CONTROLS ON CHALK CLIFF EROSION IN THE EASTERN CHANNEL

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1 Aims

- Review the present understanding on the controls of chalk cliff erosion
- Identify and assess potential controls and their contribution to explain chalk cliff erosion
- Identify controls and how to measure them to better understand variability of chalk cliff erosion

2 Summary

First attempts to explain the local and regional variations in the rate of cliff retreat have focussed on the factors cliff height, platform width, cliff aspect and beach width. Correlation

between these factors and cliff retreat rate is poor if all data is considered and can be in contradictory directions if data subsets are used, indicating that these factors are poor predictors of the rate of cliff retreat

3 Introduction

The retreat of coastal cliffs is a natural process. While the rate of retreat on a large scale is clearly linked to the rock of which the cliff is composed (e.g. Carter, 1988, 173), the variability seen on a small scale is likely to be influenced by other factors. Knowing the controls on retreat rates allows for a more accurate prediction of future retreat rates, rather than the simple extrapolation of past rates, as these may have a temporal variation in relation to some factors (e.g. the existence of a substantial beach at the cliff toe will reduce the retreat rate, resistant layers in the shore platform may reduce downwearing and consequently cliff erosion). Better prediction of cliff behaviour can influence the type of management employed when a decision on cliff protection is taken. This is of particular importance for the French side of the Channel were the chalk cliffs are still largely unprotected but where pressure to implement such protection works is likely to rise.

Within Phase 1 of BAR controls that are relatively easy to measure were to be assessed and if they proved to be of limited predictive capabilities data collection methods for other possible controls are to be devised for use in the following phases.

4 Background

Measurement of rates of cliff retreat along the eastern Channel coastlines has a long history (Bialek, 1969; Cleeve and Williams, 1987; LCHF, 1972; May, 1971; May and Heeps, 1985; Prêcheur, 1960; Thorburn, 1977). However, the controls that influence cliff retreat have only rarely been investigated in any systematic detail (e.g. May & Heeps 1985). It is generally acknowledged that the geology of the cliff (e.g. rock type and structure, but also water saturation or the presence of aquifers) sub-aerial processes (especially precipitation influencing the saturation of the rock) and marine processes (waves) all contribute to mass movement phenomena or in preparing the cliff for their occurrence by removing accumulations at the cliff foot. Shepard and Grant (1947) sited in (Pethick, 1984), list hardness of rock, structural weakness, configuration of the coastline, solubility of the rock, height of the cliff and nature of wave attack as factors that control cliff erosion. Additionally, human activity on the coast has increasingly influenced marine processes and the distribution and volume of beaches by the construction of coastal defences that have an additional impact on cliff retreat rates mainly on a local scale.

Although the chalk cliffs are soft in comparison to other rock cliffs, they are sufficiently resistant not to respond immediately to individual storm events like soft clay cliffs, such as occurs at Holderness (Valentin, 1954).

May & Heeps (1985) correlated erosion rates of the chalk cliffs along the south coast of England with cliff height, the dip of strata, fetch length, platform width and cliff toe height, but found a significant correlation with platform width only (for a discussion of the data used in the analysis see report 3 (Retreat of chalk cliffs). Along the chalk coast of the eastern English Channel, the roles of geology and rainfall have been looked at in detail, on the basis of individual events, by Mortimore *et al* (2004).

For the cliffs of Sussex, (Dornbusch et al., in press-b) have compared erosion rates and cliff height and found that correlations differ for different parts of the coast, so that cliff height alone is a poor predictor of cliff retreat. Costa *et al.* (2004) found that at a large-scale retreat rates relate to the type of chalk found at the cliff foot. Also for the French coast, Costa *et al* (2003) correlated retreat rates for 200 m stretches of the coast with beach width, the width of the shore platform and the cliff height but found only very poor correlations, with shore platform width giving the best correlation of the three. This agrees with the results of May and

Heeps (1985), for the English coast.

While controls like cliff height and platform width are easy to quantify, even from maps, other controls (e.g. width of beach at the cliff foot) change over time, which makes them more difficult to measure. To statistically assess the importance of geology of the cliff foot data needs to be collected in the field over a standard interval (e.g. for each 50 m stretch) and converted into a quantitative value.

Height of the cliff foot / platform junction can be measured either in the field, where it is sometimes masked by debris or by photogrammetry, which is also often difficult because the cliff foot is frequently hidden by the cliff top. Although the width of the shore platform seems to be a relevant measure, the topography of the platform is likely to be equally important as it determines the transition of wave energy over the platform to the cliff foot. A smooth platform, for example, will have a different impact from a stepped one, or one which is strewn with boulders from previous cliff falls, because roughness of the surface influences the speed and energy of the waves reaching the cliff foot.

Precipitation, seems to influence the timing of cliff fall events as would be suggested by the observation of numerous cliff falls in the wet winter of 2000/2001. However, it is almost impossible to quantify in its variation along the coast so that it can be treated only as a ‘global’ control that may influence the temporal pattern of the retreat rates but not the spatial pattern. Even then, as cliff falls seem to have a ‘typical’ return period along different stretches of coast (Costa *et al* 2004) the timing of falls may show only a poor correlation with precipitation over longer time scales.

The last control likely to have a major impact on the retreat rate is the wave energy impacting on the cliff foot. This is also the most difficult to quantify. A simple, broad scale approach could simply investigate changes in mean wave heights along the Channel coast and take the aspect of the cliffs into account. However, a more detailed approach needs to model the transition and dissipation of wave energy over the shore platform, for which a detailed digital elevation model (DEM) of the shore platform is essential.

Finally, because the factors controlling cliff erosion rates interact, analysis needs to involve multiple-correlation of the measured controls.

This report correlates cliff retreat rates with cliff height, platform width and aspect for the entire English and French BAR coastlines based on measurements over 50 m segments.

5 Methods

The method for measuring cliff retreat rates is detailed in Dornbusch (2005) and Dornbusch *et al*. (in press-b). Cliff height in 2001 was taken along a line 10 m inland from the cliff top based on the Environment Agency Annual Beach Monitoring DEM from 2001 (English side) and photopgrammetric data (French side). Platform width was measured as the distance between the mean low water line (Ordnance Survey Land line data) and the cliff foot (English side) and between the mean low water line and the cliff foot or beach toe (French side). This means that at present a comparison between the English and French side is not strictly possible as cliff-foot beaches do not exist below long stretches of cliff on the English side whereas a fringing shingle beach exists in most places along the French cliffs. This mixes the influence of the platform width with that of the beach on the French side.

6 Results

6.1 Cliff height

Taking the entire cliff line along the UK and French coasts, cliff height shows only a weak correlation (Figure 1, Figure 2 and Figure 3) that only for the UK coast is significant. If stretches of coast with similar geology and/or aspect are used, the correlation can be quite good (e.g. between Cuckmere Haven and Eastbourne) or can actually be inverse (e.g.

Brighton to Newhaven). The correlations for the French coast are not significant.

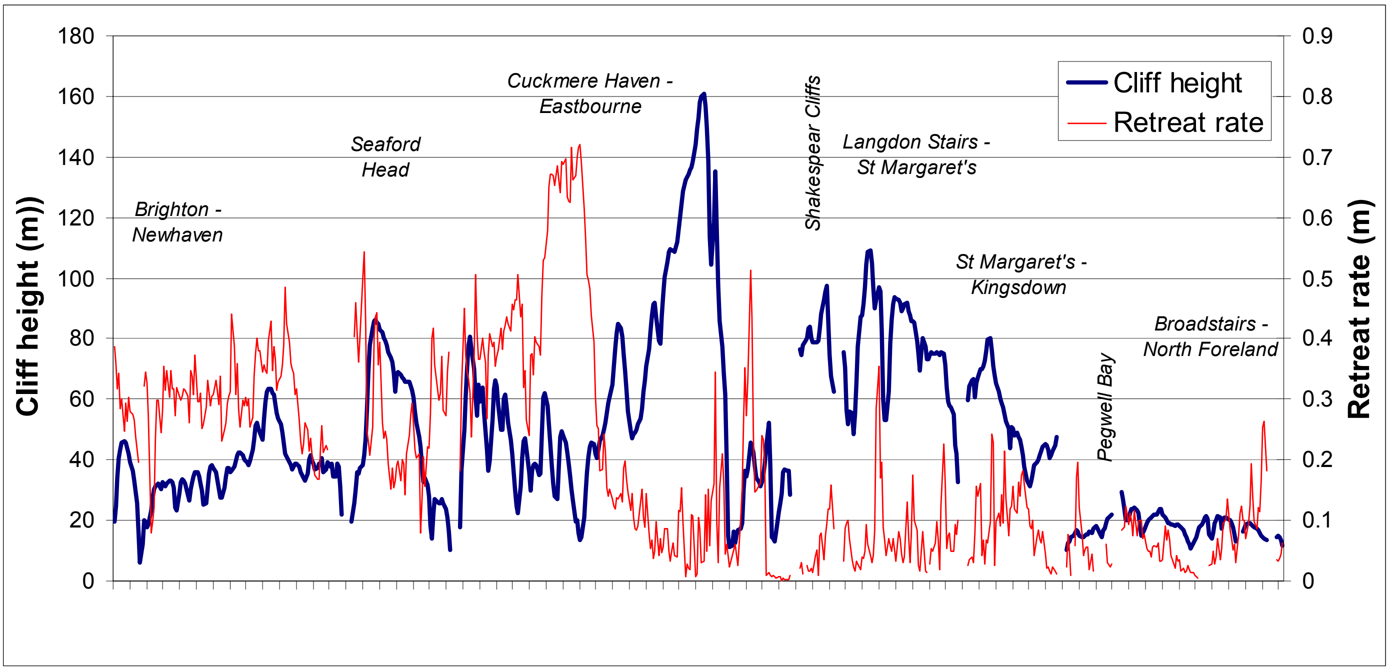

Figure 1: Comparison between rate of cliff retreat for the period 1870s to 2001 and cliff height for the cliffs of East Sussex and Kent. Gaps between the different stretches not to scale.

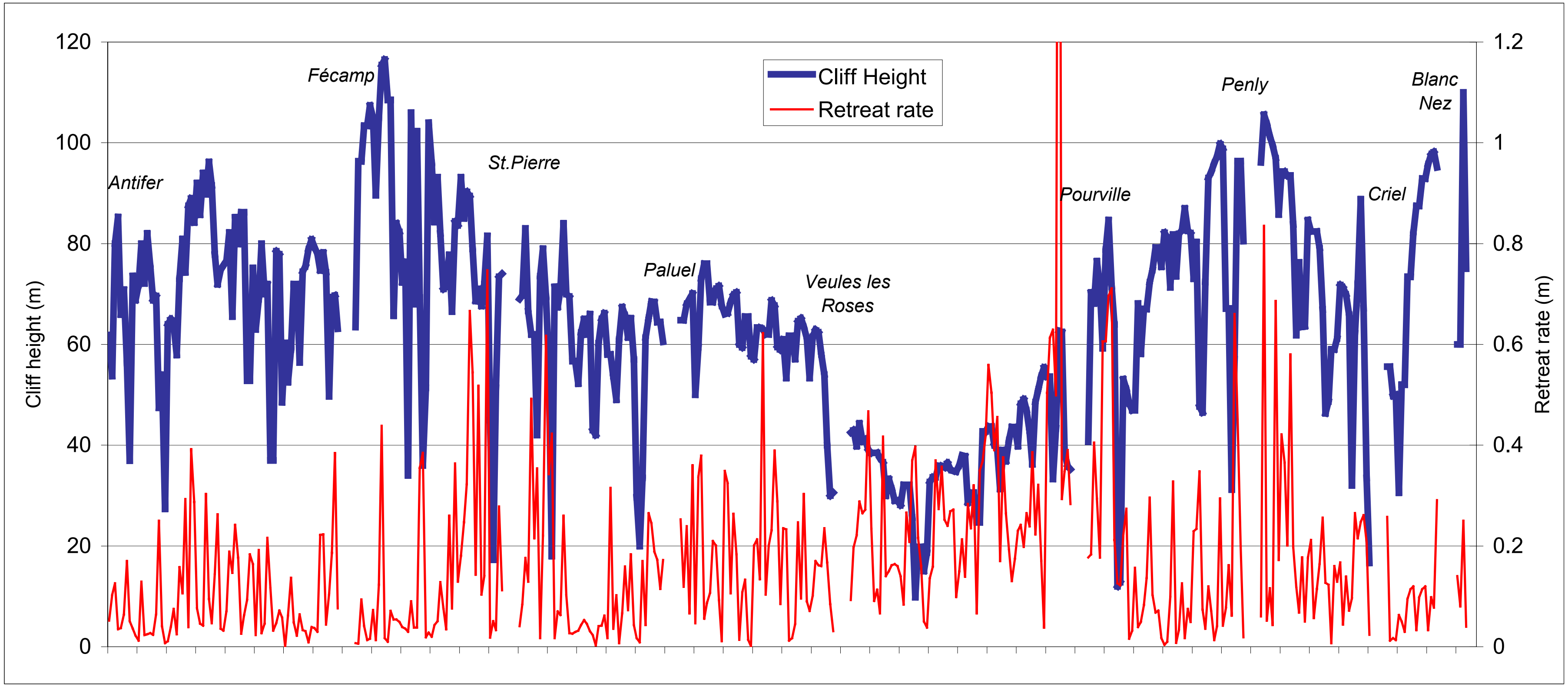

Figure 2: Comparison between rate of cliff retreat for the period 1966 to 1995 and cliff height for the cliffs of Northern France. Gaps between the different stretches not to scale. Names refer to the location of the gaps. Erosion spike near Pourville is due to erosion of overlying sediment rather than retreat of the actual chalk cliff and its values have been excluded from statistical analysis.

	Correlation	Sig.	n
6.1.1.1 All UK	**-0.17**	**0,1%**	**663**
Brighton - Newhaven	0.37	0,1%	138
Cuckmere Haven - Eastbourne	-0.40	0.1%	199
Dover - Kingsdown	-0.01	ns	124
6.1.1.2 All France	**-0.09**	**ns**	**419***
Antifer - Fécamp	0.13	ns	79
Fécamp – St Pierre en Port	-0.02	ns	49
Veules les Roses - Pourville	0.23	ns	71

Figure 3: Correlation coefficients for the relationship between retreat rate and cliff height for different stretches of coastline. Negative correlations indicate that higher cliffs relate to lower retreat rates while positive correlations indicate that higher cliffs relate to higher retreat rates.
* Although erosion rates are available for 50 m intervals cliff height was averaged for 200 m sections which are the basis for correlation

6.2 *Platform width*

Platform width does not show a high correlation with cliff retreat rates (Figure 4, Figure 5 and Figure 6). Indeed, the correlations for the French and English coast are in opposite directions. While the correlation is poor if the whole coastline is considered, significant variation can be found if smaller sections of the coast are considered. The two extremes can be found on the English side along the Seven Sisters, and between Ramsgate – North Foreland (Figure 7). The relationship for the Seven Sisters is strongly positive whilst for Ramsgate – North Foreland although significant it is inverse.

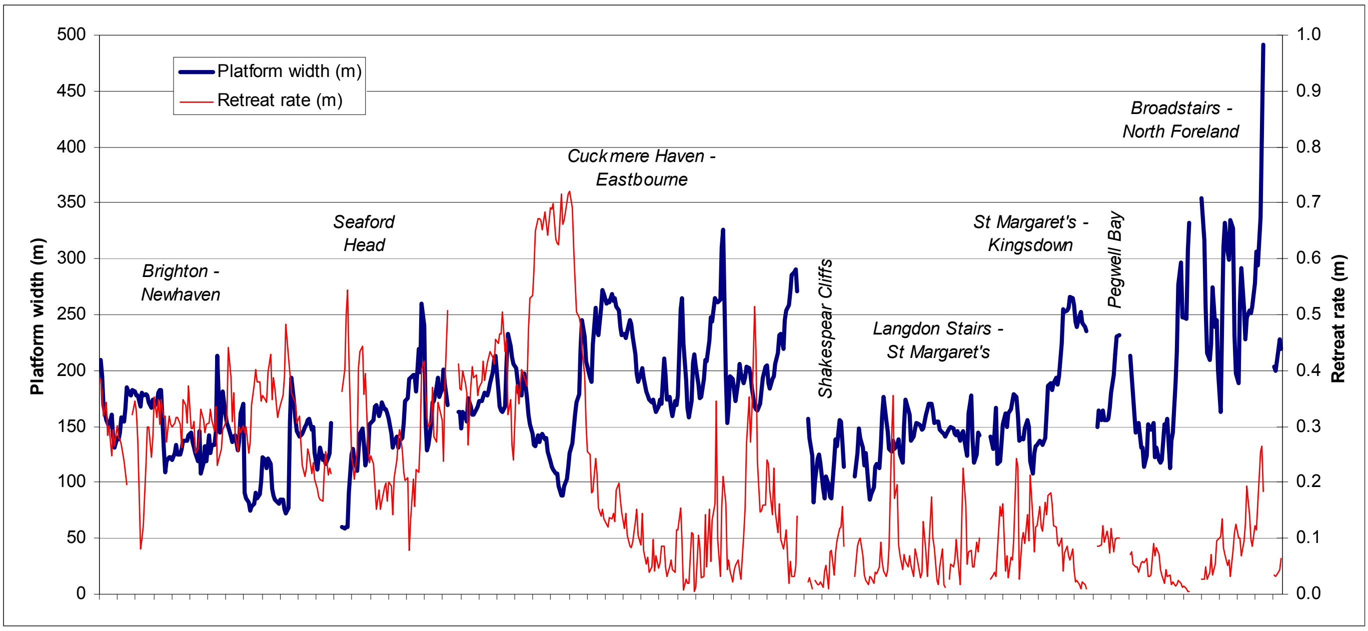

Figure 4: Comparison between the rate of cliff retreat for the period 1870s to 2001 and platform width for the cliffs of East Sussex and Kent. Gaps between the different stretches not to scale.

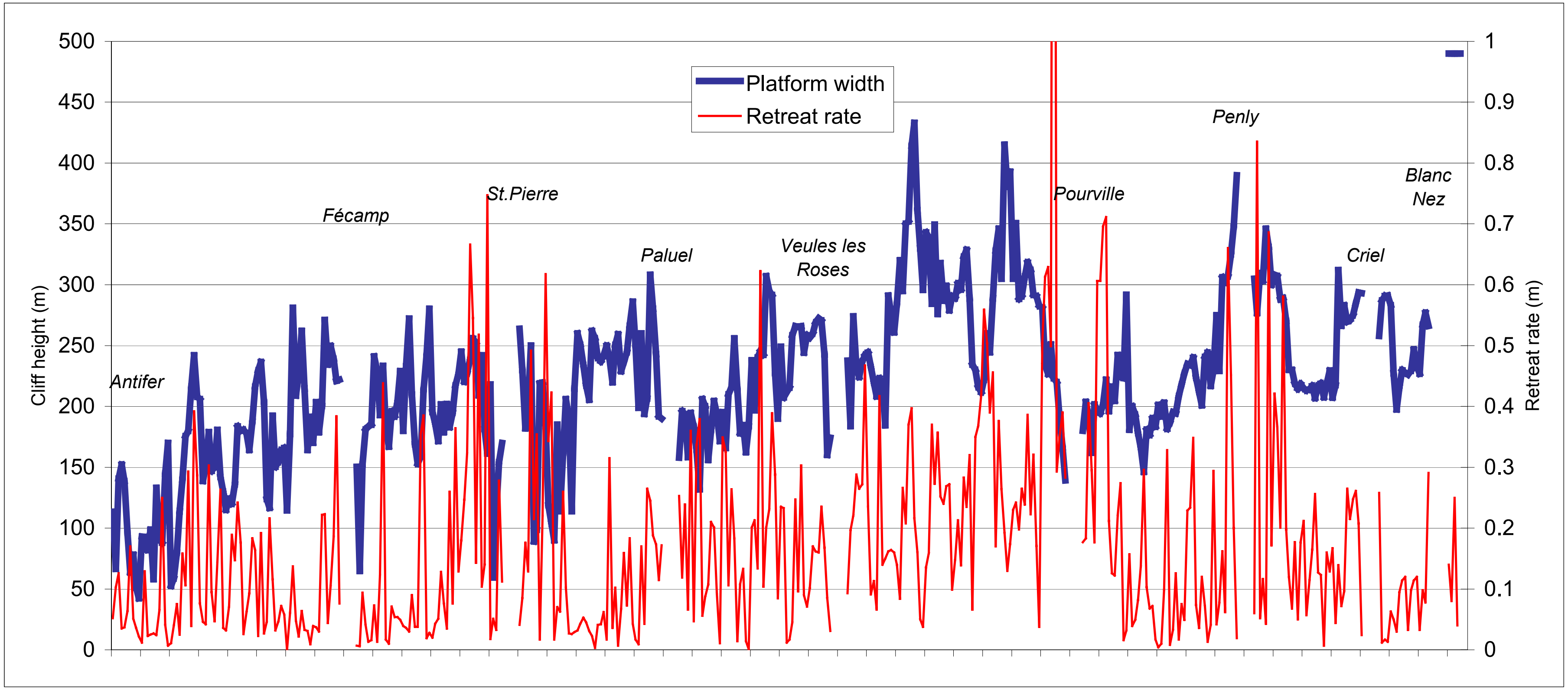

Figure 5: Comparison between rate of cliff retreat for the period 1966 to 1995 and cliff height for the cliffs of Northern France. Gaps between the different stretches not to scale. Names refer to the location of the gaps. Erosion spike near Pourville is due to erosion of overlying sediment rather than retreat of the actual chalk cliff and its values have been excluded from statistical analysis.

	Correlation	Sig	n
6.2.1.1 All UK (only where LWL is on rock)	**-0.28**	**0.1%**	**557**
Brighton - Newhaven	-0.28	0.5%	127
Seven Sisters	-0.78	0.1	82
Dover - Kingsdown	-0.12	ns	123
6.2.1.2 Ramsgate – North Foreland	0.32	1%	82
6.2.1.3 All France	**0.22**	**0.1**	**419**
Antifer - Fécamp	0.29	1%	79
Fécamp – St Pierre en Port	0.18	ns	49
Veules les Roses - Pourville	-0.05	ns	71

Figure 6: Correlation coefficients for the relationship between retreat rate and platform width for different stretches of coastline. Negative correlations indicate that wider shore platforms relate to lower retreat rates while positive correlations indicate that wider shore platforms relate to higher retreat rates.

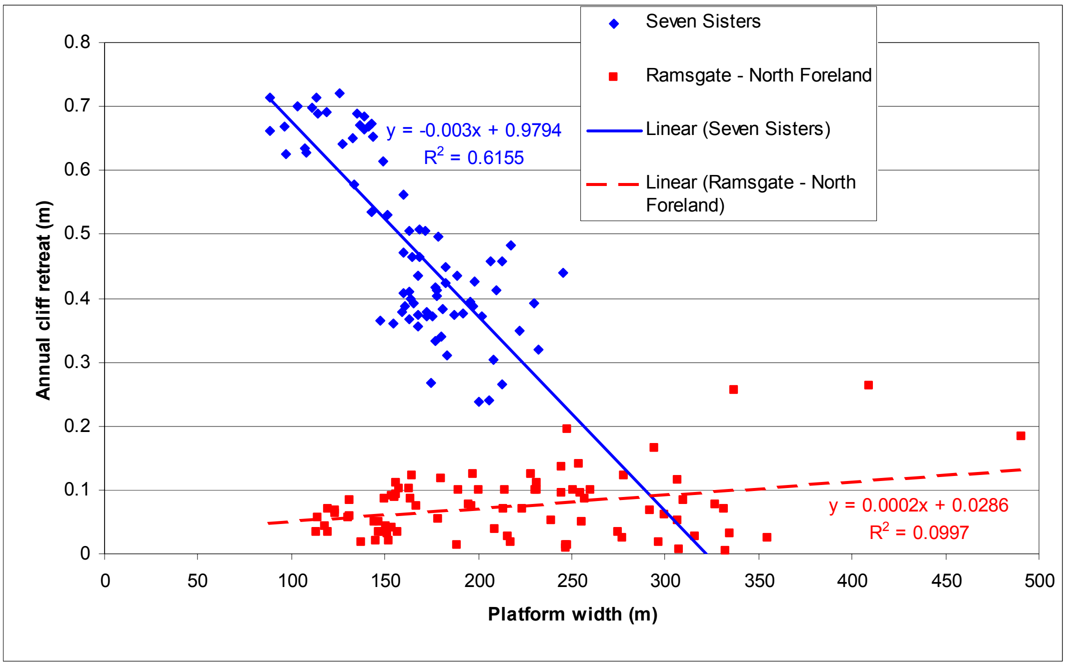

Figure 7: Graphic correlation and regression between shore platform width and cliff retreat rate for the Seven Sisters and Ramsgate – North Foreland showing individual points and linear regression lines.

6.3 Aspect

The Sussex, Kent and French coasts face different directions so it is reasonable to expect retreat rates to differ. A pattern of retreat does exist in that rates are generally lower in Kent and northern coast of France than in East Sussex and French coast west of the Somme estuary (Figure 8). This is most probably explained by a decrease in average wave energy from west to east. The higher rates around Cap Blanc Nez are likely to be a result of waves generated in the North Sea.

The difference between East Sussex (SSE) and France (NNW) may be attributable to the dominance of winds from WSW and West over any with a northerly component (Figure 9).

East Sussex (SSW)	0.31
Kent (SSE)	0.07
Kent (NE)	0.08
France (NNW)	0.21
France (NNE)	0.15

Figure 8: Mean annual retreat rates averaged over large stretches of similar exposition.

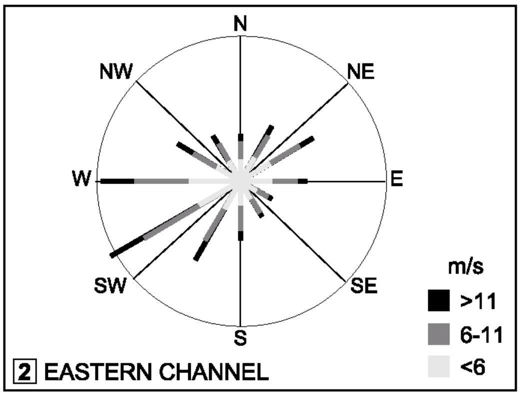

Figure 9: Synoptic wind rose and wind speeds for the eastern English Channel based on data from 1960 to 1980 compiled by Meteo France (1991).The rose shows the importance of winds from a southwesterly to westerly window. Source: Anthony (2002)

Variation in aspect between individual segments is small and for analysis at this scale the question as to how to measure the aspect becomes important. Should one use the direction of the old cliff top or the present cliff top, which in some cases diverge significantly. Where aspect changes gradually, as at Seaford Head, aspect bears no relationship to the retreat rate (Dornbusch et al., in press-a).

In summary, aspect alone is a poor predictor. It has an influence on the wave energy impacting on the cliff, but this factor needs to be investigated in much more detail.

6.4 Beach width

Beach width has a great influence on retreat rates but not necessarily in a linear manner. Obviously, once a beach attains a width that prevents waves from reaching the cliff toe even under storm conditions, any marine action on the cliff will cease and any material that accumulates at the bottom of the cliff will not be removed, further protecting the cliff. Therefore there must be a threshold width of beach above which retreat will be zero.

However, beach width changes on a temporal scale, as a consequence of both erosion (possibly increasing the rate of cliff retreat) and accretion (possibly reducing the rate of cliff retreat) of beach material. Thus, when correlating beach width with retreat rate it is necessary to decide which of the range of beach widths that occur at a site should be used. Beach width will tend to be greater and vary more for a mixed sand/shingle beach than for a pure shingle beach.

Beach width has only been measured so far for the French coast for stretches of 200m length. Most of the cliffs on the UK side have no or only very narrow fringing beaches today while the beach width in the late 19th century seems to have been wider and rather uniform. This make it difficult to provide figure to be used in relation to the retreat rates covering 125 years and analysis has not been carried out.

For the French coast, as a consequence of the above, the correlation between retreat rate and beach width (Figure 10) is weak (-0.07). Even at the local scale, on stretches where a beach is absent, e.g. at Criel, the rate of retreat varies considerably.

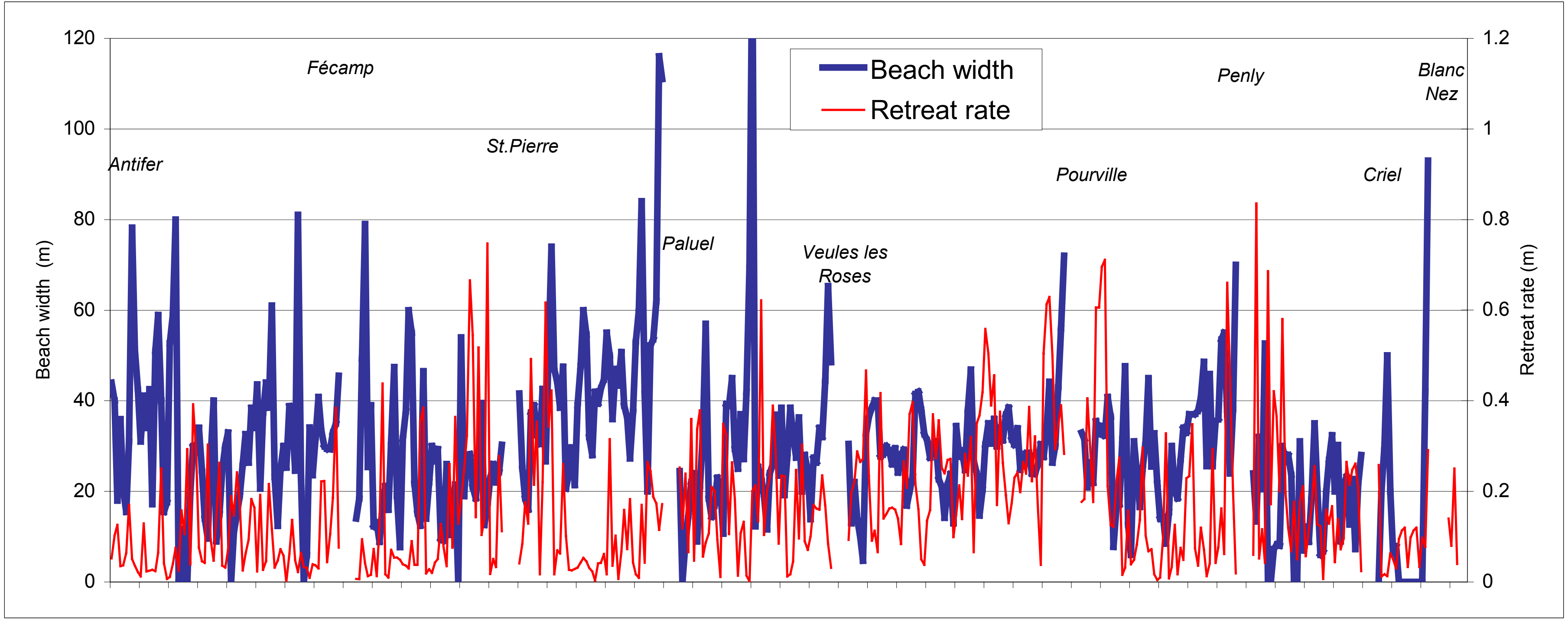

Figure 10: Comparison between rate of cliff retreat for the period 1966 to 1995 and beach width for the cliffs of Northern France. Gaps between the different stretches are not to scale. Names refer to the location of the gaps. No data available on beach width at Cap Blanc Nez.

7 Discussion

In agreement with the results of previous studies, none of the factors investigated is a good predictor of rates of cliff retreat. The large number of data points and their high spatial density suggest strongly that these results are unlikely to result from the methodology, but are true results. Correlations are generally weak and often change direction for different sections of the coast.

8 Outlook for Phase 2 of BAR

Phase 2 of BAR needs to investigate in more detail the factors that influence the dynamics of the wave attack and the resistance offered by the cliff toe. This will require field measurement of the height of the cliff toe and identification of the geological strata being attacked. Height can be easily measured with the available equipment and techniques (GPS). The geology of the cliff toe and shore platform is often obscured by vegetation (*enteromopha*), cliff fall debris or beach material and is thus difficult to determine directly. However, using clearly identifiable marker horizons in the higher cliff and knowing the vertical distance between the marker horizons and individual chalk beds, the layer exposed at the cliff toe and shore platform can be determined (Figure 11). Once different layers are identified on the shore platform these can be mapped using air photographs.

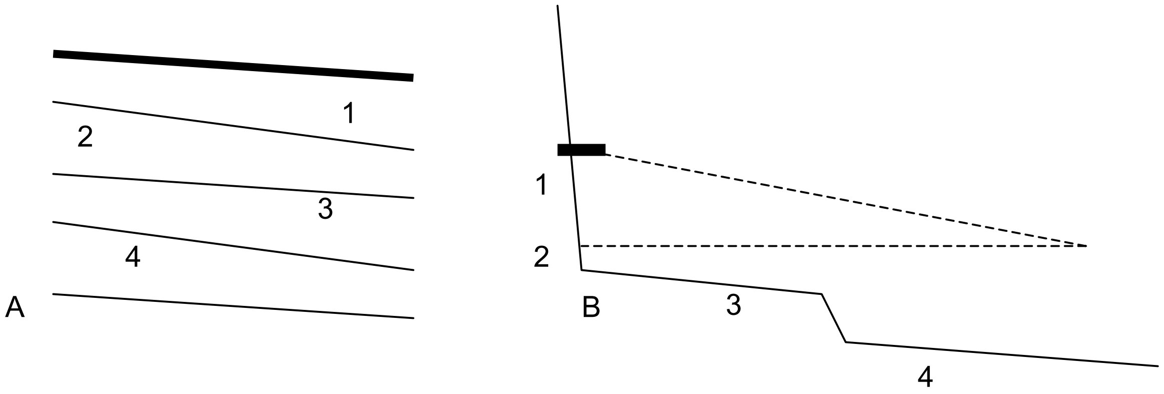

Figure 11: Sketch of measuring technique for identifying chalk layers from positional relations ships with marker horizons. A. shows the general relation ship in the face of neighbouring cliffs (vertical distance between layers needs to be averaged. B shows the situation in profile. Measuring distance to the cliff and angle to the marker horizon (broken lines) allows for the calculation of the height of viewing position in relation to the marker horizon. Consequently in this example, the cliff toe is located on the boundary between layers 2 and 3 with the lower part of the shore platform being composed of layer 4.

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