Sussex coast, southern England, show that in situ reductions in volume of beach material may be more significant than has been thought. Two beaches composed almost entirely of flint shingle were seeded with hard quartzite from a Devon beach and less resistant limestone from a South Wales beach that are readily distinguishable from the flint.

The seeding commenced in January 2001. The pebbles, similar in size and shape to the natural flint shingle, were left in the surf zone at two sites. Prior to exposure the pebbles were engraved with a code number and weighed. At regular intervals those that could be re-found were re-weighed and returned to the beach. Abrasion rates were calculated for each pebble as percentage weight loss per tide. By the end of October 2001, more than 700 measurements of abrasion rates had been made from a total of 431 pebbles.

Average limestone abrasion rates (0.0266% loss of weight per tide) were three times greater than those of quartzite (0.0082% per tide). Measurable abrasion rates were recorded over just a few tidal cycles, not only in severe wave conditions but also in much calmer weather. The maximum abrasion rates recorded exceeded 1% per tide for limestone.

ADDITIONALINDEX WORDS: *Attrition, quartzite, limestone, Sussex coast, pebbles, cobbles, beach, flint*

INTRODUCTION

Shingle beaches1 in East Sussex (UK) protect low-lying land from flooding and chalk cliffs from erosion by dissipating wave energy. They are therefore valuable assets in coastal zone management and a major amenity for tourism. Beach volume changes are usually attributed to longshore or across shore movement of material but intensive groyning of large parts of the East Sussex coast has increasingly restricted longshore movement. Across shore movement of shingle along most of the Sussex coast over shore platforms 100-200m wide appears to be infrequent, and movement in shallow nearshore waters is assumed to be negligible (Joliffe, 1964) so that the loss of material may largely be due to in situ abrasion.

It is generally thought that abrasion on flint beaches "is probably a very slow process" BIRD (1996, p. 777) and that "well rounded pebbles abrade very slowly" BRAY (1997, p. 1041). Recent laboratory experiments carried out in tumbling barrels showed virtually no abrasion of beach flint from Kent (LATHAM *et al*., 1998). Experiments on cubes of chert in a surf simulator (KUENEN, 1964) produced measurable abrasion though KUENEN (1964, p.42) estimated that it would "take a thousand years for chert to form an ellipsoid". In contrast, tumbling experiments on flint shingle from Sussex beaches by DORNBUSCH *et al*. (in prep.) show much faster abrasion rates and indicate the need for field measurements.

In situ assessment of shingle abrasion has been undertaken by MATTHEWS (1983) who measured the roundness development of limestone tracer pebbles on greywacke and argillite beaches, but only SALMINEN (1935) and ZHDANOV (1958) have measured actual abrasion rates for individual pebbles. SALMINEN (1935), using four freshly broken angular gneiss and two rounded

---

In this paper the term shingle is used as the plural term and pebble as the singular for both pebble and cobble sized beach material local granite 'stones' (between 300g and more that 1000g) on a beach near Helsinki, recorded in one case considerable weight loss. The granite on a 'stony' beach lost 3.26% of its weight in 24 days although when found it appeared not to have been moved at all. The other granite on a sandy beach lost only 0.03% of its weight in six days, which SALMINEN (1935, p.57) attributed to its movement into deep water out of the "wearing field of the beach". It would be a mistake to assume that SALMINEN's results prove that hard lithologies undergo rapid abrasion because too few stones were used and insufficient attention was paid to standardising the drying process prior to weighing. ZHDANOV (1958) undertook a much more rigorous experiment that involved deployment of 2000 marked sandstone pebbles with a mean weight of 305g (mean size between 50 and 60mm) on one day on a shingle beach between two groynes near Sotchi (Black Sea). A small hole was drilled into each pebble, a numbered tag inserted, the hole sealed with cement and the pebble weighed. Over the following five years 20% of the pebbles were recovered during 19 searches. The pebbles were weighed and then broken to identify them. From the abrasion of the 500 pebbles ZHDANOV calculated the annual weight losses to be 4.8% after adjusting for seasonal variations in wave energy.

These results prove that in situ abrasion of shingle on beaches can be quite rapid. In the case of groyned beaches, where no natural input of beach material from longshore movement or cliff erosion occurs, the beach volume can therefore be expected to decrease with time.

STUDY AREA

Two beaches have been studied on the East Sussex coast (Figure 1). At Saltdean beach a recharged beach segment protected by two massive concrete groynes 85m apart was selected. The beach width is ~95m, 30m of which is the storm beach. Under normal conditions considerable proportions of the beach face are covered with sand and gravel but shingle usually covers the surface close to the groynes. The recharge material consists mainly of brown subangular to subrounded flints brought in from offshore sources during protection works carried out between 1996 and 1997 (Figure 2a).

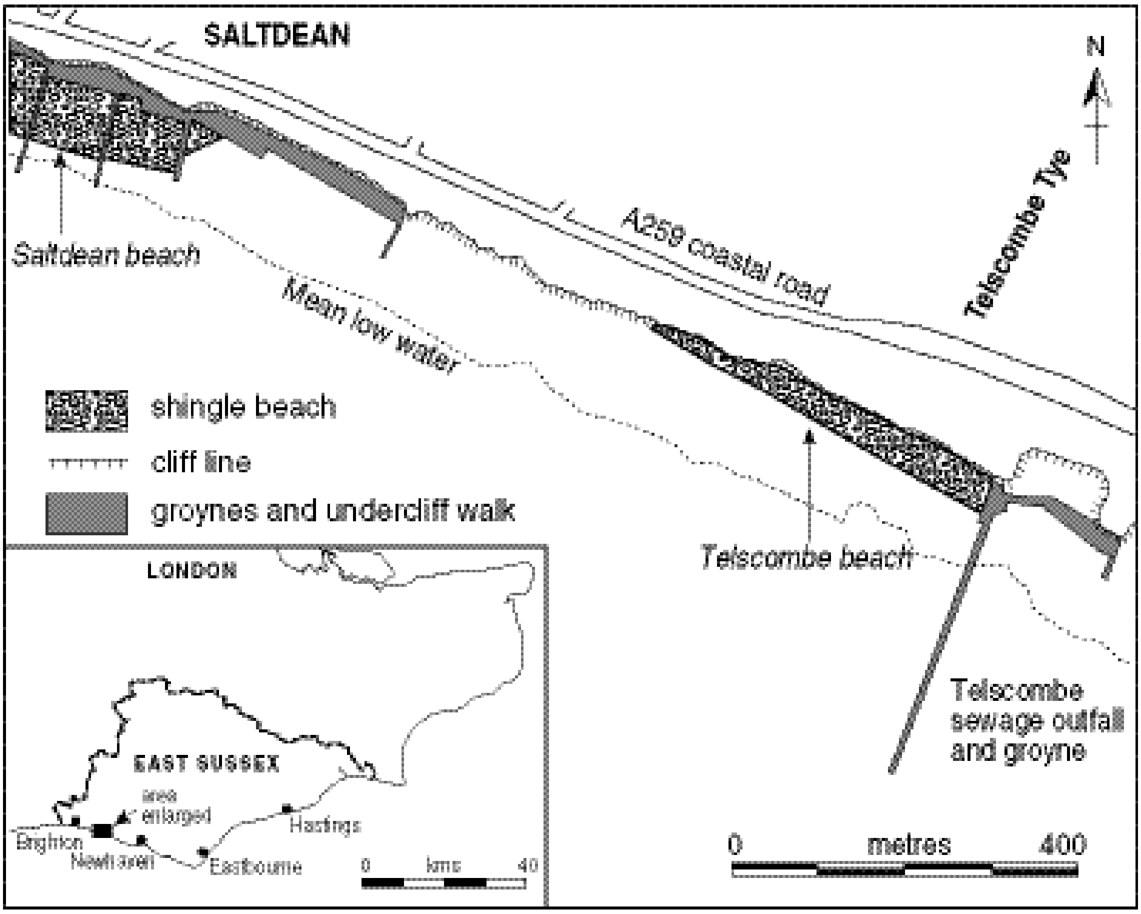

Figure 1. Location of test sites at Saltdean and Telscombe beach.

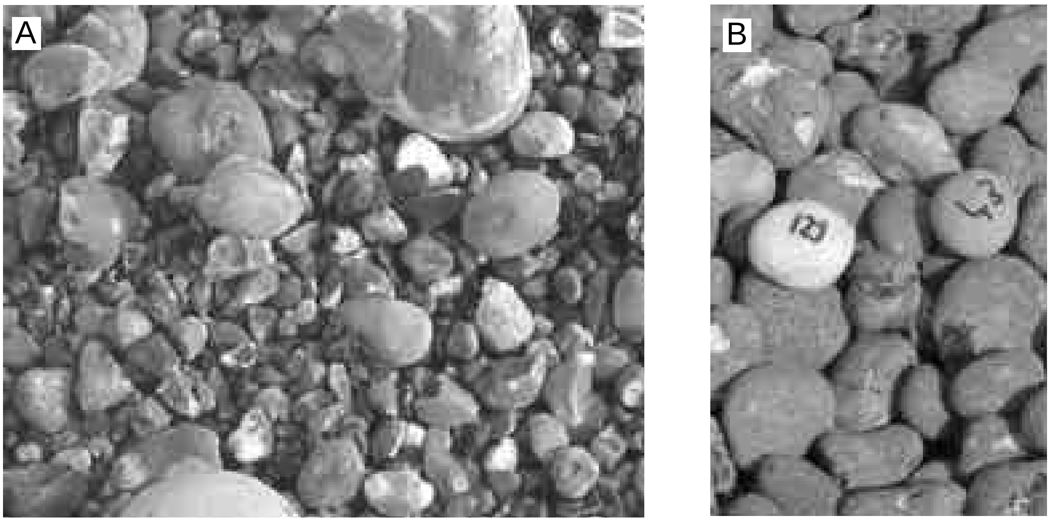

Figure 2. Limestone pebble on Saltdean beach (limestone CL is 7.2cm long) and limestone and quartzite pebble on Telscombe beach (Quartzite 129 is 6.9cm long).

Telscombe beach, the second study site, is a more natural beach consisting of rounded black flints (Figure 2b) that are thought to have been eroded from the chalk cliffs behind and to the west of the beach. It is bounded on the east by the groyne of the Telscombe sewage outfall but tapers out along the cliff towards its western end (Figure 1). The beach is ~430m long and up to 40m wide at its eastern end. Only storm waves coinciding with spring tides reach the beach-cliff contact. Under average conditions the beach face is predominantly covered with shingle.

Both beaches have an average slope of 5-10° and face southwest at ~200°. The mean and spring tidal ranges are 4.5m and 6.6m, respectively. POSFORD DUVIVIER (1993) provide a frequency analysis for wave height and direction at Shoreham, 25km to the west, which indicates that 1.6% of the significant wave heights exceed 3m, and 43.4% of all waves arrive from 180° - 240°.

METHODS

In situ measurement of the abrasion of shingle requires the recognition and identification of individual pebbles on a beach and the measurement of weight changes over a period of time. The local material cannot be used because it would be nearly impossible to recognise individual pebbles unless they were first marked with paint as is often done when tracing the movement of shingle. For the present experiment the pebble surfaces could not be altered in this way without affecting their abrasion potential.

To allow recognition and re-finding of test shingle on the surface of the flint beaches, hard quartzite from a Devon beach, (originating from the Triassic, Budleigh Salterton Beds), and less resistant limestone from a south Wales beach, (originating from the Lower Liassic Limestone of the Porthkerry Formation) were used (Figure 2). Both rock types are lighter in colour than the majority of the local flints. Their smooth surfaces lack chatter marks that are found on the black flints. They are also well rounded which aids recognition on the beach. In addition, the limestones are distinctive because their surface dries faster than that of the flints making them particularly visible when the beach is otherwise still wet. The mean weight of the limestones was 397g (ranging from 140 to 970g) and the quartzites 295g (ranging from 45 to 1700g), which translates into a mean size between 60 and 70mm. The size and shape of the test shingle were similar to the flint on the two test beaches.

To identify individual pebbles each was engraved with a number or letter combination, inked in using a water resistant marker pen (Figures 2 and 3). This method is simpler than ZHDANOV's (1958) and allows for the pebble to be returned to the beach repeatedly, without destroying it as was necessary in his experiments. The engraving is 1-2mm deep and remains legible even if a pebble loses up to 5% of its weight (Figure 3). To identify pebbles that lost their engraving, photographs were taken before they were released and identification was based on visual, size and weight comparison. Pebble weight in grammes was recorded to three decimal places for those <410g and to two decimal places for larger ones. The pebbles were dried at 50°C for five days prior to weighing to minimise the influence of varying moisture contents on the pebble weight. Experiments with saturating and then drying quartzite and limestone shingle showed that a five day period is sufficient to reduce the moisture content to a level where any further drying produces insignificant changes compared with the weight change due to abrasion and balance error.

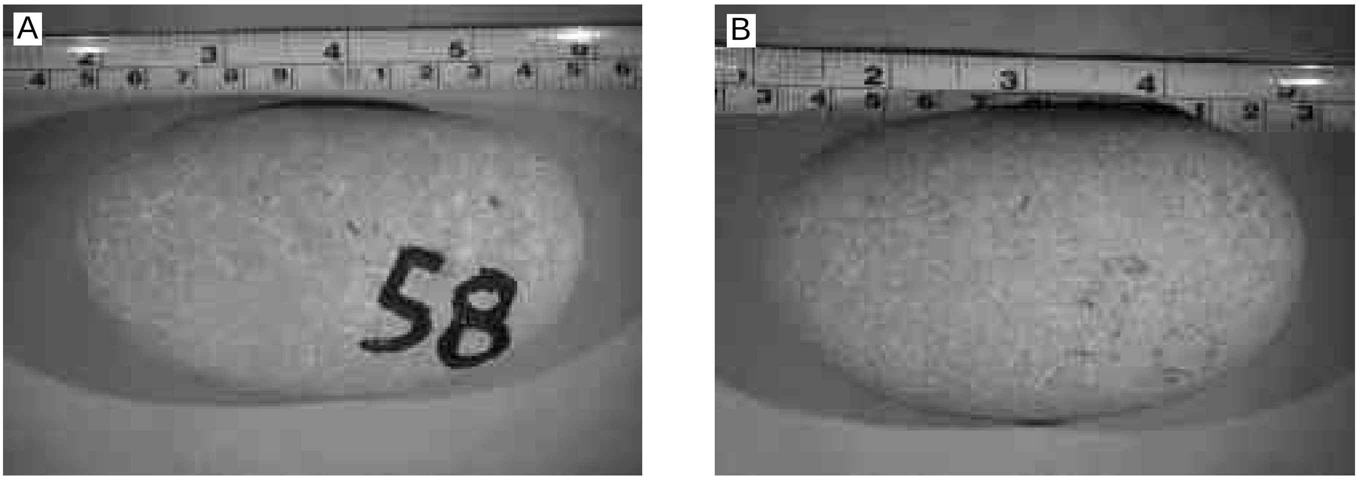

Figure 3. Limestone pebble no 58 (354.92g in A) lost 5.3% of its weight during 5 tides on Saltdean beach in April 2001 (mean wave height 1.7m).

Seeding and collecting

Engraved and weighed pebbles were placed on the middle of the beach face at each site, within a short distance of the eastern groyne during low tide, and the preceding high tide was recorded as the ‘set out’ time. The beaches were then visited several times each week during low tide and searched for pebbles that, when found, were collected, dried for five days and weighed in the laboratory. The preceding high tide was recorded as the 'collection time' so that the period a pebble spent on the beach could be calculated as the number of high tides that have moved over the beach face. The precise shingle collection location was not recorded regularly, but observations at Saltdean beach indicated that although the majority of pebbles were recovered close to the eastern groyne, westward movement was common, and several crossed the 85m long beach to within one metre of the western groyne.

Wave data

Wave and wind data was obtained from the UK Met Office's UK wave model for a point at 50.72°N 0.08°W, 9km south of the study beaches. Model output provided significant wave height at three-hourly intervals for the study period. The off-shore location of the data point (water depth 28m), however, provided only a general representation of the near shore wave conditions. Offshore wave height was averaged for each period between high tides to provide mean conditions.

RESULTS

Seeding of the beaches started in January 2001 and by the end of October 2001 involved a total of 431 pebbles (217 quartzites and 214 limestones). Pebbles recovered and weighed were put out again. 165 (38%) have never been recovered but many of the remaining 266 have been found, weighed and released several times, resulting in 710 abrasion rate measurements. Comparing the average weight of those 165 never recovered (267.9 g for quartzites and 429.15 g for limestone) with those found at least once (306.9 g for quartzites and 401.4 for limestones) no systematic collection bias towards larger or smaller pebbles could be found. Nine measurements recorded no abrasion (only with quartzites) and 20 measurements recorded a minor weight gain (only with limestone). Weight gain as well as no change are likely to have been artefacts introduced in the weighing and drying process (e.g. balance error) and these measurements were therefore excluded from further analysis. These measurements occurred only when the pebbles had been exposed to very weak waves over a short period (< 4 tides) of time. Exposure time for individual pebbles ranged from 1 to 537 tides (Figure 4). The best collection results were obtained one or two tides after the seeding (Figure 4) when only moderate wave conditions prevailed during the intervening period. The mean weight loss over a period of 10 months between seeding and collection for all quartzites recovered was 0.36% compared with 1.44% for limestones. A better measure of the abrasion is the percent weight loss per tide shown in Figure 5. This was very variable and ranged from 7.5x10-5 to 1.27 %.

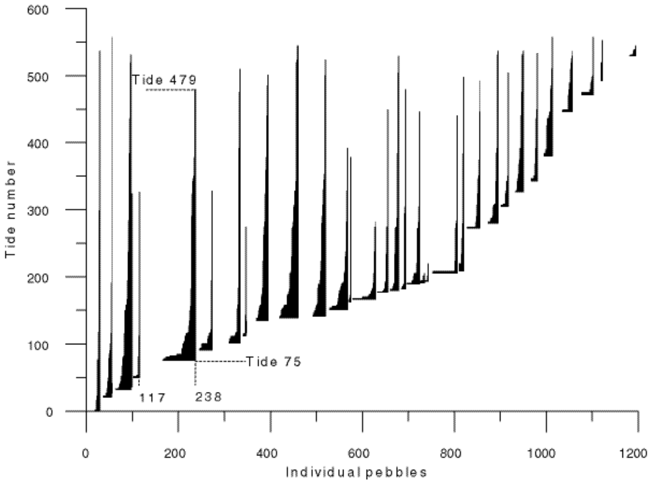

Figure 4. Summary of pebble seeding times and collection times. Column height represent the amount of time a particular pebble has spent on the beach between seeding and collection. Gaps indicate pebbles that have been seeded but not yet recovered. Of all the pebbles put out at tide 75 (pebble 117 to 238), for example, 49 are still on the beach indicated by the gap and two pebbles (at 237 and 238) have been recovered after 404 tides (between tide 75 and 479) indicated by the very long column.

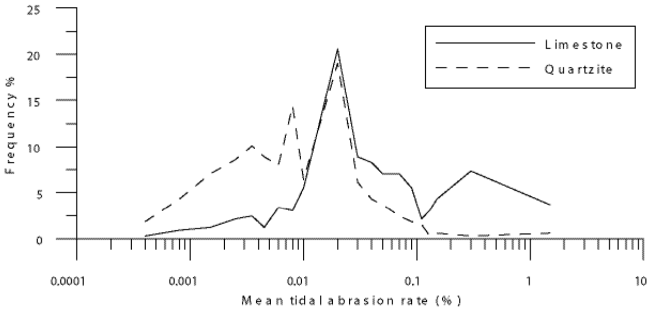

Figure 5. Frequency graph for 681 pebble records with abrasion rate >0%.

DISCUSSION

In situ abrasion rates for limestone and quartzite shingle have been successfully measured for a large number of individuals. The abrasion rate depends on pebble characteristics (hardness, weight, density and shape), beach characteristics (energy input, sediment hardness, size and shape) and pebble movement characteristics (movement involving high velocity impacts, movement on or within the mobile layer and burial or inactivity times). Although the pebble characteristics can be determined easily, energy input in the swash zone or pebble movement characteristics can be determined accurately only with special equipment (WILLIAMS and ROBERTS 1995, VOULGARIS *et al*. 1999) and are difficult to even estimate in the absence of such equipment. Pebble characteristics can be excluded when analysing abrasion rates for individual pebbles assuming these do not change significantly. In addition, if the shingle has been on the beach for only a short time and has undergone appreciable abrasion it can be assumed to have moved during most of this time and that burial and inactivity has been minimal. The main factor influencing the abrasion rate under these conditions should be the wave energy. A clear relationship between abrasion rate and mean wave height can be seen in Figure 6a and 6b for most of the 17 pebbles that have been out more than five times each and in Figure 7 for all pebbles. The skewed distribution of the abrasion rates in Figures 5 - 7 reflects the skewed distribution of the mean wave heights recorded for each pebble with low or moderate waves being much more frequent than large waves resulting in more measurements of small and moderate abrasion rates.

Figures 6 and 7 also show the influence of different mineralogical hardness on the abrasion rate with the limestones abrading at up to three times the rate of the quartzites under similar wave conditions. The lithological difference can also be seen in Figure 6c where the abrasion rate for 15 pebbles that have been out on the same beach over the same time is plotted. The mean tidal abrasion loss for limestone is 0.0266% compared to 0.0082% for quartzite (Figure 7).

Multiple correlation analysis of the 681 measurements (Table 1) shows that abrasion rate is linked most strongly to mean wave height and that the pebble type is the next most important factor. The pebble weight also influences the abrasion rate but whether the shingle was put on Saltdean or Telscombe beach does not seem to make a difference. The higher correlation with the 'set out' time may indicate seasonal variations.

The ratio of quartz against limestone abrasion of 1:3.2 echoes that of 1:3.3 found by KUENEN (1964 – 1958 in references) during experiments with chert, quartz and limestone in a wave simulation machine.

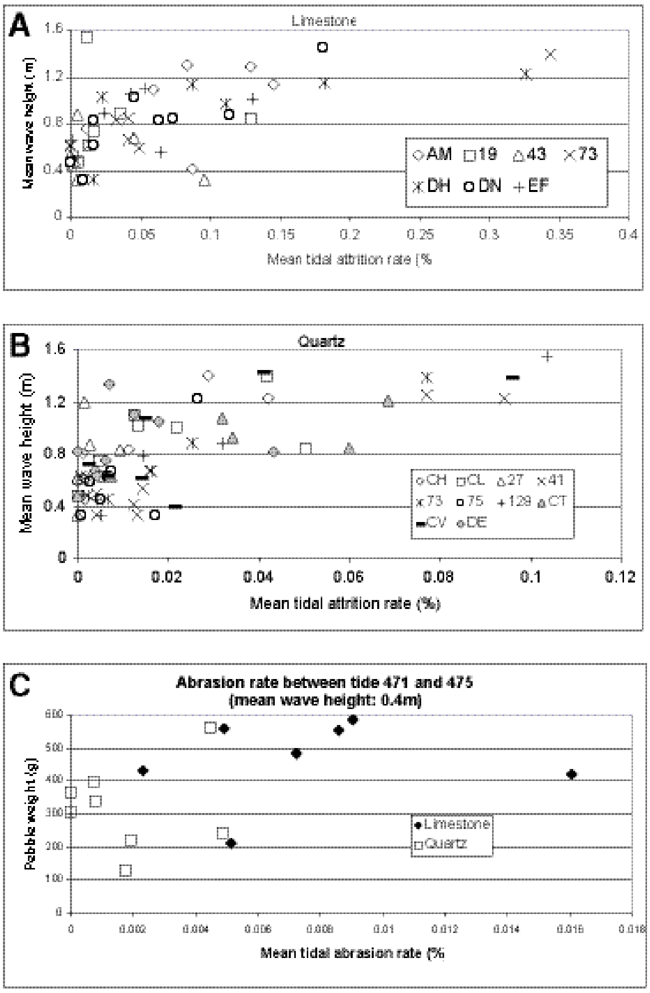

Figure 6. A + B: Mean tidal abrasion rates for 7 limestones (A) and 10 quartzites (B) with five or more abrasion rates plotted against mean wave height. Legend shows individual pebble identifications. (C) Mean tidal abrasion rate for 15 pebbles after four tides on the same beach under weak wave conditions.

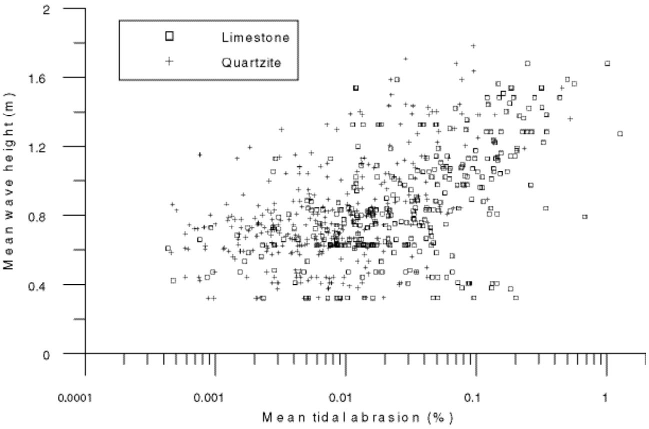

Figure 7. Mean tidal abrasion rate in relation to mean wave height for 681 pebbles.

Although these mean tidal abrasion rates may seem small, when sustained over one year with ~700 tides the mean weight loss due to abrasion could be expected to range between 5.7% for quartzite and 18.6% for limestone. If one assumes the abrasion relationship found in experiments with rock cubes by KUENEN (1964, p. 29) where "losses by quartzite are one-third and losses by chert one-tenth of those of limestone" the annual weight loss of flint shingle could be as high as ~1.9% per year. This weight loss only applies to the material in the profile envelope. To provide more accurate estimates for the local flint beaches, the field abrasion rates of limestone and quartzite will be correlated with laboratory tumbling data for flint (DORNBUSCH *et al.*, in prep.).

Table 1. Pearson correlations for shingle abrasion

Pearson Correlation	Abrasion rate	Mean wave height	Pebble type	Pebble weight	Set out time
Mean wave height	.410				
Pebble type	-.276	-.121			
Pebble weight	.206	.183	-.274		
Set out time	.104	-.129	.028	.171	
Beach location	-.020	-.062	.005	.098	.219

Acknowledgements

The authors would like to thank S. Dornbusch, H. Morley and S. Hill for their support in searching for and collecting shingle on the beach and S. Rowland for help with drawing Figure 1. Wave model data was kindly provided by the UK MetOffice.

LITERATURE CITED

BIGELOW, G.E., 1984. Simulation of pebble abrasion on coastal benches by transgressive waves. *Earth Surface Processes and Landforms*, 9, 383-390.

BIGELOW, G.E., 1988. Laboratory study of the role of seawater in basalt pebble abrasion. *Journal of Coastal Research* 4(1), 103-113.

BIRD, C. F., 1996. Lateral grading of beach sediments: a commentary. Journal of Coastal Research, 12(3), 774-785.

BRAY, M. J., 1997. Episodic shingle supply and the modified development of Chesil Beach, England. *Journal of Coastal Research*, 13(4), 1035-1049.

DORNBUSCH, U., C. MOSES, D.A.ROBINSON and R.B.G. WILLIAMS (in preparation): Laboratory abrasion tests on flint beach shingle.

JOLIFFE, I.P., 1964. Movement of shingle on the margins of Seaford bay. Hydraulics Research Station Wallingford, Report No INT 35, 36p.

LATHAM, J.-P., HOAD, J.P. and NEWTON, M., 1998. Abrasion of a series of tracer materials on a gravel beach, Slapton Sands, Devon, UK. *Advances in Aggregates and Armourstone Evaluation*. Geological Society, London, Engineering Geology Special Publication, 13, 121-135

KUENEN, P.H., 1964. Experimental abrasion: 6 surf action. *Sedimentology* 3, 29-43.

MATTHEWS, E.R., 1983. Measurements of beach pebble attrition in Palliser Bay, southern North Island, New Zealand. *Sedimentology* 3, 787-799.

POSFORD DUVIVIER,1993. Report: Brighton Borough Council, Brighton Sea Defences, Brighton Marina to Saltdean, numerical modelling. 22p.

SALMINEN, A., 1935. On the weathering of rocks and the composition of clays. *Annales Academiæ Scientiarum Fennicæ Series* A 44(6)

VOULGARIS, G., WORKMAN, M. and COLLINS M.B., 1999. Measurement techniques of shingle transport in the nearshore zone. *Journal of Coastal Research* 15 (4), 1030-1039.

WILLIAMS, A.T. and G.T. ROBERTS 1995. The measurement of pebble impact and wave action on shore platforms and beaches: the swash force transducer (swashometer). *Marine Geology* 129, 137-143.

ZHDANOV, A.M., 1958. Attrition of pebbles under the wave action. *Bulletin of the Oceanographic committee of the USSR Academy of Sciences* 1, 81-88. Original title: Istiranie galechyh nanosov pod deistviem volneniya. Bulleten Okeanograficheskoi komissii ANSSSR.