UNIVERSITY OF SUSSEX AT BRIGHTON

BERM Final Report

Technical Report

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Contents

List of figures

Map 1 and 2 are provided as additional DIN A3 sheets at the end of this report.

The technical report outlines in detail the methods employed and the results obtained by the BERM researchers. For an overview of the project please refer to the BERM interim report (http://www.geog.sussex.ac.uk/BERM/report.pdf).

1 Area of investigation

The research area on the English side comprises the coastline of East Sussex. Investigations of cliff erosion focus on the chalk cliffs between Brighton and Eastbourne; the cliffs at Hastings are composed of sandstone and do not contribute any flint shingle to the coastal system.

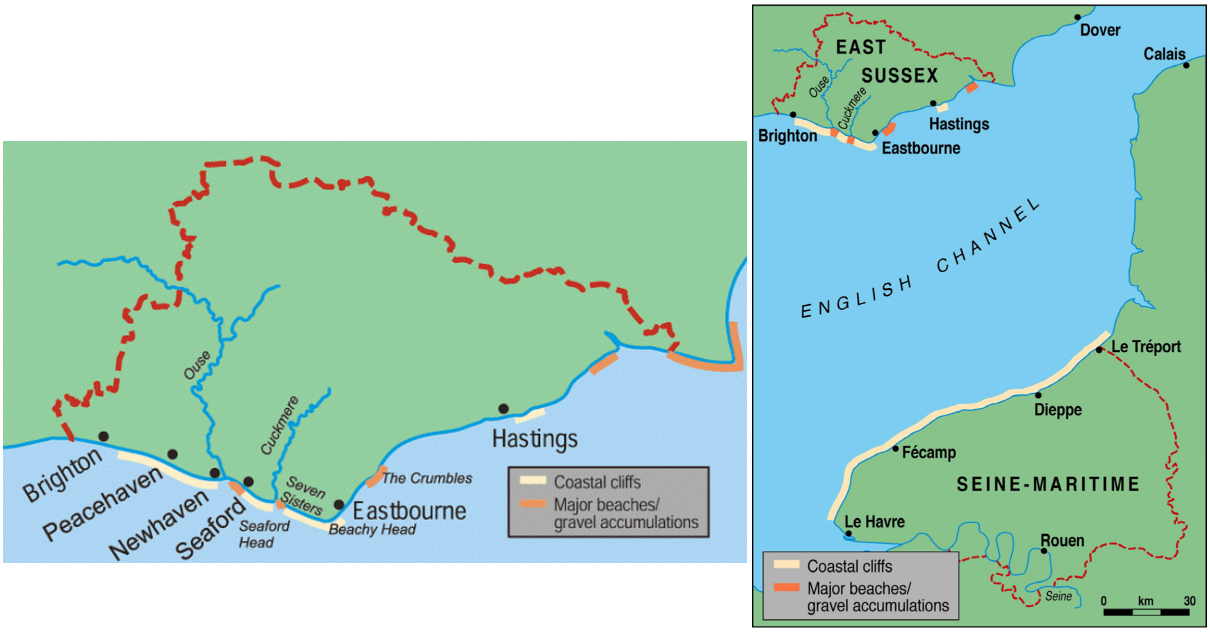


Figure 1: Overview of the Rives Manche and locations on the East Sussex coast.

2 Cliff retreat measurements

Measurement of the rate of cliff retreat along the coastline of East Sussex has been attempted in a number of previous studies (Figure 2).

Locality	Time period	Average annual loss at cliff top in cm (figures with * have been calculated from imperial measurements)	Source
Bexhill and Glynde Gap	1925-1955	~10 to ~20	Thorburn, illustration nr. 8 [5]
Birling Gap	1875-1961	91	May, page 203
Birling Gap	1875-1961	91	Castleden, Table 3
Birling Gap	1955-1962	99	May, page 203
Birling Gap	1950-1962	97	Castleden, Table 3
Birling Gap	1973-1975	122	Castleden, Table 3
Birling Gap	1925-1955	~90, maximum ~126*	Thorburn, illustration nr. 8 [5]
Birling Gap (stretch 70m east and west of the steps)	1873-1976	69	Cleeve & Williams, Fig. 10[1]
Cuckmere Haven to Birling Gap	1973-1975?	125	Thorburn, page 7
East Sussex chalk cliffs	n.a.	30-50, maximum 125	Robinson & Williams (1983) page 61
Ecclesbourne Glen	1872-1987	15 to 33[3]	Cleeve & Williams, page 48
Fairlight Cove (Haddock's Cottage)	1873-1986	57 to 77[4]	Cleeve & Williams, page 59
Hasting to Cliff End	1925-1955	~50, maximum 186*	Thorburn, illustration nr. 8 [5]
Peacehaven	1973-1975	45	Castleden, Table 3
Peacehaven (Portobello to Maline Avenue South)	1875-1967?	45.7	Hove, page 1
Peacehaven (Maline Avenue South to Steyning Avenue)	1875-1967?	38.1	Hove, page 1
Peacehaven (Roderik to Steyning Avenue)	1873-1976	29	Cleeve & Williams, page 28[2]
Peacehaven (Steyning Avenue to Southdown Avenue)	1875-1967?	30.5	Hove, page 1
Peacehaven (Southdown Avenue to Cornwall Avenue)	1875-1967?	60.9	Hove, page 1
Peacehaven (Cornwall Avenue to Friars Bay)	1875-1967?	38.1	Hove, page 1
Peacehaven and Telscombe cliffs	1973-1975?	45	Thorburn, page 6
Peacehaven to Newhaven	1925-1955	~30, maximum ~90	Thorburn, illustration nr. 8 [5]
Seaford Head	1973-1975	30	Castleden, Table 3
Seaford Head to Beachy Head	1872-1962	42	May, page 203
Seaford Head to Beachy Head	1872-1962	42	Castleden, Table 3
Beachy Head to Eastbourne	1925-1955	~20, Maximum ~106*	Thorburn, illustration nr. 8 [5]
Seaford Head to Cuckmere Haven	1973-1975?	30	Thorburn, page 7
Seaford Head to Cuckmere Haven	1925-1955	~30, maximum ~126*	Thorburn, illustration nr. 8 [5]
Seven Sisters	1873-1962	50.5	May, table 1
Seven Sisters	1873-1962	51	Castleden, Table 3
Seven Sisters	1973-1975	125	Castleden, Table 3
Seven Sisters	1925-1955	~40	Thorburn, illustration nr. 8 [5]

* see note 5

1 Cleeve and Williams (Fig. 8) suggest a 'fairly constant' retreat rate based on measurements taken from maps with survey dates 1873-74, 1908, 1925, 1960, 1976, 1987.

2 Cleeve and Williams (Fig. 16) show the retreat rate to be fairly constant based on measurements taken from maps with survey dates 1873, 1899, 1926, 1960, 1976.

3 data for four profiles along 5km of coastline

4 data for three profiles along ~3km of coastline

5 retreat rates are estimated from the graph in Thorburn which provides detailed retreat rates for the whole of the cliffed coastline of East Sussex, maximum values with an * are taken from table 1, assuming the data relates to the same time interval

Figure 2: Published rates of retreat along the East Sussex coast in the literature

Most measurements have been obtained by comparing the position of the coastline on maps of different ages by manually tracing the cliff lines from the maps, overlying the lines and then measuring the distance between the lines at a number of points. Only rarely has the area of cliff retreat been measured and a mean retreat rate for different lengths of coastline calculated (e.g. Cleeve & Williams 1983). The only comprehensive survey of the entire Sussex coastline is that of Thorburn (1977). Unfortunately this study was based on maps covering only the 30 year period 1925-1955, which is likely to introduce significantly larger errors due to positional errors on the maps, than if maps covering a longer time span are used. The method of manually tracing and overlaying introduces errors by itself (tracing errors, pencil width, shape changes of the paper). These errors are further aggravated by the necessity of enlarging or reducing maps to facilitate overlaying of maps of different scales (e.g. change from imperial to metric scales).

In the BERM project a consistent methodology using ArcView GIS was applied to the whole length of the chalk cliff coastline, thus producing the first truly comparable retreat rate estimates.

2.1 Present cliffline

As the modern data Ordnance Survey digital Landline data was kindly provided by East Sussex County Council for use in this project. The data was directly imported into ArcView without any alterations. The positional error of the OS Landline data depends on the scale at which it was surveyed and is only available as a gross figure (i.e. for whole map sheets). The OS provide accuracy statements for their data (Ordnance Survey 2000) where an accuracy of ± 0.5m is given for the survey scale 1:1250 and of ± 1.1m for the survey scale 1:2500. From a letter received from the Ordnance Survey (Appendix 3) the majority of the coastline was surveyed at a scale of 1:2500 thus the positional error of the Landline data is assumed to be ± 1.1m. The date for the cliffline position in the data was taken from the date of the airphotos on which the revision of the map sheets was based (figure 3).

Map sheet number	Dates of air photographs used for revision of Landline data
TQ3O	8/4/97
TQ4O	5/6/96
TQ8O	16/3/99
TQ81	16/3/99
TV49	23/7/97
TV59	23/7/97
TV69	23/7/97

Figure 3: Dates of air photographs used for revision of Landline data based on the 1:10,000 map sheets (source: see Appendix 3)

For the presently defended coast at Peacehaven maps surveyed prior to the installation of sea defences and the trimming of the cliffs were used. These comprise the Ordnance Survey maps at a scale of 1:10,000 surveyed in 1954 and ground surveys carried out on behalf on Lewes District Council in 1970 and 1996 (see map 1). These maps were scanned and referenced in a similar way to the historic maps (see below).

2.2 Historic cliffline

The earliest maps that could be used were the 1st Edition of the Ordnance Survey 6-inch scale maps (1:10,560) because these maps are the first to have been surveyed with regard to a geographical reference system that is displayed on the map itself.

Prior to scanning the graticule was transferred as small markers into the areas to be scanned using a long metal ruler so as to cause the least damage to the maps that are available as originals from University of Sussex Geography Resource Centre. Maps were then scanned at 300dpi using an A3 scanner. The maps were georeferenced to the National Grid in ArcView using the markers. Georeferencing was performed using a first order transformation with RMS-errors in most cases <0.6m. Line features such as the cliff top line the Mean High Water Line and Mean Low Water Line were then digitised by ‘head-up’ digitising in ArcView at a scale of 1:1000. The centre of the line as it appeared in the scanned image was used for digitising.

Map sheet number	Survey years
66	1873-75
77	1873
78	1873
79	1873-74
80	1875-76
81	1875
82	1875-76

Figure 4: 1st Edition Ordnance Survey 6-inch maps used

The survey accuracy of historic maps is not given though it is unlikely that it surpassed the accuracy of the modern Landline data set. The accuracy can therefore only be estimated by comparing features in both data sets.

1) Comparison of features in the Landline data and in the scanned and georeferenced historical maps (assuming that features such as houses or roads have not moved) indicate position variations between the two data sets from naught to several metres.
2) The cliffs seem to have advanced at 20 stretches along the cliff in the vicinity of Beach Head. Because an advance is not physically possible these 'advances' must be due to survey inaccuracies of one or both of the data sets. The mean length of these stretches is 20 m and the mean advance over 124 years is 1.94 m with a maximum in one location of 7.49 m. If one assumes that the cliff line along these stretches has not changed at all between the two surveys, the observed mean 'advance' can be nearly accommodated by the positional error of ± 1.1 m of the Landline data (see above).

The RMS error for the georeferencing employed on all maps has a mean of ~ 0.6m. The comparisons, together with the assumption that former surveyors who worked on the ground have considered the cliff line as a feature worth surveying accurately as it represents an important feature, allows one (erring on the safe side) to assume a positional error for the historic cliff line of ± 5m.

The error for the distance measurements between 1st Edition maps and the Landline data is therefore $\sqrt{1.1^2 + 5^2} = 5.12$ m. The average time interval between the surveys for the 1st Edition OS maps and the air photos on which the Landline data is based is 124 years, resulting in an error for the annual retreat rate of ±0.04m / year.

2.3 Cliff retreat

Annual retreat rates were calculated from the area lost between the two cliff lines of different age and position by dividing the area by the length of the cliff line and the number of years between the two surveys (see Appendix 1 for a description of the method using ArcView). To provide retreat rates on a small scale the length of the cliff was divided into 50m long segments. The length of 50m was taken to use the same interval as was used by the French partners of the BERM project.

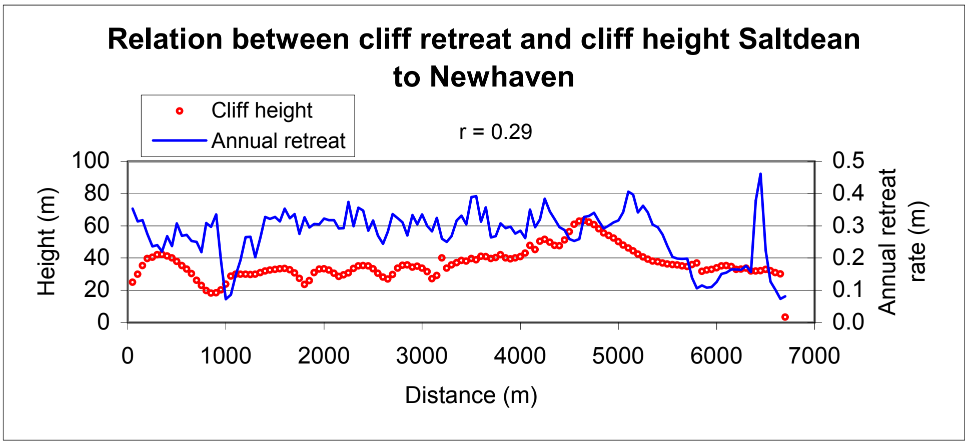
2.4 Results

Map 1 shows the mean annual retreat rates. Cliff retreat along the Saltdean to Newhaven stretch averages at 28cm y^{-1}. Particularly low retreat rates are found just east of the Telscombe Treatment Works where a bay seems to develop between the treatment works and the developing promontory. Low retreat rates are also found west of Newhaven breakwater where parts of the cliff are protected through the shingle accumulation west of the breakwater. A change in the orientation of the coast, affording a less direct wave impact from south-westerly storm waves may partly explain the retreat rate decrease. That factors other than orientation towards predominant storm waves are likely to have an influence on the retreat rate can bee seen along the stretch Seaford to Cuckmere Haven where the southeast orientated coast east of Hope Gap abrades at nearly twice the rate of the central part with a south-southwestern orientation.

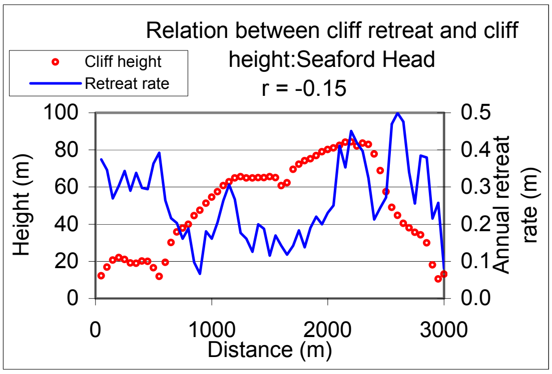
The Seven Sisters coastline, usually described as 'straight in plan' (Castleden 1996: 37), shows varying erosion rates, notably with high erosion rates at Crowlink and low rates east of Flagstaff Brow indicating a development away from the straight line. While interest regarding the highest erosion rates along the chalk cliffs of East Sussex is usually centred on Birling Gap (e.g. Cleeve & Williams,

Castleden) the highest rate seems to be located about 200 m west of Birling Gap and erosion rates over 60 cm a^{-1} can be found for a stretch of over 1 km west of Birling Gap.
West of Birling Gap, towards the Belle Tout lighthouse the erosion rate decreases to values <10cm a^{-1} east of Belle Tout lighthouse. Given the error in the retreat of ± 4 cm a^{-1} it seems to be possible that larger parts of the Beach Head cliffs have not retreated at all over the last 124 years.

Possible factors influencing the retreat rate have been investigated. Assuming the wave energy is able to remove a given volume of cliff fall debris at the foot of a cliff at a 'constant' rate and that removal of the material is necessary to allow for renewed wave attack leading to another cliff fall, then the height of the cliff should be proportionate to the cliff retreat because higher cliffs produce a larger volume of debris than lower cliffs (see Sunamura 1992:105).



A



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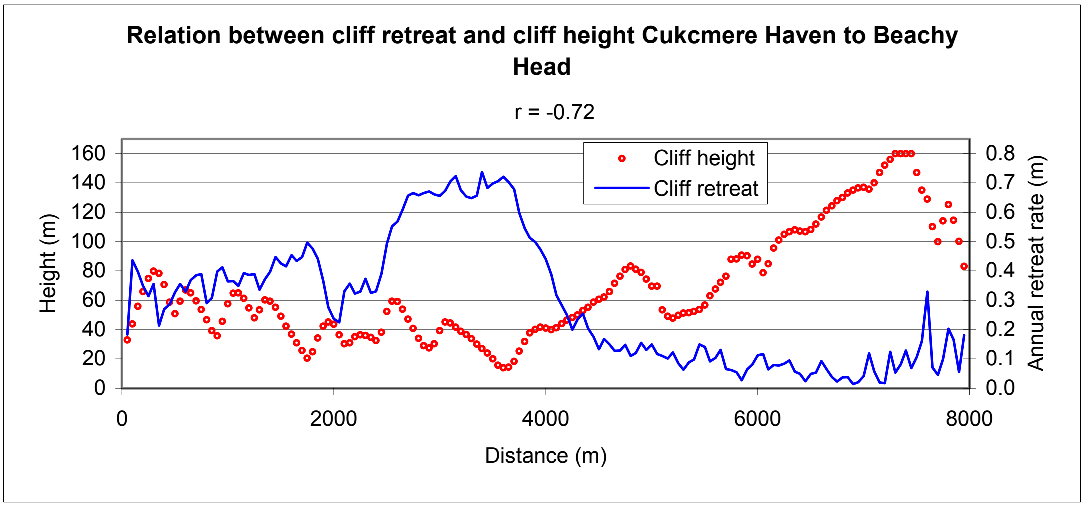


C

Figure 5: Comparison between cliff height and retreat rate for 50m segments along the chalk cliffs of East Sussex. Distance always from west to east.

There is a significant correlation supporting the assumption that higher cliffs retreat slower for the coast between Cuckmere Haven and Beach Head (C) but judging from the other two sections (A, B) no correlation seems to exist indicating that other factors may have a greater control over the rate of cliff retreat. If a correlation is performed including the whole coast (N = 357 segments) r is significant with -0.499.

2.5 Outlook

Cliff retreat may display changes in the rate over decadal time spans so that investigating smaller time spans within the 124 years is necessary. To reduce location accuracy problems involved with digitising cliff lines from maps it is suggested that cliff lines are digitised from orthorectified air photographs, though the production of orthophotos for the whole coast is likely to take up considerable resources.
To predict future rates of cliff retreat it is necessary to investigate the factors influencing / determining the retreat rate. Factors to be taken into account are the geology at the shore platform-cliff junction and the topography and extent of the shore platform.

3 Flint input to the coastal environment

To estimate the volume of flint deposited on the beach from the Chalk cliff erosion the percentage of flint in the chalk needs to be calculated together with the volume of chalk eroded.
Gross estimates of the percentage of flint in the Chalk together with gross estimates about the volume of cliff retreat (estimates of mean height and mean retreat rate) can produce highly varying results as the following sample calculations show (Figure 6).

Cliff length (m)	Mean cliff height (m)	Mean cliff retreat (m)	Flint percentage (%)	Flint production (m^3)
22,000	45	0.5	5	24,750*
22,000	40	0.4	2	7,040

Figure 6: Calculation of the flint content from Jennings and Smyth (1990: 215-216)* and a sample calculation with changed paramenters.

Only a few flint content estimates for the Chalk cliffs of East Sussex can be found in the literature and none of them provides the method upon which their estimates are based. Mortimore (personal communication cited in Jennings and Smyth 1990) provides an estimate of 5% as an average for the whole of the East Sussex cliffs from which Jennings and Smyth (1990) calculate the annual flint production at 'approximately 25,000m^3 yr^{-1} ' (Figure 6). Jenner and Burfitt (1975, cited in Posford Duvivier, 1993: 6) estimate "that flint makes up about 2% of the Middle Chalk strata".

3.1 Volume calculations

To obtain more accurate estimates of the supply of flint to the beaches the following procedure was undertaken. The chalk volume was calculated from the area of retreat (see above) and height information of this area. A detailed Digital Elevation Model (DEM) for the coastal parts of the cliff was created because existing DEM data from the Ordnance Survey (PANORAMA dataset) has an unsatisfactory resolution of 50m cell sizes. These cell sizes, especially along the breakline of the cliff, do not contain the the necessary detail.
The DEMs were created from digitised contour line information (contour line interval 5 m) taken from OS topographic maps at a scale of 1:10,000. The contour lines were extrapolated beyond the current cliff line to allow for the DEM to include the retreat area. DEMs were created as Triangular Irregular Network (TIN). Combining the DEM with the retreat area the volume of cliff eroded was calculated. As the base height for these volume calculations the height of Mean High Water was used as it

represents approximately the position of the cliff foot. The following base heights were used: Peacehaven to Newhaven 2.55 m, Seaford Head 2.6 m and Cuckmere Haven to Beachy Head 2.65 m. The annual volume of cliff removed has been calculated to be 170,000m³.

3.2 Flint content

The volume of flint in the Chalk is bound to vary between different members (vertically) and within individual members (laterally). Additionally, the cliff face is only accessible at the cliff foot and along steps and access roads cut into the chalk for example at Peacehaven. Due to the heavy rains over the winter 2000-2001 the cliff face along long stretches has been covered by soil from the cliff top making the identification of flint difficult. The cliff faces along the steps and access roads are weathered and in many places obscure the chalk-flint relationship. Therefore only a limited number of measurements have been obtained leading to a relatively high error margin assigned to the flint percentage value.

Flint percentage has been measured by taking digital photos of 2m x 2m sections of the cliff base using a purpose built quadrat (Figure 7a). The images were downloaded to a computer and flint was then identified on screen and painted black. This manual approach was superior to automated image analysis techniques because it allowed for the exclusion of dark holes and crevasses and for the inclusion of flint nodules that were still coated with chalk or a white patina. After identification and painting the images were resampled and the percentage of black pixels in relation to the image size determined providing the flint percentage for the 4m² section of the cliff.

A B C

Figure 7: Process steps for calculating flint content in Chalk (flint content for this 4m² section is 4.9%).

Flint content can than be calculated for different members within the Chalk (Figure 8) and from the distribution of the Chalk members within the cliff the flint content for larger stretches is determined (Figure 9).
Additional to the survey along the cliff foot photographs were also taken of vertical sections of the cliff face using a conventional SLR camera with a 400mm tele-lens. The images were pasted together, scanned at 300dpi and evaluated as outlined above. This method proved to be similarly successful, although, the demand on computer memory is much greater.
Based on over 150 photos, one cliff face transect and the distribution of different beds of chalk along the cliff faces the following flint percentage have been calculated:

Cliff stretch	**Flint content (%)**
Saltdean to Newhaven	1.5 ± 0.5
Seaford Head	3.5 ± 0.5
Cuckmere Haven to Belle Tout	2.5 ± 0.5
Belle Tout to Beachy Head	4.5 ± 0.5

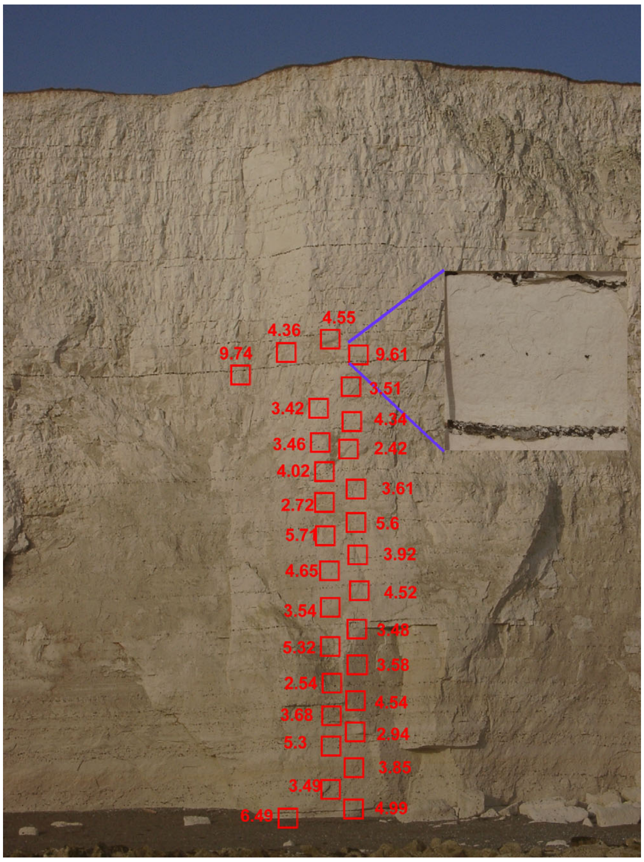


Figure 8: Overview of flint content for Belle Tout beds in the lower Seaford Chalk east of Birling Gap. Inset image shows the Seven Sisters flint band.

The flint content for each stretch of coastline was then imported into the GIS and a map showing the mean annual flint production for 50m segments along the entire chalk cliff coast of East Sussex compiled (Appendix 2). The mean annual flint production of the whole undefended coast was calculated at 4610 ± 890m³.

Given a mean annual retreat rate of approximately 28cm and the low flint content of the upper Newhaven and lower Reculver Chalks the coast between Saltdean and Newhaven produces comparatively small amounts of flint. The protection of the cliffs at Peacehaven has therefore had only a relatively small impact on the overall flint input with a reduction of 8.2%. The figures for the eastern part of this stretch at Newhaven are likely to be too high because a significant proportion of the cliff is not in Chalk but in the overlying Palaeogene beds of sand and clay.

In contrast, the relatively high retreat rates at Seaford Head combined with greater cliff heights and the higher flint content of the Seaford Chalk leads to a flint production that is almost half of that of the much longer stretch between Cuckmere Haven and Beach Head.

With a decrease in height of the Seven Sisters towards the east the amount of flint produced declines, especially east of Crowlink, but again increase towards Birling Gap as a result of the high erosion rates. Despite the increasing cliff height east of Birling Gap the lower retreat values of 10cm a^{-1} leads to significant drop in the amount of flint produced that is almost equivalent to that of the Stretch Saltdean to Newhaven were the cliffs are much lower. The maximum amount of flint produced per 50m segment can be found though east of Beachy Head lighthouse but it has to kept in mind that towards the east the cliffs are no longer vertical and the retreat of the cliff top may not reflect a similar retreat of the cliff foot. It is therefore possible that the annual flint production of 91m³ overestimates the true amount considerably.

4 Laboratory abrasion of flint from the Rives Manche coast

Previous studies

Laboratory investigations of rock abrasion have a long history from early tumbling experiments using stone and iron jars (Daubrée 1879), wood lined drums (Wentworth 1919, Krumbein 1941) and rocking troughs (Kuenen 1964) to more recent experiments using rubber lined metal drums (Bigelow 1984, Latham et al. 1998, Loveday & Naidoo 1997). Interpreting the results of these experiments is made difficult by the variety of rock types, sizes and shapes that have been tested, as well as the lack of standardisation of container size, shape and revolution velocity. Many of the experiments have been concerned to study shape changes rather than measure abrasion rates, and have used materials such as angular limestone or sandstone clasts that become rapidly rounded when subjected to artificial abrasion. Flint, and its pale coloured variant chert, abrade less quickly, and so have been relatively neglected, although flint has been used as an abrasive for tumbling with softer rock materials (e.g. Latham *et al*. 1998). The result is that views on the abrasion rate of flint are, at best, semi-quantitative. For example, Kuenen (1964, pp. 29 and 42) reports form experiments that “rounded chert is ten times as resistant as quartzite”, and estimates that it would take “a thousand years for chert to form an ellipsoid”. Bray (1997, p. 1041) suggests, from laboratory and field experiments, that fresh angular flint gravel “suffers an approximate 10% loss within the first year on the beach, whilst well rounded pebbles are abraded very slowly”. He does not disclose whether his view is based on field observation or laboratory experimentation. Using flint from Reculver in Kent as an abrasive for other lithologies Latham *et al.* (1998) report negligible abrasion rates for the flint.

Method

All the laboratory experiments to be described were conducted by tumbling flint shingle collected from beaches in Sussex and Normandy in rubber lined hexagonal barrels, rotating at about 28 rpm. The smallest diameter of the barrels was 20cm, the largest diameter 22.5cm and the length 20.5cm, giving a volume of about 7000cm³. Individual pebbles varied from 20g to 500g in weight with grain size varying from 15mm to 70mm (b-axis). The pebbles were tumbled in reconstituted seawater, with a salinity of 3.6% which was prepared by mixing additive-free, culinary sea salt from France with deionised water. The tumbling was stopped at intervals to allow the pebbles to be weighed. Any loss of weight was assumed to be due to abrasion. Before tumbling was resumed, the seawater in the barrels was changed and any abrasion debris that had collected was removed.

In order to establish a standard test procedure preliminary experiments were carried out using a variety of flint loads, water to flint ratios, tumbling periods and water types.

Tumbling time is given either in revolutions or hours with 1 hour being 1680 rev or 100,000 rev being ~ 60 hours.

4.1 First experiment on abrasion rates of rounded and angular flints

This was designed to explore the different abrasion rates of well rounded and freshly broken flint. Eight flints between 56 and 211g were tumbled in a barrel for a total of 156 hours. One was a freshly broken angular fragment of flint from a recent rock fall at Friars Bay, Peacehaven, Sussex (TQ4070 0020) and the other seven were well-rounded flint pebbles from the beach next to the fall. The flints were tumbled in the reconstituted seawater, except between hours 90 to 107 of the experiment when deionised water was temporarily substituted.

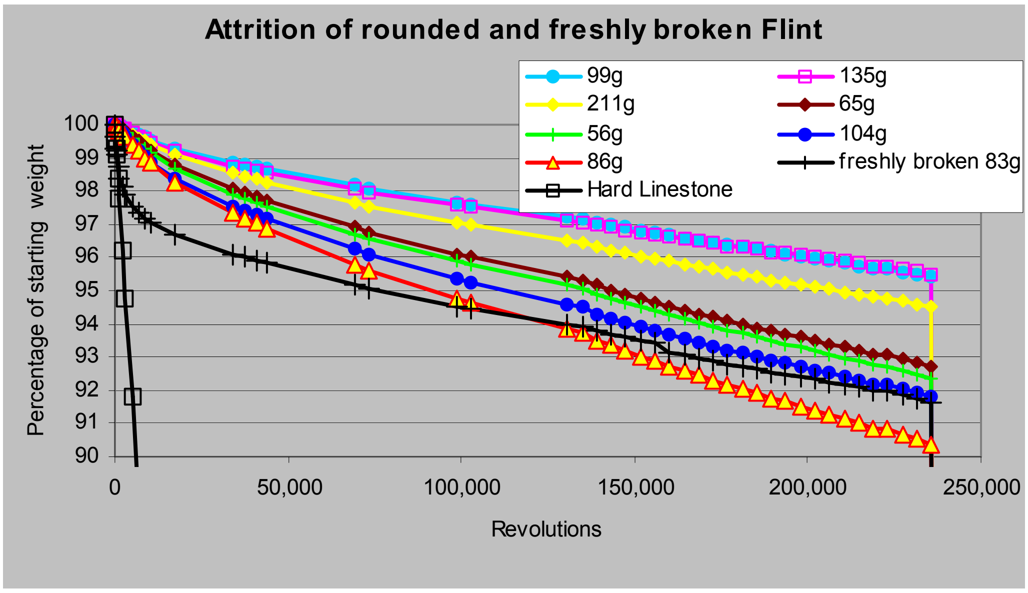


Figure 9: Graph showing the wear of nine flints in relation to tumbling time and tumbling interval. The slight change in abrasion rate at 132 hours is due to a balance error. The hard limestone abrades extremely quick in comparison and was removed after 10,000 revolutions.

Five minutes after the start of the experiment, the tumbling was stopped and the flints were removed from the barrel, surface dried using paper towels and re-weighed. They were then returned to the barrel for further tumbling. The tumbling was interrupted for re-weighing many more times, at intervals varying up to 16 hours until, after 76 hours of tumbling, the interval was standardised at 2.5 hours. (accommodating three tumbling intervals into one working day). During the first few hours of tumbling the angular flint fragment lost ~3% weight from breakage of its edges and corners producing fragments up to 0.18g, but after this it wore down much more slowly with no visible fragments, except at 93 hours when a small piece of 0.1g became detached (Figure 9). The rounded flint pebbles initially suffered less wear than the angular fragment, but, as the experiment continued, the total amounts of wear increased, and, by the end, one of the pebbles had suffered a greater percentage weight loss than the angular fragment. The abrasion rate was quite variable, and not obviously correlated with the size of pebble.

Changing to deionised water during the experiment did not appear to affect the abrasion rate, although Bigelow (1988) found that distilled water induces more wear than seawater. However, in the interests of standardisation, it was decided to continue to use reconstituted seawater in all subsequent experiments.
The change of the tumbling interval to a constant 2.5 hours at 72 hours marks a break in all curves indicating that the tumbling interval (probably in relation to the removing of the attrition debris) influences the attrition rate.

A subsidiary experiment confirmed that the relatively rapid abrasion shown by the angular flint was a real effect and not chance sampling. Figure 10 records the progressive rounding of the edges and corners of 10 freshly broken tabular flint fragments from the cliff fall at Friars Bay totalling 640g. Eleven grams or nearly 2% of small broken fragments were produced during the first 15 minute tumbling interval and rapid wear occurred until 50 hours after which further breakages did not occur. These two experiment support the findings of Bray (1997), Loveday & Naido (1997), and field observations around fresh cliff falls that freshly broken angular fragments lose several percent of their weight in a short period of time and become subangular.

Figure 10: Abrasion of freshly broken flint after 0.15 and 186.15 hours of tumbling.

4.2 Abrasion rates and different barrel loads: Experiment 1

10 well rounded nearly spherical pebbles (~900g) were tumbled at regular 2.5 hours intervals in reconstituted saltwater (figure 11). From 44,000 rev similar pebbles were added (figure 12) so that by 92,400 revolutions the load had doubled.

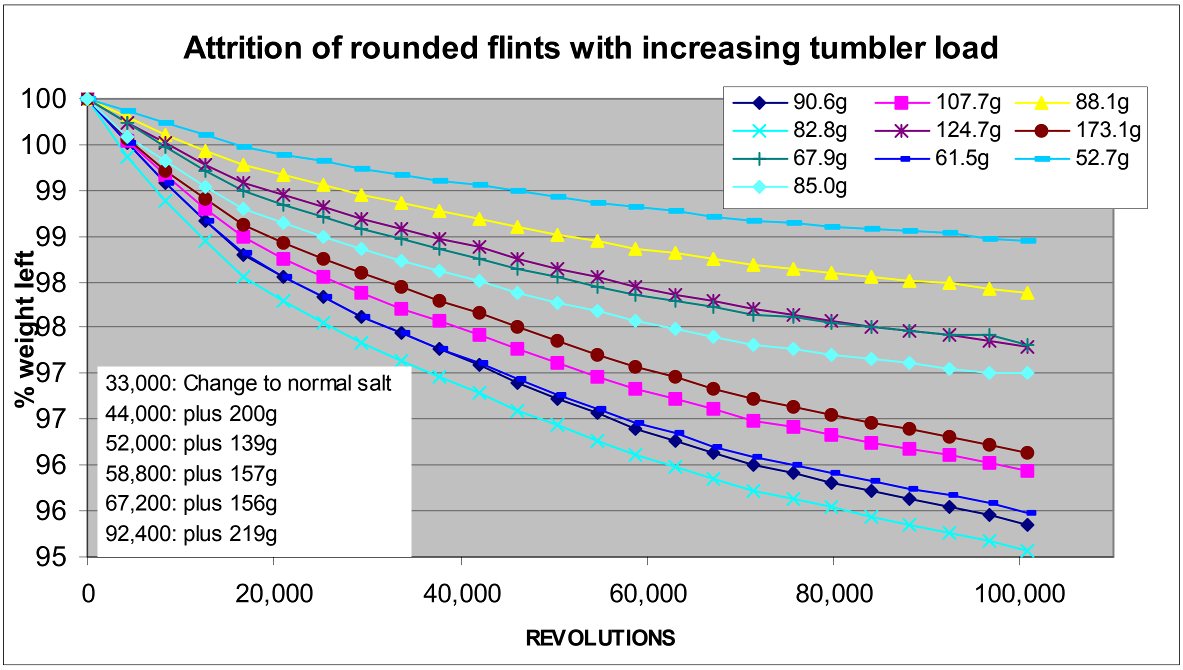


Figure 11: Change of abrasion rate with a gradual increase in the tumbler load. Abrasion of individual pebbles decreases with the time.

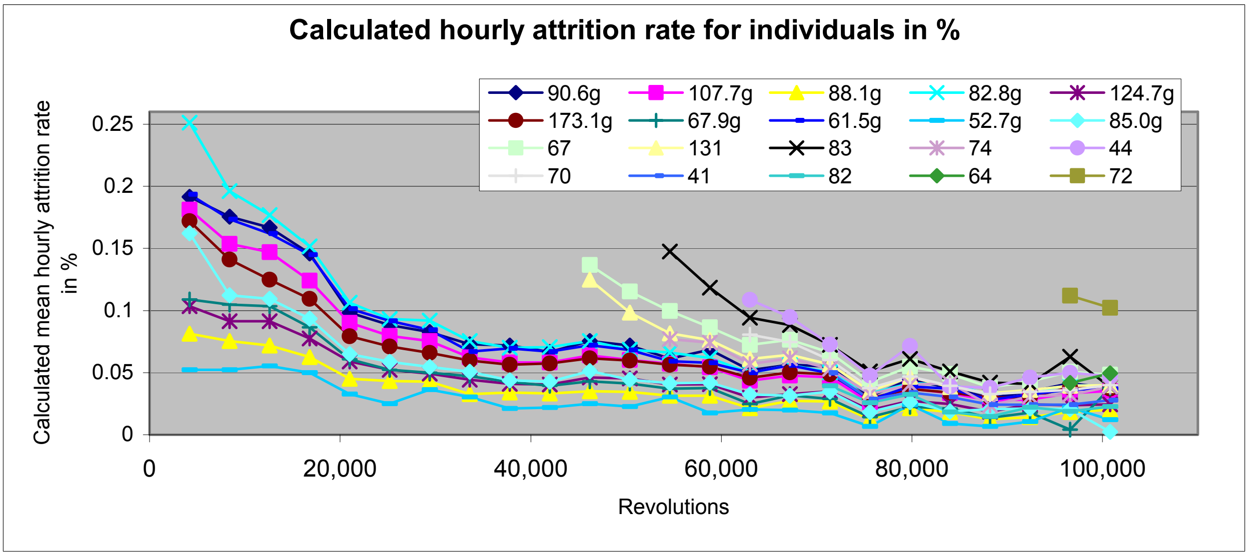


Figure 12: Individual curves for the change in abrasion rate of the 10 initial pebbles shown in figure 11 and those added at intervals.

Almost all pebbles show an initially higher attrition rate that seems to stabilize after ~35,000rev also seen in the mean attrition rate for all 10 initial pebbles (figure 13).

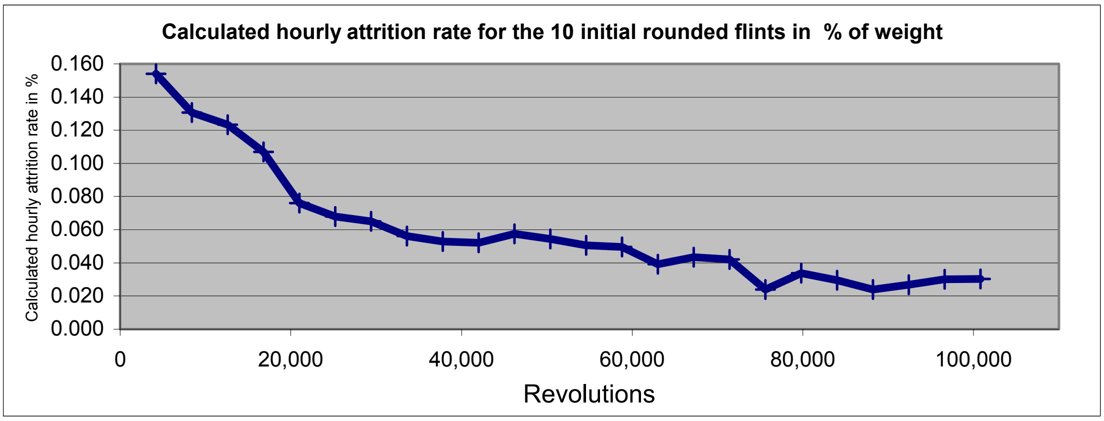


Figure 13:Averaged mean hourly abrasion rate for the 10 pebbles starting the experiment.

4.3 Abrasion rates and different barrel loads: Experiment 2

The aim of this experiment was to assess the influence of barrel load on abrasion rates. One barrel was filled with well rounded, near spherical flint pebbles, all approximately the same size (32-48.5 mm in diameter, mean weight 104 g), collected on Newhaven beach (TV 5446/0999). Reconstituted seawater was added to fill the voids and cover the pebbles. The pebbles were then decanted and randomly assigned to three barrels to create 50%, 35% and 15% flint loads. The interstitial water was divided amongst the barrels according to the same percentages so as to maintain a constant shingle:water ratio. Prior to weighing the pebbles were surface dried using a paper towel. Each barrel was then tumbled for three successive tumbling intervals of 2.5 hours. The total average weight loss of the pebbles over 7.5 hours was 0.4%.

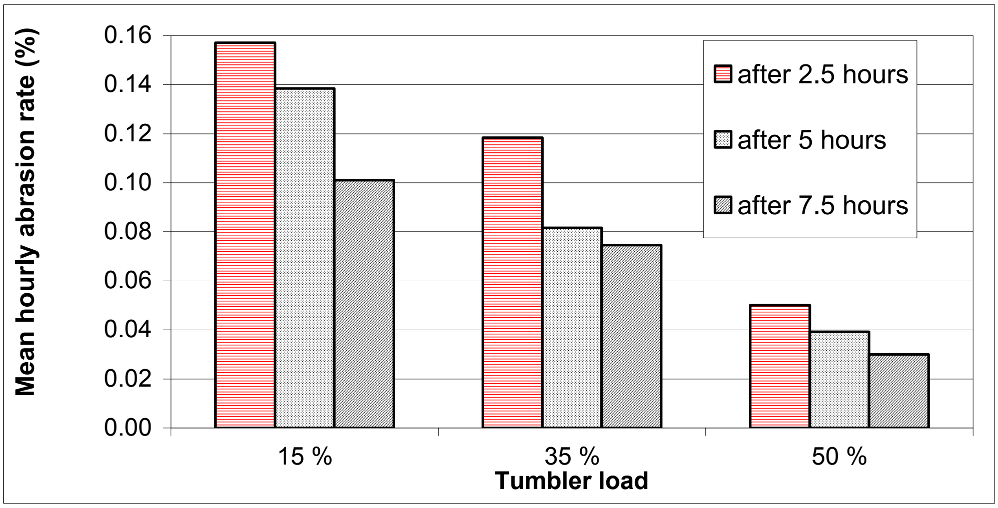


Figure 14: Mean hourly abrasion rates expressed as %weight loss for three different barrel loads and three successive tumbling intervals each of 2.5 hours duration.

As shown in Figure 14, the abrasion rate in all three barrels decreased from one tumbling interval to the next. The rate also decreased with increasing barrel load. As more and more stones are placed in a barrel, their freedom of movement becomes increasingly restricted, thus reducing the abrasion. The decrease of the attrition rate with time which was also observed in other experiments not described in detail in this study seems to indicate that the pebble surface changes during the tumbling.

Experiment 3

This was designed to establish whether the shingle:water ratio is an important determinant of flint abrasion rates and is based on the observation that the attrition rate decreases over time. Three barrels were each one-third filled with flints (mean weight 80g) from Newhaven beach, and then tumbled for four successive intervals of 2.5 hours each, followed by reweighing. For the first and last tumbling intervals, seawater was added to each barrel until it filled the voids and just covered the flints when the barrel was placed in an upright position. For the second and third tumbling intervals one barrel (A) was recharged with the same amount of water as before, a second (B) was recharged with only 50% as much water for the second interval and with 150% for the third interval, while the third barrel (C) was recharged first with 150% and then with 50% in mirror image of B.

The pebbles were weighed before and after each tumbling interval after they had been surface dried with a paper towel. The mean hourly abrasion rate for the three barrels is shown in Figure 15. Barrel A with the unchanged shingle:water ratio should have shown a gradual decrease in the attrition rate like the one seen in Figure 14. However, during the second tumbling interval the abrasion rate was lower than expected. Barrel B shows a similar abrasion rate for the second interval to the first, indicating that the reduced amount of water increases abrasion. With an increased water amount the abrasion rate drops during the third interval and increases again when the water amount is decreased to 100%. Barrel C shows a mirror image with a decreased abrasion rate during the second interval coinciding with an increased amount of water, an increased abrasion rate during the third interval coinciding with a decreased amount of water, and a decreased abrasion rate during the fourth interval again coinciding with an increased water amount. The experiment therefore seems to indicate that with an increased water:shingle ratio the abrasion rate decreases.

The preliminary experiments indicate that in order to ensure comparability between tumbling experiments tumbling interval, barrel load and water:shingle ratio in the barrel should be kept constant. The mean hourly abrasion rate for the three barrels is shown in Figure 15. Barrel A recorded a relatively high abrasion rate in the first 2.5 hours, then an appreciably lower rate, as in Experiment 1. In the case of barrel B there was almost no decline in the abrasion rate in the second tumbling interval.

Presumably, this was because any decline of the type shown by barrel A was masked by enhanced abrasion due to the lower water content. When the water content was increased threefold in the third tumbling interval, the abrasion rate dropped markedly. Barrel C experienced a smaller decline in the abrasion rate in the second interval than barrel A and no decline in the third interval when the water content was switched from 150 to 50%. The experiment, therefore, appears to show that small amounts of interstitial water lead to enhanced abrasion, presumably because the pebbles are less cushioned by water as they are tumbled. With larger amounts of water, differences in the shingle:water ratio would appear to have less effect on the abrasion rate.

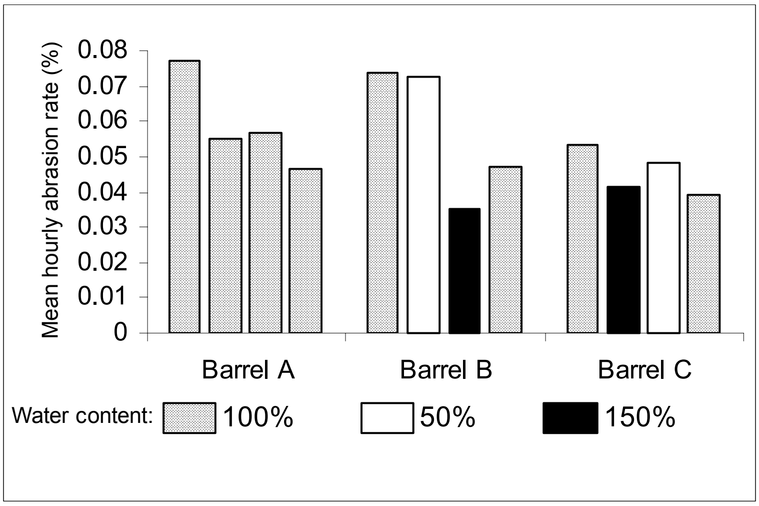


Figure 15: Mean hourly abrasion rate for a random samples of beach flint from Telscombe. Barrels were filled to 33% with pebbles, water content varied between 50 and 150%.

4.4 Drying times

During the preliminary experiments it became clear that the drying of the flints needed to be standardised for the main experiments because different levels of moisture content may affect the weight changes. To determine a drying time that is practical under the whole experimental design and also minimises the effect of different moisture levels on the weight changes recorded the following experiment was carried out. 15 flint pebbles with a mean weight of 261g underwent three wetting and drying cycles during which the weight of each pebble was recorded at intervals (figure 16). Pebbles were soaked in reconstituted seawater for 24 hours, than rinsed with deionised water and dried at 50°C. Drying at 50°C was thought not to alter the flint itself and allowed to handle the pebbles straight out of the oven. Figure 16 shows the average weight change for the three cycles. After 24 hours of drying at 50°C the difference between the pebbles weights of the three cycles was less than 0.01g indicating that the pebbles were dried down to the same level of moisture content. Comparing these weight changes due to drying with average weight losses of 0.6g for pebbles of similar size over the first 2.5 hours of tumbling (see sections below) it becomes apparent that, using 24 hour wetting and drying cycles, weight changes due to different moisture levels will be insignificant.

Additionally, the rate of weight change during drying is important because weighing of several samples cannot occur exactly at the same time and the 24 hour drying interval will range from 23.5 to 24.5 hours. The average hourly weight change after drying for 24 hours was less than 0.002g indicating that unavoidable variations in the drying time of ± 0.5 hours will be insignificant compared to 0.6g weight change due to abrasion.

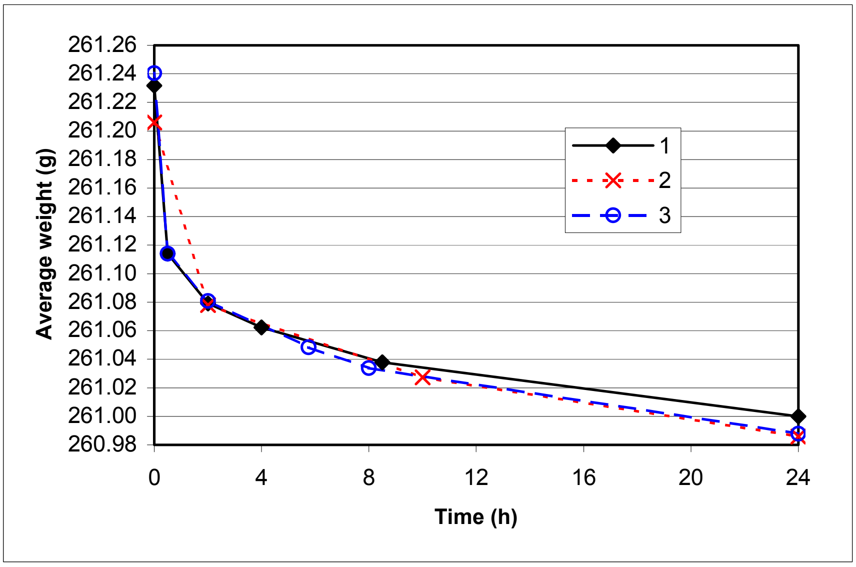


Figure 16: Average weight change of 15 f lint pebbles after 24 hours of wetting and 24 hours of drying at 50°C. The initial weight at room temperature was 261.072 g. Curves 1 to 3 show three successive drying cycles.

4.5 Main experiment

The aim was to assess the influence of shingle size and origin on abrasion rates. In the light of experience gained through the preliminary experiments a standardised procedure was adopted. A sufficient number of pebbles of a chosen size were collected to fill one barrel. The barrel was than filled with water to determine the interstitial void space and the pebbles left to soak for 24 hours. The number of pebbles was than halved randomly and dried for 24 hour at 50°C after which the weight was recorded. They were than placed into a tumbler which was filled with half the amount of water using reconstituted seawater. After being left to soak for 21.5 hours, the pebbles were tumbled for 2.5 hours; they were then removed, cleaned, once again dried for 24 hours, and re-weighed. This procedure was repeated two more times, giving a total tumbling period of 7.5 hours. As before, abrasion rates were recorded as percentage weight loss per hour.

The pebbles tested were from East Sussex beaches at Newhaven (samples Sussex A-B in Figure 17 and 18) and Telscombe (TQ 5392 1014, samples Sussex C-H) and from Normandy beaches at Fécamp (~3110/55158, samples Normandy A and C) and Étretat (~2980/55098, samples Normandy B, D and G). The number of pebbles used ranged from 14 (Sussex F) to 137 (Sussex A) per barrel**.**

In the case of the Sussex flint samples, the abrasion rate increased quite markedly (and linearly) with increasing pebble weight. Figure 17 summarises the results for the first 2.5 hours of tumbling. A similar increase in rate with size has been reported for other lithologies (e.g. by Daubrée 1879, Krumbein 1941, Loveday & Naido 1997). Unexpectedly, however, the flints from the Normandy coast showed no increase in rate with size, and were much more resistant than the English flints. However, this seems to be the case only for the white flints from Etretat as grey flints from Le Criel with a mean weight of 130g had a mean hourly abrasion rate of 0.52% which is much higher that that for pebbles from Etretat but is very similar to abrasion rate found for grey flints from Sussex.

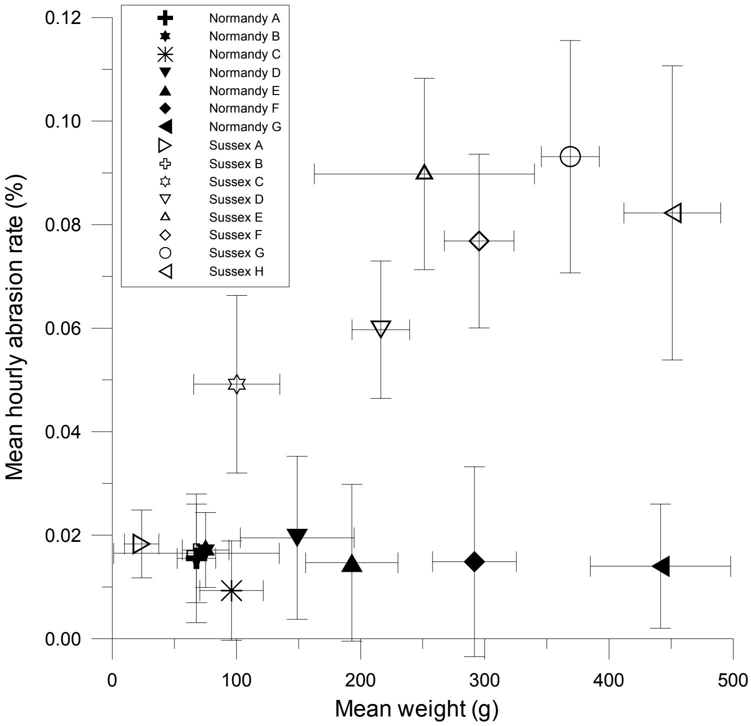


Figure 17: Comparison of abrasion rates between flints from East Sussex and Normandy in relation to size (weight). Error bars are 1 standard deviation.

The abrasion products were predominantly silt sized (Figure 18), though the samples Sussex D-F each produced between 0.7 to 0.15% of fine sand grains in the range 300μ to 500μ. With the exception of Normandy C, the abrasion products of the Normandy flints were finer than those from Sussex. The mean size of the abrasion products appeared to be unrelated to shingle pebble size.

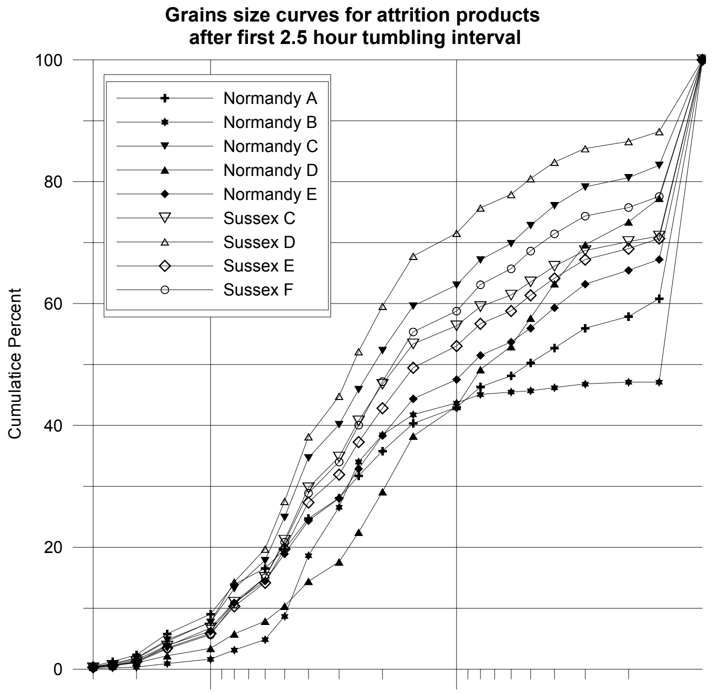


Figure 18: Comparison of grain size of the abrasion products after the first 2.5 hours tumbling interval.

Figure 19 shows the variation in the abrasion rate with time. With the Sussex samples the abrasion rate decreased, fairly rapidly at first and then more slowly, repeating the trend observed in Experiments 1 and 2. The behaviour of the Normandy samples was quite different: the rate of abrasion dropped after the first 2.5 hours, but then rose after 5 hours to exceed the initial value.

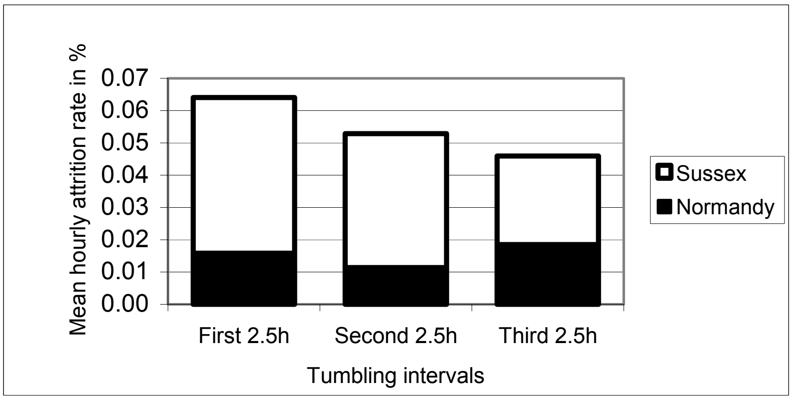


Figure 19: Abrasion rates for three successive tumbling intervals of 2.5 hours each, averaged over all samples from Normandy and Sussex included in the main experiments

Discussion

Several researchers (e.g. Krumbein 1941, Bigelow 1984, Sunamura et al. 1985) have observed decreases in abrasion rates over time but only from initially angular fragments to more rounded pebbles and have attributed this to changes in shape or weight. Sunamura et al. (1985), investigating sliding rock cubes, claim that the reduction is merely a function of decreasing pebble size. However, this explanation cannot apply to the Sussex flints. As Figure 6 shows, the abrasion rate in the first 2.5 hours roughly doubles (abrasion rate = 0.0002mean weight + 0.0183 with $R^2 = 0.828$) with increasing pebble weight from 100 to 500 g. Yet in the tumbling experiments described here, the abrasion rate drops 15% in the first 2.5 hours even though weight loss is of the order of 0.2% for a mean pebble size of 300g. Only a small fraction of the decrease in abrasion rate can thus be attributed to weight loss. With such small weight changes appreciable changes in shape or roundness do not occur. Most of the reduction must be due to other factors, the most important of which may be changes in pebble surface texture.

Minute crescentic fractures develop on the surfaces of flint pebbles on Sussex beaches causing the initial black surface to appear grey. These “chatter-marks” are believed to develop during storms when the pebbles make high-energy impacts with each other (Williams & Roberts, 1995). When the pebbles are tumbled in the laboratory, where most of the movement is rolling and sliding, the chatter marks are likely to be slowly worn away so that the pebbles become smoother. Impacts between the pebbles are evidently too gentle and too few to create new, or sustain existing, chatter marks.

The failure of the tumbling to renew chatter-marked surfaces may well explain why the rate of wear of the pebbles decreased with time. It may also mean that the experiments underestimate the abrasion rate of flint pebbles in the high-energy beach environment. Differences in the extent to which the surface of individual pebbles in the field are chatter-marked may result from differences in exposure to waves and could explain the large variability of abrasion rates indicated by the error bars in Figure 6.

Further experiments are planned to quantify the degree of surface microfracturing and brittleness, and to investigate its influence on abrasion rates. These experiments will also examine the question of why the samples of flint shingle from the Normandy beaches proved much more resistant to abrasion than the samples of Sussex shingle. All the flint pebbles tested are thought to have originated from erosion of the Chalk strata exposed in the cliffs and shore platforms immediately adjacent to, or just west of the sampling sites, and not from Quaternary gravels or other secondary sources. The dark grey to black Telscombe and Newhaven flint pebbles (Figure 20) were almost certainly derived from the High

Santonian-Lower Campanian Newhaven and Culver chalks, which form the local cliffs and shore platforms. Likewise, the flint pebbles from Étretat and Fécamp can be assumed to have originated from the older Turonian and Coniacian chalk, which forms the local cliffs and platforms. They are pale grey to white and sometimes banded, unlike flints from equivalent strata in Sussex which are dark grey or black. Despite their different age and colour, the flints from both the Sussex and Normandy locations have a density of 2.5-2.6 gcm^{-2} and Schmidt Hammer hardness tests conducted on samples Normandy E ($x = 60.47$, $\sigma = 3.2$) and Sussex E ($x = 60.4$, $\sigma = 2.8$) showed no appreciable differences (N for each sample = 17).

Although the Normandy coast is more sheltered from the prevailing southwest gales than its Sussex counterpart, significant wave heights are on average only slightly lower than for the Sussex coast (BODC 1998). Significant wave heights for extreme conditions, however, are ~0.5m lower on the French than on the Sussex coast (Posford Duvivier 1993, Allen & Delannoy 1990). Thus, the wave environment on the two coasts does not appear to be sufficiently different to explain the significantly different abrasion behaviours of the flint pebbles. Nevertheless preliminary examination suggests that the Normandy pebbles may be smoother and less intensely chatter-marked than the Sussex pebbles. Further tests are planned to examine the influence of different surface texture characteristics. That the flints from Étretat and Fécamp are likely to be much different from other Normandy flints is indicated by the tumbling of two barrels filled with dark grey and black flints from Criel-sur-Mer, which at a mean size of 122g abraded at 0.052% per hour and fit well into the abrasion curve of the Sussex flints.

It is difficult to explain why abrasion rates increase with pebble size for Sussex but not for Normandy flints. Because large pebbles are heavier than smaller pebbles they could be expected to generate greater impact pressures. This explanation ought to apply equally to the Normandy pebbles but clearly it does not, perhaps because they are much more resistant to the relatively weak abrasion forces of the tumbler. However, this is not supported by the Schmidt hammer values.

Figure 20: Visual comparison between the samples Normandy E and Sussex E.

Conclusion

The tumbling experiments, using flint pebbles from the Sussex and Normandy beaches, have shown that the Normandy flints are much more resistant to abrasion than those from Sussex. In the first 2.5 hours of tumbling, Sussex flints lose on average about 0.06% of their weight per hour whilst the Normandy flints lose 0.018%. Impacts in the tumbler are frequent but of much lower energy than those on the actual beaches, which could suggest that abrasion losses on the beaches are by no means negligible. If flint shingle volumes on Sussex beaches are being appreciably reduced by abrasion, the beaches may provide less effective protection from flooding and cliff erosion than is commonly supposed. The implications for coastal zone management are considerable, and further research will combine field experiments with laboratory tests to estimate rates of flint pebble abrasion on actual beaches.

5 Field abrasion

Prior to the main experiment detailed below two tests were run to assess the possibility of measuring in situ abrasion. The first test was carried out on Seaford beach where two freshly broken angular flints (620 and 272g) were placed in the surf zone for a short period of time (43 and 13 minutes). Weight losses of 2.9 and 1.6g were measured giving weight losses of 0.6% and 2.6% per hour, clearly indicating the rapid wear of freshly broken flint.
The second test was carried out at Saltdean where a large quartzite cobble (1714g) was put into the surfzone unrestrained and four rounded flints (46 to 260g) where put into the surfzone attached to a string fastened to a metal road driven into the beach. All were recovered after 2 hours and during which they had been moved by 1 to 1.5 m high plunging waves. The hourly abrasion calculated ranged from 0.02% (large quartzite) to 0.2% for one of the flints. The pebbles in both test were only dried with a paper towel so that the weight changes may not accurately reflect the weight loss. The results demonstrated that measurable abrasion could be expected.

5.1 Introduction

[In this chapter the term shingle is used as the plural term and pebble as the singular for both pebble and cobble sized beach material]
Shingle beaches 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 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.

5.2 Location

Two beaches have been studied on the East Sussex coast (Figure 21). 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 pebbles and cobbles usually cover 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 1996 to 1997 (Figure 22a).

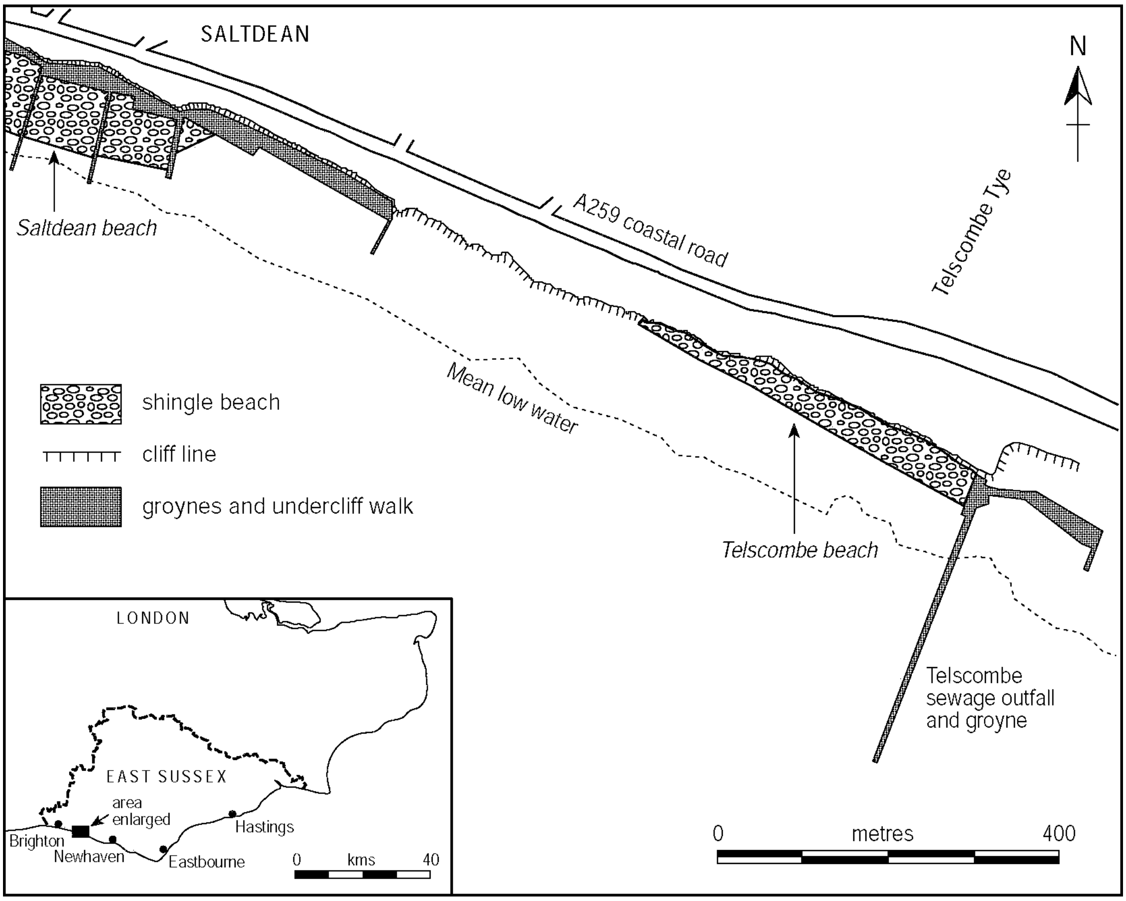


Figure 21: Location of test sites at Saltdean and Telscombe beach.

Telscombe beach, the second study site, is a more natural beach consisting of rounded black flints (Figure 22b) that are thought to have been eroded from the chalk cliffs behind and to the west. It is bound on the east by the groyne of the Telscombe sewage outfall but tapers out along the cliff towards its western end (Figure 21). The beach is ~430m long and up to 40m wide at its eastern end. Only storms waves coinciding with spring tides reach the beach cliff contact. Under average conditions the beach face is predominantly covered with pebbles and cobbles.

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, with 1.6% of the significant wave height exceeding 3m, and 43.4% of all waves arriving from 180° - 240°.

5.3 Methods

In situ measurement of the abrasion of shingle requires the recognition and identification of individual stones 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 22).

A B

Figure 22: a)Limestone pebble on Saltdean beach (limestone CL is 7.2cm long) and b) limestone and quartzite pebble on Telscombe beach (Quartzite 129 is 6.9cm long).

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 aiding 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 limestone pebbles and cobbles 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 rocks 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 21 and 22). 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 23).

Figure 23: Limestone pebble no 58 (354.92g in A) lost 5.3% of its weight (B) during 5 tides on Saltdean beach in April 2001 (mean wave height 1.7m).

To identify pebbles that lost their engraving, photographs were taken before they were put out and identification was based on visual, size and weight comparison. Pebble weight was recorded to three decimals for pebbles <410g and to two decimals 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 (Figure 24). Figure 24 shows the weight change for 10 randomly selected quartzite and limestone pebbles (mean weight for quartzites 398g ranging from 11g to 1123g and for limestone 313g ranging from 75g to 586g). Prior to the experiment the pebbles had been in the lab for several weeks. The wet pebbles were soaked for 72 hours under vacuum whereas the others were left on the workbench in the laboratory. At time 0 in figure 24 all pebbles were placed in an oven at 50°C. The wet quartzites reach the weight of the dry quartzites after 23 hours and the limestone after 120 hours. The difference between mean weights prior to the experiment and after 120 hours was -0.0372 g for the wet quartzites (actually a weight gain though well within the balance error), 0.183 g for the dry quartzites, 0.193 g for the wet limestone and 0.3 for the dry limestones. Experiments with saturating and then drying quartzite and limestone pebbles 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. The average weight loss for all pebbles was 1.44g for limestones and 0.36g for quartzites indicating that weight changes exceed those measured over the drying procedure. Thus the drying procedure reduces errors associated with the weighing procedure.

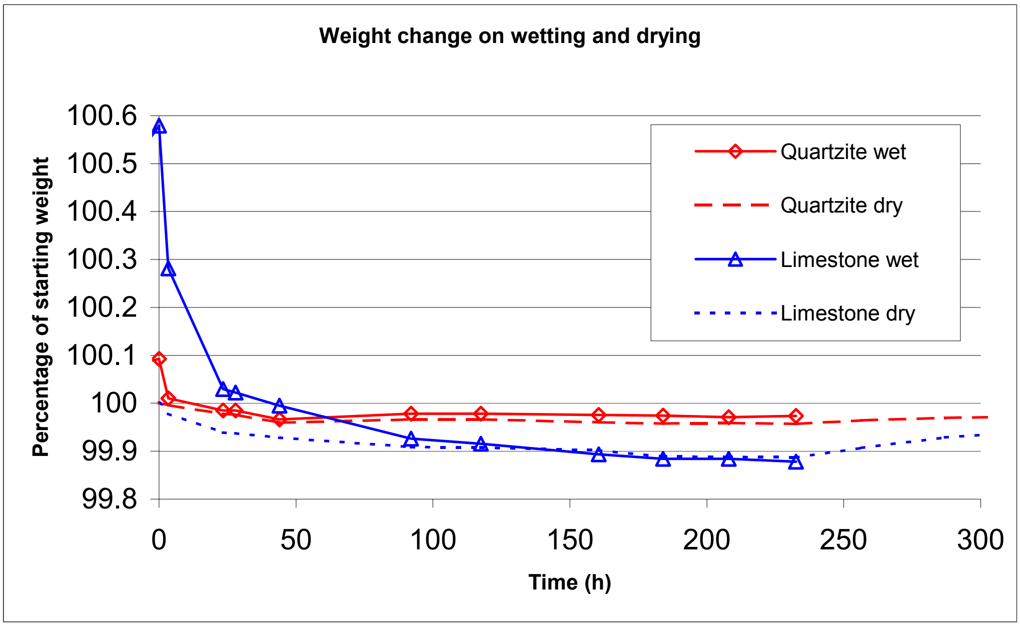


Figure 24: Weight changes for 10 limestones and 10 quartzites.

5.3.1 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 pebbles crossed the 85m long beach to within one metre of the western groyne.

5.3.2 Wave data

Wave and wind data was obtained from the UK MetOffice'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.

5.4 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 pebbles (38%) have never been recovered but many of the remaining 266 pebbles have been found, weighed and released several times, resulting in 710 abrasion rate measurements. Comparing the average weight of those pebbles 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 can be found. Nine measurements produced 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 25). The best collection results were obtained one or two tides after the seeding (Figure 25) 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 quartzite pebbles recovered was 0.36% of the pebble weight compared with 1.44% for limestones. A better measure of the abrasion is the percent weight loss per tide shown in Figure 25. This is very variable ranging from $7.5x10^{-5}$ to 1.27 %.

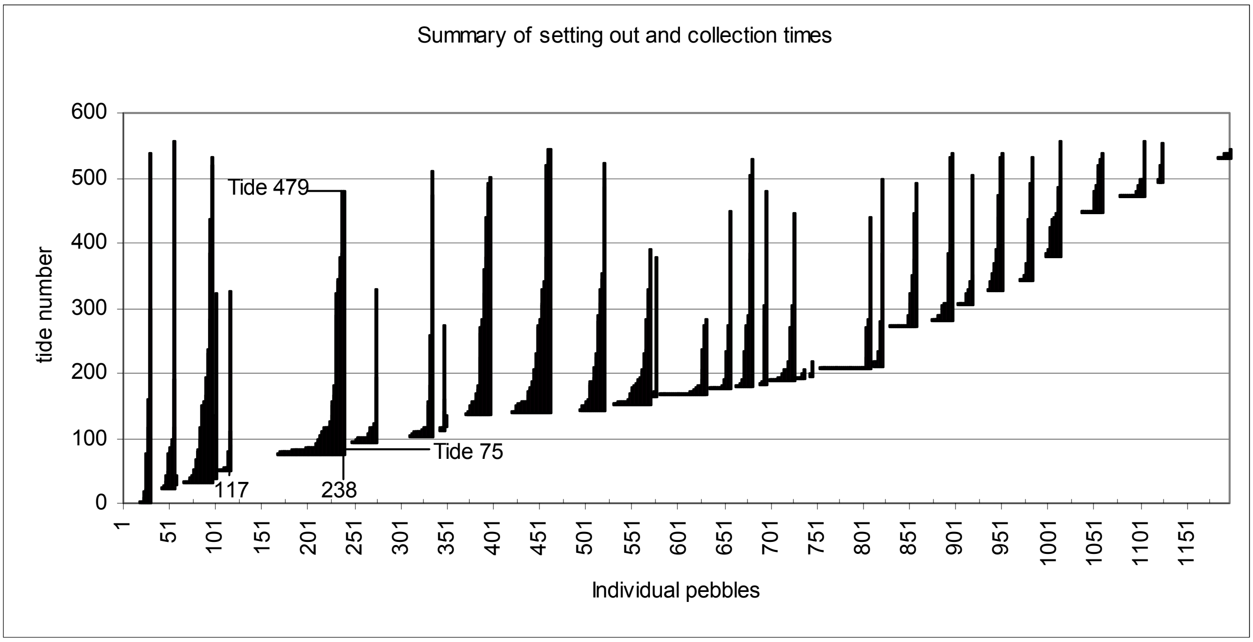


Figure 25: Summary of pebble seeding times and collection times up to October 2001.
Column height represent the amount of time a particular pebble has spent on the beach between seeding and collection. Gaps indicate pebbles that have been seeded but not yet recovered. Of all the pebbles put out at tide 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.

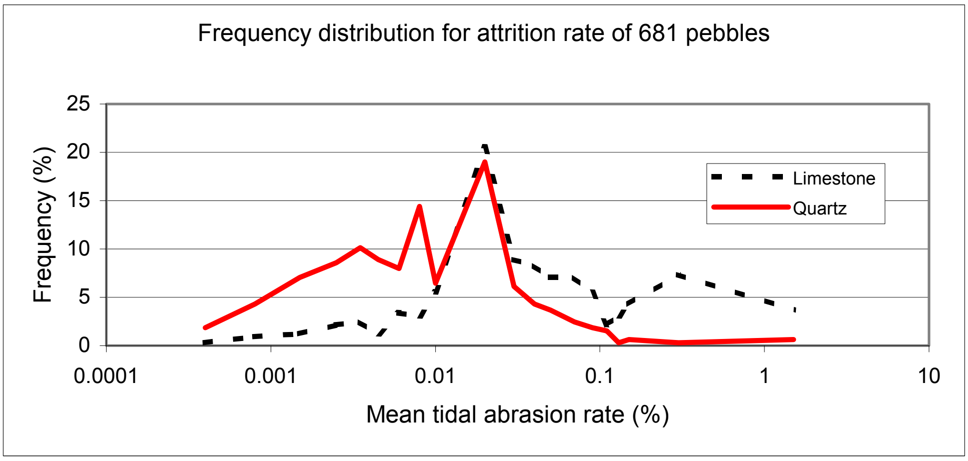


Figure 26: Frequency graph for 681 pebble records with abrasion rate >0%

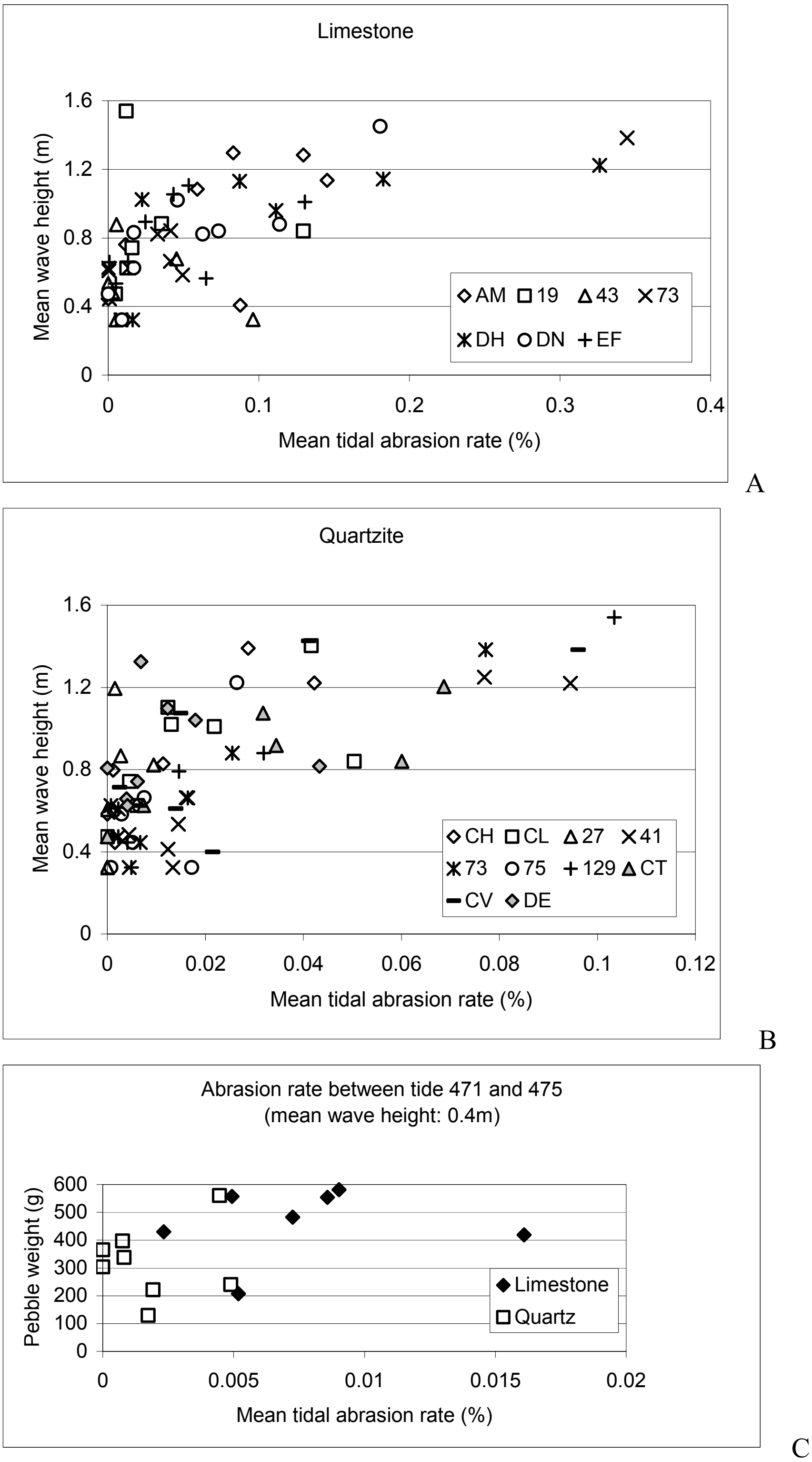


Figure 27: A + B: Mean tidal abrasion rates for 7 limestone cobbles (A) and 10 quartzite cobbles (B) with five or more abrasion rates plotted against mean wave height. Legend shows individual cobble identifications. C: Mean tidal abrasion rate for 15 pebbles after four tides on the same beach under weak wave conditions.

5.5 Discussion

In situ abrasion rates for limestone and quartzite pebbles 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 & 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 pebble 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 27a and 27b for most of the 17 pebbles that have been out more than five times each and in Figure 28 for all pebbles. The skewed distribution of the abrasion rates in Figures 25 - 28 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.

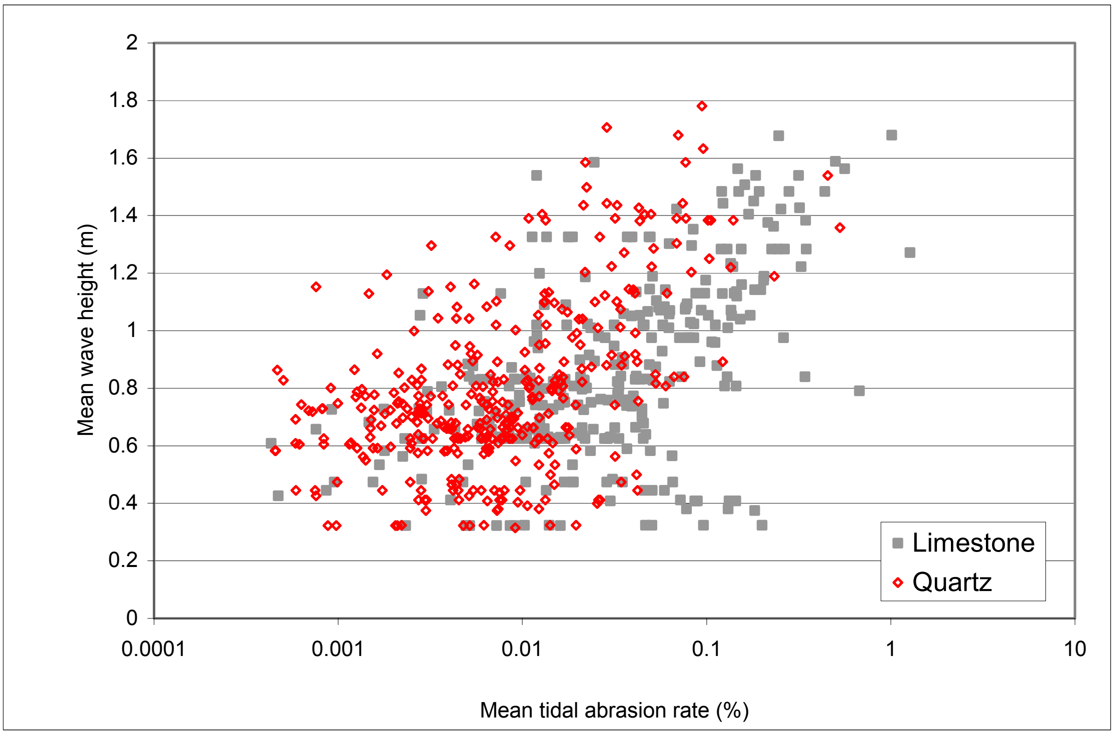


Figure 28: Mean tidal abrasion rate in relation to mean wave height for 681 pebbles.

Figures 26 and 27 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 27c 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 for limestone is 0.0266% compared to 0.0082% for quartzite (Figure 28). Mean tidal abrasion rate for all quartites was 0.008g and for limestones 0.026g. 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.

Multiple correlation analysis of the 681 measurements (Figure 29) 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 pebble is 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.

Pearson Correlation	Abrasion rate	Mean wave height	Pebble type	Pebble weight	Number of tides	Set out time
Mean wave height	.410					
Pebble type	-.276	-.121				
Pebble weight	.206	.183	-.274			
Number of tides	-.137	-.009	-.062	-.112		
Set out time	.104	-.129	.028	.171	-.159	
Beach location	-.020	-.062	.005	.098	-.160	.219

Figure 29: Pearson correlations

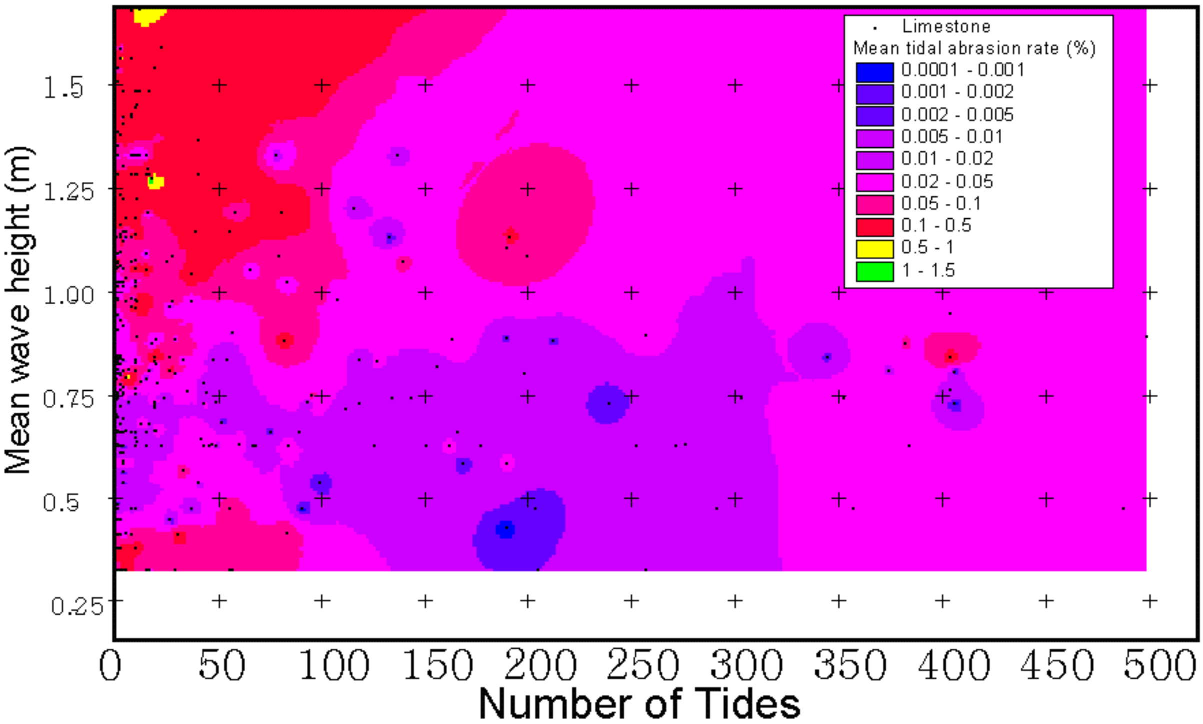


Figure 30: Abrasion rate for limestone in relation to mean wave height and the number of tides.

Figure 30 shows the abrasion rate in relation to mean wave height and the number of tides on the beach for each pebble. The mean number of tides pebbles have been out on the beach is 48 (compare with Figure 25) so that the highest data concentration for the surface plot in Figure 30 is found on the left hand side. The general pattern to be observed is that high abrasion rates have been recorded for pebbles that have been out for ~20 tides over which period high waves have been predominant (increase of the abrasion rate on the y-axis). With an increase in the number of tides a pebble has spent on the beach the abrasion rate decreases, given a similar wave height (decrease on the x-axis). This could indicate that pebbles that are found after more than 100 tides have spent a significant part of that time buried deeply in the beach and out of the mobile layer.

6 Calibration of flint abrasion rates in the field

To estimate the abrasion rate of flint in the field the laboratory tumbling experiments of flint are combined with the field abrasion rates of quartzite and limestone. Tumbling experiments were carried out as described previously except that one of the flints in each barrel was substituted with a quartzite or limestone. This arrangement provides for each barrel a mean abrasion rate for the flints and for the test pebble in that barrel (Figure 31).

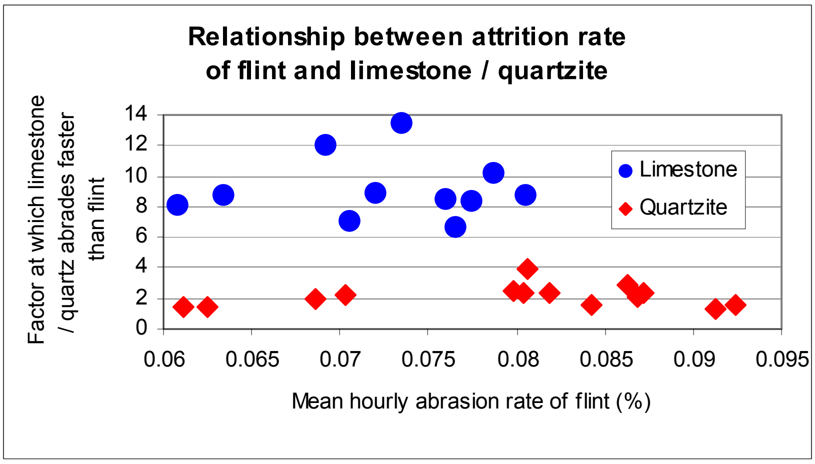


Figure 31: Abrasion rate of 11 limestones and 14 quartzites in relation to the abrasion rate of flint.

According to the correlation tumbling experiments quartzite abrades 2.1 times and limestone 9.3 times faster than flint. The ratio between the abrasion rate of quartzite and limestone based on these figures is 1:4.4.

Based on the mean tidal abrasion rates for quartzite 0.0082% and limestone 0.0266 (see above) and the relationships shown in Figure 31, flint pebbles are likely to abrade at a rate of between 0.00286% (based on limestone) and 0.0039% (based on quartzite). If one assumes the abrasion relationship found in experiments with rock cubes by KUENEN (1963: 29) where "losses by quartzite are one-third and losses by chert one-tenth of those of limestone" the flint abrasion rate would range from 0.00265 (based on limestone) and 0.027 (based on quartzite). All four of these estimates for the field abrasion rate of flint indicate a mean tidal abrasion rate of ~0.003%, that is ~2% per year.

If this figure is applied to the beach at Telscombe (section 7.3) the following calculations can be made. The beach as surveyed has a volume of 31,000m³ and a surface of 1,500m². From observations it can be assumed that, averaged over a lunar cycle, 50% of the beach surface is acted upon by the waves. If the mean depth of the sediment disturbed by wave action is 0.5m the volume that will actively abrade is 3,750m³ or 12% of the whole beach. Given the mean annual abrasion rate of 2% for the flint, the beach is likely to lose 75m³ of its volume annually. This would be counterbalanced by an average annual input of 96m³ from cliff retreat. This example calculation includes many unknown variables such as the depth of sediment disturbance and the present day flint production as the average has been calculated over the past 120 years. Nevertheless, it illustrates that in situ abrasion of flint on the beach may have a significant impact on the beach budget.

Tumbling of two limestones and two quartzites that have been recovered several times (Figure 32) allows for a first comparison of hourly abrasions rates in the tumbler with tidal abrasion rates in the field. The hourly abrasion rate for the 2.5 hour interval for Q129 = 0.23%, for QCV = 0.25%, for L19 = 0.65% and for LDH = 0.64%. This indicates that the abrasion achieved in one hour of tumbling is double the amount achieved on the beach even under relatively high energy waves.

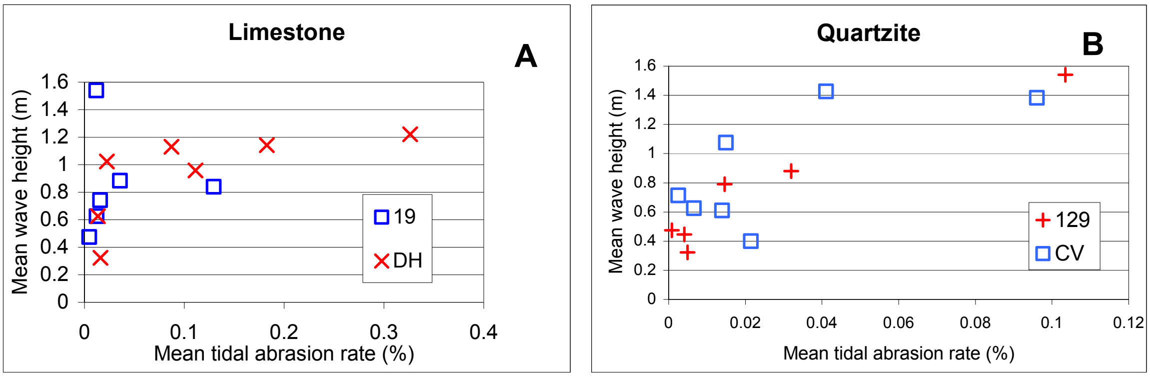


Figure 32: Field abrasion rate for two limestones and two quartzites.

Figure 33 shows the relationship between the field abrasion rate and the tumbling abrasion rate for three limestone and eight quartzite pebbles. For each a number of field abrasion rates under different wave conditions and one tumbling abrasion rate have been measured. It shows that the abrasion obtained during one hour in the tumbler might equal the abrasion rate during one tide only under very heavy wave conditions; under weak waves the hourly abrasion rate in the tumbler may equal 100 or more tides on the beach.

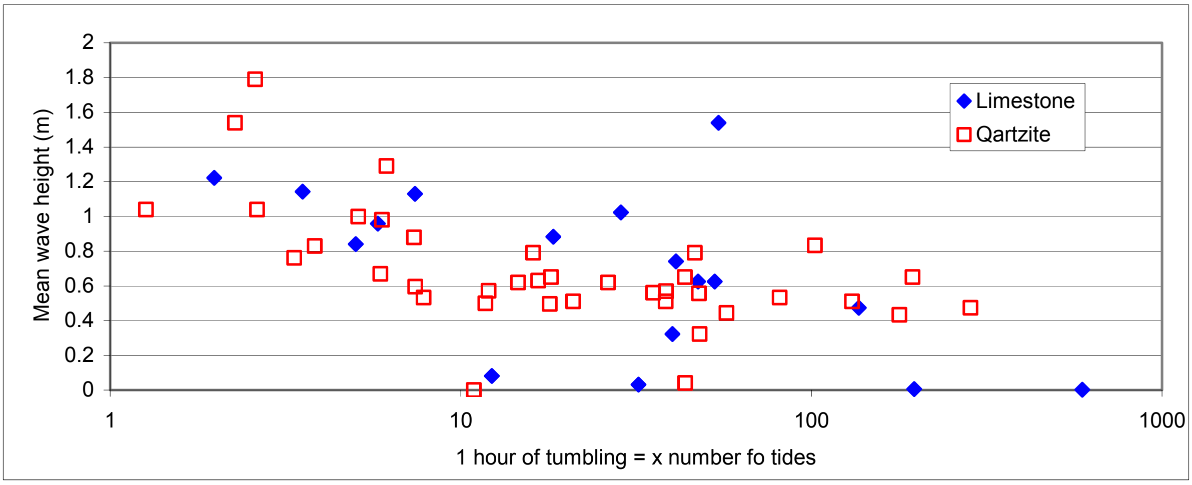


Figure 33: Comparison between field and tumbler abrasion rates.

7 Beach volume changes

To calculate the volume loss due to in situ abrasion the beach volume has to be known. Furthermore changes of the beach volume of beaches in closed systems (e.g. between groynes) could support the results of the filed abrasion experiments or the results from the flint input.

It was thought that changes of beach volume could be estimated from shore profile data provided by the Environmental Agency (and the predecessor organisations). Nearly 300 beach profiles along the East Sussex coast have been surveyed annually since 1973. The photogrammetrical survey has changed format over the years so that the profile data is of different quality. Form 1975 to 1976 height measurements where recorded at equal distances of 5m. This changed to variable distances in 1977 and since 1990 a description of the shore surface is also provided in the record, allowing for the identification of the beach and its composition.

Other problems with the data involve the lateral displacement of the profiles, the vertical accuracy and the displacement of the profile starting point. Both of these seem to be responsible for apparent shore developments that are contrary to what would be expected from natural processes.

7.1 Example Belle Tout

Figure 34 shows that a rock platform was present during the last years (i.e. 1991 – 1995) along profile 515. The contour lines (e.g. the 0m contour line) are located shoreward of their previous positions. The only explanation for this change in the elevation of the shore platform is rapid (in the order of several decimetres) uplift which is not a process observed on the East Sussex coastline. Therefore the tendency shown by that profile must be due to the problems mentioned above.

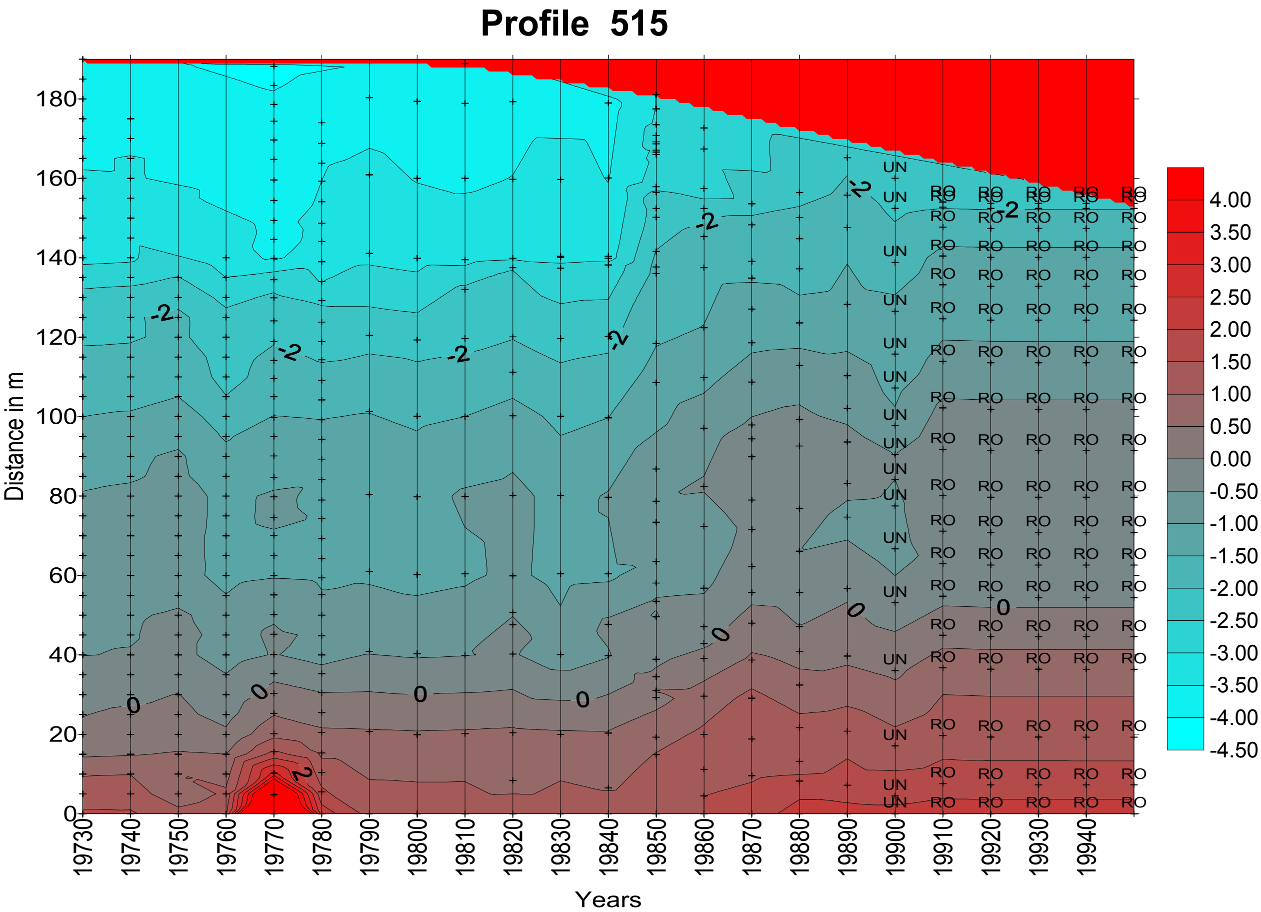


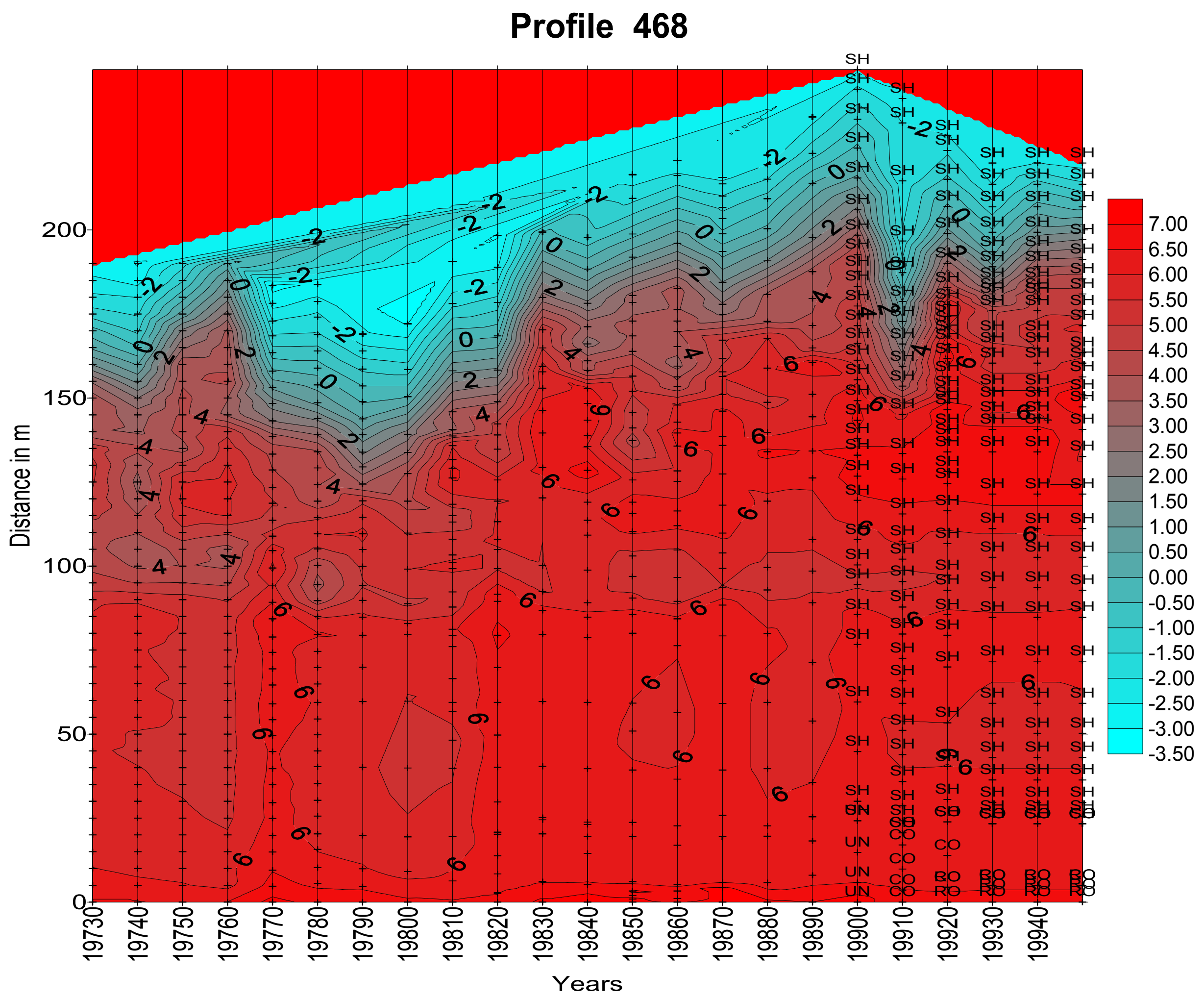
Figure 34: Graphs showing the surface elevation of profile G515 in front of the Belle Tout lighthouse for the years 1975 to 1995

Figures 34 and 35: Graphs showing the surface elevation (contour lines) of survey profiles; profile years on the x-axis (1973-1995, the 0 behind the years is a necessary artefact of the graphic program), distance offshore from the profile starting point on the y-axis. Letters on the profiles from 1990 onwards denote surface cover (SH= shingle, SA= sand, RO= rock, CO= concrete, UN= undifferentiated). Seaward movement of a contour line indicates accumulation of material, landward movement of the contour line indicates erosion. Positive heights well seaward in the profiles are an artefact of the graphic program.

7.2 Example Newhaven

Profile 468 (Figure 35) seems to cover shingle so that one could assume that the seaward movement of the contours indicates shingle accumulation. However, from 1982 to 1983 there is a jump seaward of the contours which may not be an accumulation (where would be the source for such a large scale accumulations) but a change of the point from which the survey line starts. This 'jump' can also be seen in the calculated beach volume (Figure 36, 'EA-volume). If one assumes a change of surveying ('corrected volume') then the volume changes are far less pronounced and it can be argued that changes are well within the photogrammetrical surveying error.

Figure 35: Profile G 468 west of Newhaven.
The whole profile is likely to represent the shingle beach (SH signature for the last years) west of the breakwater. This profile seems to record an increase in beach volume though the inter-annual variation can be considerable (see 1991)



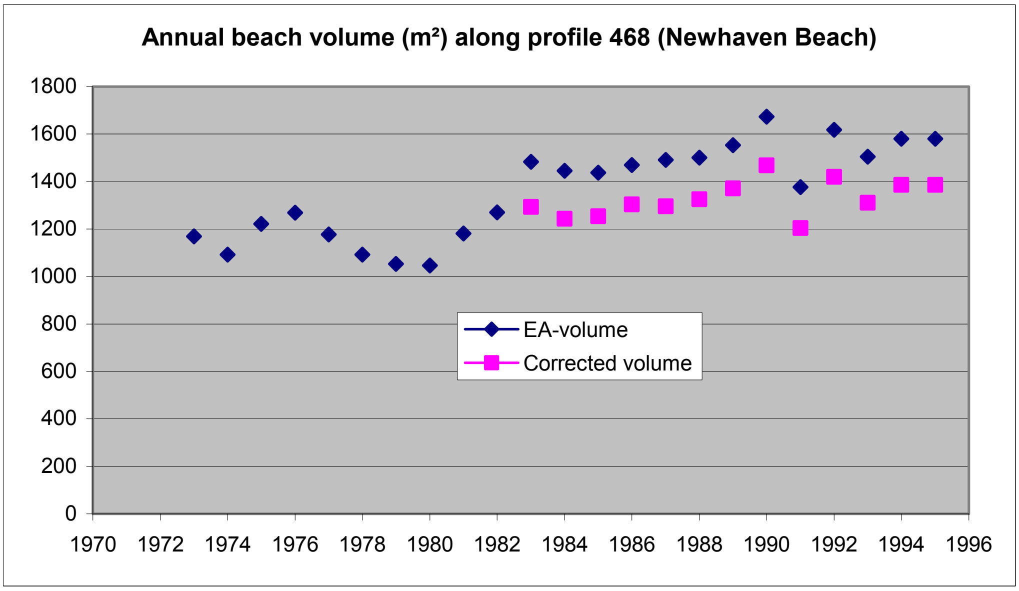


Figure 36: Beach Volume in m³ for profile 468 representing different survey assumptions.

A more general problem lies in the assumption that every part of a profile above –2mOD is beach material. At Telscombe beach the profile length above –2m is ~95m whereas a terrestrial survey and observations over one year indicate that the lowest point of the beach is at ~-0.5m. The profile area above –2m therefore severely overestimates the beach amount

7.3 Example Telscombe:

A terrestrial survey of Telscombe beach in August 2001 allows for some comparison with the ABMS data, though profiles were only available for 1995. The 2001 profiles (Figure 37) end at the beach-shore platform interface which lies significantly above the –2m level assumed for the ABMS survey. For 1995 the volume for both profiles is provided to be 46322.71m³ for profile 444 and 57356.13m³ for profile 445 (Figure 38). From the terrestrial survey in 2001 a volume for the total beach was calculated to be 31000m³ (that is shingle above the platform height taken at the beach platform interface which is actually sloping) significantly less than the volume for the individual profiles.

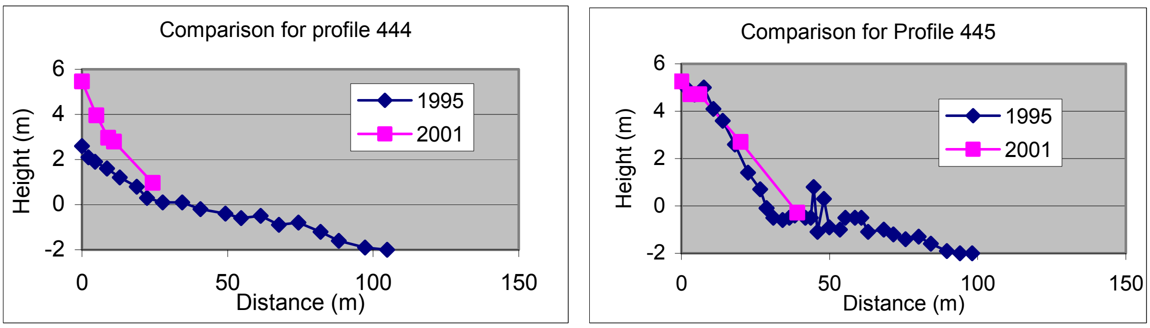


Figure 37: Comparison of profile data for the two profiles of the beach between Telscombe Treatment works and Saltdean. Profile 1995 from EA data, profile 2001 from terrestrial survey.

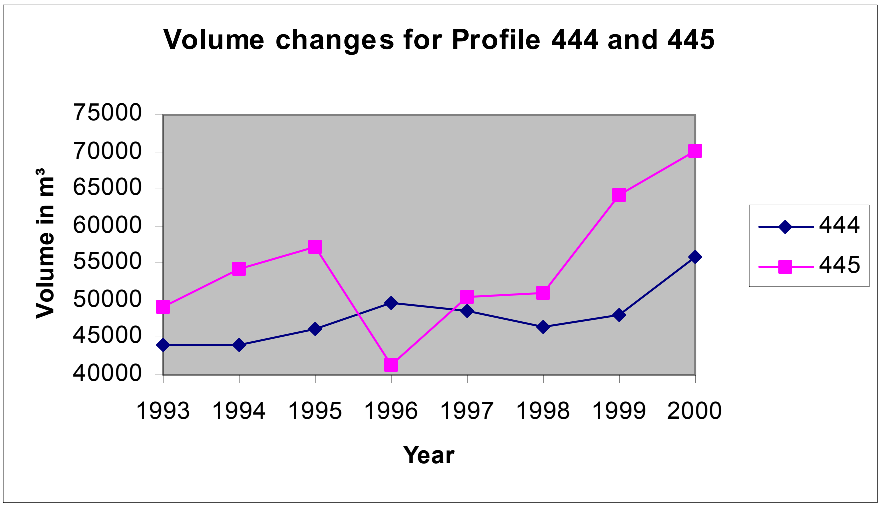


Figure 38: Volume changes for the two profiles of the beach between Telscombe Treatment works and Saltdean.

Qualitative assessment of the EA airphotographs for Telscombe beach indicate, that the beach area has increased from 1973 to 2001 (Figure 39), especially its western end seems to have grown. However, no quantitative analysis has been carried out because the airphotographs could not be orthorectified.

Figure 39: Qualitative comparison between outline of Telscombe beach in 1973 and 2001.

Possible solutions:
First attempts have been made to use the original EA air photos to create DEM's of beaches using modern photogrammetrical software. Air photographs are scanned and orientated with regard to the camera calibration and the ground using fiducial marks, ground control points and tie points. All this information is available and with the digital Superplan plus data from the Ordnance Survey ground

control can be achieved to a fairly high degree. The DEM extraction process works by comparing the parallax difference between pixels in two photographs.

This process depends very much on the identification of pixels in the two images. Problems have arisen form potentially 'featureless' surfaces such as beaches. Though a pebble beach has certainly more features that a sandy beach at a scale of 1:5000 (EA photos) a pebble of 5cm is 0.01mm (10microns) large on the air photo. Not only needs a scanner to be able to achieve such a resolution (2540dpi hardware resolution) but geometric accuracy of the scanner needs to be smaller than the resolution as well.

Test using an A3 scanner (UMAX Powerlook 2100XL, hardware resolution 800 dpi = 30mircons, no specification as to the geometric accuracy) show that either the resolution in itself or combined with a low geometric accuracy is insufficient to show any unique features on the beach and consequently the resulting DEM is of very limited accuracy.
It is possible that photogrammtrical scanners (e.g. Vexcel Ultrascan5000, at 40,000 US$ with a hardware resolution of 10 microns and a geometric accuracy of ± 2 microns) will provide better scans though whether the software would be able to produce more detailed DEM's would need to be investigated further.

8 Acknowledgements

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10 Appendix 1:Cliff retreat measurement using ArcView

Length:

Annual retreat rates are calculated from the area lost between two cliff lines of different age and position by dividing the area by the length of the cliff line. To provide retreat rates on a small scale the length of the cliff is divided into 50m long sections. The length of 50m was taken to use the same interval as was used by the French partners of the BERM project.

Cliff retreat measurement using ArcView

1. One needs two lines showing the cliff location at two different points in time (survey dates need to be known).
2. Create new shape files from the line themes and add them into the same View or a new view
3. Move the end nodes so that they nearly match to form a polygon
4. Using the Avenue Script **View.LineThemes2PolygonTheme.ave** create a polygon out of the polylines extending landward (the younger cliff line) and seaward (the older cliff line) thus leaving an empty space between the two polygons. (**the script apparently only works when there are no images in the view!!**)
5. Create a new Polygon theme and digitise loosely a polygon overlapping both cliff line polygon themes
6. Using the extension **Clip Theme** two times the polygon representing the area of retreat can be created (use clip outside!).
7. Create a new Line theme and draw a simplified line half way between the two cliff lines.
8. Use the extension **divideLineByAddingPointsEvenly** using 50m intervals to mark the retreat compartments on the 'half way' line.
9. Use the ArcView feature to cut the retreat polygon every 50m by cutting through the 50m point at right angles to the half way line (currently done visually!).
10. Use Intersect Themes from the **XTOOL** extension to cut the mean line with the ~50m polygons to obtain the exact length of the polygon.
11. Join the intersect file with the 50m-polygon-shape file and in its table add three new columns with the area ([shape].returnarea) the retreat (area/length of section) and the mean annual retreat (retreat/years).

Volume

For the following procedures in ArcView the extensions Spatial Analyst and 3-D Analyst are needed (extensions are only available from ESRI http://www.esri.com/software/arcgis/arcgisextensions/index.html).

Creating the DEM as a TIN

1. Digitise contours landwards of the present cliff as a point theme from recent maps (scale 1:100,000) with a contour line interval of 5m and save as a point theme (e.g. Land.shp). Add points along spurs and valleys so that interpolation is unlikely to produce horizontal triangles.
2. Extrapolate the line of the contours seawards and digitise points seawards of the present cliff line and beyond the oldest cliff line (e.g. sea.shp).
3. Digitise breaklines such as valleys, spurs or crest lines (e.g. breakline.shp).
4. Digitise a new polygon theme around the two point themes (e.g. border.shp).
5. Create a TIN with 3D Analyst extension using the point themes as mass points, the breaklines as hard breaklines and the border as hard clip polygon.
6. Check the TIN by using the contouring tool and compare with topographic map. It is probably necessary to add/delete some point features or to change the breakline or border feature and than create another TIN until satisfied with the TIN.
7. To create a TIN only for the retreat area load the Surface Tools for Points, Lines and Polygons (v. 1.3) extension. Select the Polygon theme that contains the retreat areas and combine it with the TIN created. Use the extension to calculate areas and volumes for the 50m retreat parcels and let them be joined to the Retreat theme (the extension has a very good guide).
8. To obtain cliff height data (average for longer stretches or for small stretches) use again the Surface tools extension with the respective line theme (the mean line or half-way-line used before is probably good enough for deriving a mean cliff height).

11 Appendix 2: ArcView Extensions used (descriptions copied from the web pages given)

ASCII <-> Shapefile Tool (txttool.avx..avx by Wei Sun)
Converts asii file containing coodrinates to shapefile and exports the coordinates of shapefiles to ascii file. Works for import space delimited ascii to point, polygon and polyline. The format for point ascii file is id, x, y (no comma for real data, space delimited). For polygon & polyline ascii files, the format is code (1 for start point, 2 for middle points, 3 for end point), x, y (no comma for real data, space delimited). Export shapefile to ascii file works for point, polyline and polygon shapefiles. The output format file is id, x, y. For polygon and polyline, the id is the sequence id of vertice.
(http://gis.esri.com/arcscripts/details.cfm?CFGRIDKEY=950645272).

ImageWarp 2.0 Updated March 16, 1999 (by Kenneth R. McVay)
March 16, 1999 In the recent March 12th update I neglected to add support for CAD drawings and AI coverages for the first input dialog. In this March 16 th release support for CAD and coverages has been included. ImageWarp 2.0 is an Windows 95, 98, and NT based extension that will allow you to geo-reference any image that ArcView will display to a feature theme, grid theme, or image theme. ImageWarp requires ESRI's Spatial Analyst ver 1.1 extension. ImageWarp 2.0 supports ouput image file types of bil, bsq, bip, jpg, and tiff. An associated header file will be created for newly warped images of types bil, bsq, and bip. For jpg and tiff output images a world file will be created with the newly warped image. ImageWarp works with 8 bit gray scale and 24 bit true color images. NEW FEATURES include Windows context sensitive help, a batch warp, restored menu,tool, and buttons bars, you can now save an ImageWarp session project, you can load a new or existing table while in a session, better dialogs and a few other things the user cannot see. If you find any problems let me know. I have chosen to put this version out with an InstallShield install program. The install directory must be your AVHOME directory. Be sure and READ the README.TXT before you install ImageWarp. If for some reason the files get installed in the wrong place just use find to find them and then copy them over into the correct folders as specified in the README.TXT. This should not happen if you specify AVHOME correctly. -peace K.
http://gis.esri.com/arcscripts/details.cfm?CFGRIDKEY=-1206309428

Polyline Themes to Polygon Theme (View.LineThemes2PolygonTheme.ave by Mel VanderWal)
This script lets you select one or more polyline themes, and convert their features (all or selected) into a polygon theme. The script offers improved results over the ESRI sample script in the following areas:
http://gis.esri.com/arcscripts/details.cfm?CFGRIDKEY=125825073

Clip Themes Extension (clipthm.avx by Peter Girard)
Clips the selected features in one theme with the selected polygons in another theme or with polygon graphics. Two buttons are added to the interface, one for inside clipping, the other for outside clipping. The buttons are enabled when a) two shape themes are active and one is a polygon theme, or b) one shape theme is active and the view contains polygon graphics. If two polygon themes are active, you will be prompted for which theme to clip. The clipped shapes can be saved in projected coordinates if desired.
http://gis.esri.com/arcscripts/details.cfm?CFGRIDKEY=1971330381

add points evenly along a line (divide2.avx by Seven Lead)
Add the specified number of points spaced evenly along a polyline, or add points separated by a specified distance. Similar to the Divide function in ArcMap.
The distances are calculated in the native units of the dataset's coordinate system (regardless of the Distance Units specified for the view).
Eg, if the datasets are stored in decimal degres, they must be projected to another coordinate system (eg UTM in meters) in order to use another distance measure. Requires a view with at least 1 polyline theme. Use the button at the far right of the view buttonbar to launch the dialog.
To "transfer" the line attributes to the output point theme, the easiest approach is to perform a spatial join. Refer to the ArcView help file under "spatial join" for further information.
http://gis.esri.com/arcscripts/details.cfm?CFGRIDKEY=947049820

Xtools (by Mike DeLaune)
Available for free download here is the **6/1/2001** version of XTools.
http://gis.esri.com/arcscripts/details.cfm?CFGRIDKEY=4D4DBAEA-25DA-11D4-942E00508B0CB419

Surface Tools for Points, Lines and Polygons (v. 1.3)

Description: This extension allows you to calculate various surface and topographic characteristics for Point, Line or Polygon Themes that overlay a GRID or TIN surface:
Point Themes: Calculate the X- and Y-Coordinates, the Slope, Aspect and Elevation, and the surface area, flat area and (surface/flat) area ratios within a circular area surrounding each point.
Line (or Polyline) Themes: Calculate the surface length, the flat length, and the (surface length)/(flat length) ratio of each line, the minimum slope, maximum slope and average slope of that line, and the minimum elevation, maximum elevation, average elevation, elevation range and cumulative elevation change of that line. You can also create a profile chart of the elevation change of the line, and generate a point shapefile of the high and low points on that line.
Polygon Themes: Calculate the surface area within polygons, the flat area and the (surface/flat) area ratio within polygons. You can also calculate the surface area and the land volume within each polygon that lies above and below a specified elevation. Finally, you can calculate the highest elevation, the lowest elevation, and the elevation range within each polygon, and you can generate a shapefile of the high and low points within that polygon.
GRID or TIN elevation theme: You can use either a GRID or TIN as your elevation theme. If you use a GRID, then this extension will create a TIN of the relevant area and calculate surface and topographic data from the new TIN.
Save and clip TINs: Because this extension uses TINs to calculate most surface and topographic data, it will either use an existing TIN or it will create a new TIN out of an existing elevation GRID. It then clips the TIN to the relevant area and gives you the option to both save these clipped TINs to your hard drive and display them on your screen. Therefore, even if you are not interested in the surface or topographic characteristics of your features, you may still find this extension to be a useful tool for clipping TINs to polygon boundaries. CAUTION: A clipped TIN may not be exactly what you think it is. See the manual or online documentation for an explanation of what happens when a TIN is clipped.
Multipart polygons and polygons with holes: This extension works with both multipart polygons (a "single" polygon shape that actually contains multiple polygons), and polygons with holes. Your TINs and your surface/topographic calculations will reflect the complete polygon.
All or only selected records: You can either use all the features (points, lines or polygons) in a theme for the analysis or you can restrict the calculations to a selected subset of features. If any of your features are selected, then only those selected features will be used in the analysis. If no features are selected, then all features in that theme will be used in the analysis.
Output: Upon completion, you will have a results table containing any or all of the data mentioned above. Please see the attached manual or online documentation for a detailed list and explanation of each field. You also have the option to create a Point shapefile containing the high and low points near your points, along your lines or within your polygons. If you are working with a Line (or Polyline) theme, you have the option to create a profile chart of the lines.
Requires: This extension requires the Spatial Analyst and 3D Analyst extensions, as well as a feature theme and an elevation theme. The elevation theme can be either a GRID or a TIN, but it must completely encompass the features. This extension also requires that the file "avdlog.dll" be present in the ArcView/BIN32 directory (or $AVBIN/avdlog.dll) and that the Dialog Designer extension be available in the ArcView/ext32 directory, which they almost certainly are if you're running AV3.1 or higher. You don't have to load the Dialog Designer; it just has to be available.
Updates: This extension replaces the extension called "Surface Areas and Ratios." This extension duplicates all functions in "Surface Areas and Ratios" and adds many new functions.
- The "1.1" update adds functionality for PointZ, PolylineZ and PolygonZ feature types, and fixes a file-naming error that occurred intermittently when the user chose not to save TINs to the hard drive.
- The "1.2" update corrects a logical error made when calculating average slopes of lines, adds the ability to calculate slopes of lines in both %-Slope (or Gradient) and Degrees, and adds the ability to save circles around points as a separate polygon shapefile.
- The "1.3" update corrects an error with Average Slopes of Lines, in which it wasn't including the first vertex of the line in the Average Slope calculations. The author thanks Ulrich Kollmeier for his observations and help in identifying these errors.
More detailed operating instructions may be found in the manual "Surface_Tools_Manual.zip", which is in Microsoft Word format, or you may view the manual on-line at:
http://www.jennessent.com/arcview/surface_tools.htm
http://gis.esri.com/arcscripts/details.cfm?CFGRIDKEY=C4F41249-4FD9-11D5-944200508B0CB419

12 Appendix 3: Letter from Ordnance Survey

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07 March 2001

Dr. Uwe Dornbusch
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Our ref: DC O9FE 01
Your ref:

Dear Dr. Dornbusch

Date of survey and accuracy of cliff coastline in OS digital data.

Thank you for your e-mail enquiry of 18 January. I apologise for the delay in replying to you. In the first part of your question you have requested information on when we last surveyed the cliff coastline (Brighton to Hastings):

- There are at least 79 different Digital Map Units (DMU) at either 1:1250 or 1:2500 capture scales covering this section of coastline; each has been surveyed and maintained under continuous or cyclic revision.

- 1:1250 data covers the large urban areas with the rural remainder covered by our 1:2500 data.

- No historical records are maintained about the date of survey for continuous revision.

- 1:1250 data is not currently subject to cyclic revision but is maintained for significant changes by continuous revision.
- Cyclic revision of the 1:2500 data has taken place between 5/6/96 and 16/3/99 using aerialphotography.

The following are the dates of photography by 1:25000 cyclic revision blocks:

TQ3O dated 8/4/97

TQ4O dated 5/6/96

TQ8O dated 16/3/99

TQ81 dated 16/3/99

TV49 dated 23/7/97

TV59 dated 23/7/97

TV69 dated 23/7/97

For comparison purposes you may be interested to know that pre 1980 OS aerial photography is available via the Royal Commission for Historical Monuments for England (RCHME). Post 1980 photography may be purchased via any of our Superplan agents.

The second part of your question requested information regarding the positional accuracy of the cliff data; the accuracy of map data is assessed using three criteria:

- Geometric fidelity, that is the principle that any real world alignment or shape must be accurately reflected in the data to the required specification.

- Relative accuracy, that is a measure of the positional consistency of a data point in relation to other points of detail (equivalent to "precision" in statistical terms).

- Absolute accuracy, that is the exactness of the position of a data point relative to its actual position defined in terms of the National Grid (OSGB36).

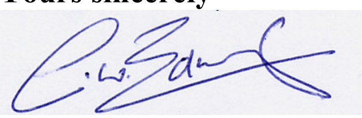
I have enclosed with this letter a copy of our statement on the accuracy of our large scale mapping.
A significant point to bear in mind when using the information is that our specification defines cliffs
as **indefinite detail:**

- This is detail which is of sufficient importance to be captured but which has an outline which is either liable to change or is not defined precisely by any surveyable feature.

- Indefinite detail is not captured precisely. The accuracy of survey is related to the degree of definition of the detail on the ground and the economy of survey.

I think you will probably gather from the above information that it is unlikely that taking measurements either from current or historical Ordnance Survey data will provide you with any consistently reliable results for this type of detail. Probably the best way forward would be to obtain the aerial photography I have referred to (pre and post 1980) and take your measurements from them.

I hope that I have been of assistance to you and would suggest that our web site at www.ordnanccsurvey.co.uk contains further information that may be of interest to you.
Yours sincerely



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