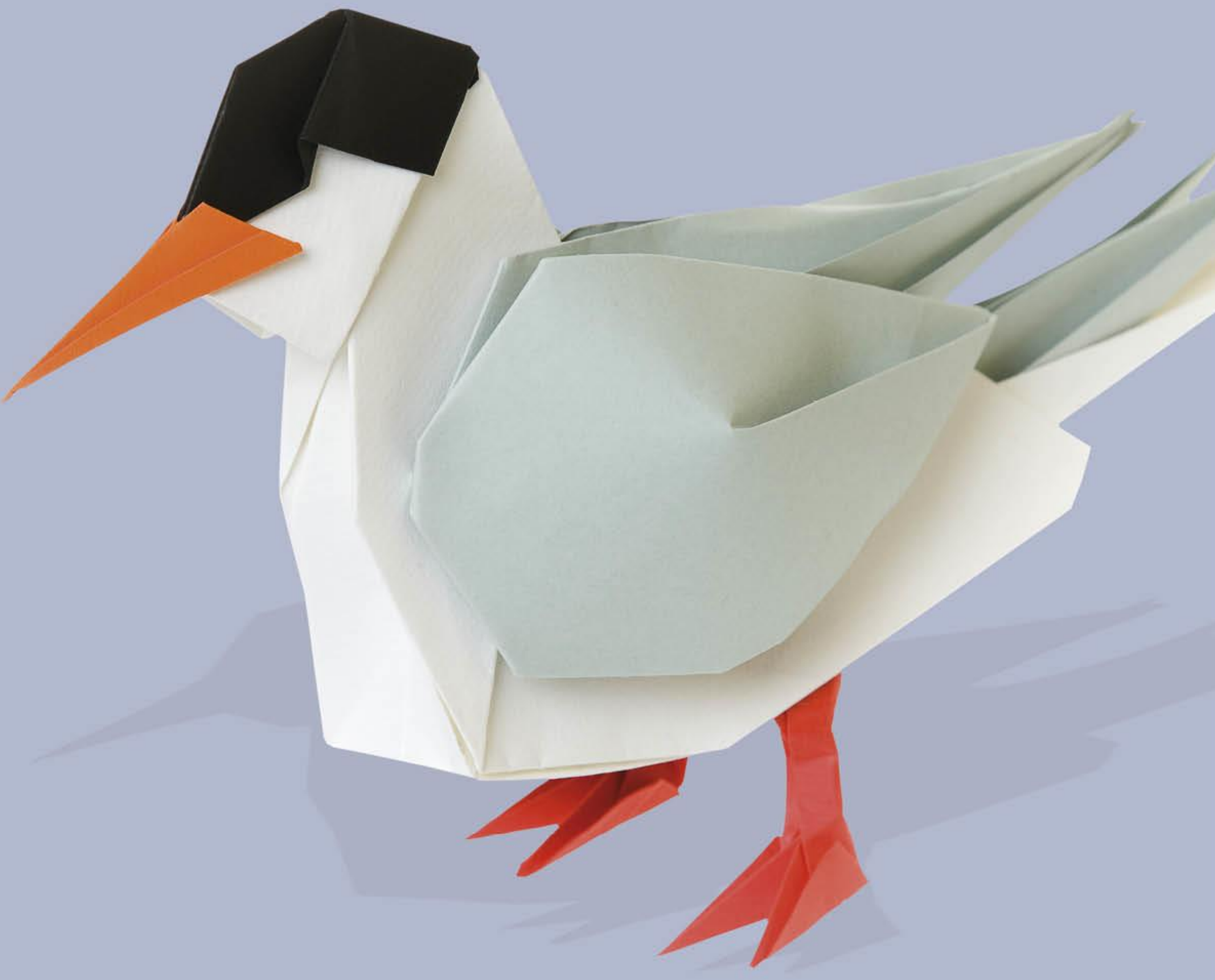
edexcel

NEA Exemplar 1: An investigation into the differences between beaches exposed to contrasting wave energies – candidate write up



A Level Geography

Pearson Edexcel Level 3 Advanced GCE in Geography (9GE0)

ALWAYS LEARNING

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Contents

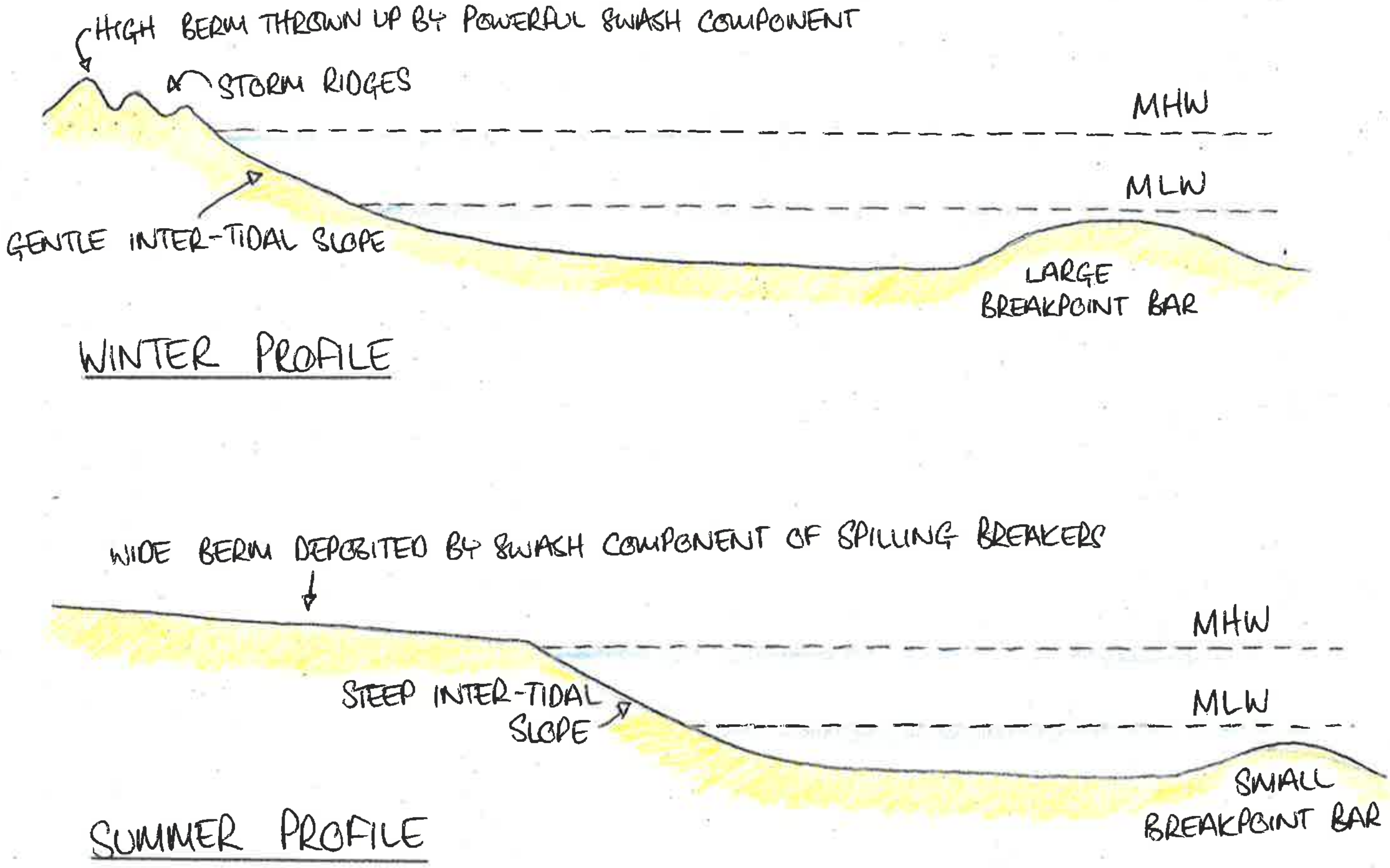
(Total words: 3,962)

Chapter One: Introduction and Hypotheses

A beach is an accumulation of sediment at the junction between the land and the sea lying between the highest levels reached by storm waves and the lowest level of spring tides. The sediment on any given beach is derived from one or more of a range of sources (including cliff erosion, inputs from rivers, onshore tansport, longshore transport and biological input) and, eventually, finds its way to a sediment sink (such as estuary infilling or dune construction)

The morphology or form of any beach is controlled by three main variables:

First, wave energies play a critical role in determining how beach sediment is transported, deposited and often re-eroded to shape the landform. Wave energies vary from place to place and through time. The variations in the beach profile that occur with seasonal changes in wave energy, for example, are well known and are shown below.



Seasonal Variations in Beach Profile with Wave Energies

Second, tidal range plays an important role in determining beach form, if for no more subtle reason than it determines the width of the beach.

Third, the sediment of which the beach is composed plays a major part in controlling beach form. Sediment varies in size, angularity, density and perhaps most importantly, in quantity. These variations control mean and maximum angles of rest, the ease with which breaking waves are able to entrain sediment and the production rates for the swash component of breaking waves. It is also important to realize that the sediment on a beach is not a completely independent variable because it is controlled, at least in part, by the energies of the waves breaking on that beach.

This investigation sets out to examine the role of contrasting wave energies in generating beach landforms by testing three separate but related hypotheses –

That there will be significant differences in beach profiles and beach gradients between beaches exposed to contrasting wave energies.

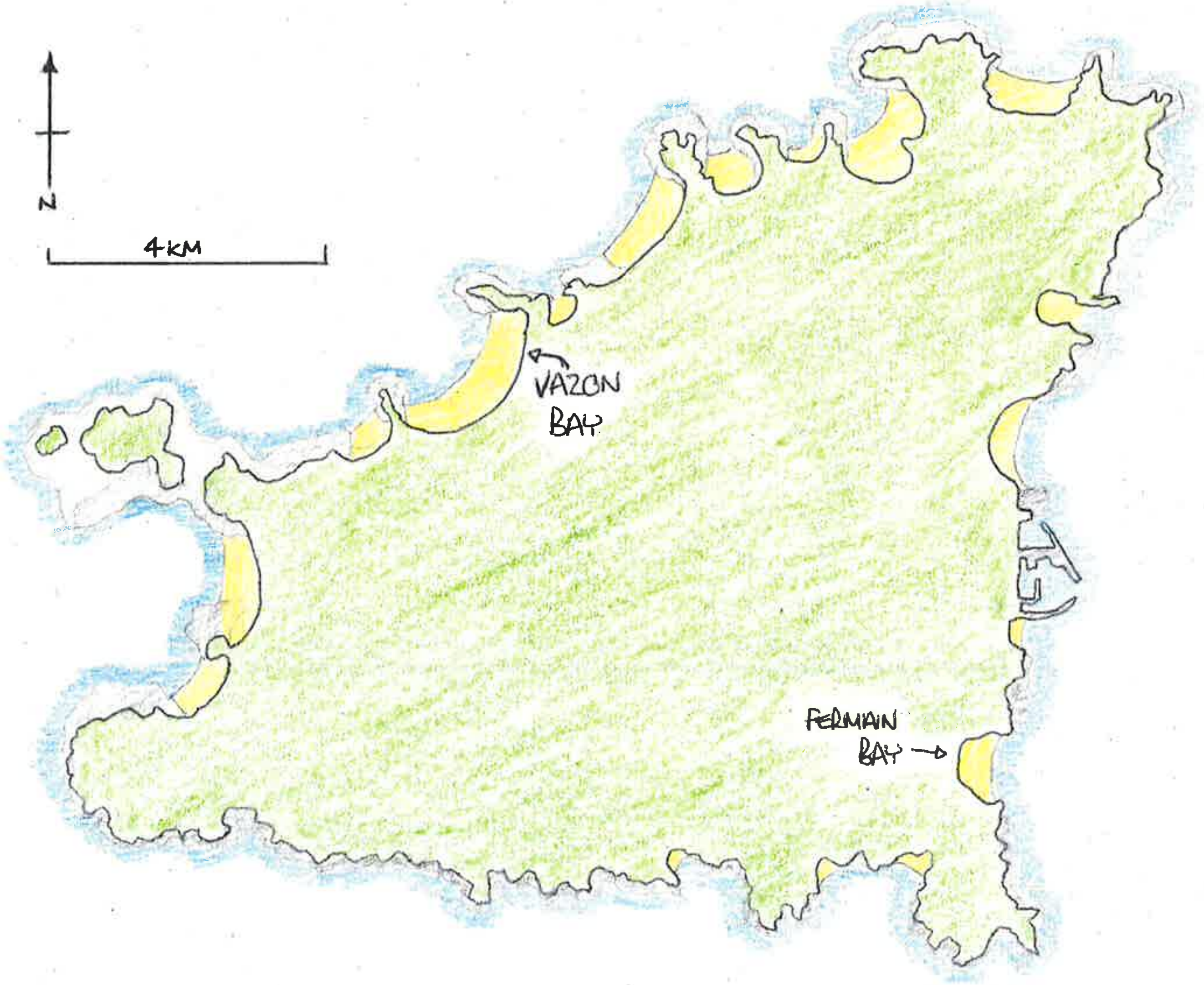
That there will be significant differences in sediment calibre between beaches exposed to contrasting wave energies.

That there will be significant differences in percolation rates between beaches exposed to contrasting wave energies.

Chapter Two: The Study Area:

It was decided to test these three hypotheses on two contrasting beaches on Guernsey in the Channel Islands – Vazon and Fermain beaches.

Vazon Beach is on the west coast of the island and is a sandy beach approximately 200m long and 150m wide (varying on different tides). Low pressure systems in the North Atlantic direct high wave energies at the west coast of the island and Vazon Beach receives the full force of large plunging breakers – hence being a popular venue for surfers. Fermain Bay, however, is on the east coast of the island and is composed of a mixture of sand (only to be found from mid to low tides) and fine shingle. It is approximately 150m long and 60m wide. The east coast of the island is sheltered from the swells from the Atlantic and receives only low wave energies from the limited fetch towards the coast of France.



A Map Showing the Location of the Vazon Beach and Fermain Beach on Guernsey

The beaches were selected for four main reasons:

First, it was clear that the beaches were exposed to contrasting wave energies. Despite the obvious differences in their orientation, which might be expected to generate contrasts in wave energy, it is difficult to obtain actual evidence of wave energy levels because they vary so much both from place to place and from time to time. However, biological indicators of wave exposure are useful because they reveal the long term wave energy levels on a coastline and were used here to assess the wave exposure on the rocky outcrops flanking the two bays. The table below indicates the biological criteria used:

A biologically defined exposure scale

A summary of species which indicate degrees of exposure

Extremely exposed	*Very exposed*	*Exposed*	*Semi-exposed*	*Fairly sheltered*	*Sheltered*	*Very sheltered*	*Extremely sheltered*	*Indicator species*
+++	++	–	–	–	–	–	–	*Alaria esculenta* (marlins)
+++	+	–	–	–	–	–	–	*Himanthalia elongata* (thong weed)
+++	+	–	–	–	–	–	–	*Porphyra umbilicalis* (laver)
+++	++	+	–	–	–	–	–	*Gigartina stellata*
+++	++	+	–	–	–	–	–	*Fucus vesiculosus evesiculosus**
+++	++	++	+	+	–	–	–	*Lichina pygmaea* (blacklichen;
+++	+++	++	+	+	–	–	–	*Patella aspera* (limpet)
+	+	+	+	+	+	–	–	*P. depressa* (limpet)
+++	+++	+++	+++	++	+	–	–	*Chthamalus stellatus* (southern barnacle)
+++	++	++	++	+	+	–	–	*Littorina neritoides* (nerite winkle)
+++	+++	++	++	+	+	+	–	Supra littoral lichens
+++	++	+	+	+	+	+	–	*Lithothamnion/Corallina* (coral weed)
+	++	+++	+++	+++	+++	++	+	*Semibalanus balanoides* (acorn barnacle)
++	+++	+++	+++	+++	+++	++	+	*Patella vulgata* (common limpet)
+++	++	++	++	++	++	++	++	*Littorina saxatilis* (rough winkle)
++	++	++	+++	++	++	+	+	*Nucella lapillus* (dog whelk)
++	++	++	+	+	+	+	+	*Mytilus edulis* (mussel)
–	+++	+++	+++	+++	++	+	+	*Laminaria digitata* (kelp)
–	+	+	++	++	+++	+++	+++	*Fucus serratus* (serrated wrack)
–	+	+	++	++	+++	+++	+++	*Pelvetia canaliculata* (channelled wrack)
–	–	+	+	++	+++	+++	++	*Gibbula umbilicalis* (purple top shell)
–	–	–	+	+	++	+++	+++	*Fucus vesiculosus* (bladder wrack)
–	–	–	–	+	++	++	+++	*F. spiralis* (spiral wrack)
–	–	–	–	+	++	+++	+++	*Ascophyllum nodosum* (knotted wrack)
–	–	–	–	+	++	++	+	*Laminaria saccharina* (kelp)
–	–	–	–	+	++	+++	+++	*Littorina littorea* (edible winkle)
–	–	–	–	++	++	+++	+++	*L. littoralis* (flat winkle)
–	–	–	–	+	++	++	+	*Monodonta lineata* (toothed top shell)

Key: + + + abundant; + + common; + present; – absent.

* This is bladder wrack without bladders

On this scale, Vazon Beach was categorised as semi-exposed with large numbers of southern barnacles, acorn barnacles, common limpets and dog whelks on the rocks but an absence of species like wrack and winkle. By contrast, the species at Fermain Bay meant that it categorised as extremely sheltered, with very few limpets and barnacles, but large numbers of wrack and winkles. In addition, the height of the black lichen Verucaria Maura in the splash zone indicated that Vazon Beach was more exposed than Fermain Beach. This black lichen only grows in the splash zone and was approximately 1.20 – 1.40 metres high on the cliffs flanking Vazon Beach, but only 0.10 – 0.30 metres high at Fermain Beach. These biological indicators of contrasting wave energies on the two beaches made them a good choice as study areas because it meant that the hypotheses could be tested at these places with confidence.

The Beaches
Top: a view of Vazon Beach at low tide, looking north east
Bottom: a view of Fermain Beach at high tide, looking south west
The layer of Verrucaria Maura is clearly visible on the cliffs flanking the bay as a black band above the high tide line

Second, the main variables identified in the hypotheses (in addition to wave energies) also seemed to be different on the two beaches. A superficial examination of the beach gradients and sediment calibre showed differences, which meant that testing the hypotheses on the two beaches was probably a realistic proposition and might produce something worth explaining.

Third, other variables that might have influenced the workings of the hypotheses were constant. The sediment on both beaches is derived from the durable igneous granites and metamorphics of the island and human activity on the beaches at the time at which the fieldwork was undertaken (late October) was minimal. Therefore, if differences between the beaches were detected, they would probably be the result of factors identified in the hypotheses and not the result of factors outside them.

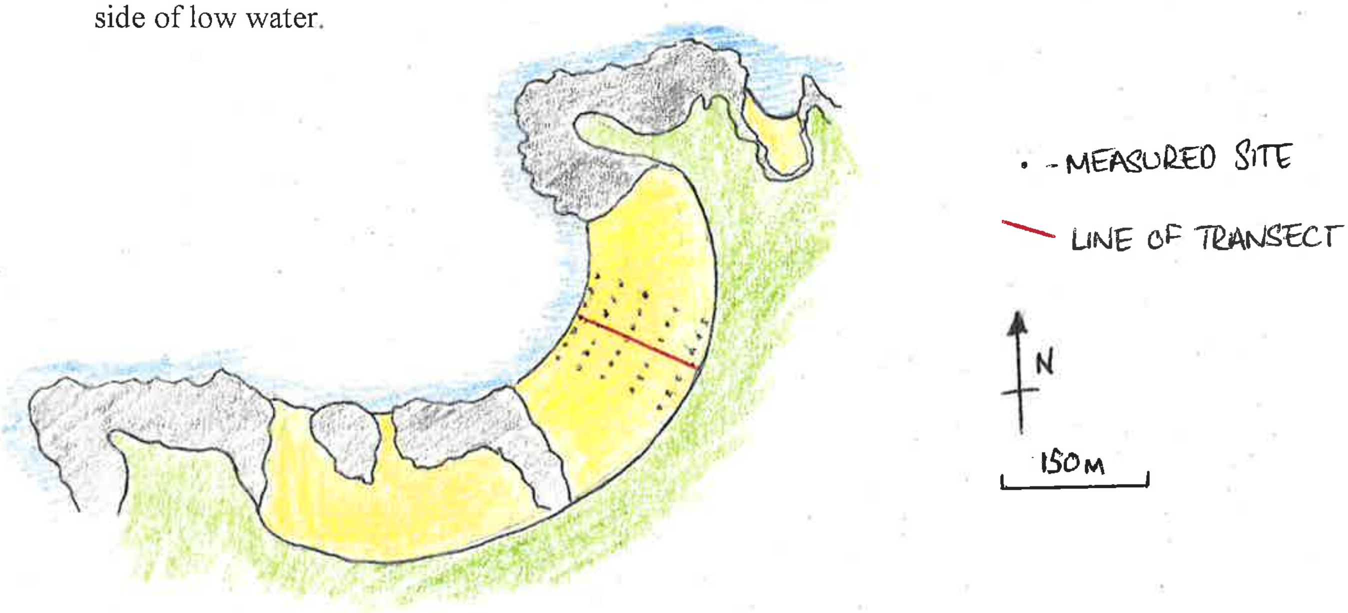
Fourth, I live on the island and was therefore able to visit both beaches on several occasions, making a thorough job of data collection and making sure that the hypotheses were tested thoroughly.

Chapter Three: Data Collection

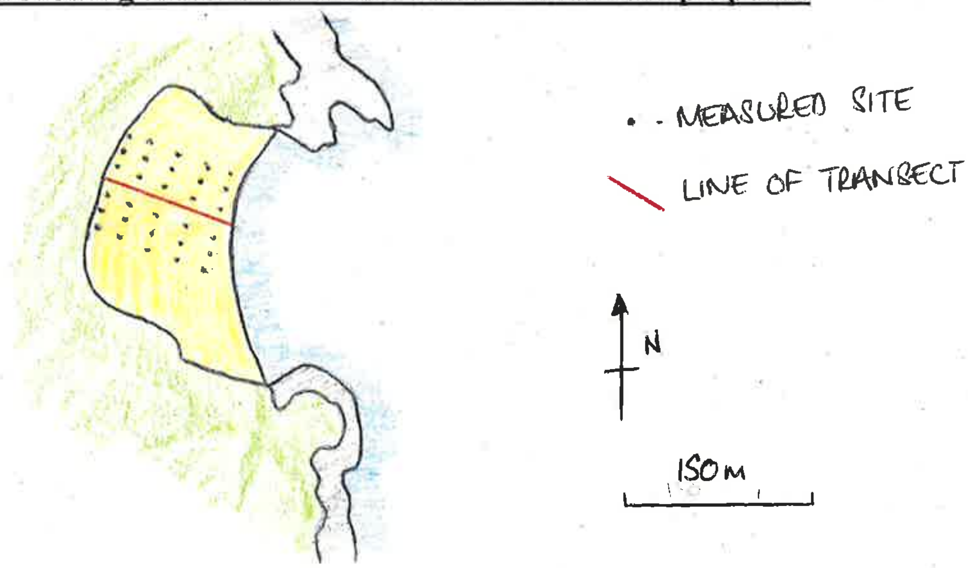
In order to test the three hypotheses, it was necessary to measure beach profiles, beach gradients, sediment calibre and percolation rates on the two contrasting beaches.

a). Sampling Strategy

It was decided to use a simple transect across each beach to measure beach profiles and a systematic point sample of 30 points arranged in a ten metre grid across the intertidal slope to measure the other variables. The transect and sample points were identified and all the measurements taken in a period approximately 90 minutes either side of low water.



Map of Vazon Beach showing the loaction of the transect and the sample points

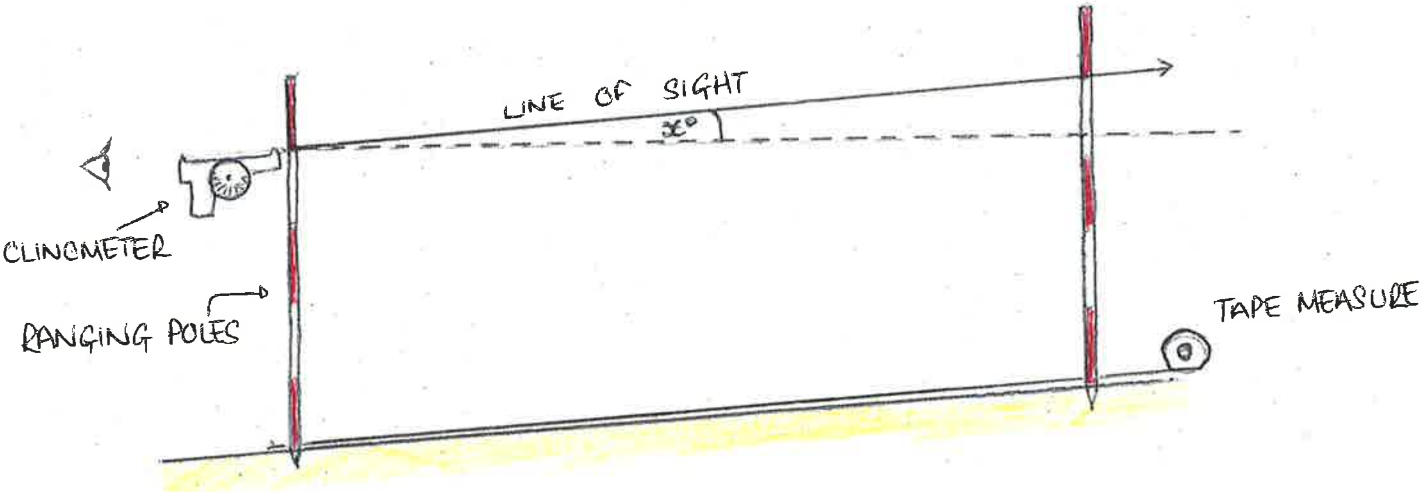


Map of Fermain Bay showing the location of the transect and the sample points

b). Measurement of Cross Beach Profile

On each beach a ten metre tape measure, a pair of ranging poles and a clinometer were used to measure the profile of the beach from the low water mark to the high tide line. The ranging poles were used to break the beach profile into a series of ten metre segments and the clinometer was used to measure the gradient of each segment simply by siting from the 1.5 metre mark on the lower pole to the same point on the higher pole.

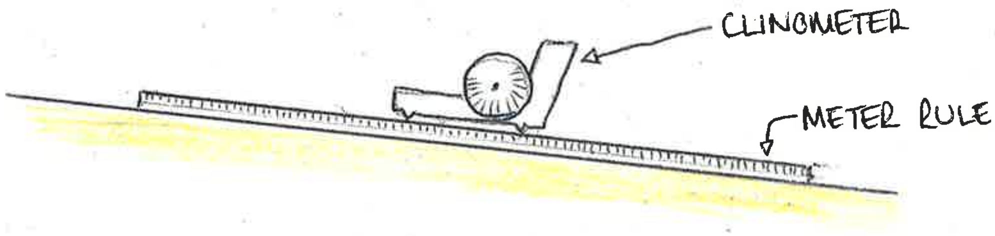
The Measurement of Cross Beach Profile at Vazon Beach



A diagram showing how the measurement of cross beach profiles was carried out.

c). Measurement of Beach Gradients

At each sample site the beach gradient was measured using a meter rule and a clinometer. The meter rule was placed onto the beach surface, and then, by placing a clinometer onto the meter rule, an accurate measurement of beach gradient was obtained.



A diagram showing how beach gradients were measured at each site.

d). Measurement of Sediment Calibre

The measurement of Sediment Calibre was taken using a shovel, a sieve and an electric microbalance. At each site a large sample of sand was extracted, placed in a plastic bag and then labelled. Later, the samples where emptied out onto newspaper in order to absorb the moisture from the sand and then left to dry. Once the sand was dry, approximately the same amount of sand was taken from each sample using a measuring cup and weighed on the microbalance. The sediment was then sieved and the sediment caught in each layer of the sieve was then weighed. Once the sieving and weighing were complete, the raw weights for each component part of each sample were then converted to percentages.

For example, at site number four at Vazon Beach, the sediment sample broke down like this:

Sieve Grade (Phi Scale)	Weight (g)	%Weight
Sieve one (-1.0)	0	0
Sieve two (0.0)	0	0
Sieve three (1.0)	40	22
Sieve four (2.0)	130	71
Sieve five (3.0)	13	7
Sieve six (4.0)	0	0

Beach sediment being dried before weighing

The seive split up into its constituent parts

e). Measurement of Beach Percolation Rates

Beach percolation rates were measured at each site using an infiltration ring. The infiltration ring was placed into the sediment and filled with water. By measuring how long it took for 15cm of water to infiltrate into the sediment, it was possible to calculate the percolation rate by dividing the 15cm of water by the time it took to infiltrate, producing a percolation rate in centimetres per minute.

For example, at site number four on Vazon Beach, 15cm of water percolated into the beach sediment in 36 seconds. This gave a percolation rate of:

$$\frac{15 \times 60}{36} = \underline{25 \text{ cm / minute}}$$

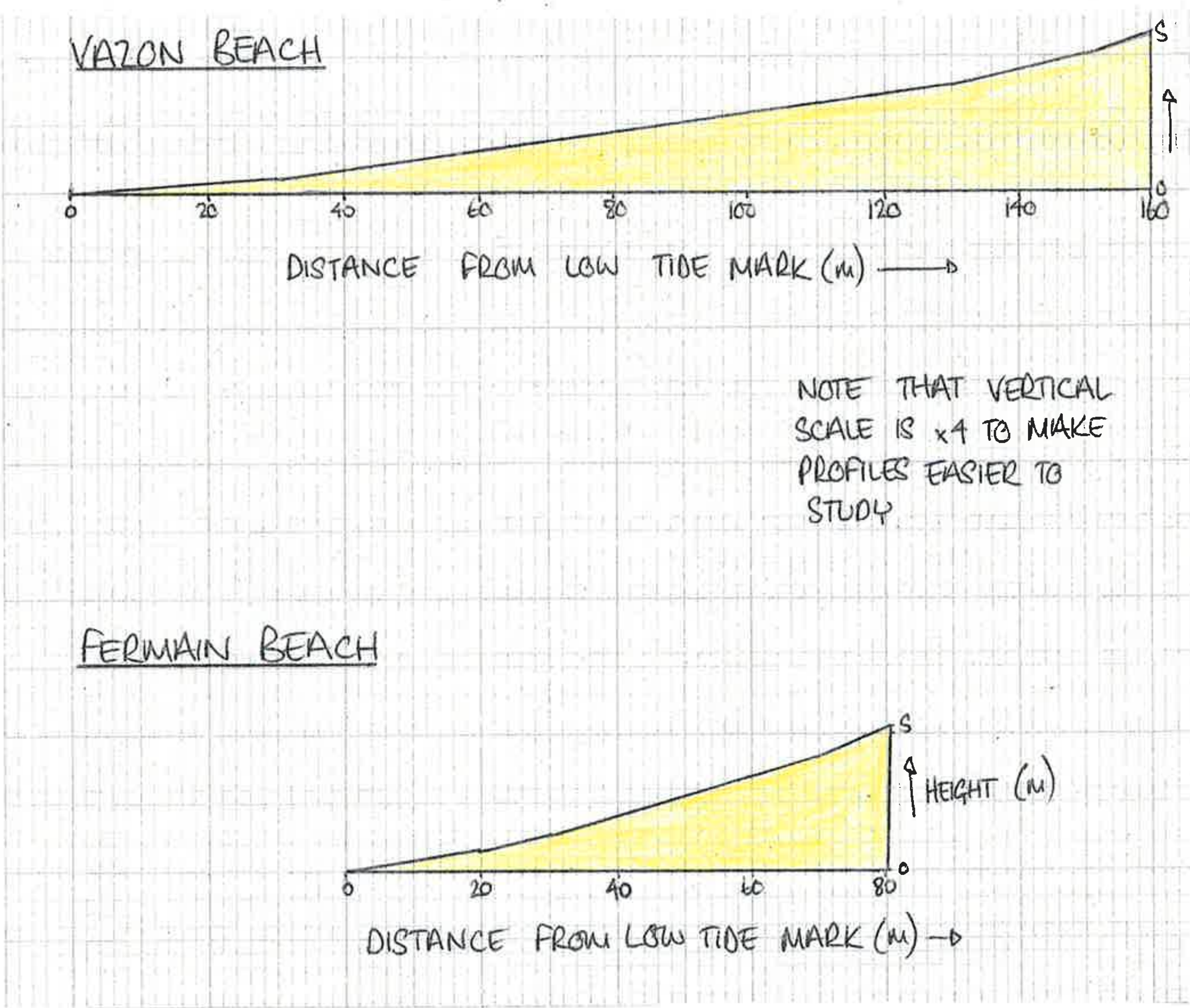
Chapter Four: Analysis of the Results

Part A: Interpretation of the Results

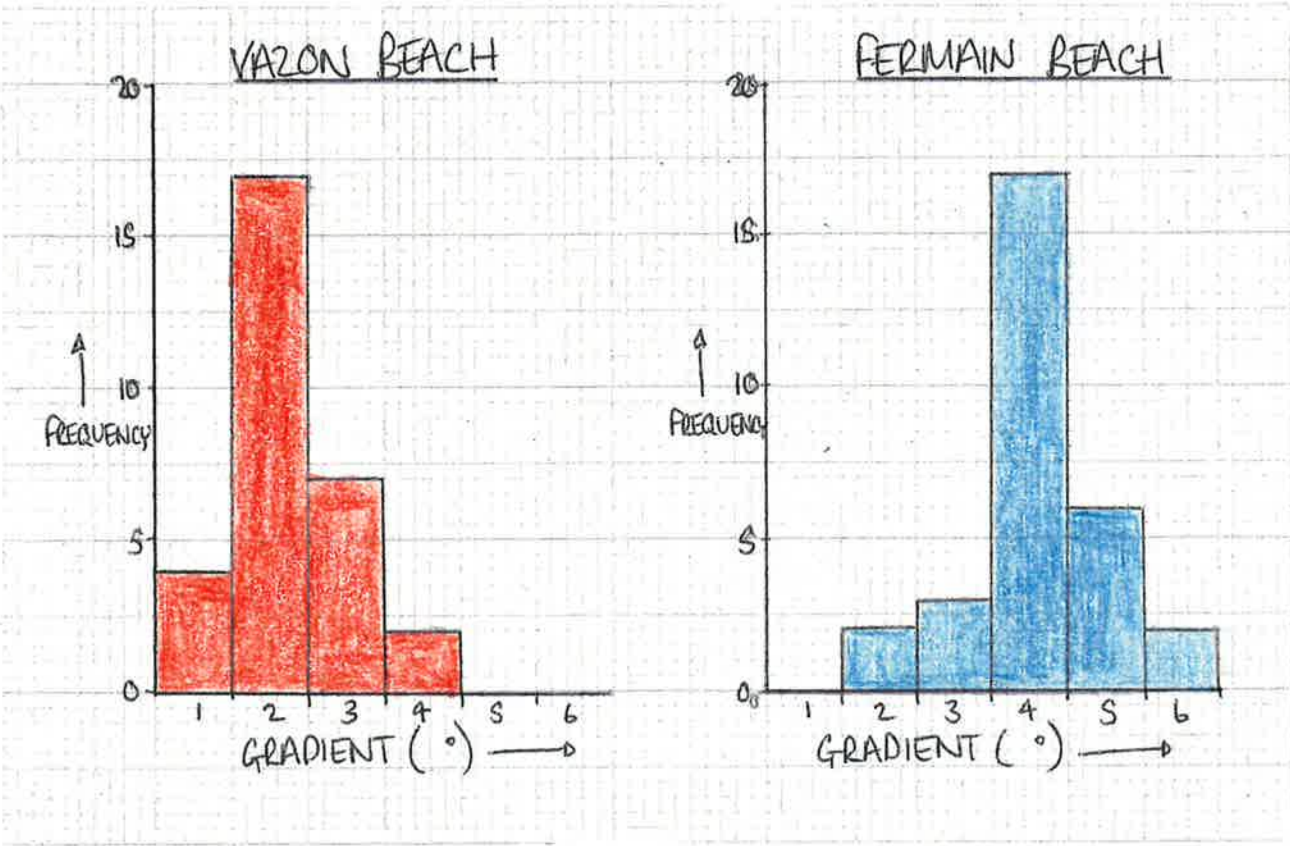
The processed field results are set out in tables in Appendix A. They have been used below to test the three hypotheses formulated at the beginning of the investigation.

Hypothesis One: That there will be significant differences in beach profiles and beach gradients between beaches exposed to contrasting wave energies

Scale cross sections of the two beach profiles have been drawn and two frequency histograms plotted of the beach gradients at each of the thirty sites on the two beaches to see whether or not this hypothesis is valid.



Scale cross beach profiles for the two transects on each beach



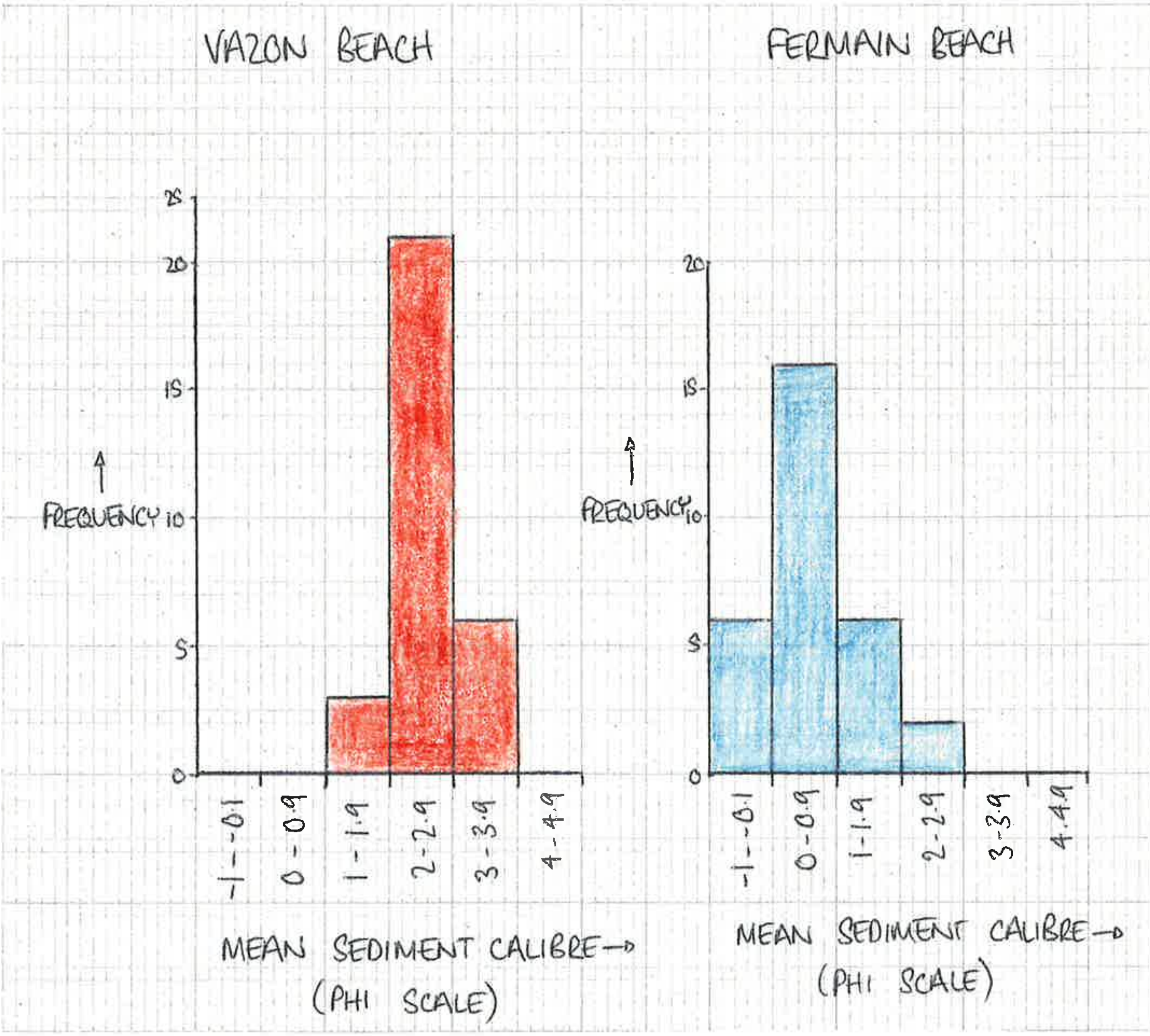
Frequency histograms of beach gradients measured at the thirty sites on each beach

This hypothesis is clearly confirmed by the results because there are obvious differences in both the beach profiles and in the gradient results. Vazon Beach is much flatter (as well as much wider) than Fermain Beach with typical beach gradients of around 2 degrees compared with around 4 degrees on Fermain Beach. Both beaches rise just over 5 metres above their respective low tide marks but this gradual increase in height occurs over 160 metres of beach at Vazon compared with half that distance at Fermain. The gradient measurements from the sites bring this contrast out even more. The modal gradient frequency at Vazon is only 2 degrees and only nine of the sites had gradients steeper than this while, at Fermain, the modal gradient frequency is 4 degrees and 8 sites have gradients of 5 degrees or more. Both beaches have shallow gradients but those at Fermain are significantly steeper than those at Vazon.

Hypothesis Two: That there will be significant differences in sediment calibre between beaches exposed to contrasting wave energies

Two frequency histograms have been plotted of the mean sediment calibre at each of the thirty sites on the two beaches to see whether or not this hypothesis is valid. Mean sediment calibre was calculated for each site by multiplying the percentage weight categories by the phi value for sediment calibre and dividing by 100 to obtain a mean value. For example, at site four at Vazon Beach the mean value was calculated like this:

Sieve Grade (Phi Scale)	%Weight	Calculation
Sieve three (1.0)	22	$\frac{(22 \times 1) + (71 \times 2) + (7 \times 3)}{100} = \underline{1.8}$
Sieve four (2.0)	71	
Sieve Four (3.0)	7	



Frequency histograms of mean sediment calibre at the thirty sites on each beach

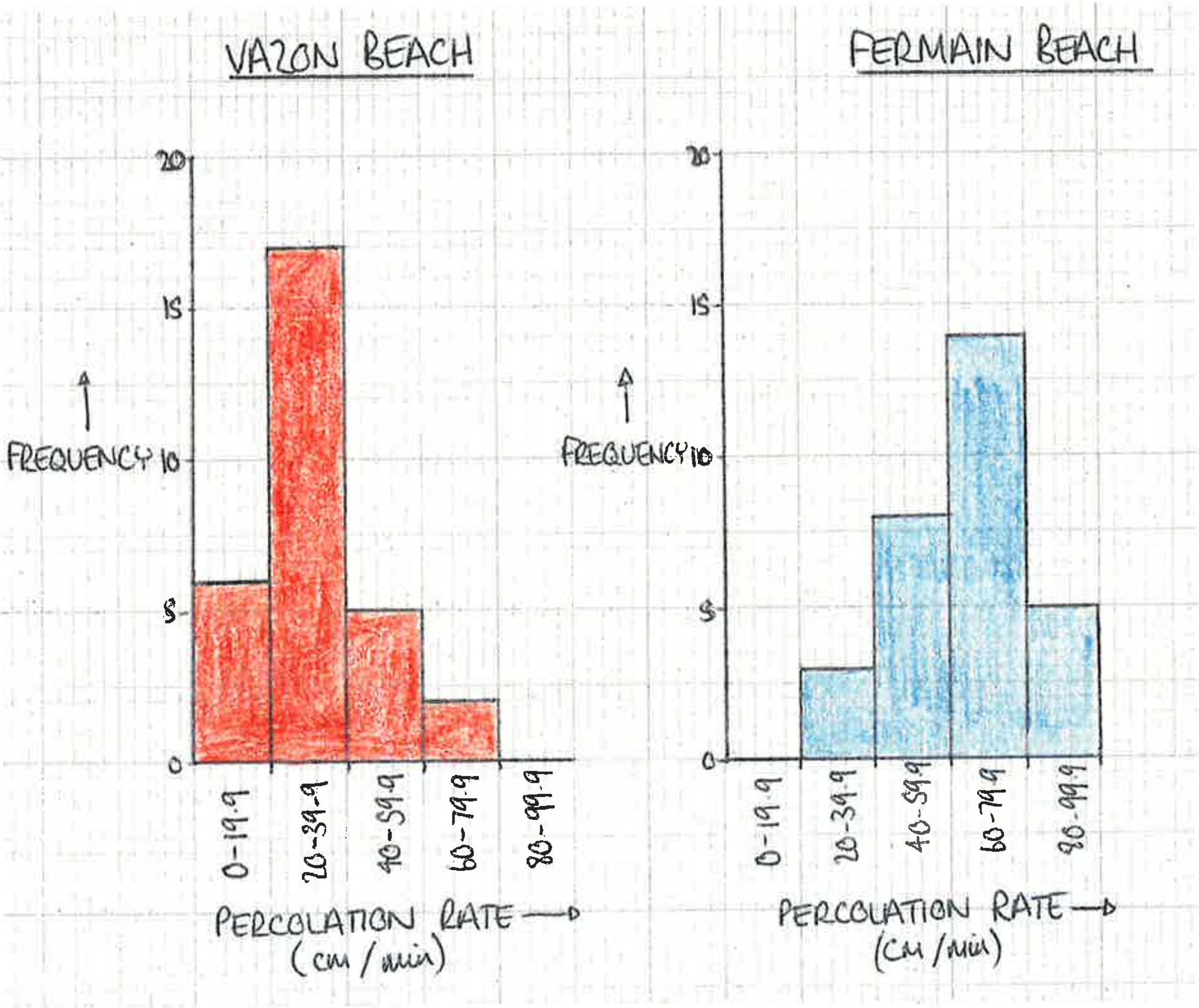
This hypothesis is also clearly confirmed by the results as the two frequency histograms are very different from each other. On Vazon Beach the sediment is very fine with a modal frequency of 2 – 2.9 phi units and only 3 sites have a mean sediment coarser than this at 1 – 1.9 phi units. The results do not vary much, with all the sediment falling between 1 and 3.9 phi units. On Fermain Beach, however, the sediment is much coarser and lower phi values are typical. The modal frequency is 0 – 0.9 phi units and 6 sites had values between –1 and –0.1. There were some sites with finer sediment here (with two sites having a mean phi value of 2 – 2.9) and there is more of a range of values on Fermain Beach. Overall, however, it is clear that the sediment of which Vazon Beach is composed is much finer than the sediment of which Fermain Beach is composed.

This difference is even more significant than the impression given by the frequency histograms because the phi scale is a negative logarithmic scale. The modal phi value for the sediment on Vazon Beach (2 – 2.9) actually equates to a sediment size of less than 0.25 millimetres while the modal phi value of sediment on Fermain Beach (0 – 0.9) equates to sediment between 0.5 and 1 millimetre in diameter. In other words, most of the sediment of which Fermain Beach was composed was between twice and four times as large as the sediment making up Vazon Beach.

Phi Scale	**Sediment diameter**
- 4.0	16mm
- 3.0	8mm
- 2.0	4mm
- 1.0	2mm
0.0	1mm
1.0	0.5mm
2.0	0.25mm
3.0	0.125mm
4.0	0.0625mm

Hypothesis Three: That there will be significant differences in percolation rates between beaches exposed to contrasting wave energies

Two frequency histograms have been plotted of the percolation rates at each of the thirty sites on the two beaches to see whether or not this hypothesis is valid



Frequency histograms of percolation rates at the thirty sites on each beach

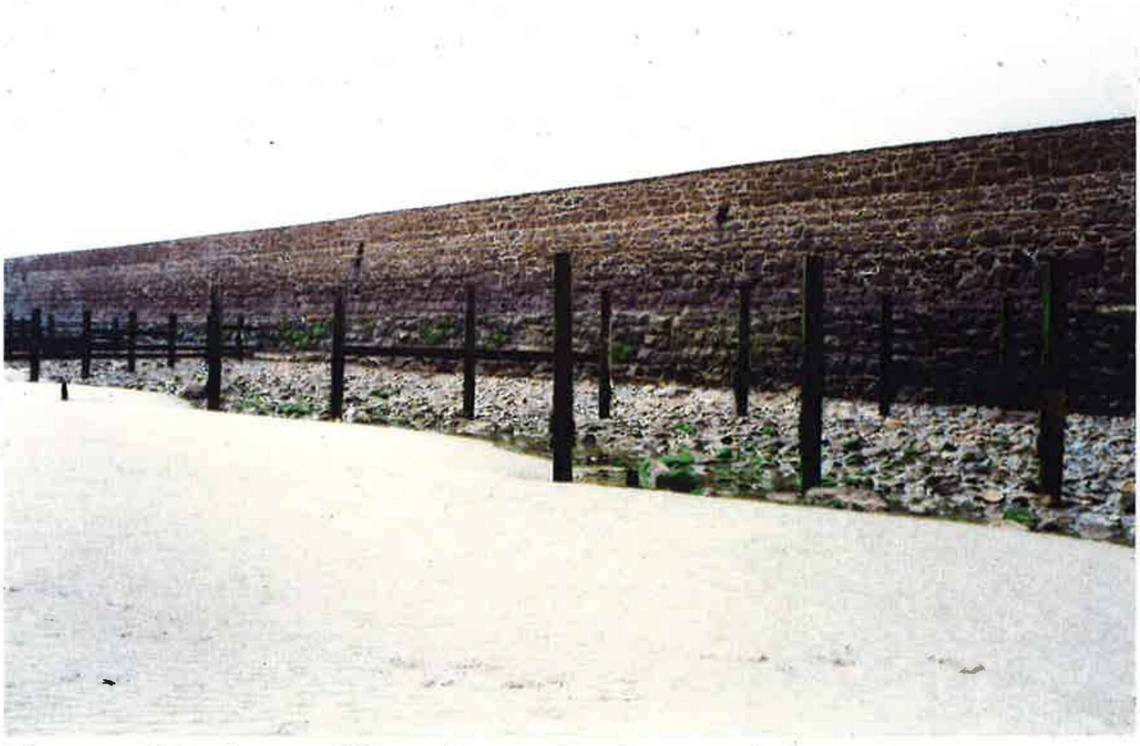
Once again, this hypothesis is clearly confirmed by the results and the frequency histograms are very different from each other. On Vazon Beach the water percolates into the fine sand relatively slowly and the modal frequency is a rate of 20 – 39.9 centimetres per minute. Seven sites do have percolation rates which are faster than this, with two sites between 60 and 79.9 centimetres per minute, but most percolation rates are much slower. Indeed, at two of the sites the rates were close to zero. On the coarser sands of Fermain Beach, however, percolation rates are much faster with a very high modal percolation rate of 60 – 79.9 centimetres per minute and five sites even have percolation rates over 80 centimetres per minute. There are some sites with slower percolation rates (including three sites with rates under 40 centimetres per minute) but, overall, it is clear that percolation rates are much faster on Fermain Beach than they are on Vazon Beach.

Part B: Explanation of Results

The results have confirmed what was suspected at the outset – that there are significant differences in the beach profiles, the gradients, the sediment calibre, and the percolation rates between the high wave energy environment of Vazon Beach and the low wave energy environment of Fermain Beach. Given that the tidal range on both coastlines on the island is constant (at approximately 4 metres) and that the rocks from which the sediments are derived are also constant, the starting point for explaining these differences must be the contrasts in wave energy on the two beaches.

As described in Chapter Two, Vazon Beach is exposed to high wave energies generated by strong winds associated with North Atlantic depressions. These high wave energies mean that rates of coastal erosion are relatively rapid on the west coast and, as evidence of this, there are extensive wave cut inter tidal platforms all along the coast. As a result, a huge volume of sediment has been eroded from the headlands flanking Vazon beach (Ford Richmond headland to the south and Fort Hommet to the north) – accounting for the width of the beach at Vazon.

It might be expected, however, that the powerful plunging breakers to which Vazon beach is subjected would have the effect of throwing up a high berm and generally steep gradients at the top of the beach above a wide, shallow intertidal slope. However, this has not happened at Vazon – the beach gradients never get above 4 degrees and the top of the beach has had to be defended by a substantial sea wall (carrying a road) which is regularly washed by high tides. Instead the backwash component of the plunging breakers appears to be dominant and sediment is removed from the upper end of the beach at high tide and moved into shallow water, further widening the beach and leading to a general beach lowering and fluttering of the beach profile.



The sea wall at the top of Vazon Beach. The fine sand in front of the sea wall has been eroded altogether (perhaps by wave reflection) and backwash has removed any such sediments that might have accumulated here. The black layer of Verucaria Mauura is evident here too, indicateing that high tides regularly reach and over-top the top of the beach.

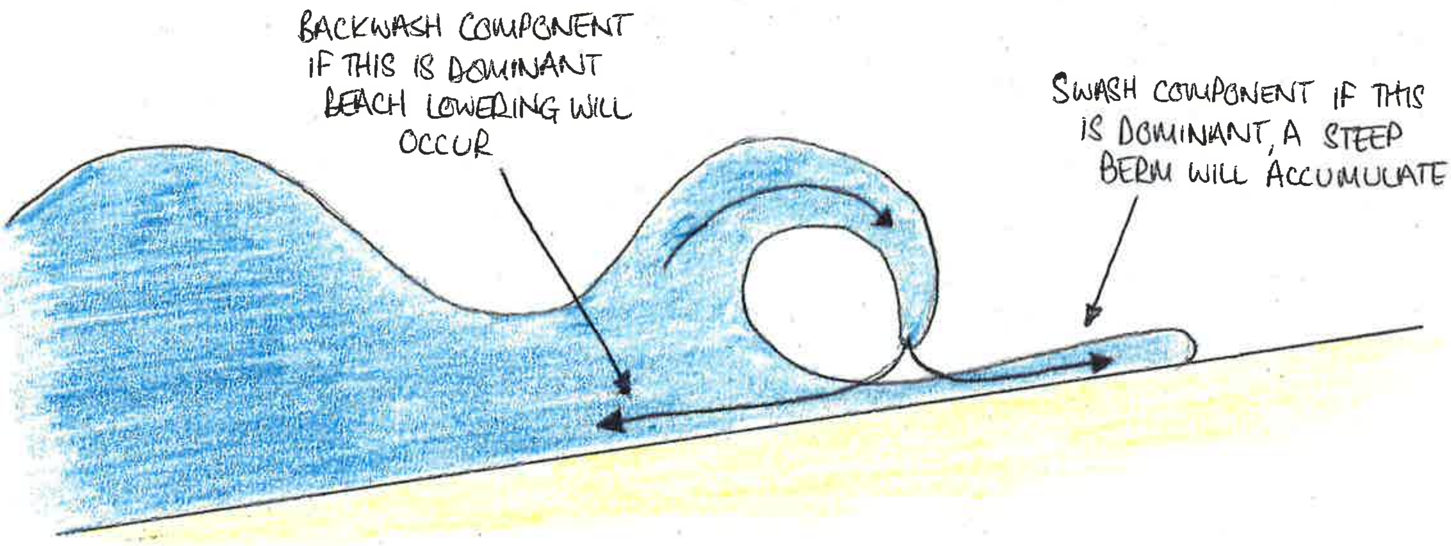
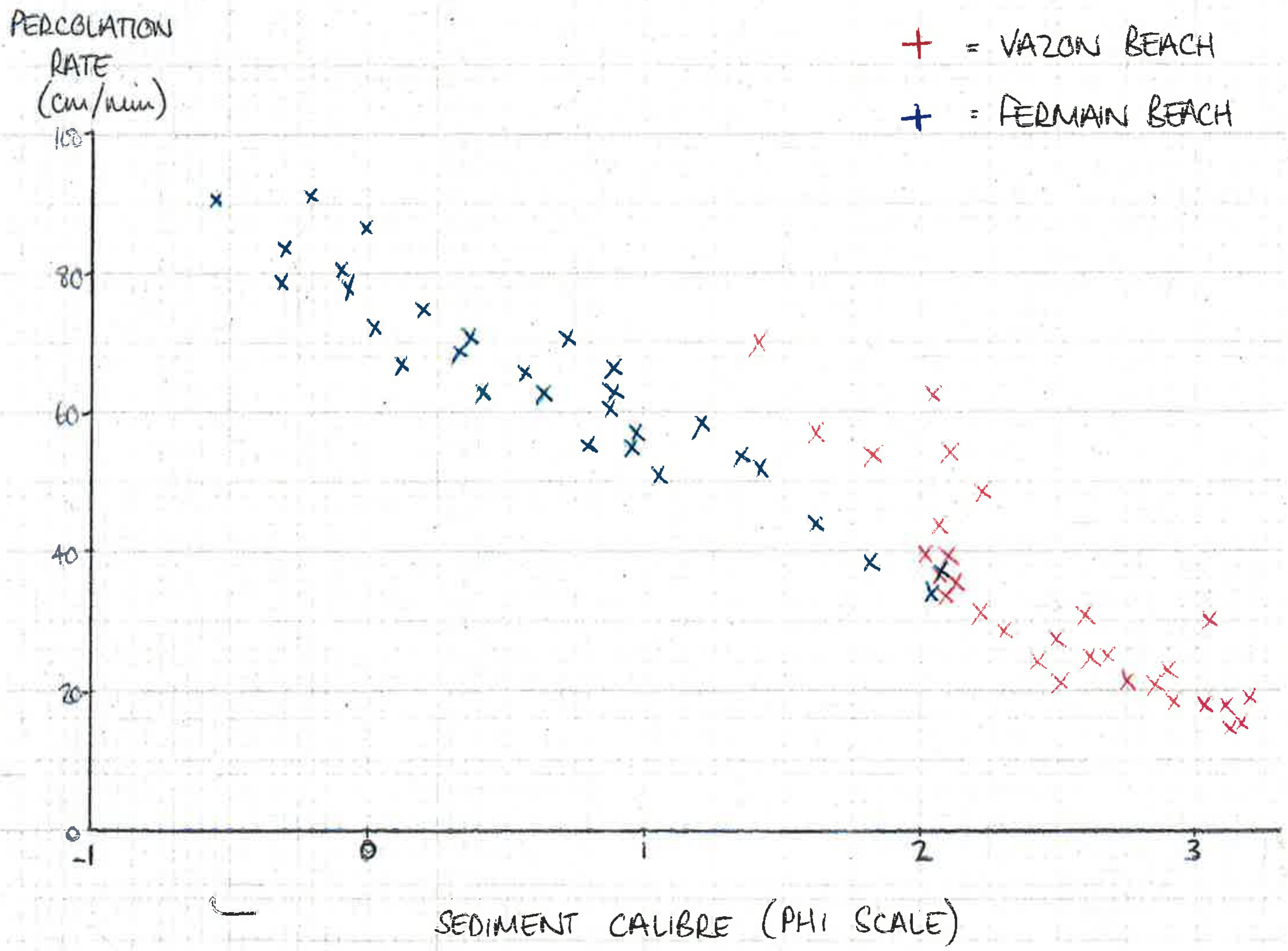


Diagram illustrating how high wave energy plunging breakers can influence beach morphology.

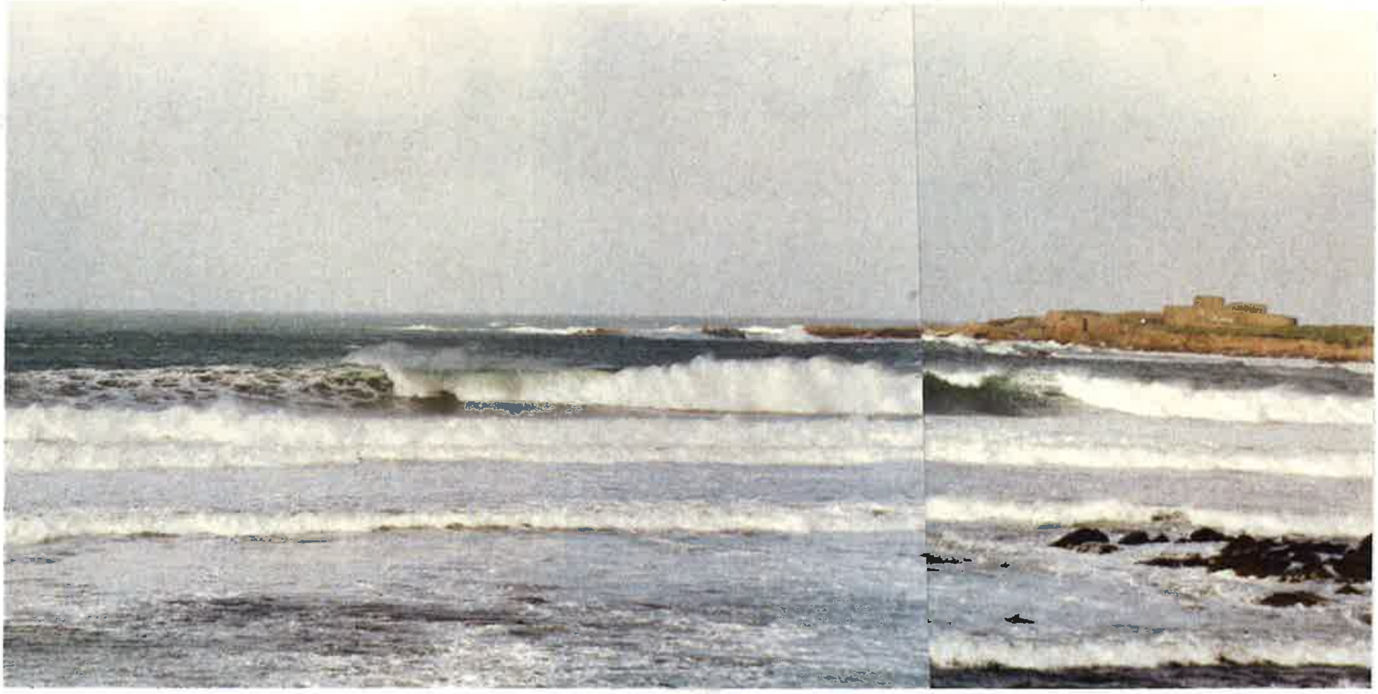
These high wave energy plunging breakers have another important influence. Such high wave energies entrain large volumes of beach sediment and subject it to attrition, reducing it in size. It is to be expected, therefore, that the sediment on Vazon Beach would be significantly finer than on the more sheltered Fermain Beach. Fine sediment has smaller voids between the particles and, consequently, slower percolation rates – as the scattergraph of the results from both beaches illustrates.



Scattergraph of sediment calibre (Phi – Scale) against percolation rates for 60 measued sites on the two beaches

The scattergraph demonstrates that fine sediment with a mean phi value of between 2 and 3 typically has a percolation value of 20-40 centimetres per minute while a phi value of between 0 and –1 for coarse sediment has a typical percolation rate of at least 80 centimetres per minute. A correlation coefficient was calculated from the data (Appendix B) and the resulting coefficient of –0.83 indicates that the relationship between the variables is statistically highly significant.

This relationship actually creates a feedback loop – because the finer the sediment and less percolation there is as a consequence, the less the swash from the breaking waves will percolate and the more dominant backwash will become. This will, in turn, make the beach wider and interfere with incoming breakers (perhaps in the form of rip currents) further reducing the power of the shoreward swash component of the waves. In addition, more sediment will be entrained, more attrition will occur and the beach sediment will become still finer.



A day of high wave energies at Vazon Beach in the Autumn, looking across the bay to Fort Hommet. In the foreground are plunging breakers, collapsing directly onto the face of the beach, generating both a powerful swash and a powerful backwash

The situation at Fermain Beach is almost the direct oppositie. The larger wave enegies have eroded much less sediment, leading to a narrower beach. However, despite the fact that wave energies here are lower, the swash of the low energy spilling breakers which are typical of this beach have piled the sediment up at steeper gradients than on Vazn Beach. This process has been assisted by the percolation of much of the swash into the coarser sediment of which the beach is composed (as a consequence of it being entrained only rarely) and there being, therefore, little backwash to move sediment offshore. This is another feedback loop with low wave energies entraining sediment rarely, resulting in little attrition and therefore high percolation rates so that backwash is free to cause beach accretion and sediment is entrained only rarely.

Chapter Five: Evaluation of the Investigation

This investigation has confirmed that contrasts in wave energy will cause significant differences between the characteristics of beaches which, in all other respects and if wave energies did not vary, might be expected to be very similar. Contrasts in wave energy put into motion various feedback loops involving the calibre of the sediment and percolation rates which control the relative influence of the swash and backwash components of the breaking waves and, thus, maintain the status quo.

It has to be realised, however, that this is just one study based on relatively small samples of just two beaches and that the conclusions above should not be seen as definitive. Other beaches composed of contrasting sediments or exposed to different levels of wave energy would probably produce very different results to other situations. It would, for example, be informative to study two neighbouring beaches exposed to similar wave energies but composed of very different sediment. The ideas developed here might not explain the patterns discovered in such a situation.

It is also important to realise that this investigation itself suffered from a number of weaknesses that might well have influenced the reliability of the results and of the conclusions.

First, there is the question of sample size. Only thirty sample sites were taken at each beach and, although they generated sets of results that could be compared, they only generated sets of results that could be compared, they only represent a very small proportion of the number of readings that could have been made on each beach. The percolation rates, in particular, showed a lot of variation which seemed to be related to height on the beach as well as sediment calibre and more sites would have produced mere relevant data here. Second, some of the measurement techniques employed at each site were rather imprecise. The use of a large, plastic clinometer to measure beach gradient, for example, was not ideal. It was really only accurate to the nearest degree and, when dealing with such a small range of gradients, more precision would have been useful. In a similar way, measurement of percolation was fraught with problems. Where percolation was relatively rapid, it was sometimes very difficult to fill the infiltration ring with water before it had started to drain away – resulting in inaccurate readings. In addition, simply timing percolation for a 15cm column of water took no account of the fact that infiltration / percolation varies over time and it might have been more instructive to study how rates varied as the tide came up the beach and saturated the underlying sediment.

Finally, this investigation left much unanswered with regard to cross beach variations in gradients, sediment calibre and percolation rates. By using a simple grid of thirty points on the inter-tidal slope to create a set of data for each of these variables, no account was taken of spatial changes in the variables – and they might have been significant. Simple observation of the processed results in Appendix A reveals that gradients seem steeper, sediment coarser and percolation rates higher at the sites towards the top of the beach and it might be useful to take this analysis further if space permitted.

Bibliography

Briggs: Sources and Methods in Geography – Sediments.	Pages 55 – 68.
Clowes and Comfort: Process and Landform.	Pages 267 – 289.
Lenon and Cleves: Techniques and Fieldwork in Geography	Pages 100 – 102.

Appendix A: Processed Results

Gradient Results from the Transects

Vazon Beach Transect

Segment Number	Gradient (degrees)
1	1
2	1
3	1
4	2
5	2
6	2
7	1
8	2
9	2
10	2
11	2
12	3
13	2
14	3
15	3
16	3
17	4

Fermain Beach Transect

Segment Number	Gradient (degrees)
1	2
2	3
3	4
4	3
5	4
6	4
7	5
8	6

Results from the Measurement Sites

Vazon Beach

Site Number	Gradient (degrees)	Mean Sediment Size (Phi Scale)	Percolation Rate (cm/min)
1	4	1.87	56.7
2	3	2.32	53.2
3	3	2.16	56.7
4	3	1.85	53.9
5	4	1.42	71.5
6	3	1.62	58.1
7	2	2.07	37.3
8	2	2.12	35.6
9	3	2.25	49.2
10	2	2.03	39.5
11	3	2.06	43.7
12	3	2.10	34.2
13	2	2.22	31.3
14	2	2.32	28.0
15	2	2.45	23.6
16	2	2.66	25.8
17	2	2.51	27.0
18	2	2.56	21.4
19	2	2.65	31.7
20	2	3.06	30.8
21	2	2.90	23.9
22	2	2.82	21.0
23	2	2.68	24.1
24	2	2.76	20.4
25	1	3.12	18.7
26	1	2.92	17.6
27	2	3.23	16.3
28	2	3.17	16.1
29	1	3.26	19.4
30	1	3.09	18.2

Results from the Measurement Sites

Fermain Beach

Site Number	Gradient (degrees)	Mean Sediment Size (Phi Scale)	Percolation Rate (cm/min)
1	5	–0.31	83.7
2	5	–0.56	90.2
3	6	–0.27	92.4
4	5	0.02	87.6
5	6	–0.35	78.8
6	5	–0.12	81.1
7	4	0.23	75.3
8	5	0.17	67.1
9	4	0.03	72.0
10	5	–0.17	79.5
11	4	0.34	68.9
12	4	0.37	70.2
13	4	0.41	62.6
14	4	0.56	65.1
15	4	0.83	67.4
16	4	0.64	64.5
17	4	0.72	70.3
18	4	0.91	63.7
19	4	1.22	59.8
20	4	0.87	61.3
21	4	0.80	56.5
22	4	1.36	54.7
23	4	0.99	58.4
24	4	0.96	56.9
25	2	2.04	34.5
26	3	1.64	43.9
27	2	1.43	46.2
28	4	1.12	37.7
29	3	1.83	39.1
30	3	2.12	50.3