3rd year Geography and Environmental Science project:
Candidate no. 30267

Investigation on the extent and effects of sub-aerial erosion on the chalk cliffs at Peacehaven.

Project Suporvisor: R. B. G. Williams
(reader in physical geography)

Abstract

This project looks at the effects of sub-aerial weathering on the chalk cliffs at Peacehaven taking into account both field and laboratory results. The accumulation of chalk debris on the promenade under the cliff provided information on the frequency and size of erosion events, showing little seasonal change from summer to winter. Weather data was correlated with this and provided a significant relationship between average rainfall and total debris. This has been interpreted as result of wetting and drying causing stresses and weaknesses to develop. Laboratory experiments to simulate frost shattering and salt crystallisation processes on chalk showed the influence of temperature fluctuations and salt solutions of varying concentrations. Samples saturated with environmentally realistic solutions exhibited greater breakdown during the salt crystallisation weathering process, reflecting the influence of wetting and drying on disintegration. It was also noted that high concentrations of salt solutions during freeze-thaw experiments caused increased breakdown.

Cliff stabilisation works carried out at one of the field sites showed that weakening of the rock had occurred, this caused a short term increase in erosion. Such man made accelerations of erosion hold implications for residence and the council.

This project provided an over view of the weathering processes occurring at chalk cliff coastlines, however it also highlights the difficulty of attributing a weathering process to an erosional event.

CONTENTS

Chapter 1. Introduction

Importance of investigation

The chalk cliffs which run along the Sussex coastline form a dominant feature. The bright white colour, which is their trademark, is a direct result of the constant removal of material through weathering and erosional processes. The weathering processes are of fundamental significance in geomorphology as “most material removed in the development of landforms has first to be weakened or loosened by one or more weathering processes before erosion can commence” (Robinson & Williams, 1994). Warm coastal environments are particularly suitable for several of these processes, however their role in cooler regions is less well documented.

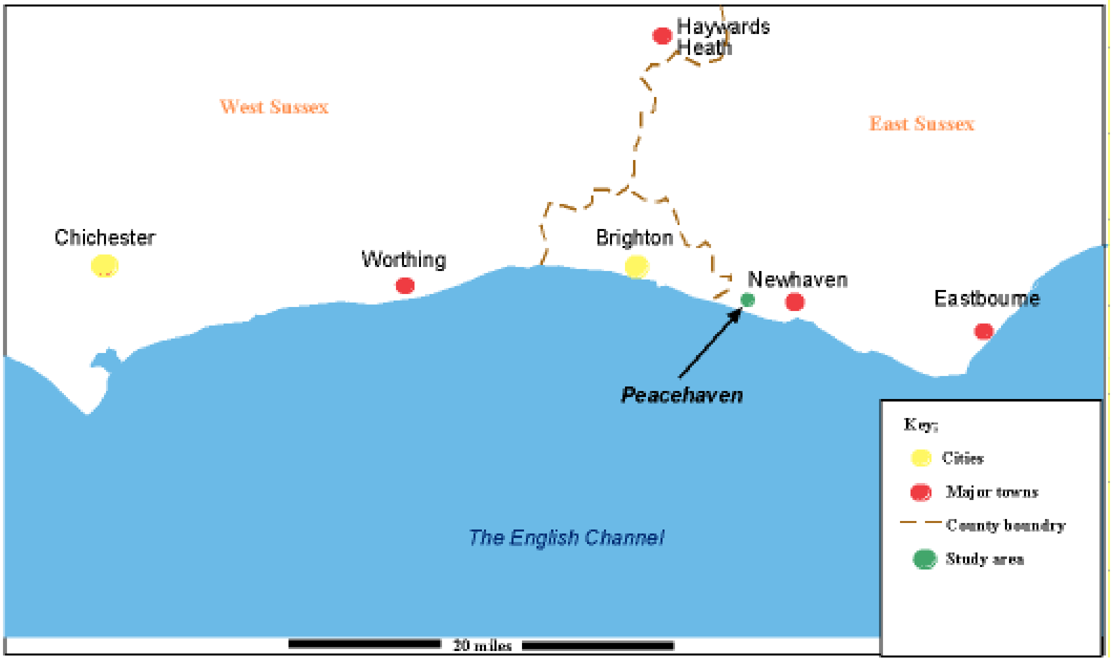
The increased rates of economic development and the spread of residential settlement along the South coast have presented a practical need to understand the dynamics of this coastline.

Location of study site

The town of Peacehaven is located on the South coast of England within East Sussex, seven miles east of Brighton (Fig 1). It sits upon the dip slope at the most seaward extent of the South Downs where the chalk forms the cliff interface with the sea. These cliffs form part of the stretch which run from Brighton to Eastbourne reaching a maximum height of 162m at Beachy Head. They are the result of erosion of the Chalk by the sea over 10,000 years, since the English Channel was flooded at the end of the last glacial period (ROCC, 2000).

The study site is situated at the access steps scaling the cliff face close to Friars Bay (fig 2). This area was chosen to mirror the previous rock weathering project carried out in this area by Katie De Wolf, thereby increasing the data set and information. The steps also provide convenient access to the sea wall promenade and the vertical extent of the cliffs.

Fig 1: Map of the South coast of England showing the location of Peacehaven.



In this section of coastline, the cliffs reach 40 meters in height, forming type A cliffs[1] (May, 1985). Homogenous in composition, they consist of Upper Chalk with successional flint banding and a near vertical cliff face exceeding 75°, where natural (fig 3).

FIG 2 and 3 missing

Fig 3: Unprotected chalk cliffs 20m east of the
Friars Bay steps showing typical Type A cliff characteristics

The rock type is typical for the category of cliff as it is highly jointed and weak allowing the vertical face to be maintained. The Upper chalk is formed from coccoliths (single-celled autotrophs covered in small light intensifying plates) and

[1] Type A cliffs are defined as; mainly homogenous in material, unresistant to erosion and producing an angel exceeding 75°.

their disintegrated products, the relative softness of the rock is due to the lack of cement.

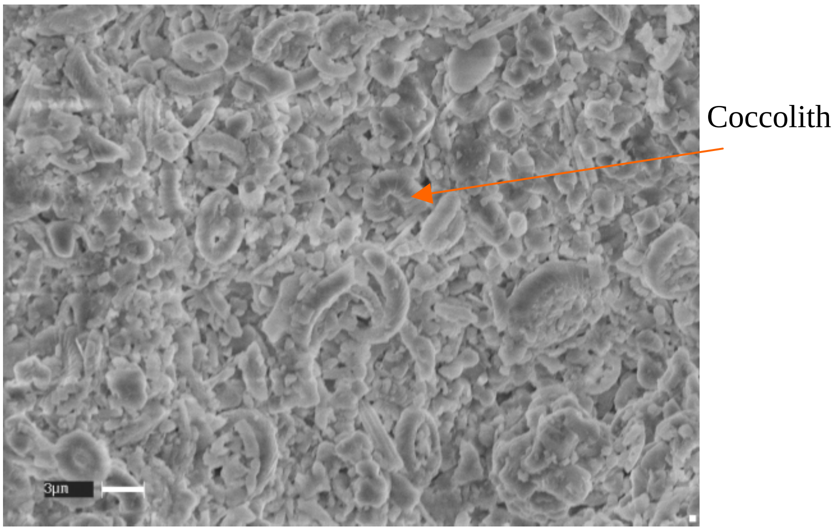


Fig 4: Scanning Electron Microscope image of chalk.

The flints are formed from black chert and are the early products of diagenetic silica precipitate in the top ten metres of sediments, producing the bands seen throughout the Peacehaven cliff profile (fig 5).

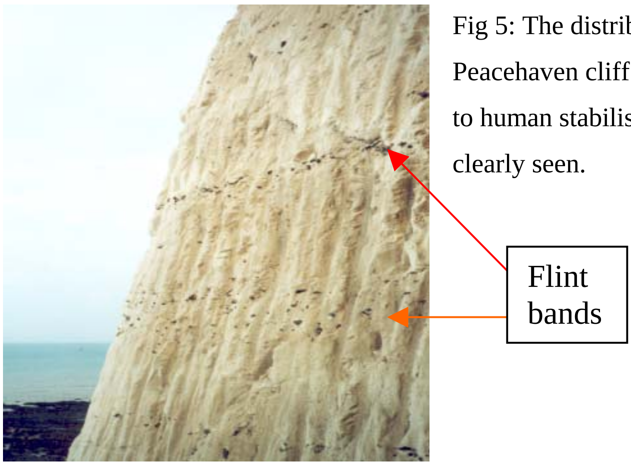


Fig 5: The distribution of flint bands through the Peacehaven cliff profile. The presence of scour marks due to human stabilising works by machinery can also be clearly seen.

At the base of the cliffs/sea wall a chalk shore platform extends seaward over an average distance of 150m to 200m (ESPED, 2001)(fig 6). The gently sloping inter-tidal border forms the coastlines natural defence as it increases the friction between incoming waves and the coastline. Due to this abrasion, the shore platform is down wearing and supplying sediment to the coastal system. Along its upper reaches a thin covering flint shingle has collected intensifying the defensive effect.

Fig 6: Chalk shore platform located opposite the Friars Bay steps. The thin covering of shingle material can also be seen.

The tides here operate on a semi- diurnal basis over a mean range of 4.7m (ESPED, 2001), making them macrotidal. The predominant wind direction is from the Southwest blowing down the English Channel from the Atlantic. This results in the south-westerly movement of sediment along the coast through long shore drift.

Increased population pressure has been brought about in this area through the expansion of tourism and prosperity, leading to the development of cliff edge. The 4.5 kms of residential and infrastructure construction at Peacehaven has increased the financial pressure on the cliffs and produced the need to reduce and in some cases prevent cliff erosion. A general report submitted to the council in 1968[2] showed that the coastline from Portobello to Friars Bay was eroding at a rate of 0.5m per annum (Lewes District Council, 1996). This prompted the coastal policy of hard engineered defences and a construction program which entailed four phases (fig 9). Phase 1 was completed in 1977 at a cost of £900,000 at Friars Bay, with the work including a 4m wide promenade, 6m height sea wall, 3m height splash wall, concrete groyne structures, trimming of the cliff face to 72° (fig 7& 8) (to produce a stable erosion surface) and the access steps.

[2] At that time Chailey R. D. C. were responsible for the coastal defence of Peacehaven.

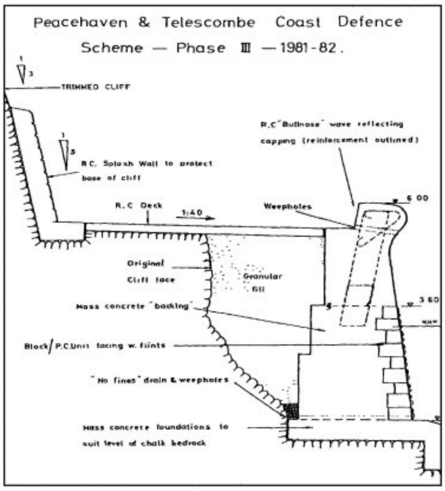


Fig 7: Design of similar coastal defences implimented at the study site.

Fig 8: The Friars Bay defence works.

These works have prevented the erosional processes of wave quarrying, abrasion and attrition, leading to the removal of basal marine erosion which maintains cliff recession (Bird *et al*, 1985). Unprotected areas such as the Seven Sisters are experiencing fairly rapid recession as a result of basal erosion, at an average rate of around 0.6 m per annum (ROCC, 2000). Here, large infrequent fall events contribute most to cliff depletion.

At Friars Bay the cliff recession is estimated to be 0.4m per annum (ESPED, 2001) despite the lack of basal erosion. This suggests that sub-aerial weathering processes must be contributing to the disintegration. In coastal environments the processes of freeze-thaw and wetting and drying are of great importance (Bird et al, 1985 & Tranhail, 1987 & 1997) as they weaken or loosen the rock allowing erosion to commence. The chalk cliffs at Peacehaven are (theoretically) particularly susceptible to these processes as they can absorbed large quantities of water with in their structure due to the multitude of cracks and joints (fig 10) within the rock allowing deep penetration around areas of weakness. These fractures within the rock are of significance to frost weathering as although it is harder to freeze water in crevices the erosion produced is considerable (Tranhail, 1987).

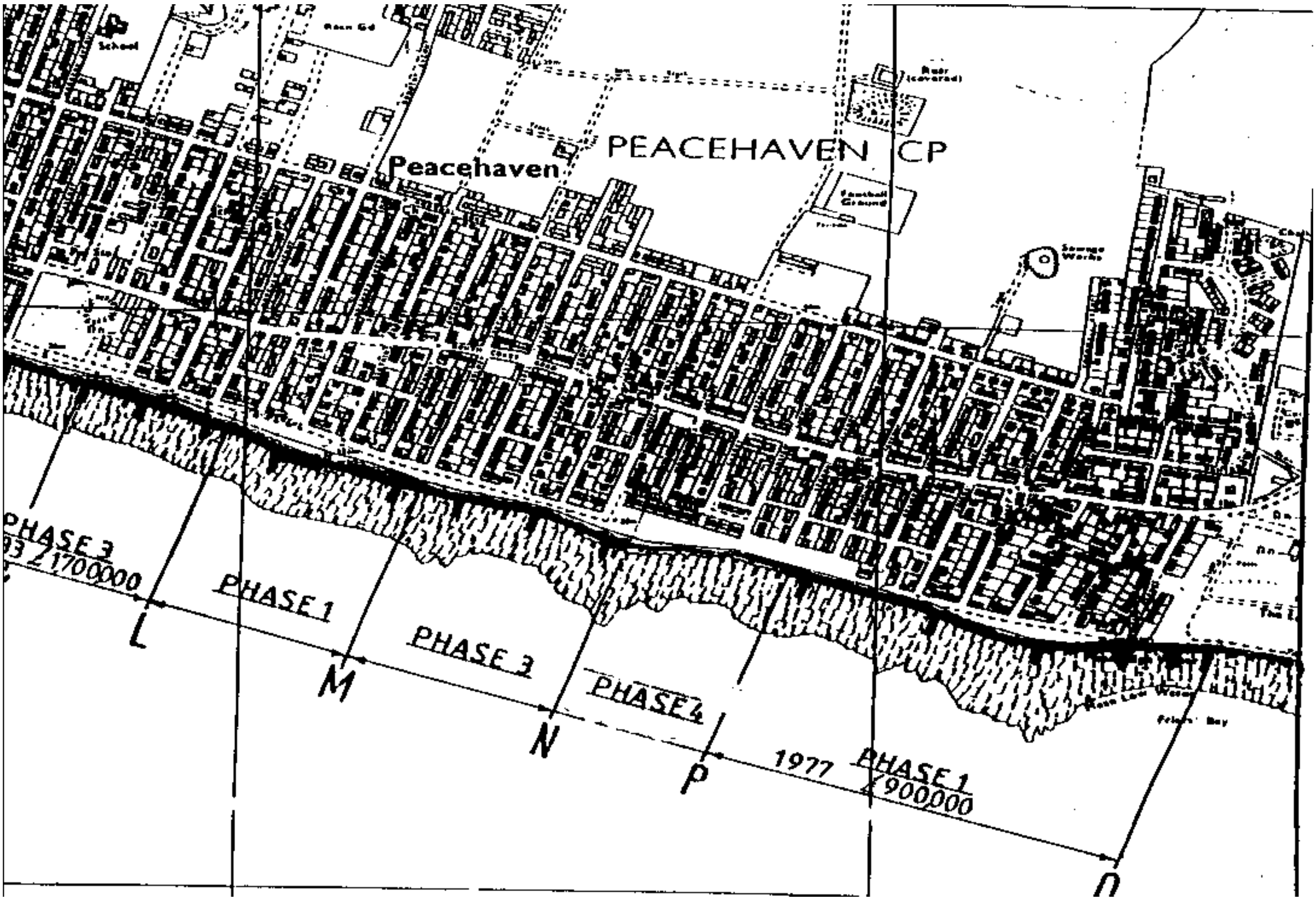


Fig. 9: Phase of coastal policy hard engineering construction implementation.

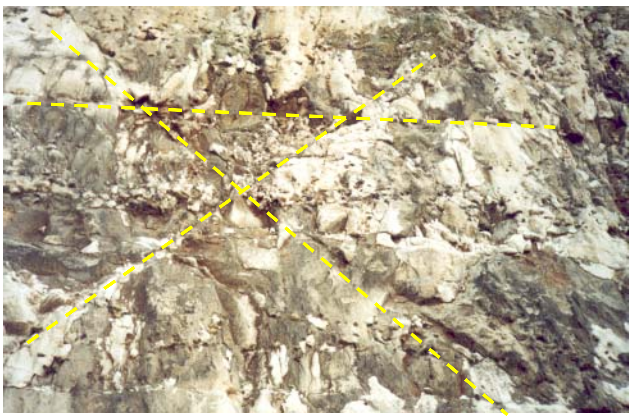


Fig 10: Section of highly fracture cliff face. Yellow dashes indicate macro-scale cracks.

The presence of salt within the fractures and capillaries of coastal rocks can cause mechanical weathering due to, volume changes by hydration; expansion of salt crystals due to temperature change and crystal growth from solution. Previous coastal studies carried out by Johonnessen *et al*, (1982) at Oregon concluded that heat expansion of salts was probably the main erosive mechanism above high tide on sunny, south facing sandstone cliffs. At Peacehaven the amount of sea spray reaching the cliff is minimal due to the splash wall facing the cliff however average surface readings of NaCl are 27ppm (De Wolf, 2001). During storm events large quantities of shingle are thrown up on to the promenade demonstrating the ability of sea water to reach the cliff face, together with this the high winds blowing on land will facilitate the deposition of salt on to the cliffs.

Aims and objectives

- To investigate the quantity of chalk being removed from the cliff face through sub-aerial weathering processes during summer and winter seasons.
- To relate local weather conditions to times of increased erosion.
- To asses the susceptibility of chalk to freeze-thaw and salt crystallisation weathering.
- To relate mean chalk fragment size produced by the erosion of the cliff to the mean fragment size of rocks subjected to freeze-thaw and salt crystallisation weathering cycles.
- To asses the impact of cutting back the cliff face for stabilisation purposes.

Expectations

Seasonal analysis of cliff recession rates along the Sussex coast have not been assessed, however observational descriptions do provide some insight. May, (1971), remarked that the most substantial losses occurred in winter[3]. Investigation on the effects of sub-aerial weathering during harsh winters by Robinson and Jerwood , (1987), revealed that the chalk shore platform was being modified by freeze-thaw processes. From this, it would be expected that for the winter period, higher rates of cliff erosion should be expected.

[3] This investigation was carried out in areas without coastal protection works and therefore wave erosion would have been dominant.

With the acknowledgement that most erosion occurs during winter both salt crystallisation and freeze-thaw processes could be acting together, however it seems unlikely that salt crystallisation would occur due to the low evaporation rates and heavy precipitation diluting the salt concentration. Freeze-thaw therefore can be expected to be the dominant process during winter months owing to the chalks susceptibility when saturated.

The growth of salt crystals within the capillaries of the rock suggests that smaller fragments will be obtained though this process. If the temperature is low enough and water is able to freeze in crevasses and the fragments obtained through freeze-thaw will be significantly larger. In experiments it has been shown that although the percentage of fragments increases with the number of freeze-thaw cycles, the larger fragments are removed rapidly (Williams, 1980). This would suggest that in the field large fragments would be seen through the beginning of the winter.

Salt crystallisation would be expected to become a dominant weathering process during the late summer and autumn months. This would coincide with periods of infrequent rainfall and warm temperatures providing optimum conditions.

The effect of cliff trimming is intended to stabilise the cliff face but little is really known about its true effects. Such work may cause destabilisation in areas located in the vicinity.

Sub-aerial weathering processes:

The term “weathering” is described by Tranhaile (1987) as “the result of the adjustment or readjustment of rock minerals to more stable mineral phases under the prevailing conditions”. The prevailing conditions in coastal environments are particularly suitable for mechanical weathering which involves the breakdown of the rock into smaller particles by the exertion of stresses sufficient to strain and eventually split it. One or many of these mechanical processes may be causing sub-aerial erosion at the Peacehaven site, therefore a description of each significant process is of use. The dominant processes are:

- Freeze-Thaw
- Salt weathering
- Wetting and Drying

Freeze- Thaw:

This process exists due to the volumetric change in water as it passes from a liquid state into a solid one. In general it is said that water expands by 9% when this occurs. If water can enter a rock through crevices, fractures or capillary spaces and subsequently freeze, the rock will be subjected to extremely high pressures which may cause shattering or cleaving if the rock is weak.

The Upper Chalk is considered highly susceptible to the actions of frost as;

- It has a high % void space within its structure allowing moisture to enter the rock and;
- It is a fine grained rock with multiple planes of weakness making it a relatively weak rock with low tensile strength and little resistance to frost action.

In conjunction with these factors, the presence of salt within the moisture from the sea may facilitate the disintegration of rocks (Williams & Robinson, 1991, 2001, Jerwood *et al.* 1990a & b) by lowering the freezing point producing longer periods of thaw which would allow for longer periods of moisture adsorption. The higher levels of saturation will result in greater break-up due to the increased pressure. This is not to say that increased concentrations of salt solutions will produce higher rates of weathering as many studies have suggested that salt (NaCl) produces a threshold for freezing to take place (Mcgreevy, 1982, MacInnis & Whiting, 1979).

Salt crystallisation:

Salt weathering, similarly to frost weathering is due to the pressures and strains established within a rock as a consequence of salt being present. There are three main mechanisms which can induce this:

- Volume change caused by hydration:

As water is absorbed into the rock, the salt crystals within can swell applying pressure to the constraining walls. The hydration and dehydration cycles will set up stresses within the rock, however the most damage will be inflicted by those salts which increase rapidly and significantly.

- Expansion of salt crystals due to temperature change:

The thermal expansion of rocks is significantly lower than the thermal expansion of salts. If salts concentrate in capillaries within the rock pressures will be established and disintegration can occur in areas with high diurnal ranges.

- crystal growth from solution:

Salt crystals can grow within the larger capillaries of a rock, unable to extend into smaller capillaries due to large increase in the chemical potential needed (Trenhail, 1987), pressure within the larger capillary increases. The precipitation of these crystals is reliant on the saturation of the solution. This can be achieved by either a drop in temperature or high rates of evaporation.

Being located at the coast the cliffs will receive high amounts of salts from the breaking of bubbles on the sea surface and the sea spray produces from breaking waves (Trenhail, 1987). This source is also accompanied by the presence of dissolved salts within precipitation along the coastline. Together with this the presence of multiple capillaries contained in the rock will allow the establishment of mechanical salt weathering.

Wetting and Drying:

The processes of frost and salt crystallisation weathering involves the absorption of moisture into the rock in order to maintain and continue disintegration. Such wetting and drying of the rock can induce stresses in themselves. As moisture enters the rock it can hydrate the minerals and become incorporated within the mineral crystal lattice structure. This results in the expansion and contraction of the minerals and can cause the breakdown of rock along lines of weakness such as cleavage planes and fractures. Chalk is particularly susceptible due to its high porosity and the location of the cliff aids this by providing a moisture source and high wind speeds which increase the rate of evaporation.

Chapter 2. Methodology

Weathering rate at Peacehaven chalk cliffs

Collection and grain size analysis of weathered debris:

From the 9th of July to the 30th of January the chalk debris covering two different sections of the promenade were collected. Site A was located two meters west of the life buoy next to the Friars Bay steps and was 9 meters in length and 2 meters deep from the splash wall.

Fig 11: Site A.

Fig 12: Site B.

This site was very close to a section of cliff that had undergone trimming in mid June. Site B was located 80 meters west from site A and covered the same dimensions. Both were swept clean of any debris a week before collection began to remove fragments of unknown age and in order to assess how far from the cliff foot (splash wall) chalk particles would travel.

The debris was collected on a weekly basis and transported to Sussex University geography laboratory where it was dried for 24 hours. To Separate the fractions the promenade debris was put into a series of sieves, which were then placed in a sieve shaker. This was allowed to run for 10 minutes in order to sort the rock adequately. Material other than the chalk fragments was disguarded and the remaining material was weighted, this was not however possible for debris smaller than 2 phi. Such small fragments were likely to have resulted from the impact with the ground following displacement from the cliff face.

The data gained from this could give an indication of monthly weathering rates for Peacehaven. Producing an average weathering rate for the year could also be possible but would be highly floured.

Some of the larger fragments were weighed before and after drying to provide data on the moisture content of the rocks, these same rocks were then soaked for 24 hours to provide data on the saturation of the material.

Meteoric data:

The weather information was obtained from the Sussex University owned Davis Instruments automatic weather station located at Saltdean[3] (fig 13). This provided daily data (which was subsequently converted into monthly data) on wind speed, direction, rainfall and temperature. This data could then be used to establish correlations between cliff retreat and external conditions.

The temperature of the cliff face was measured using a hand held temperature sensor. Measurements were taken on several occasions throughout the investigation with both the chalk and the flint being measured.

Fig 13: Map to show location of Saltdean in relation to Peacehaven (Multi Map, 2001)

3 http://www.cpes.sussex.ac.uk/es/meteo/

Micro erosion Meter:

To asses the finer material weathered from the cliff face a standard micro erosion meter (MEM) was used[4] (fig 14). Study sites were located in four positions distributed across the vertical extent of the cliff face, this was made possible due to the Friars Bay access steps next to the study site. The MEM was mounted on three brass round head screws embedded in the rock (when not in use the screws were rotected from corrosion by blue tac plugs). Three readings were taken on a dial calibrated to 0.0025 mm to obtain more accurate result accurate results.

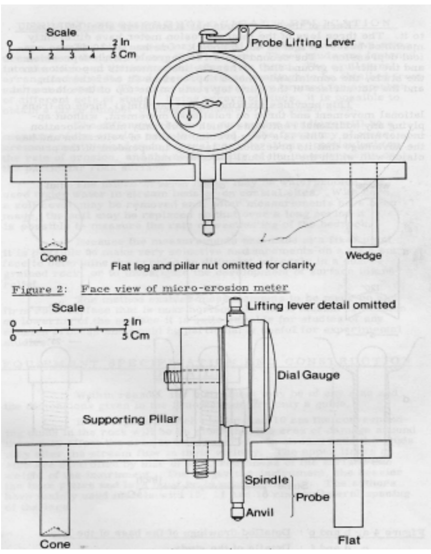


Fig 14: Diagram of MEM equipment
(High and Hanna, 1970)

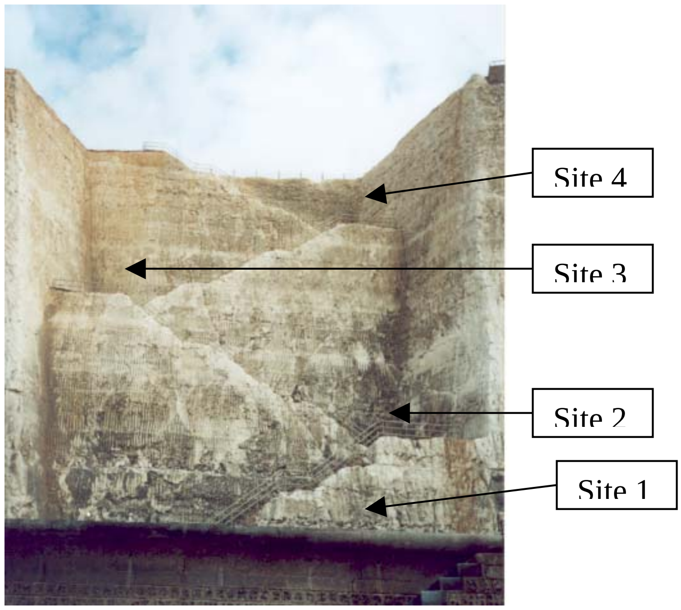


Fig 14b: Location of MEM sites scaling the cliff.

Laboratory weathering experiments

Freeze-thaw experiments:

[4] Full descriptions of the standard MEM can be found in High and Hanna, 1970.

Chalk cubes measuring 75 x 75 x 75 mm were cut from large eroded fragments obtained from a cliff fall close to site A. Seven in total were used for the experiment all of which were dried for 69 hours to attain a constant weight. After cooling for an hour they were weighted and placed into separate plastic containers measuring 110 x 110 x 130 mm. Three salt solutions were produced with 1 g/l (the concentration of salts found at the chalk cliff surface), 5 g/l and 35 g/l (the mean salinity levels of coastal sea water around the UK (Barne *et al*, 1997)) of NaCl (halite) and each added separately to pairs of the chalk blocks. The final block was used as a control and soaked in deionised water. The blocks were left soaking at room temperature for 72 hours after which much of the solution was removed leaving the bottom 15 mm of the cubes submerged. This was done to prevent excessive and unrealistic pressure on the rock occurring as the blocks could relive strain by extrusion and displacement of water (McGreevy, 1982) They were then placed in insulated containers containing 55 mm thick polystyrene (to allow unidirectional freezing (Jerwood, 1990) and put in the Environmental Cabinet and subjected to 20 cycles of freezing and thawing (fig 15). Each cycle lasted 13 hours, with a 30 minute change between the maximum temperature of 5°C and the minimum of -10°C.

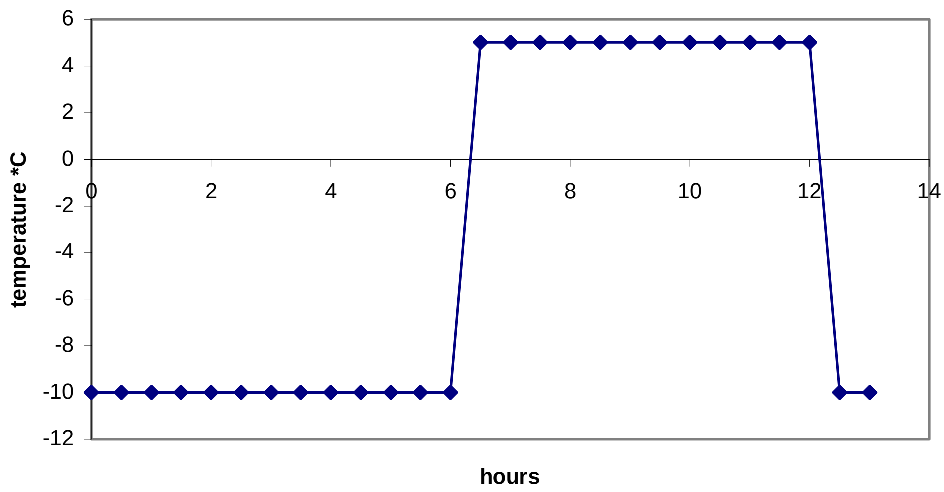


Fig 15: Environmental cycle produced to induce freeze-thaw conditions.

At the end of the cycles the blocks were removed from the cabinet and leached of their salt using deionised water. They were then dried for 69 hours, sieved to separate clasts of differing sizes and weighted accordingly.

Salt weathering experiments:

Chalk blocks from the same location and of the same dimensions as the freeze thaw experiments were also used for the salt weathering experiments. After drying seven blocks at 50°C for 69 hours they were left to cool for an hour, then weighed and placed in plastic containers measuring 110 x 110 x 130. Solutions of the same concentration used in the freeze thaw experiment were used and the blocks were soaked for 2 hours. They were then placed in a bag of fine plastic mesh and returned to the oven for 69 hours at 50°C. This 72 hour cycle (fig 16) was repeated 20 times with the eroded fragments being collected, sieved and weighed after each cycle.

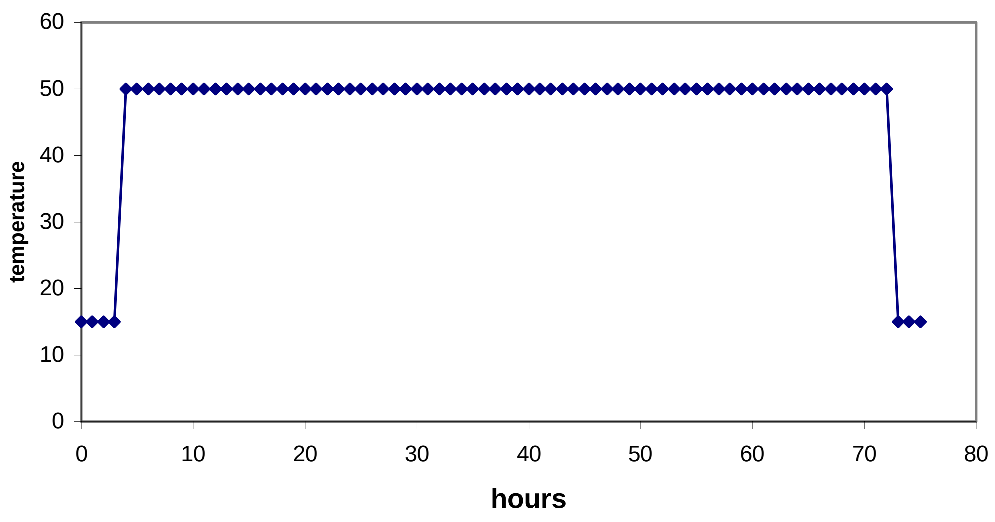


Fig 16: Environmental cycle produced to induce salt weathering conditions.

Scanning electron microscope:

Samples of the salt weathered block were placed under the microscope in order to establish the presence of NaCl crystals within the rock structure. This became impossible to achieve due to the breakdown of the analysis machine and therefore no results could be taken. Figure 4 shows the chalk structure.

Limitations and problems with the methods used

- Due to the height of the cliff and the ridged concrete promenade, lumps of chalk which became detached from the cliff may have disintegrated on impact (fig 17). This would be particularly true if the rocks were saturated and consequently softened. Indeed rock splatters were observed during times of heavy rain during winter months.

Fig 17: Disintegrated block of Chalk debris found on the promenade from the Peacehaven cliffs.

It could also be feasible that chalk particles from the sections of cliff being considered did not enter the study site and were not recorded. These fragments may have either bounced or been blown out of the sites, or as was seen in other locations, become lodged on the top of the splash wall.

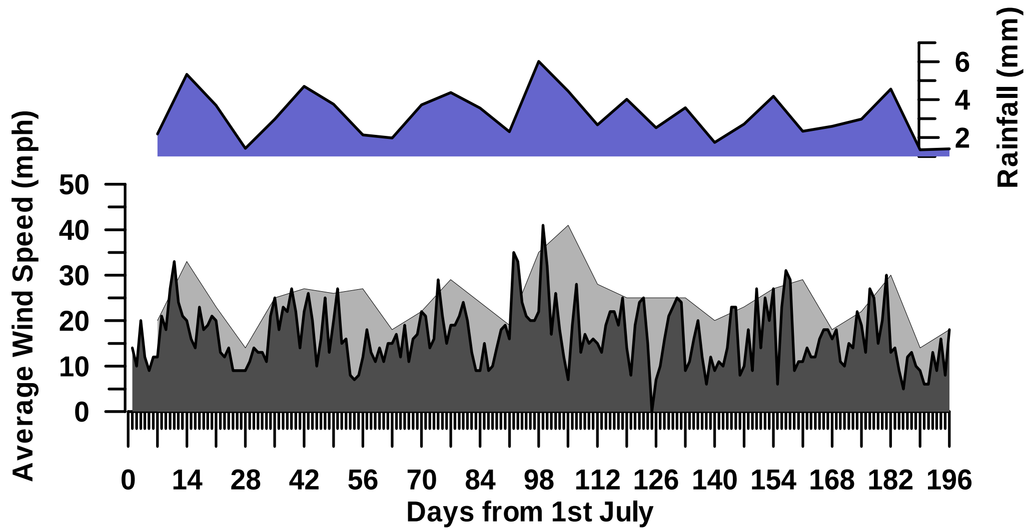
Fig 18: Eroded chalk material lodged on the splash wall.

- Due to the quantity of storm debris thrown on to the promenade (fig 19) from the beach it was impossible to record the amount of flint being eroded from the cliffs.

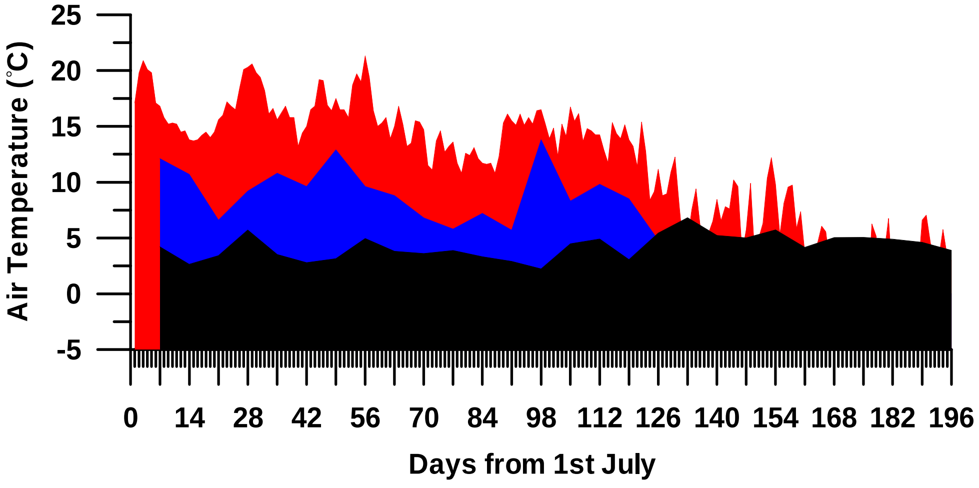
Fig 19: Accumulation of both eroded material from the cliffs and storm debris from the beach.

- Meteoric data obtained from Saltdean, despite being close to the study sites it does not reflect the true weather that the cliffs are subjected to.
- The MEM instrument, even though it is reasonably reliable and easy to use does have its limitations. These include; temperature change of the instrument can cause errors; temperature change of the screws and rock can result in errors and erosion of the rock due to the MEM probe can occur (Spate *et al*, 1985, Williams and Robinson, 2000)
- The laboratory experiments used solutes which would not be encountered in the environment. Sea water contains many more varieties of salt than just NaCl, however this does make up the bulk of it. Also the relatively small blocks of chalk used are not representative of a cliff face as they provide a larger surface area.
- The freeze-thaw experiments are limited at representing the real environment as they exert far more cycles than would be encountered within a winter season at Peacehaven. The rapid freezing of the block may have weakened the rock significantly by not allowing the rock to respond (McGreevy, 1982) to the stress.
- The rock weathering experiments were intended to model one process however in reality the weathering processes can be interlinked (Goudie, 2000), for example the salt weathered blocks may have been worn by the wetting and drying or hydration.

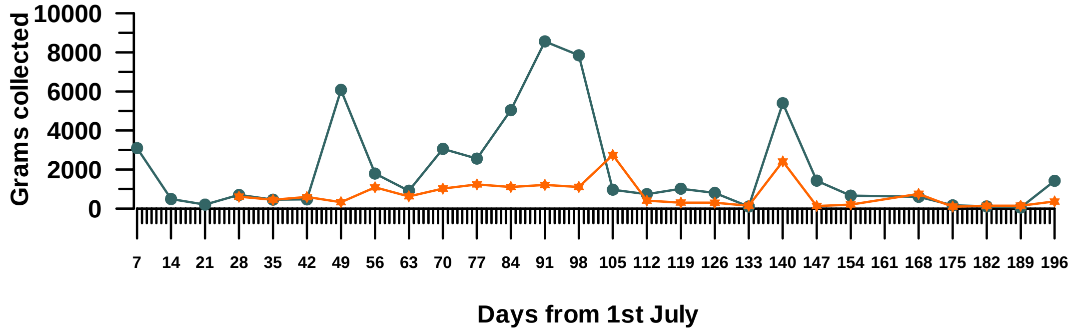
Chapte 3: Results



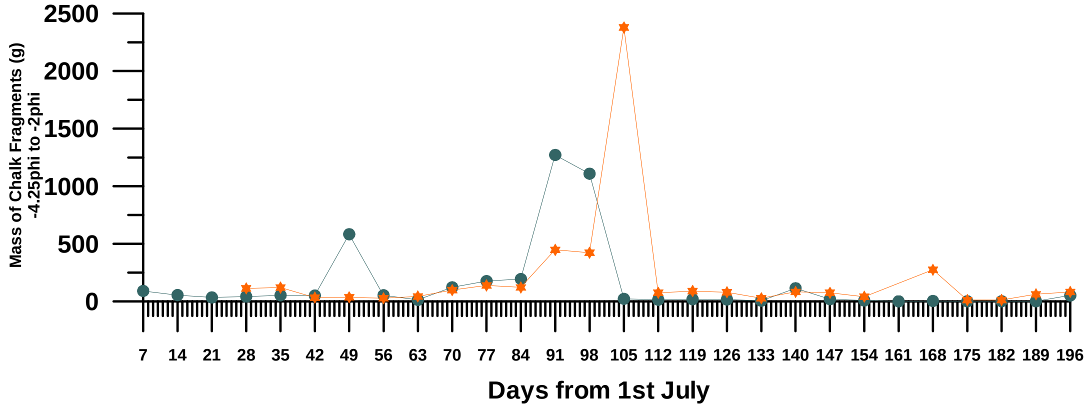
Graph 1. Precipitation and Wind speed as recorded by Peacehaven Weather station (courtesy of Mr Phil Chitty). Daily precipitation indicated in Blue. Saturation of chalk with water will increase chalk fragment mass and reduce friction coefficents and therefore potentially cause loose fragments to fall down the cliff. Water saturated chalk also has a habit of "splatting" on the underlying concrete upon impact rather than landing intact. Water is also necessary for freeze-thaw action during winter. Maximum recorded daily wind speed is shown in grey. Daily mean wind speed indicated in black. Peak winds may dislodge particles and general wind speeds will effect surface drying of rock.



Graph 2. Air temperature records from Peacehaven Weather Station (courtesy of Mr Phil Chitty) Red indicates daily maximum temperature. Blue indicates daily minimum temperature. Black indicates daily temperature range which may potentially have effect on differential thermal expansion rates between the flint nodules and the supporting chalk.



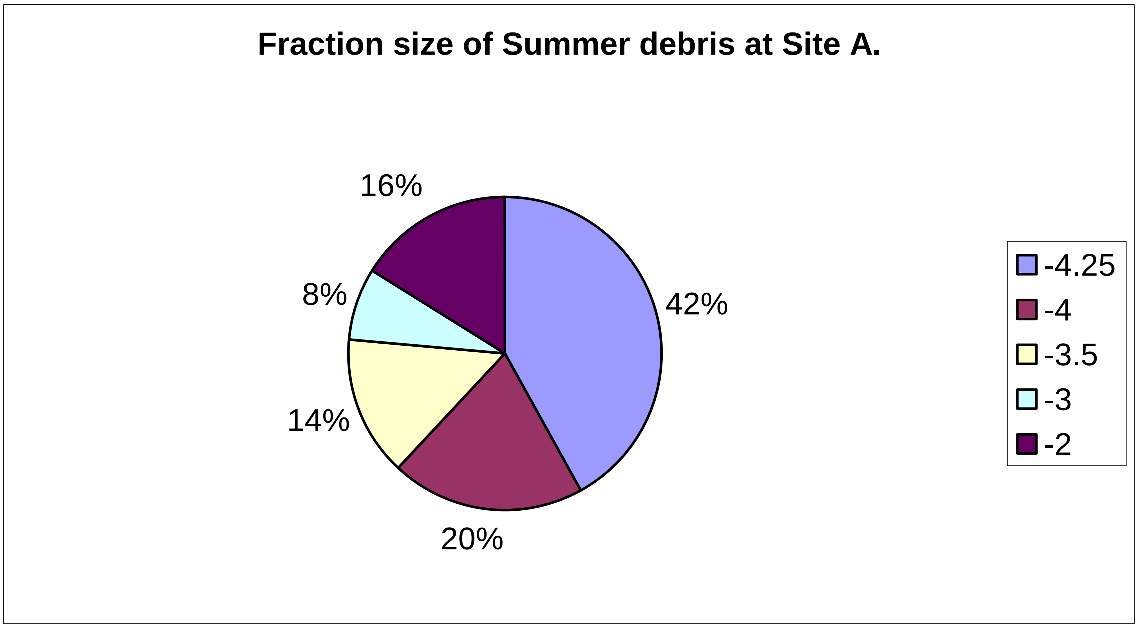
Graph 3. Mass of total material collected weekly. Green plot indicates Site A. Orange plot indicates Site B.



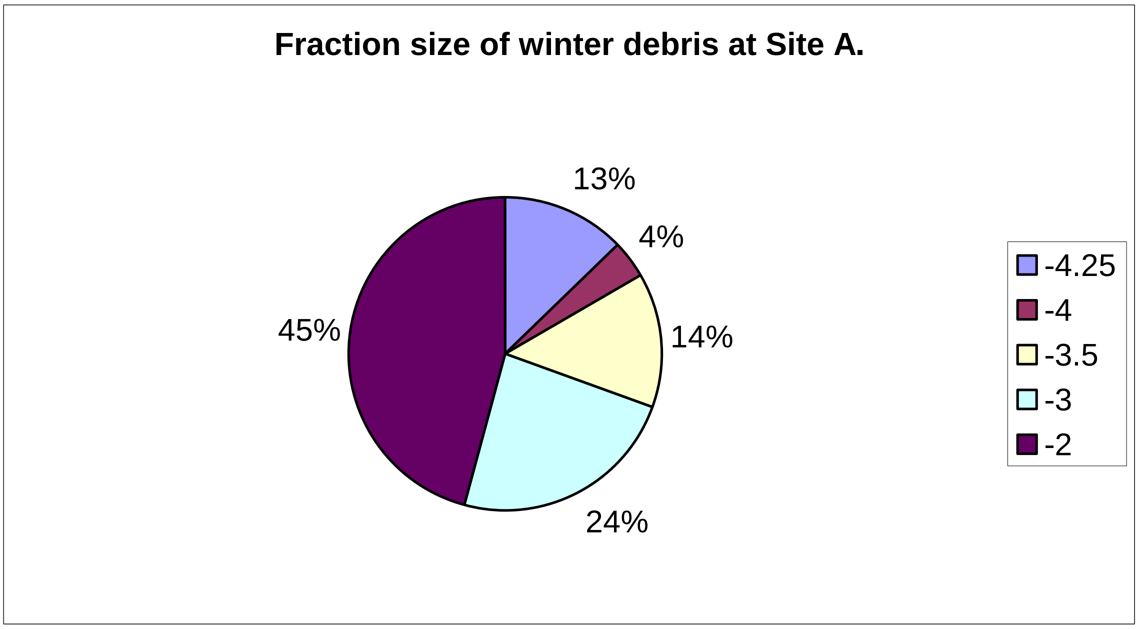
Graph 4. Combined sum of chalk fragments (g) in size range of -4.25 to -2phi. Green plot is Site A. Orange plot is Site B.

Seasonal differences in chalk debris fraction size at site A

Graph 5



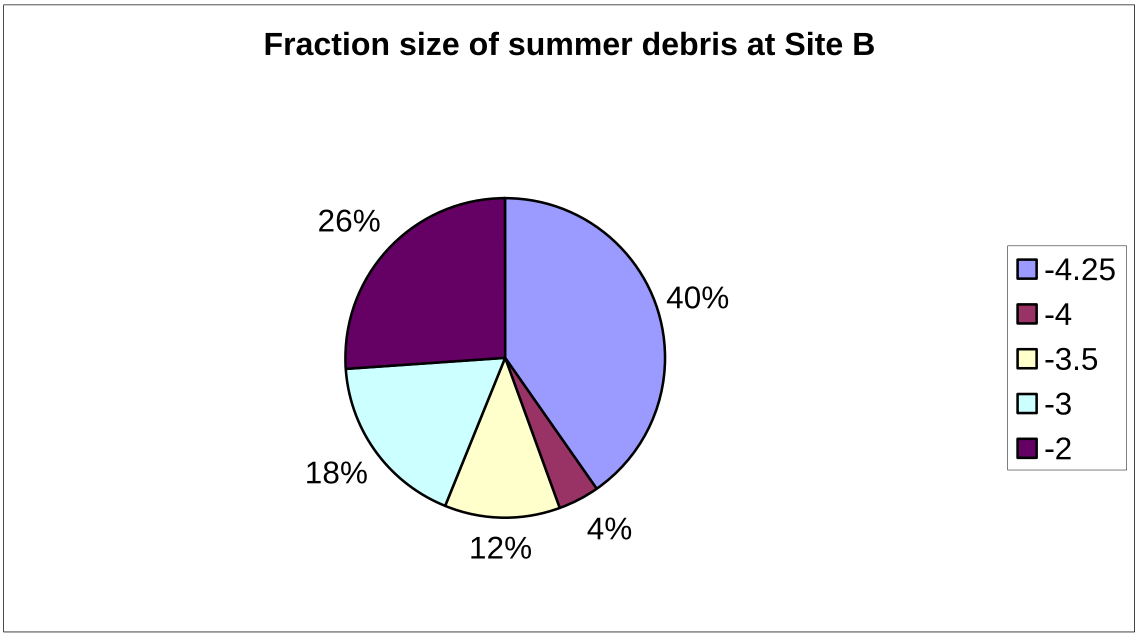
Graph 6



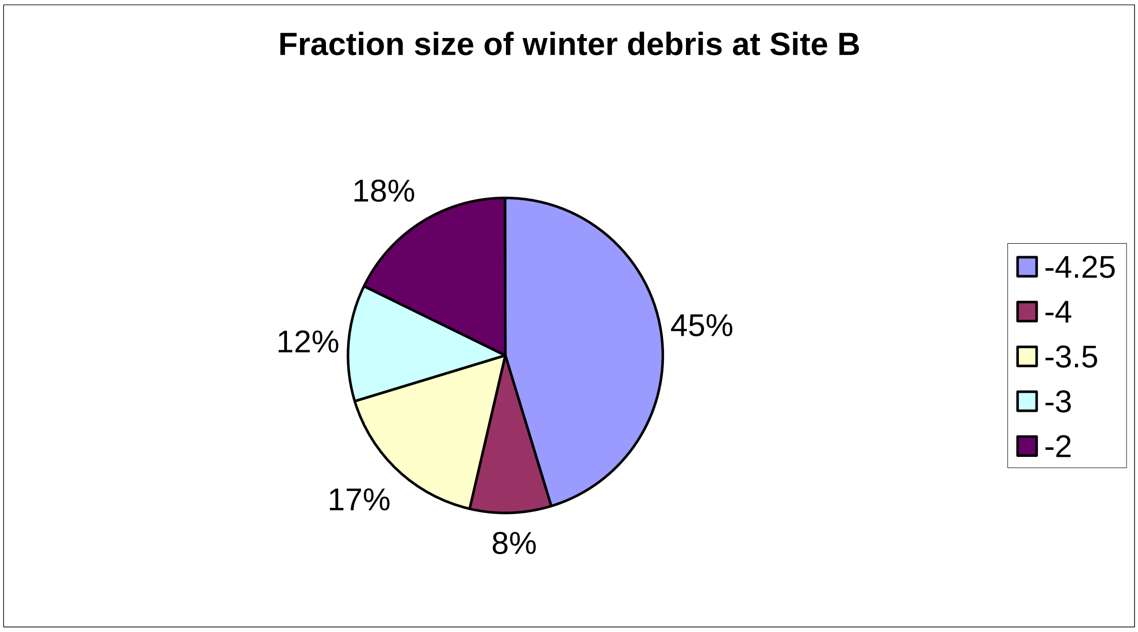
Summer data was calculated from day 7 to 63 (9 weeks), corresponding to the months of July and August. Winter data was calculated from day 126 to 196 (10 weeks) corresponding to the months of November and December. Ten weeks were covered for the winter data as day 161 had no data due to debris clearence by the council.

Seasonal differences in chalk debris fraction size at site B.

Graph 7



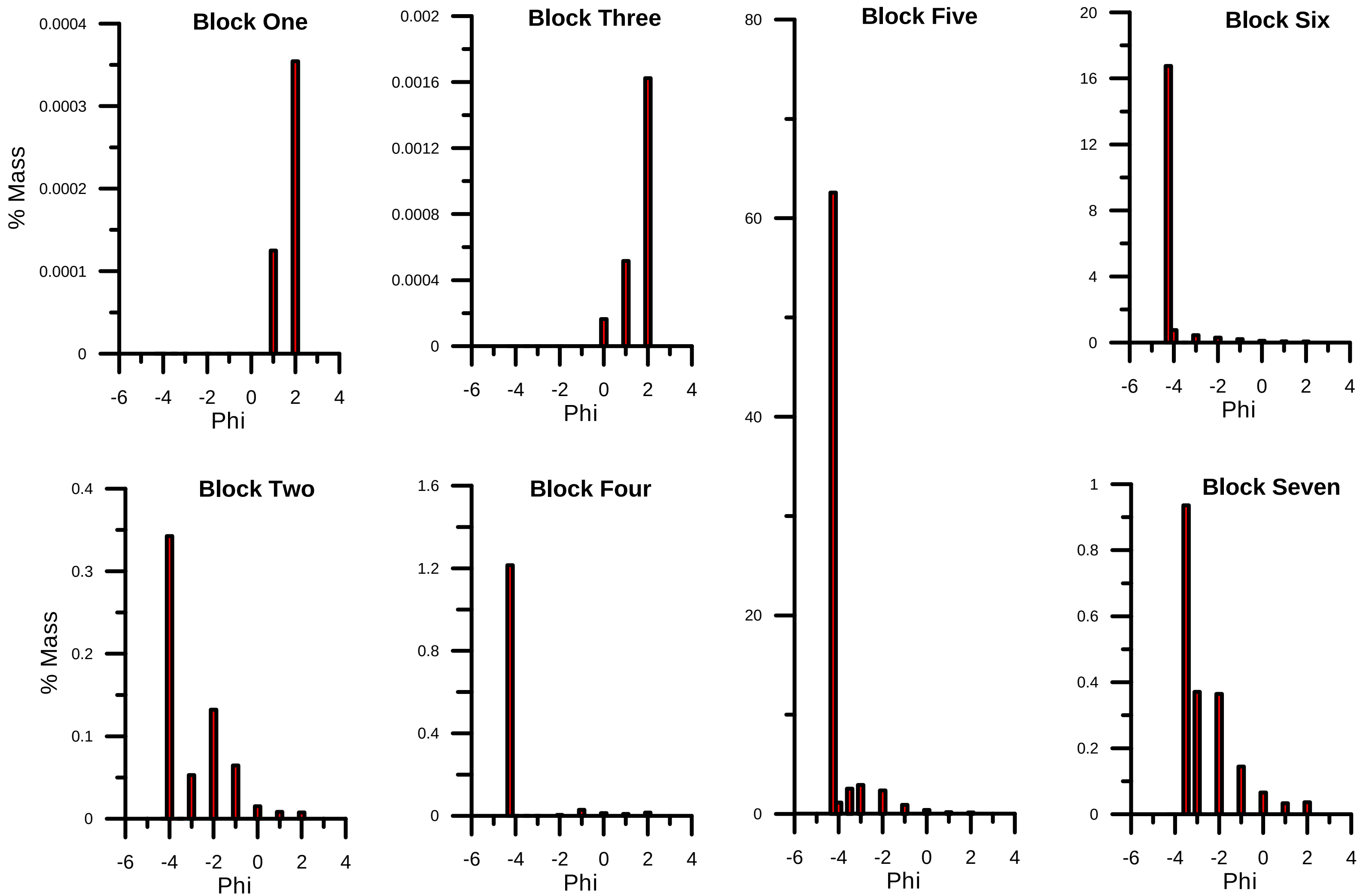
Graph 8



Summer data was calculated from day 28 to 63 (6 weeks), corresponding with the end of July and the whole of August. This was due to the late investigation of site B. Winter data was calculated from day 126 to 168 (7 weeks), corresponding with November and the beginning of December. Seven weeks were covered for the winter data as day 161 had no data due to debris clearence by the council.

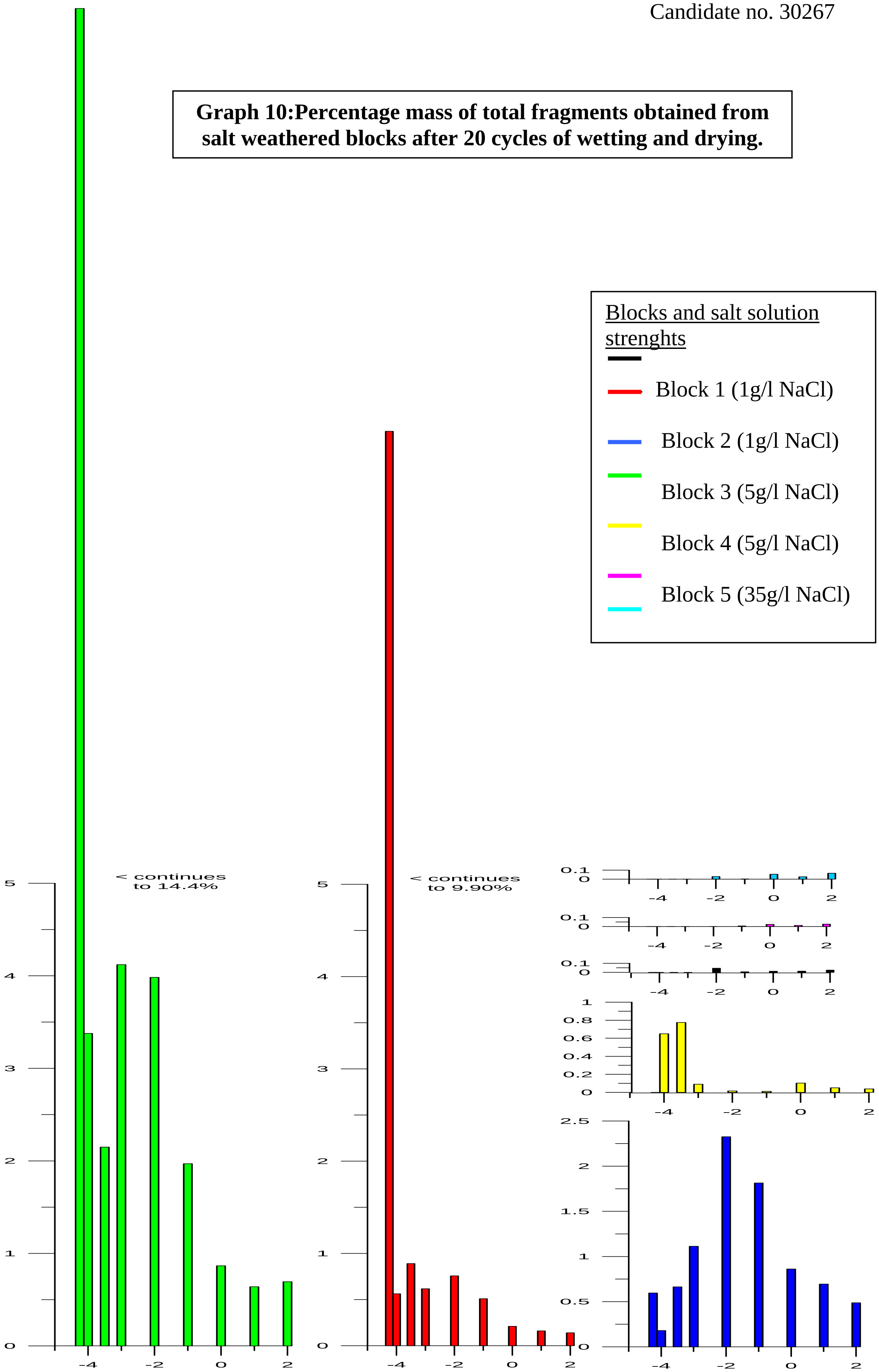
.

Graph 9 :Frost weathered debris fraction size.



The % mass of each fraction is representative of the % loss from each initial block. Salt solutions (NaCl) varied in concentration; blocks 1 & 2 – 1g/l, blocks 3 & 4 – 5g/l and blocks 5 & 6 – 35g/l. Block 7 was a control sample and was soaked in deionised water. The results were produced after 20 cycles of freeze and thaw.

Graph 10:Percentage mass of total fragments obtained from salt weathered blocks after 20 cycles of wetting and drying.



Graph 11: Percentage change in mass of chalk blocks during salt weathering experiment.

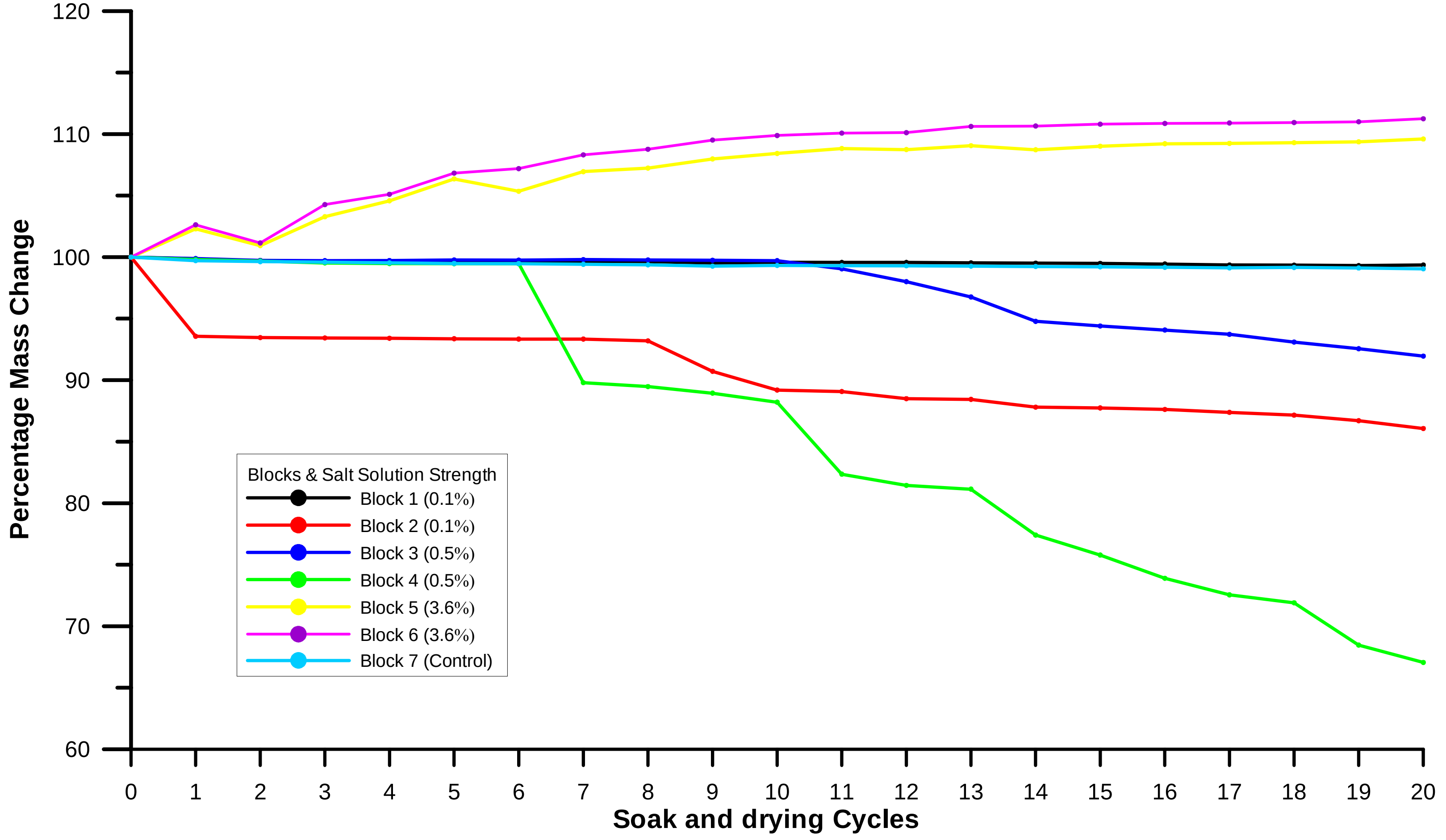


Figure showing the change in relative mass of Chalk blocks saturated with different strengths of NaCL solution throught 20 soaking and drying cycles.

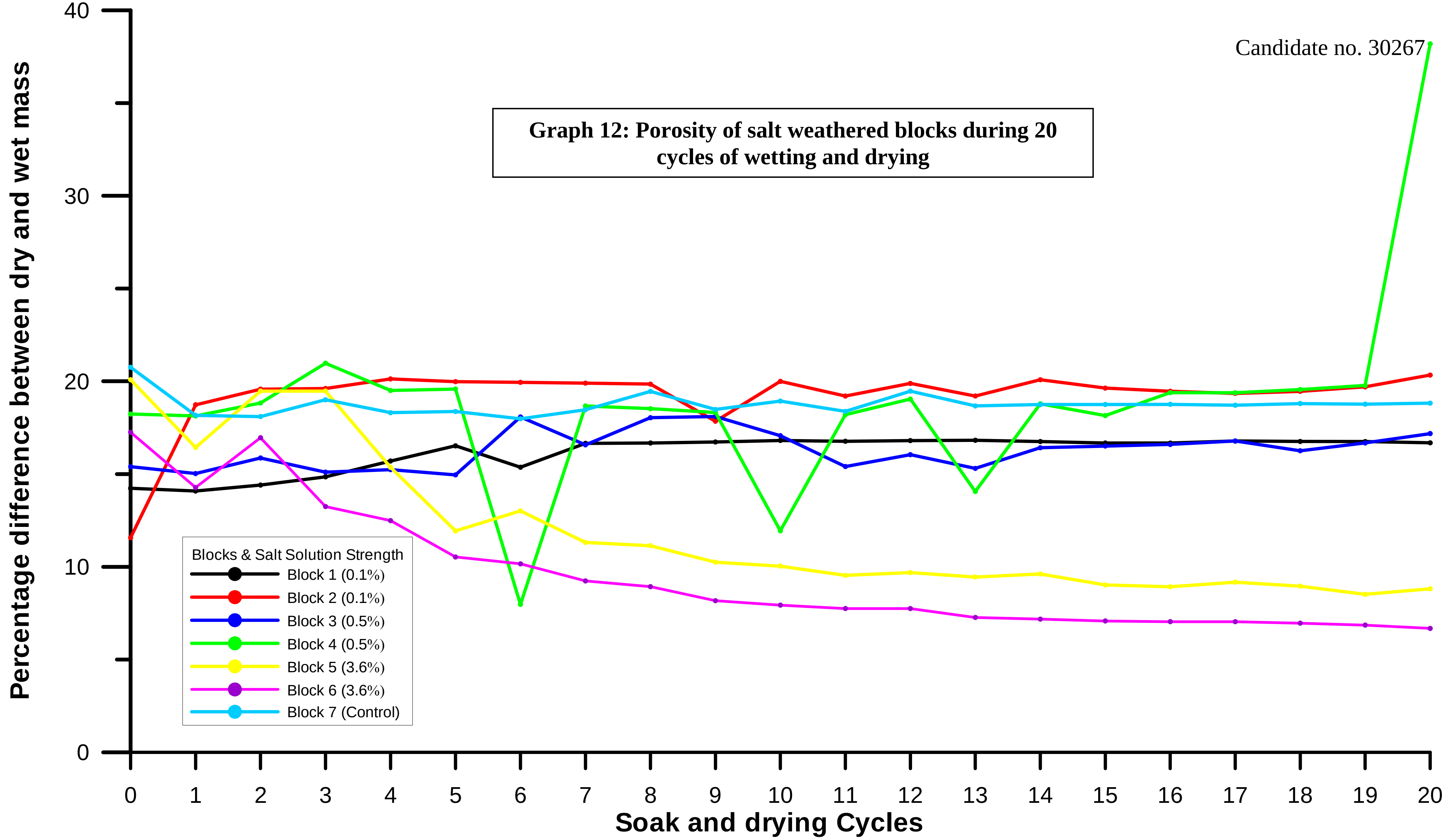
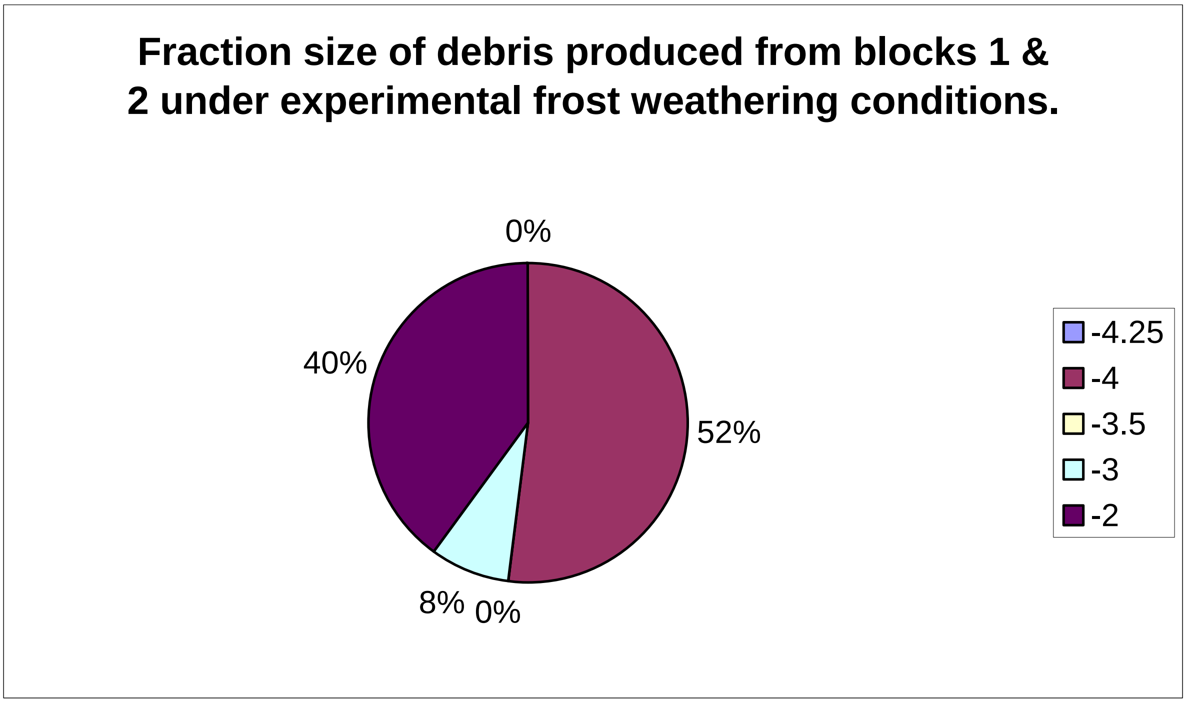


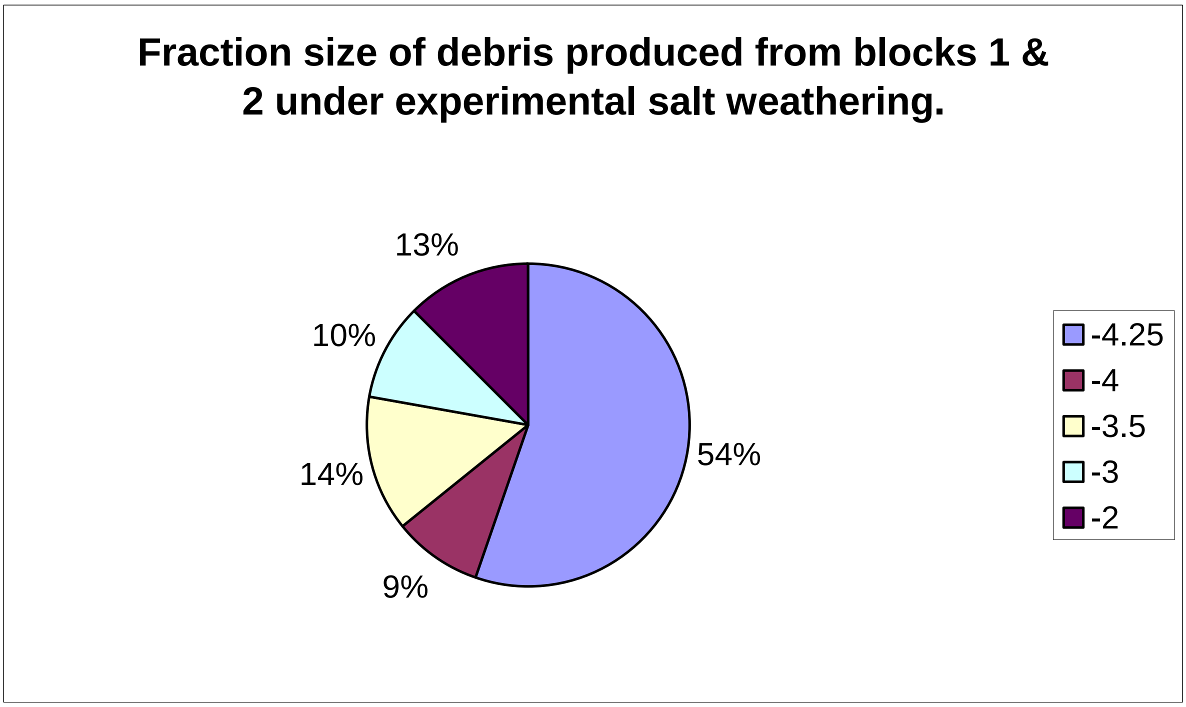
Figure relative mass difference of chalk blocks between wet and dry masses during 20 soaking and drying cycles.

Fraction size of chalk debris produced under different experimental conditions.

Graph 13

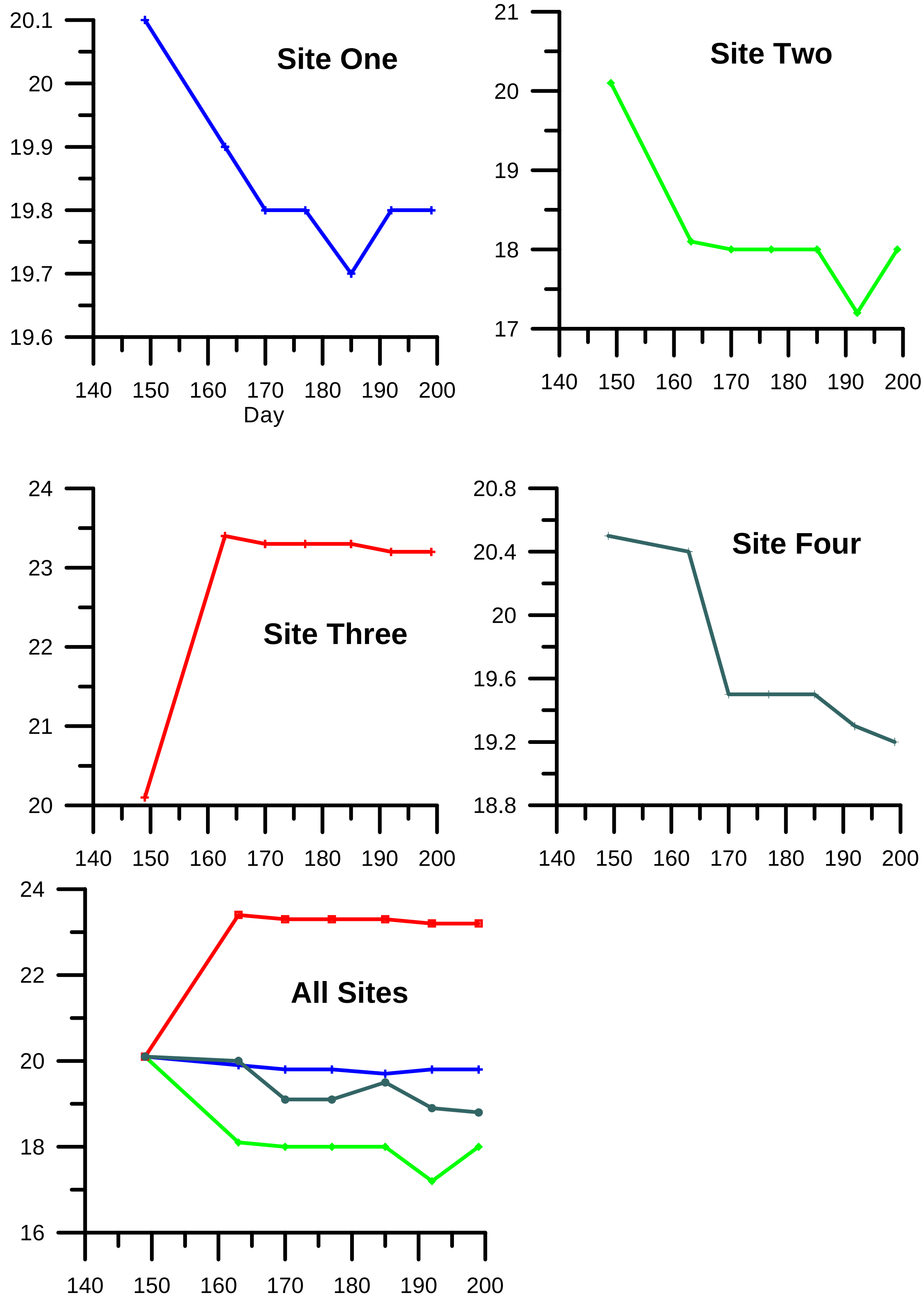


Graph 14



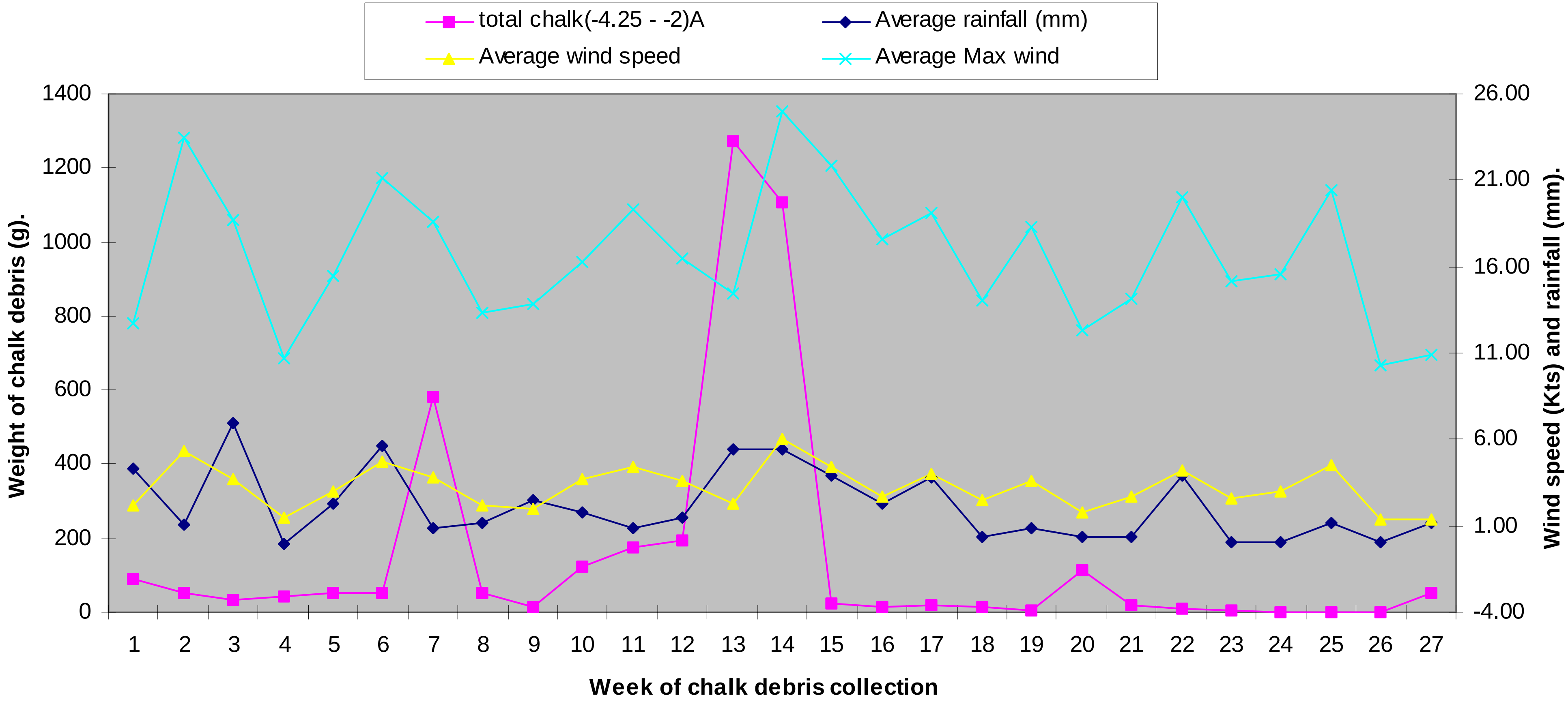
Blocks 1 & 2 in both experiments were soaked in 1 litre solutions containing 1g of NaCl. This solution is most representitive of the conditions at the cliff face according to calculations produced by K. DeWolf, 2001. The percentage was calculated from the average debris of both blocks taken collectively. The blocks tested were not identical and differences in weathering rate were noted

Graph 15: Downwearing observations using the MEM equipment.



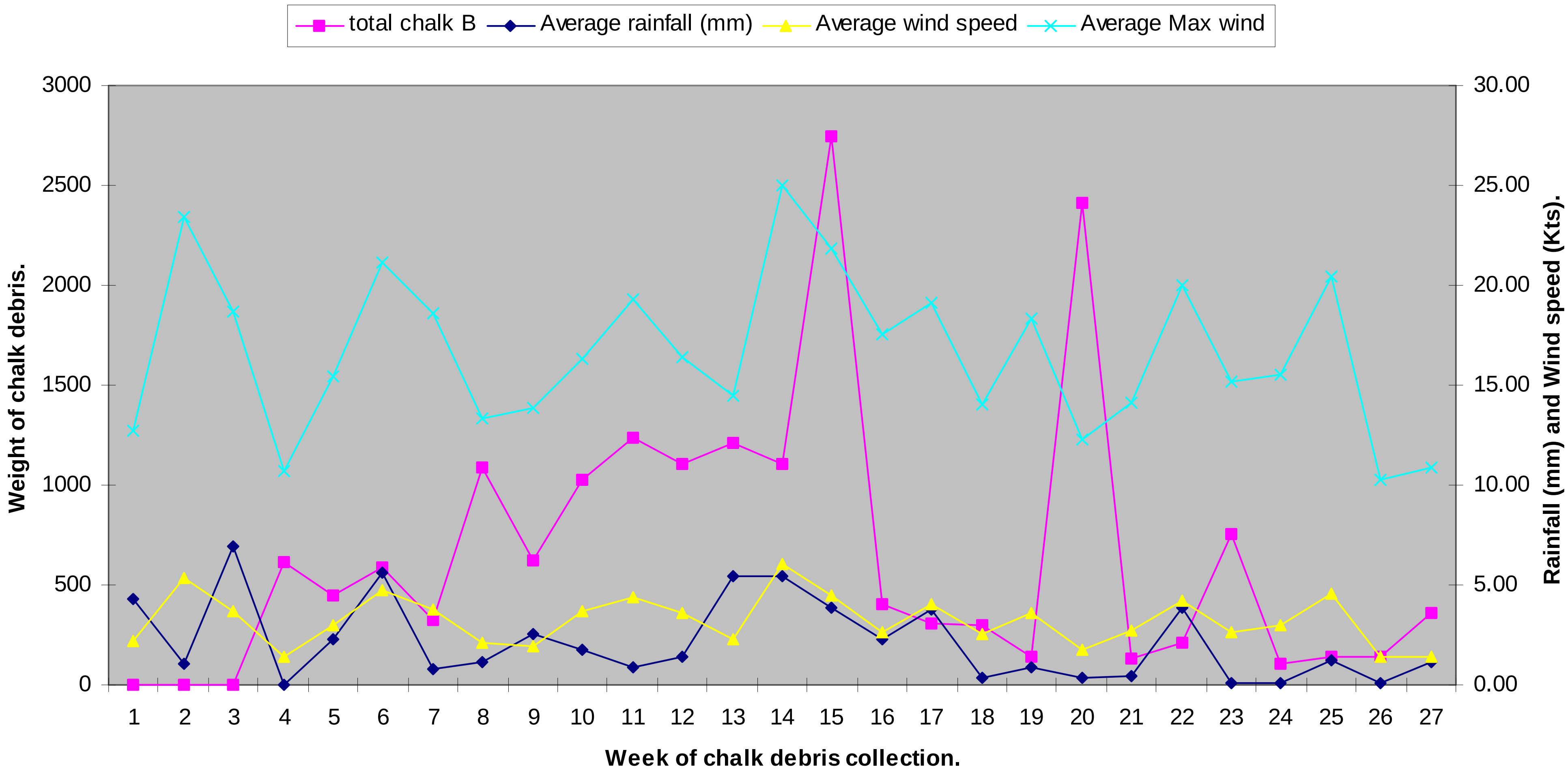
Sites were located vertically up the cliff face at irregular intervals with site one being located closed to the base of the cliff. Measurements were taken from the 26th of November, day 149 of the investigation. Downwearing measurements were taken three times for accuracy and converted from inches to mm. The starting point of the downwearing at all sites was the same except at site four, due to this on the "All Sites" graph the start point was adjusted to make it relative to the other data sets.

Graph 16: Site A chalk debris compaired to average weekly rainfall, average weekly wind speed and average maximum wind speed.

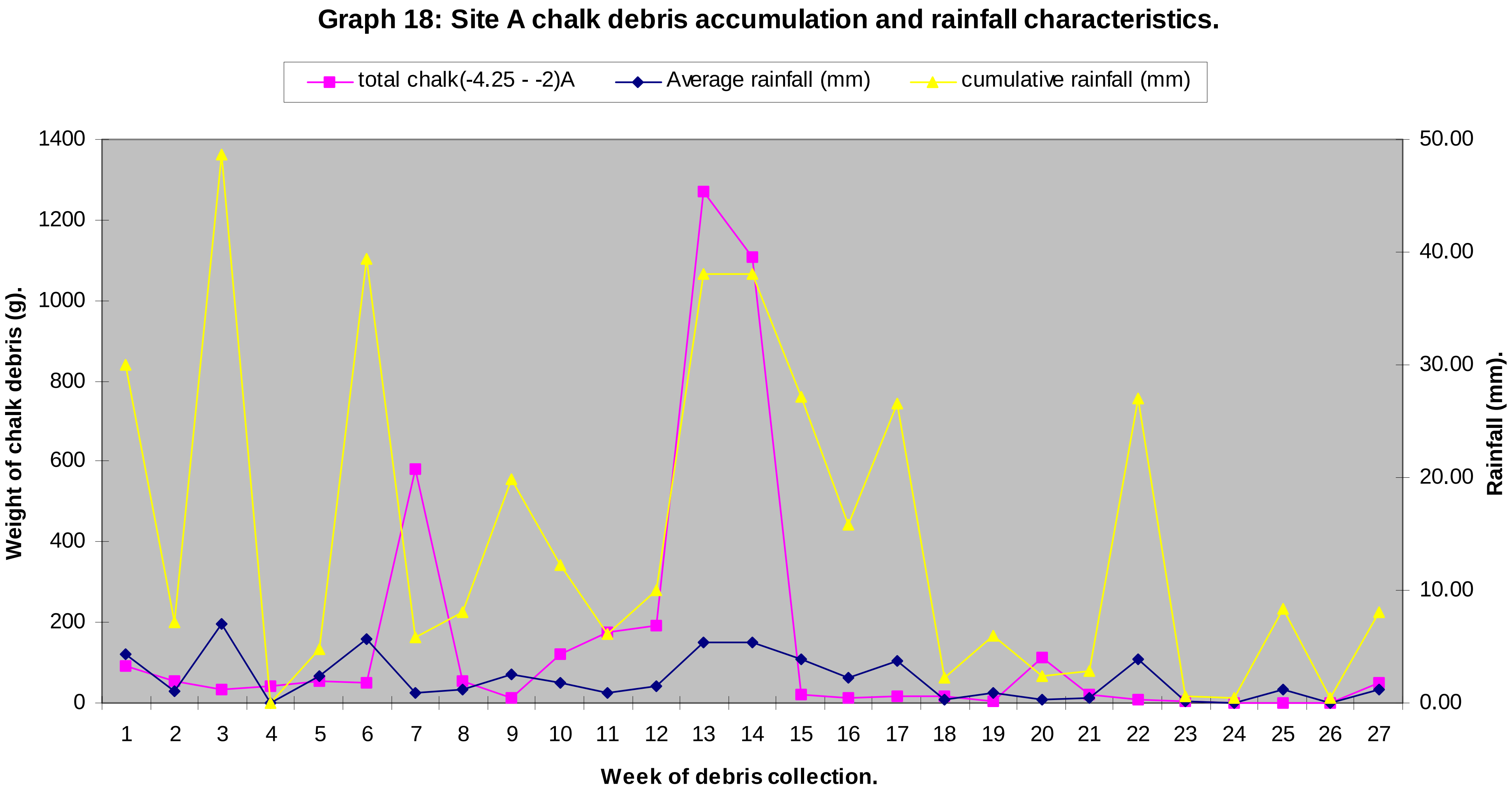


Chalk debris collected weekly from july 1st 2001 (1) at site A. Weather data calculated for the seven days prior to collection. Data taken from Saltdean and provided by Phill Chitty.

Graph 17: Site B chalk debris compaired to average rainfall, average wind speed and maximum wind speed.

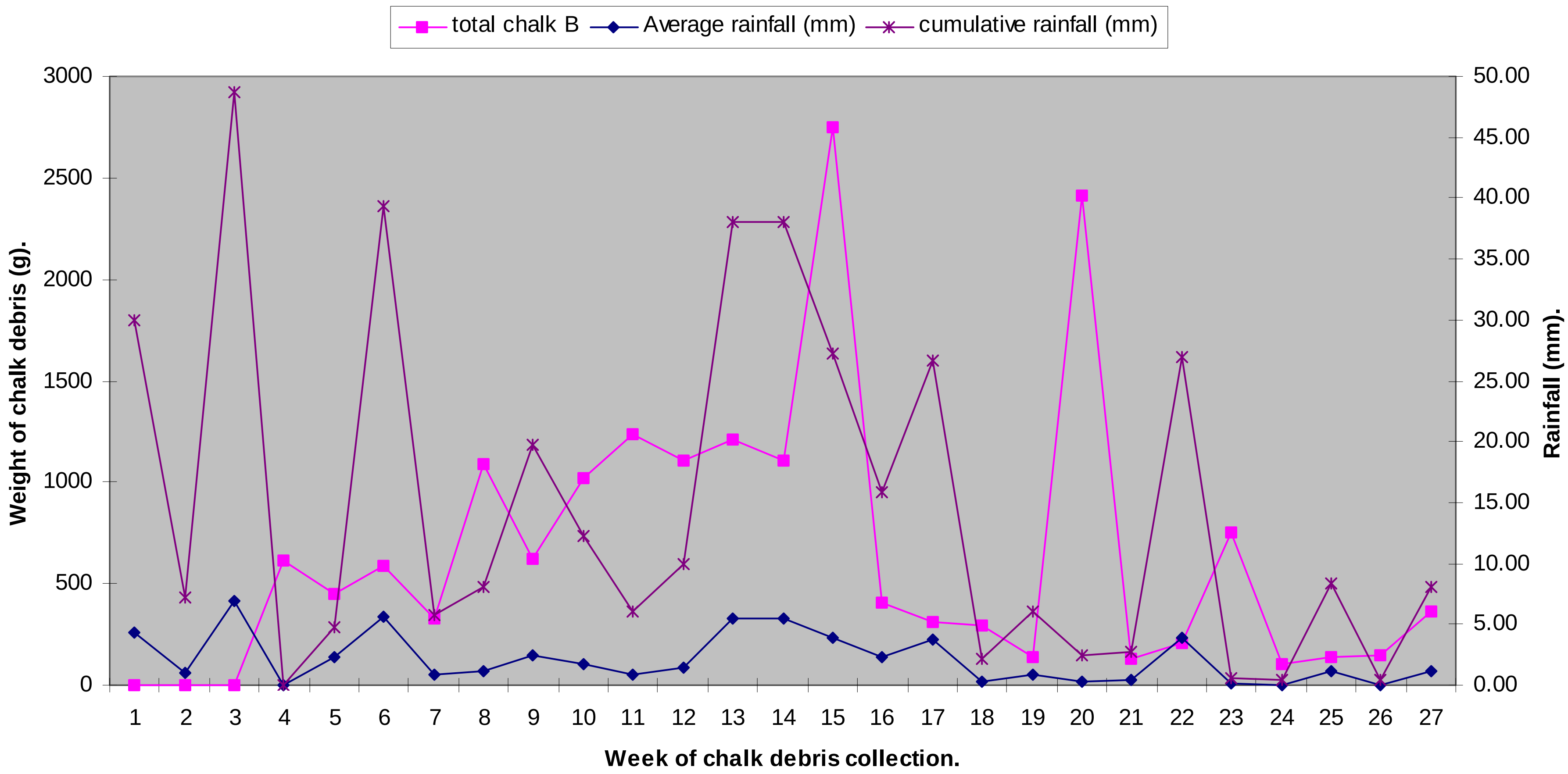


Chalk debris collected weekly from july 28th 2001 (1) at site B. Weather data calculated for the seven days prior to collection. Data taken from Saltdean and provided by Phill Chitty.



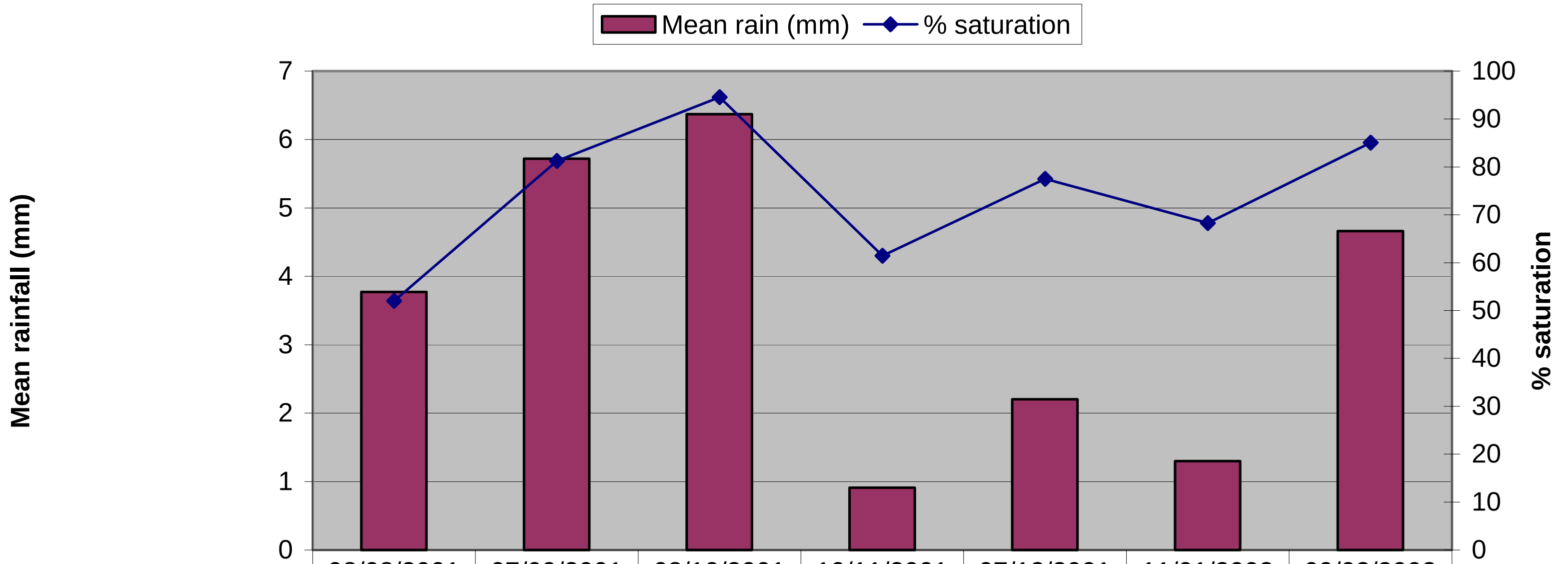
Chalk debris collected from site A on week comencing the 1st of july 2001 (1a). Average and cumulative rainfall was calculated from the privous seven days from collection. Weather data taken at Saltdean provided by Phill Chitty

Graph 19: Site B chalk debris accumulation and rainfall characteristics.



Debris collected from site B on week commencing the 28th of july 2001 (4). Average and cumulative rainfall was calculated for seven days prior to collection. Weather data was taken from Saltdean and provided by P Chitty.

Graph 20: Saturation of chalk debris and mean rainfall at Peacehaven



	08/08/2001	07/09/2001	08/10/2001	10/11/2001	07/12/2001	11/01/2002	09/02/2002
Mean rain (mm)	3.77	5.72	6.37	0.91	2.2	1.3	4.66
% saturation	52.01108895	81.23600537	94.57079971	61.41941392	77.50118415	68.26613351	85.05236194

Date of collection

Chalk debris to be tested was selected on or near the study site with the larger fragments being favored. Saturation of the rock was calculated by establishing total saturation through soaking in deionised water. Some material was removed during this but due to the large size of the fragments they were insignificant. Mean rainfall was calculated for a week before the collection of debris to establish short term reponses between the cliff and rainfall. The weather data was provided by Phill Chitty, Sussex University.

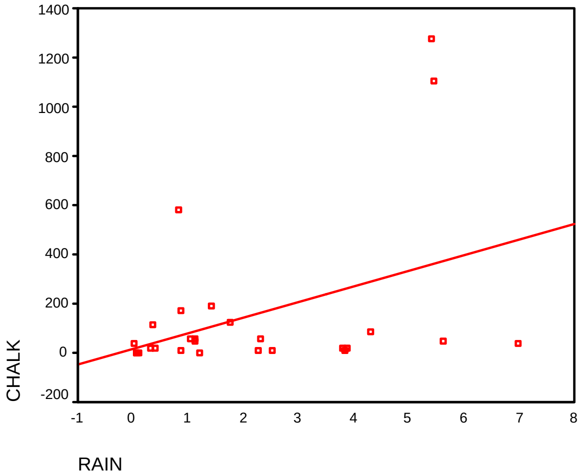
Correlations: Site A chalk debris (-4.25 - -2)
Correlations

Correlations: Site A chalk debris correlated with the average rainfall (mm) for the week prior to collection.

		CHALK	RAIN
CHALK	Pearson Correlation	1	.397*
	Sig. (2-tailed)	.	.040
	N	27	27
RAIN	Pearson Correlation	.397*	1
	Sig. (2-tailed)	.040	.
	N	27	27

*. Correlation is significant at the 0.05 level (2-tailed).

Graph 21



Correlations: Site A chalk debris correlated with the average temperature difference for the week prior to collection.

		CHALK	AVETRANG
CHALK	Pearson Correlation	1	-.515**
	Sig. (2-tailed)	.	.006
	N	27	27
AVETRANG	Pearson Correlation	-.515**	1
	Sig. (2-tailed)	.006	.
	N	27	27

**. Correlation is significant at the 0.01 level (2-tailed).

Graph 22

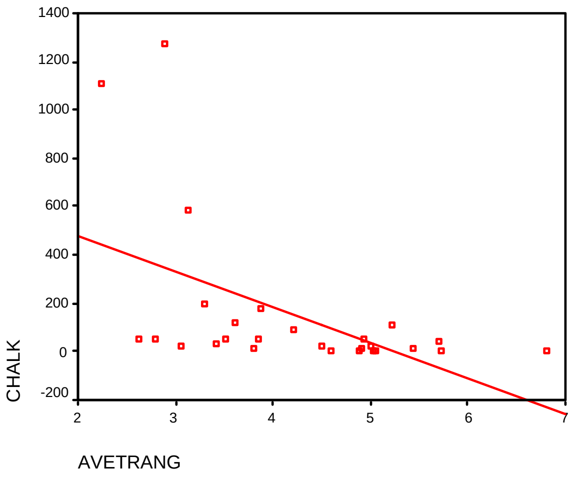


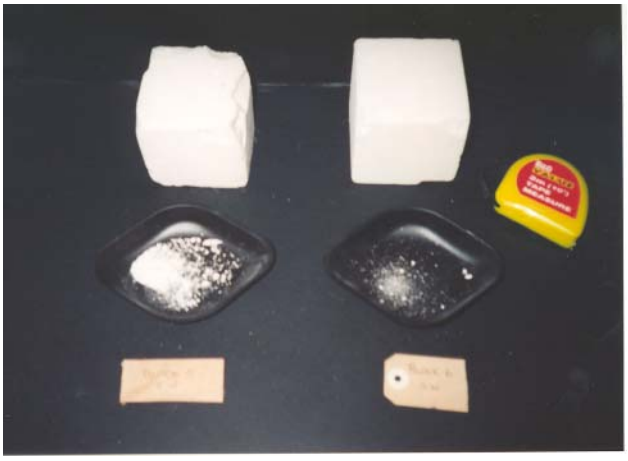
FIG 20 missing

Fig 21: Block disintegration results after 20 cycles of Wetting and drying regimes designed to induce salt crystallization weathering.

(A)

(B)

(C)



(D)

Pictures A-D show the disintegration of chalk blocks after 20 cycles of wetting and drying intended to mimic salt crystallization weathering. (A) Shows block 1 and 2 respectively, subjected to 1g/l NaCl solution. (B) Shows block 3 and4, subjected to 5g/l NaCl solution. (C) Shows block 5 and 6, subjected to 35g/l NaCl solution. (D) Shows block 7 (control), soaked in deionised water.

Chapter 4: Discussion

Peacehaven chalk debris

Of the two sites greater quantities of total debris were found at site A . This site is prone to high energy wave attack over topping the defences due to the proximity of the steep down to the shore platform. As a result large quantities of debris accumulated on the promenade. Although this does not reflect the weathering or erosion occurring on the cliff face it does indicate the environmental conditions at this site. In this situation the cliff could possibly be expected to have weakened due to the high volumes of sea spray which may have induced higher salt concentrations in the rock and a greater percentage saturation. The presence of stabilising works in the vicinity of site A may have lead to the destabilising of areas close by and the weakening of the chalk structure. When studying the total volume of chalk removed, this was not found to be the case as site A was found to be weathering at a relatively similar rate as site B despite the latter being slightly more sheltered and undisturbed by stabilising works (graph 4). It would be fair to say that in this study the action of cliff stabilisation had not caused localised areas to become weakened in the long term. It is reasonable to assume that any weakening of the rock would have resulted in loosened fragments being dislodged within a short time span of the works.

From the results collected over the period of the investigation it is possible to produce a figure for the average quantity of chalk debris lost from the cliff face of 182.4g per week over a year. This would result in a yearly erosion figure of 9486.9g per annum. During the summer the weekly erosion was on average 84.8g per week and only 41g per week during the winter. It would appear that more erosion occurs during the summer period in comparison to the winter from the averages calculated however this pattern was strongly influenced by the results at site A. The extensive erosion during the summer months at site A and minimal loss through the winter may be due to the stabilisation works causing short term disturbance followed by an increased resistance. If this is the case and site B offers a more general picture of the amount of chalk eroded, it would then be the case that more debris is produced during winter months. These figures can not be used to infer future losses from the cliff face as the results are site specific. Also these figures can not be used to infer cliff line retreat as they do not include the removal of the flint nodules.

Statistical analysis of the relationship between the weight of chalk debris and meteroric data showed few conclusive correlations. It did provide a correlation between the chalk debris at site A and average rainfall quantities to a significance of a 0.05 level (graph 21). From the scatter graph and regression line produced of this relationship it can be seen that an increase in rainfall coincides with an increase in the chalk cliff erosion. This same significant correlation did not apply for site B, or a combination of both sites, however, the scatter graphs and regression lines produced from this data showed weak but positive correlations. Correlations between chalk debris and cumulative rainfall (mm) did not produce significant results at either site (graph 18 & 19) suggesting that infrequent storm events cause less erosion to the cliffs than frequent showers do. From this information it is possible to infer that the process of wetting and drying and salt crystallisation must be acting. During a week with one large rainfall event, saturation of the surface material will occur and excess run off will be produced. This one rainfall event will lead to just one period of drying. In a week with several smaller showers the rock will become saturated and subsequently dry many more times .This will lead to an increase in stresses within the rock and amplified erosion. This can be seen from graph 18, during weeks 13 and 14 the associated average rainfall had remained high due to the occurrence of heavy showers. The extended time span of the saturation may have caused weakening to occur however the warm temperatures (around 17°C for week 13) and reasonable wind speed would have caused drying of the rock to be accelerated.

From the analysis it was found that large fluctuations in temperature do not assist rock breakdown. The data shows that during weeks with low ranges in temperature, higher rates of erosion were produced, this relationship was found to be significant to a 0.01 level of confidence (graph 22). This may simple be due to temperatures fluctuating by a small degree around those optimal for erosion. For example during freezing periods it may not be of advantage for temperatures to fluctuate from +10°C to -3°C if the freezing temperature is only held for a short period of time, this could result in the moisture within the rock only partially freezing. If the temperatures simply oscillate around 0°C there will most likely be a longer period of time in which the moisture can freeze completely. Within the data collected, minimum temperatures of at or below freezing point were not associated with increased levels of debris as expected. This may be in part due to the large temperature ranges present at those times, diminishing the time of freezing.

The influence of wind on the erosion of the chalk cliff was not found to be significant (graphs 16 & 17). That is not to say that the wind did not assist the breakdown of the rock prior to erosion. As noted before, wind can facilitate the evaporation of moisture from the rock surface, increasing the concentration of salts which may lead to salt crystallisation and rock disintegration.

Relating local weather conditions to the type of debris produced is complicated by a number of problems associated with this type of analysis. Generally weather conditions will be site specific, i.e. sheltered conditions will have lower wind speeds and rainfall. Both the sites of debris collection chosen were in exposed locations close to each other making them comparable, however the weather data was collected some distance away in Saltdean may have caused some differences. Also the weathering of the chalk may require (for example) several periods of low temperatures to occur before erosion can take place. If this is the case, correlations between the two variables will be difficult to locate using correlative statistics alone.

The rock surface temperature readings taken at the cliffs at Peacehaven showed a 13°C difference between the flint and the chalk. The flint material was consistently warmer than the chalk due to its low albedo. In theory this may have caused variations in the expansion and contraction across the cliff face, allowing stresses and strains to establish, causing disintegration. This process, however, would be extremely difficult to substantiate in the field.

Salt weathering experiments

From graph 11 it can be seen that blocks 5 and 6 actually increased in mass during their 20 cycles of wetting and drying. These blocks were saturated with the 35g/l solutions and gained around a 10% increase in mass. This is most likely due to the accumulation of salt crystals within the porous structure of the chalk, indeed while the experiment was being carried out thin sheets of salt crystals could be seen on the rock surface itself. Increase in block weights have also been attributed to the enlargement of pores within the rock allowing greater absorption and retention of water within the rock structure (McGreevy, 1982). The blocking of the pore spaces by the salt crystals resulted in a 10% decrease in porosity of the chalk (graph 12). The decrease in porosity accelerated after the third cycle showing a relatively rapid process of cementing within the chalk structure. This reduction in saturation and the cohesive properties of the salt acting as a cement may well have caused the lack of disintegration.

Blocks 1,2,3 and 4 all reduced in mass to some degree, however the extent to which this occurred does not appear to relate to the concentration of solution but may have more to do with the associated fractures within the rock. Both blocks 2 and 4 under went the most disintegration with block 4 losing over 30% of its initial mass during the 20 cycles. From the blocks which weathered significantly it can be seen that the level of damage accelerated after cycle 6 in the case of block 4 and after cycle 10 in block 3. The porosity within the blocks which were most degraded fluctuated through out the experiment but all increased in overall percentage porosity through the duration of the experiment.

Both block 1 and the control block showed very minimal breakdown during the test (graph 10 & fig A + D). With both block 1 and block 2 being subjected to the same solution concentration but resulting in a 15% difference in breakdown it is fair to assume that block 2 had considerably more fractures and weaknesses within the rock structure than block 1. This is supported by the consistently higher porosity of block 2 shown on graph 12. These blocks were meant to represent the most realistic salt concentrations at the cliff face surface, however the results obtained would suggest that little or no weathering will occur on the cliffs if the rock itself is not in a weakened or fractured state. On the chalk cliffs themselves the associated weaknesses within the rock can vary significantly over short distances suggesting that both block 1 and 2 may still represent the cliff, showing the influences of the lithology. The control block remained constant throughout the experiment showing only very limited changes in the mass or porosity. This may suggest that salt solutions are more capable of weathering chalk, conversely, it may be the case that the control block was taken from an abnormally resistant area of rock and would have remained in tact (like block 1) even if a salt solution had been added.

These results suggest that there is threshold concentration of NaCl which gives optimum levels of erosion. The most concentrated solution of 35g/l used in our experiments was obviously above this threshold, as it actively reduced the breakdown of rock. The weak concentration of 1g/l did not appear to produce as extensive a disintegration as 5g/l. Research of these threshold values has been mostly limited to Freeze thaw experiments with many examples of optimum concentration levels being found, (for example Whiting (1979) (McGreevy, 1982) however these are mostly concerned with the anti-freezing properties of concrete.

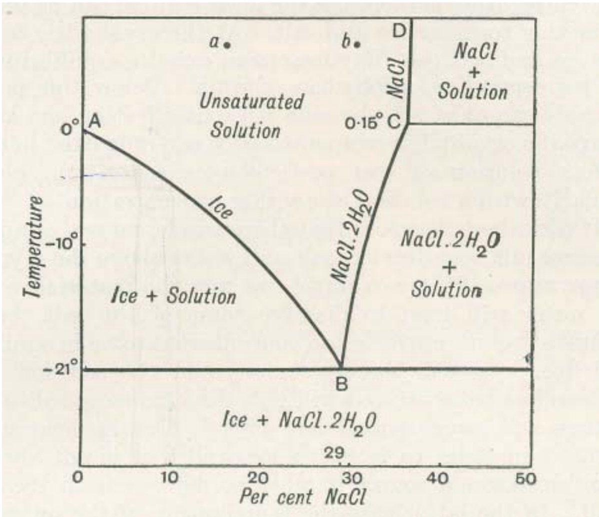
There seems to be a strong correlation between the percentage saturation and the associated breakdown of the rock. This can be most easily seen for block 4. Between cycles 6-7 the porosity of the rock increases by over 10% (graph 12), this coincided with a percentage mass loss also just over 10% (graph 11). This relationship would suggest that the greater the volume of moisture which can enter the rock, the greater the stresses induced within the block.

From graph 11 it can also be noted that once the weathering processes begin to cause rock breakdown subsequent erosion is accelerated. This can be most clearly seen from block 3 which has a relatively constant mass up to cycle 11. During cycle 12 it losses almost 2% of its mass, leading to a steady decline in mass over subsequent cycles. This trigger and following acceleration in erosion is likely to be caused by the increase in surface area, surface roughness and the exposure of internal weaknesses and fractures within the blocks.

The size of the block fractions removed through weathering as a total mass varied greatly between blocks. Block 1 and 2 which were subjected to the same concentration solution produced markedly different results (fig 21A). Block 1 which under went very limited weathering produced very fine fractions, with all fines being -2 phi or under. In contrast block 2 lost a large proportion of its mass, with most of the fractions being -2 phi or greater. This large removal of mass is significant, however the smaller fragments make up the most frequent fines. The fragment proportion graph for block 3 shows an interesting pattern with both larger and small fractions being produced in fairly equal masses, however this means that for every one larger fraction produced many more smaller ones must have been removed.

Frost Weathering

The effect of salt solutions on the chalk blocks subjected to Freeze-Thaw cycles is considerable. In contrast to the cementing effect of concentrated solutions in the salt weathering experiment, these high concentrations appear to have accelerated the breakdown significantly(fig 20C). As can be seen in graph 9 block 5 lost 73.98% and block 6 lost 19.32% of its mass over the 20 cycles. The control block also broke down considerably losing 36.53% of its mass. The disintegration in block 7 (fig 20D) was expected as the sample did not contain any salts within its solution. The presence of salt within a solution will lower the melting point of ice resulting in a much lower temperature needing to be applied to induce extensive or complete freezing within the chalk. Deionised water therefore will freeze at a higher temperature (O°C) than a halide solution, allowing block 7 to undergo longer periods of stresses and greater breakdown. The occurrence and extent of this freezing point depression increases with the addition of larger quantities of NaCl as can be seen from fig 22.



From the phase diagram it is clear that for the 35g/l NaCl solution, freezing would not have occurred during the minimum temperature of -5°C. Despite not being completely frozen, these blocks underwent the most extensive breakdown. This may be due to some of the NaCl precipitating out of solution with the drop in temperature causing salt crystallisation and increasing the stresses within the rock. It may also be the case that lower freezing points allow for slower freezing rates which produce larger ice crystals.

From looking at the block fragments (graph 9) it can be seen that smaller fractions under -2 phi are extremely uncommon and that if the rock is to breakdown it will do so in large blocks. This can be most clearly seen in blocks 4,5 and 6 small fragments produced totalled such a small mass that they are negligible. Frost weathering of the chalk produced larger chunks of chalk compared to the thin sheets of chalk which were removed through salt weathering. The production of larger lumps of chalk debris suggests that water was able to freeze within cracks and fractures within the rock, this produces much greater weathering. Blocks 1 and 2 underwent the most realistic conditions as they were soaked in the solution which best represented the salt concentration at the cliff face. These blocks lost very little of their mass, with debris comprising of both large and small fragments.

MEM data.

As noted in the literature the MEM is an effective tool in the field for gaining relatively accurate figures on the rates of downwearing however it was not affective at the Peacehaven field site. The soft lithology and shear vertical rock surface made probe erosion and reading of measurements difficult. This is illustrated by the anomalous result at site four which apparently increased the surface elevation. It can be seen from the results collected (graph 15) that all the sites were subjected to downwearing by some extent with Site 2 receiving most erosion. The denudation noted can not be directly linked to the sub aerial-processes acting on the cliff, as if this were the case Site 1 would have been expected to weather the most due to its exposed location and proximity to the coast.

Differences in lithology through the cliffs vertical section may have induced differing weathering rates however with such a short study period it would be misguided to use such data to infer either rates or spatial extent of micro erosion.

Comparison of Experimental and Field Work results.

Variations in fraction sizes between those blocks subjected to freeze-thaw and those subjected to salt weathering under solutions of 1g/l NaCl can be seen. Frost weathering produced approximately even quantities of large (< -4 phi) and small (>-3 phi) fragments (52% and 48% respectively)(graph 13) while the salt weathering produced significantly more large remains (63% compared to only 23% being small fragments)(graph 14). These results are contrary to the popular belief that frost weathering in rock causes the disintegration of the rock into large chunks of debris and that salt weathering removes considerably smaller particles. The conflicting results may be due to the continual soaking of the salt weathered rock in the salt solution leading to a build up of NaCl within the rock, way above the concentrations initially introduced. This however would seem a relatively natural process to occur in porous rocks along the coast. This type of concentration build up would not be expected to occur during periods of freeze-thaw as accumulation of salts within the rock through the evaporation of moisture would be unlikely owing to the dampness of the English winter. It may also be due to the relatively mild intensity of the weathering cycles. A minimum temperature of -5°C is significantly warmer than the air temperature of -12°C experienced within the permafrost region of North Alaska. Under these extreme conditions large spoil would be expected.

The salt weathering relationship was followed by the seasonal analysis of debris at site A. During summer months (graph 5)when salt weathering would be expected to be most dominant, large fragments made up the bulk of the mass (62%) while small remains totalled only 24%. The relationship between the winter and frost weathered fractions was not so clear, however small fractions dominated the collection with 69% of the total (graph 6).

Associations between the field and experimental results were less clearly seen at site B. Here during summer months the fraction size was relatively well spread with the small and large fragments both totalling 44% (graph 7). Likewise the winter results did not follow the experimental outcome with the majority of the mass consisting of large fragments (graph 8). In both cases it the differences may have been due to a number of factors including; variations between the two sites in the salinity at the rock surface; relative strength of the lithology or the surface area. It may have been the case that during the winter the moisture within the rock contained less salt than the experiment used. The high rainfall at this time (graph 1) would diluted weakened the solution and increased the effect of frost weathering as illustrated by the prevalent breakdown of the control block during the freeze-thaw tests .

From the results it is difficult to relate environmental weathering directly to experimental breakdown. Despite attempts to produce realistic weathering conditions the experiment was unable to reproduce these due to the rigidity of the variables. With such ridged variables it could be that the experiment only reflected one very specific weather regime and therefore does not relate to actions in the field.

Chapter 5: Conclusion.

It is clear from this study that sub-aerial weathering is causing frequent but small scale erosion of the chalk cliff face at Peacehaven. The occurrence of these small scale falls are not an immediate threat to homes and infrastructure but with sea defences at a maximum along this stretch of coast line the best safety precaution for local residents is reliable and informative information.

The results illustrated the detrimental effects of wetting and drying to the cliff face. In the field this relates to the frequency of heavy showers promoting periods of saturation and destabilisation of the chalk. Laboratory data upheld this correlation with the blocks subjected to phases of wetting and drying (saturated with low salt solutions) disintegrating considerably. Isolating a single weathering process is however difficult, especially in coastal areas with such susceptible lithology to the weathering processes.

Field collection of chalk debris (at site B) showed that erosion of the cliffs occurred at a relatively constant rate through the study. The winter season accumulated slightly more fragments than the summer season but the difference was so small that no conclusions or future predictions can be made without an extended study.

Relating experimental weathering results to those found in the field is a seemingly impossible task. Direct comparisons cannot be drawn due to the restraints of the research and the changeable nature of the environment. Nether the less the experiments gave some insight into the relative erosional strength of the processes tested. Frost shattering of the chalk was limited in blocks saturated with low concentrations ofNaCI solutions in contrast to disintegration cause by the salt weathering experiments.

The trimming of the cliff face in this study showed short term but significant increases in erosion in the months following the work. In future stabilisation works it would be advisable for the public areas to be out of bounds to prevent the possibility of injury to pedestrians. An extensive search for no.s of pedestrians casualties caused by rocks fall at Peacehaven found that no records were h~ld, however if this were to occur the council may be liable and should take preventative steps.

Chapter 6: Suggestions for future research

- Temperature probes set into the cliff face would provided an accurate source of weather data and could give insight into the air/rock temperature relationship. This would be most interesting in the case of the chalk rock at Peacehaven due to the abundance of flints within the Upper chalk and the differences in albedo.

- A set of sensors measuring the rate of expansion of the rock could also be of use. Stresses set up between the differential expansion of the flint and chalk could then be measured as well as the development of crack or joints.
- Saturation of the cliff could be measured with depth using a probe. This would show the intensity and frequency of wetting and drying cycles and the depth to which it affects the chalk structure.

- The effectiveness of experimental weathering regimes and equipment should be tested to refine future techniques. Reconstructing weather patterns with known rates of erosion in the field could provide some insight into unknown but important variables.

- The collection of chalk debris could be improved by constructing some sort of net at the top of the splash wall. This would eliminate the disintegration of fragments on impact with the ground producing an accurate picture of the size of partials being removed.

Acknowledgements

I would like to thank the following people:

Rendel Williams my supervisor for his guidance and advice; Dave Robinson for his help with my chemistry questions; Dave Randal for his assistance with the electron microscope equipment; my mother for taking me down to the field site and Tim Cane for his help and support.

Bibliography

ROCC (Risk of Cliff Collapse)web site: http://www.bton.ac.uk/environrnentiROCC/sussex.htm

ESPED (European Shore Platform Erosion Dynamics) web site: http://www.sussex.ac.uk/ESPED/

The geology shop web site: http://www.geologyshop.co.uk/chalkl.htm

Permafrost at the Geological Survey of Canada. http://sts.gsc.nrcan.gc.ca/permafrostlwhatis.htm

Andrews, C. E., 2000. The measurement of the erosion of the chalk shore platform of East Sussex, the effect of coastal defence structures and the efficacy of macro scale bioerosive agents, in particular the common limpet, Patella Vulgata. Unpublished, Sussex university.

Bird, E. C. F., 1985. Coastline changes- a global review. John Wiley and son ltd, London.

Bowden S. T., 1960. The phase rule and phase reactions theoretical and practical. MacMillan & Co L TD, London.

Carter P. G. and Mallard D. J., 1974 A study of the strength compressibility and density trends with the Chalk ofS E England. Quarterly journal of Engineering

Geology. Vol. 7, pp 43-55.

De Wolf, K., 2001. Cliff erosion and salt weathering at Peacehaven. Unpublished, Sussex University.

Goudie A. S., 2000. Experimental physical weathering. In, Resent advances in field and laboratory studies of rock weathering"Supplementband 120, pp 133-144. Ed, Viles H. A. Zeitschrift fur Geomorphologie, Gebruder Borntraeger, Berlin.

High C. and Hanna F. K., 1970. A method for the direct measurement of erosion of rock surfaces. British Geomorphology Research group technical bulletin 5.

Jerwood, L. C., Robinson, D. A. and Williams, R. B. G., 1990a. Experimental frost and salt weathering of chalk-I. Earth surface process and landforms. Vol 15, pp 611- 624.

Jerwood, L. C., Robinson, D. A. and Williams, R. B. G., 1990b. Experimental frost and salt weathering of chalk-II. Earth surface process and landforms. Vol 15, pp 699- 708.

Lewes District Council, 1996. A brief summary of coastal defence in the district. May V. J., 1971. The retreat of chalk cliffs. The Geographical Journal. Vol 137, pp 203-206.

May, V. and Heeps, C., 1985. The nature and rates of change on chalk coastlines. In: Geomorphology of changing coastlines, supplementbond 57, pp. 81-94. Ed, Bird, E. C. F. Zeitschrift fur Geomorphologie, Gebruder Borntraeger, Berlin.

McGreevy J. P., 1982. "Frost and salt" weathering: Further experimental results. Earth Surface Process and Landforms. Vol 7, pp 475-488.

Mellor J. W., 1974. Inorganic and theoretical chemistry, volume two. Longmans, London.

Mortimore R. N., Wood C. J. and Gallois R. W., 2001. British Upper Cretaceous Stratigraphy, Geological Conservation Review Series, No.23. Joint Nature Conservation Commitee, Peterborough.

Robinson D. A. and Jerwood L. C., 1987. Sub aerial weathering of chalk shore

I platfoffils during harsh winters in southe~t England. Marine Geology. Vol 77, pp 1- 14.

Robinson D. A. and Williams R. B. G., 1994. Rock weathering and landform evolution. John Wiley & Sons, Chichester.

Spate A. P., Jennings J. N., Smith D. I. and Greenaway M. A., 1985. The micro- erosion meter: Use and limitations. Earth Surface Processes and Landforms. Vol10, pp 427-440.

Trenhail,A. S., 1987. The geomorphology of rocky coasts. Claredon Press, Oxford. Trenhail, A. S., 1997. Coastal dynamics and landfoffils. Claredon Press, Oxford. Williams R. B. G., 1980. Weathering and erosion of chalk under periglacial conditions. In: The shaping of Southern England. Ed, Jones D. K. C. Academic Press, London.

Williams R. B. G. and Robinson, D. A., 1991. Frost weathering of rocks in the presence of salts-a review. Peffilafrost and Periglacial Processes. Vo12, pp 347- 353.

Williams R. B. G. and Robinson, D. A., 2001. Experimental frost weathering of sandstone by various combinations of salts. E~ Surface Processes and Landfoffils. Vol 26, pp 811-818.

Williams R. B. G. Swantesson J. O. H. and Robinson D. A., 2000. Measuring rates of surface downwearing and mapping microtopography: The use of micro-erosion meters and laser scanners in rock weathering studies. In: Resent advances in field and laboratory studies of rock weathering, Supplementband 120, pp 51-66. Ed, Viles H. A. Zeitschrift fur Geomorphologie, Gebruder Borntraeger, Berlin.