COLLIERY WASTE ON THE DURHAM COAST

A study of the effect of tipping colliery waste on the coastal processes.

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This investigation has been undertaken with the object of providing information on the transport of colliery waste from tipping points on the Durham Coast and on the despoliation of the adjacent beaches, with particular reference to Crimdon. The geology of the Durham Coast is briefly described, followed by notes on the past and present tipping rates, the constituents of the waste and its general effect on the coast. The coastline changes since 1858 are also discussed; the area has changed from one of general erosion to accretion, which has been rapid in places. The areas of accretion consist mostly of colliery waste and are found close to the tipping points. The transport of colliery waste both on the beach and on the offshore sea bed is described; this is based on the evidence of a site investigation undertaken by Easington R.D.C., the National Coal Board and the Hydraulics Research Station between April 1969 and April 1970.

The investigation has shown that the despoliation by colliery waste at Crimdon and beaches to the south is unlikely to diminish unless action is taken; in fact, the trend at Crimdon is probably towards further deterioration. Possible solutions to the problem, as outlined in a recent M.H.L.G. report, are briefly discussed. It appears that the only way to alleviate the despoliation along the coast would be to terminate tipping and barge the waste to sea as other possible solutions could still create serious hydraulic or amenity problems. However. this would still leave a "reservoir" of coal material, derived from the colliery waste, on the sea bed, and cause intermittent

pollution on the beaches to the south of Crimdon. A breakwater or groyne installation could be constructed to the north of Crimdon to intercept the waste but it would also inhibit sand transport along the coast and could result in some erosion of the beach. This erosion would probably be confined to the beach immediately to the south of the breakwater. A study has been made, see Appendix 1, of the advantages and disadvantages of constructing a breakwater and/or groyne installation to intercept the waste. The existing waste on the beaches could be removed mechanically but this would be a difficult task; alternatively natural wave action would probably remove the bulk in about 10 to 20 years. Finally, a limited research programme to keep the rate of despoliation at Crimdon under observation in the future is outlined.

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INTRODUCTION

Colliery waste has been tipped on the foreshore at a number of sites on the Durham Coast since the latter half of the nineteenth century. In the early days the quantity of waste involved was relatively small and natural coastal erosion was able to keep pace with the rate of tipping. As the result of a higher degree of mechanisation in recent years the coal output has increased and with it the quantity of waste. The present total output of waste deposited at the tipping points is 2 440 000 tons/year and it has been suggested that this rate will increase to 3 000 000 tons/year by the mid 1970's. By far the largest proportion of the waste consists of washery refuse and pit stones but other refuse such as rubber belting appears on the beaches from time to time.

It has been estimated that 85% of the waste tipped onto the foreshore has been removed by wave and tidal current action and there is now a large "reservoir" of small coal particles on the sea bed. The remainder has spread out over approximately 8 miles of the coast and in some areas the high water mark has moved seaward by as much as 400 ft since 1858. The coal material transported to the offshore sea bed is moved southwards by wave and tidal current action and appears on a number of beaches from time to time. The quantity of coal adjacent to, and to the south of, the tipping points, is sufficient to warrant the granting of licences for its removal by local traders.

The tipping of colliery waste on these beaches has been the subject of a number of investigations; one of these was a report in 1966 by the Ministry of Housing and Local Government entitled "Tipping of colliery waste on beaches in north-east England" (Ref. 1). This report described the state of the beaches as being "deplorable" and recommended a course of action aimed at improving them and increasing their amenity value to the area as a whole.

The object of the present investigation is to provide reliable scientific information on the present quantity of colliery waste on the beaches and on the offshore sea bed. Further, to illustrate the general mechanism of movement of the waste, with particular reference to beach conditions at Crimdon where Easington R.D.C. have established a holiday centre. In addition, a number of measures aimed at improving the state of the beaches have been discussed from a coastal hydraulic viewpoint.

Throughout this report the comments made have been confined to the coastal engineering aspects of the despoliation problem. No attempt has been made to study the far reaching implications of terminating the tipping or the difficulty of removing existing debris from the beaches. Further studies will be needed to examine the practical aspects of the remedial measures and H.R.S. would be pleased to be involved in such an exercise.

The recent report is complementary to "Crimdon Benefit Study", Durham County Council 1970, (Ref. 2).

This investigation has been carried out for the Ministry of Housing and Local Government and Mr. G.E. Forward, Assistant Chief Engineer, has acted as co-ordinator. Information on beach conditions was collected between April 1969 and April 1970 by the National Coal Board and Easington R.D.C. Durham County Council planning department have been closely associated with the study throughout.

THE DURHAM COAST

The County of Durham is situated on the north east coast of England and is exposed to the severe storms that occur in the North Sea. The 8 miles of coast on which tipping takes place extends from Dawdon which is just south of Seaham in the north, to Blackhall in the south. Cliffs extend over all of this coastline and for another two miles to Crimdon; they reach a maximum height of approximately 100 ft. The lower part of the cliffs consists of magnesium limestone of variable hardness; the harder areas form the many small headlands along the coast. Small streams have cut valleys, or have enlarged planes of weakness, through the limestone; the valleys have the local name of dene. The denes provide interesting study areas for naturalists and ornithologists The upper part of the cliffs consists of two types of unconsolidated boulder clay separated by a band of water bearing gravel and sand. To the south of Crimdon a series of sand dunes and a low boulder clay cliff forms the coast and further south at Hartlepool the coast is protected by a limestone outcrop and a massive sea wall.

1. Tipping colliery waste on the coast.

Colliery waste was first tipped on the coast during the latter part of the nineteenth century. Initially, natural erosion kept pace with the rate of tipping. As the tipping increased erosion was overtaken and replaced by accretion which tended to protect the cliffs from further wave attack.

At present colliery waste is tipped on the foreshore at four sites along the coast, see Fig. 1. The rate of tipping is as follows:

Disposal point:	Colliery waste, tons/year
Dawdon	1 340 000
Easington	480 000
Horden	360 000
Blackhall	260 000
	2 440 000

It is expected that by the mid 1970's the total tonnage of waste to be tipped will be approximately 3 000 000 tons/year. The quantity for Dawdon Colliery includes waste from Hawthorn, South Hetton, Seaham and Vane Tempest Collieries which is taken by rail to Nose's Point where all waste is tipped over the cliff and spread by a bulldozer. Waste at Easington, Horden and Blackhall is tipped directly on the beach from aerial flights.

The colliery waste consists of washery refuse and shale with a maximum size of approximately 12 inches. It has been estimated that 2% of the washery refuse is coal, specific gravity 1.35, but a much larger proportion consists of coal-like material with a specific gravity up to 1.9. Many large pieces of rubber belting are to be found on the beaches and a number of streams of black liquid effluent from the washeries discharge on the foreshore.

It has been estimated that the total quantity of colliery waste tipped on the beaches is approximately 40 million tons and of this, about 85% has been transported to the offshore sea bed by wave and tidal current action. The remaining 15% forms the present despoliation on the beaches.

2. Coastline changes since 1858.

The coastline changes that have taken place between Dawdon and Crimdon since 1858 have been studied during the present investigation. Fluctuations in the position of mean high and low water marks have been obtained from the Ordnance Survey maps (25 inches to 1 mile) for 1858, 1919, 1939 and 1958. The following is a brief summary of the coastline changes that have taken place since 1858.

In 1858 almost the whole of the limestone cliff between Dawdon and Crimdon was exposed to wave attack at high water, the lower foreshore was, in general, wide flat and sandy. The tipping of small quantities of colliery waste in the late nineteenth century was probably enough to balance the coastal erosion that was taking place at the time. As the quantities of waste increased accretion took place adjacent to the tipping points. In the bay to the south of Nose's Point, near Dawdon where the maximum rate of tipping has taken place, the high water mark has gradually moved seawards, some 400 ft since 1858. The bay is now filled with waste and so are all the small bays in the northern part of the tipping area. Due to the addition of coarse material the beaches have become steeper. The beaches have built-up considerably near the Easington, Horden and Blackhall tipping points and the small bay immediately to the north of Blackhall Point is full of waste. It is clear from recent beach studies that large quantities of waste are transported from the north to the south of Blackhall Rocks during north easterly storms. There is evidence that the beach immediately to the south of Blackhall Rocks is starting to accrete, although further south, near Crimdon, waves still reach the cliff at high water. The sandy foreshore to the south of Crimdon has remained the same width over many years whilst the sand dunes have increased in area.

THE TRANSPORT OF COLLIERY WASTE BY WAVES AND TIDES

Wind generated waves produce an orbital motion which decreases exponentially from the surface towards the sea bed. In deep water the orbital motion is approximately circular and the net water particle movements are small. As a wave travels into shallow water both the surface profile and the orbital velocities become asymmetrical, this has the effect of exaggerating the net orbital motion. In the absence of wind, the shallow water wave drift near the surface and the bed, is in the direction of wave propagation, while at mid-depth it is in the reverse direction. The magnitude and direction of the net drift depends upon the wave characteristics and wind on the water surface. It follows from the wave orbital velocity pattern that coarse material travelling in the layers close to the sea bed will have a tendency to move towards the shore, whereas fine material which is capable of moving in the layers between the surface and the bed will have a tendency to move offshore, during most wave conditions. However, this movement can be reversed and it is dependent upon wave height, period and the depth of water.

Colliery waste remains on the beach and is moved southwards by wave action until it has been broken down to a small size afterwhich it is transported to the offshore sea bed, where it's further movement is probably dominated by tidal currents.

1. The transport of colliery waste on the beaches.

One of the objectives of the present investigation was to determine whether increasing quantities of waste are likely to arrive at Crimdon beach in the future. Waste arrives at Crimdon beach, either as large pieces of rock, coal and coal measure rock transported along the coast, or as small particles of coal washed up from the offshore sea bed. It had been the contention of several observers that large quantities of coal particles were washed up on the beach at frequent intervals of time. A site investigation was therefore programmed to determine the mechanism of transportation of waste at Crimdon, it included:

(i) The sampling of material on the beach.
(ii) Surveys of beach cross sections.
(iii) Photographs of the beach.
(iv) Wind, wave and tidal data.
(v) Daily inspection of the beach.

Items (i), (ii) and (iii) were undertaken by the Scientific Department of the National Coal Board based at Blackhall Colliery and items (iv) and (v) by Easington R.D.C.

(i) The sampling of material on the beach.

It has been the practice of the Coal Board and Local Authority officials to examine the beaches in the vicinity of Crimdon at regular intervals. The conclusions drawn from these inspections suggest that in general beach conditions have become worse since about 1964. In 1957 the Hydraulics Research Station remarked on the intermittent pollution by coal particles but no mention was made at that time of the larger fractions of waste material that are now to be found on the northern part of Crimdon beach.

During the present investigation an attempt has been made to study the pollution of Crimdon beach objectively, by measuring the proportion of colliery waste in surface samples taken from the beach.

The only other sampling that has taken place on Crimdon beach, connected with the colliery waste problem, was carried out between April 1960 and October 1968 by the National Coal Board. Surface samples were collected between Blackhall Colliery tipping point and Crimdon Dene on thirteen occasions and analysed for coal content. Except for occasions when there were bands of coal on the beach the sampling showed that there was usually less than 1% of coal present. There was little evidence to suggest that increasing quantities of coal were deposited on the beaches during the sampling period. The total number of occasions during the sampling period on which bands of coal appeared on the beaches was not noted.

In order to make the percentages of coal, specific gravity 1.35 and coal-like material, specific gravity < 1.9, more meaningful so far as "visual pollution" is concerned it is necessary to be subjective. It would probably be accepted that 10% of coal material on a beach resulted in an unpleasant appearance, even 1% is visible.

As part of the present investigation surface samples have been taken along a line on the beach between high and low water marks, every month at the following sites, see Fig. 2.

(a) Limekiln Gill.

(b) Caravan Steps.

(c) First North Point.

(d) The Pavilion

(e) North Sands.

Each sample was divided into coal, coal measure rock, and natural stone and then sieved into the following size fractions - above 50mm, 50mm to 12.5mm, 12.5mm to 1mm, 1mm to 0.5mm, below 0.5mm. The natural stone below 1mm in size was sand. The detailed beach sample records are available but have not been included in the present report.

The analysis of the data was as follows, the strip of beach from high to low water marks was divided into percentage areas of bedrock, gravel, sand and coal-like material, i.e. coal plus coal measure rock. The proportions of each material have been plotted graphically for each of the five sampling sites on a monthly basis between April 1969 and April 1970. The results of this analysis can be seen in Figs 3 to 7.

(a) Limekiln Gill.

Large quantities of coal material were present on this part of the beach during the investigation. There was a decrease during October 1969 but the original proportions were re-established by the end of the study. Large quantities of sand appeared on the beach from time to time and covered the bedrock and some of the coal waste. In general, when the proportion of sand was high the proportion of exposed bedrock was low and vice versa.

(b) Caravan Steps.

During the early part of the sampling period the proportion of coal waste on the beach averaged about 5%, this increased to 15% in October, which coincided with the reduction at Limekiln Gill. An examination of the beach at that time indicated that a large quantity of coal waste had been transported around the small headland between Limekiln Gill and Caravan Steps which accounted for this increase. Again, when the proportion of sand was high the exposed bedrock was low and vice versa.

(c) First North Point.

The area covered by coal waste on this beach averaged just less than 10% during the sampling period. It is interesting to observe, that large quantities of coal material have reached the northern end of the popular part of the beach. The relationship between sand and bedrock was again marked.

(d) The Pavilion.

This is the popular area of Crimdon beach. It can be seen from the graph that large quantities of coal material reach this part of the beach, and although there was a measurable increase in the quantity of waste on the beach during the sampling period on the evidence available it is thought unlikely that this rate of increase will be sustained in the future. It is clear from the analysis and observations that fluctuations in sand levels resulted in the coal material being covered from time to time only to reappear during a period of beach sand erosion.

(e) North Sands.

This has remained a predominantly sandy beach with only small quantities of gravel and coal material present.

During the earlier National Coal Board sampling programme it was noticed that the minimum size of coal on the beach was 1/50 inch, .5mm, this has been confirmed by the present study. Coal particles ground to a smaller size by wave action are unstable on the beaches and are transported offshore by the assymmetry of the wave orbital velocities. In addition, the larger fractions of coal material particles are transported towards the offshore sea bed from time to time. The results of the sampling programme suggested that there was a reduction in the size of the coal measure rock as it was transported along the rocky part of the beach, to the north of First North Point but little loss in size when transported on sand. Therefore, once the waste reaches the popular area of Crimdon beach there is little further reduction in size.

(ii) Surveys of beach cross sections.

Surveys of the beach cross section at the five sites near Crimdon were made on the same day that beach sampling took place. The cross sections have not been included in the present report, but the cross sectional area of the beach between a high water datum and -5 ft O.D., has been calculated for each of the five sampling lines, and plotted against time, see Fig. 8.

The graphs illustrate that only small net beach changes have taken place at Limekiln Gill, Caravan Steps, First North Point and the Pavilion but at North Sands, in general, a steady increase in beach area has taken place.

This is in agreement with the known accretion in the area over the years. Although at most cross sections little net change has taken place large quantities of sand have been moved by wave action from the upper to the lower beach and vice versa, this has resulted in changes in beach levels of up to 6 ft. In general, sand on the beaches is transported from upper to lower levels during storms and returns during quieter conditions. This natural onshore-offshore movement can result in colliery waste on the beach being covered and uncovered by the sand.

(iii) Photographs of the beach.

Photographs have been taken of the beach between Blackhall Rocks and Crimdon Dene at approximately two-weekly intervals between April 1969 and April 1970; the photographic locations are shown in Fig. 2. The photographic appendix, six of which have been produced, illustrates the many and varied changes that have taken place on the beach during the year. The photographs will provide a basis for comparison between present and future beach conditions.

The following is a summary of the changes in beach conditions between Blackhall Rocks and Crimdon as seen on the photographs.

The most striking feature is the large fluctuation in sand level, particularly in the Crimdon area. The photographs have confirmed the main observation from the beach sampling and cross section surveys, i.e. that the waste remains on the upper part of the beach and is covered and uncovered by natural fluctuations in the level of the beach. It has not been possible from the photographs to determine whether the quantity of colliery waste on Crimdon beach has increased during the year under investigation. It was fortunate that during the peak holiday months of 1969 beach sand levels were high and a large proportion of the waste was buried. The photographs show that large quantities of colliery waste were transported to the beach immediately to the south of Blackhall Rocks. This transport takes place during periods of high wave activity from the north east, the material probably originates on Blackhall Beach.

(iv) Wind, wave and tidal data.

Prior to the present investigation it had been suggested that large quantities of small particles of coal material were washed up on Crimdon beach from the offshore sea bed from time to time. To assist in the determination of the mechanics of this movement wind, wave and tidal data were collected daily during the study. However, as there was little evidence of coal material being transported to Crimdon beach from the offshore sea bed during the investigation,this data has not been included in the present report.

(v) Visual inspection of the beach.

Two sets of visual observations of Crimdon beach have been made:

(a) A joint bi-monthly inspection by N.C.B. and Easington R.D.C. officials from 1964 to 1969.
(b) A daily inspection by Easington R.D.C. officials between April 1969 and April 1970.

Briefly the results of the inspections with respect to changes in the amount of colliery waste on Crimdon beach are as follows:

(a) A joint bi-monthly inspection.

The report by J.W. Green of the N.C.B. see Ref. 3 emphasises the differences that occur in the appearance of the beach during the two phases of the 28 day spring to neap cycle. When the tides are decreasing in height from springs to neaps flotsam is left by preceding tides whereas the rising neap to spring tides remove the flotsam. It is interesting to note that, "a very high 'spring' tide accompanied by strong gale force winds - usually in a north easterly direction - tended to leave the foreshore in a reasonably clean condition". The present study has shown that in general high tides plus storms remove sand from the beach and tend to leave the colliery waste exposed.

It is clearly difficult to compare these visual inspections made over a 6 year period with one another. However, the N.C.B. report says, "insofar as the northern half - of Crimdon beach - is concerned, the current picture presented is not as clear as in 1964", and "With respect to the southern half - of Crimdon beach - there does not appear to be any change in the appearance of the beach 'sea coal wise' ". No mention is made of the encroachment of other types of colliery waste, i.e. coal measure rock and shale.

(b) The daily inspections.

The impression gained from the daily inspections is that a high level of despoliation already exists on Crimdon beach. This, of course, is a subjective assessment but one with which the average visitor would probably agree. It is clear that large fluctuations in sand levels take place in response to changes in wave conditions. It has not been possible, during the study, to detect an overall trend in the level of despoliation on Crimdon Beach.

Summary of the transport of colliery waste on the beaches

Colliery waste is discharged at four points on the Durham coast and is transported southwards by wave action on the beaches. The investigation has shown that there is already a high level of despoliation at the northern end of Crimdon beach. This is due to waste being transported from the north to the south of Blackhall Rocks during periods of high wave activity from the north east. Long term trends in the level of despoliation on Crimdon beach are impossible to predict from a single year of observations. However, it appears that during the last 10 years the amount of colliery waste on the beach has increased, although the proportion of coal has probably remained about the same. Particles of coal material less than 0.5 mm diameter are unstable on the open beach and are transported seawards by wave action. It appears that there is only a small decrease in the size of coal measure rock as it is transported southwards along Crimdon beach.

Large natural fluctuations in sand level take place on the beach in response to changes in wave conditions. In general, storms tend to erode the upper beach and leave the waste exposed. During periods of calmer weather sand is transported from the lower to the upper beach, tending to cover, at least part, of the waste deposit. There was little net change in beach cross sectional area at Limekiln Gill, Caravan Steps, First North Point and the Pavilion but at North Sands, in general, a steady increase in the cross sectional area of the beach has taken place, which is in agreement with the known natural accretion in the area over the years as shown on the Ordnance Survey maps.

In general, the beach samples taken during the investigation failed to indicate a trend in the quantity of waste on Crimdon beach. However, it is probable that the despoliation will gradually increase and spread southwards as it appears that more waste is transported to the area from Blackhall beach than is ground away by wave action.

2. The transport of colliery waste on the offshore sea bed

An examination of the beaches shows, in general, that the size of colliery waste decreases in a southwards direction, this results in steep beaches near the tipping points and flatter beaches elsewhere. When waste is ground to a small size the coal is released from the heavier and softer shale, producing two separate materials, i.e. coal specific gravity 1.35 and shale specific gravity 2.4. Both materials may then be transported seawards by the asymmetry of the wave orbital velocities. It has been estimated that 85% of the waste deposited on the beaches has been transported to sea in this way.

The intermittent appearance of bands of coal material on Crimdon beach, prior to the investigation, and on several beaches some miles to the south, during the investigation, led to the conclusion that there must be a "reservoir" of coal particles on the offshore sea bed. The object of this part of the study was to gain some knowledge about the extent of the "reservoir" of coal particles. This section has been divided into the following sub-sections:

(i) Surface samples of material on the sea bed.
(ii) Core samples of material on the sea bed.
(iii) Sediment in suspension
(iv) Tidal current data.

The items outlined above were all investigated by the Hydraulics Research Station survey team during June and July 1969, when the Station's survey boat the "Sir Claude Ingles" was based at Hartlepool.

(i) Surface samples of material on the sea bed.

In order to gain an overall picture of the extent of coal on the offshore sea bed 91 surface samples were collected over an area extending from north of Easington to south of Hartlepool, a distance of approximately 11 miles and about 3 miles seawards, to the 10 fathom contour. The surface sample locations are shown in Fig. 9. About 10 lbs of sea bed material was collected at each site. The samples were subjected to sieve analysis to determine the mean grain size of both the sand fraction and the coal/ carbonaceous fractions. The proportion of coal material was determined by ignition and thus includes both pure coal, specific gravity 1.35, and middle density, carbon rich, material, with a specific gravity up to 1.9. This method of determination does not give precise results, due to the chemically combined water in coal measure rock and to chemical changes which occur during ignition. However, this would not affect the general picture of the sea bed composition.

The results of the analyses of the 91 surface samples are shown in Table 1 and Fig. 9. It can be seen from the analysis that coal material occurs over a wide area of the sea bed and generally the mean size is less than 1.3 mm. The concentrations are greatest in the north, near Easington and Shippersea Bay and in the south, near Hartlepool. The deposition of coal in Hartlepool Bay probably takes place because of the absence of high velocity tidal currents, the Bay is sheltered from the main coastal tidal flow by The Heugh. Coal material from the Bay is transported to Middleton Strand, immediately to the south of Hartlepool Dock entrance, during storms. A 2-inch to 6-inch layer of coal material covered the lower foreshore during a site visit made during the Autumn of 1969. In the area as a whole the sand and coal material are usually confined to the sea bed inshore of the 10 fathom contour, beyond this contour the sea bed consists of hard ground with some patches of soft mud. To the south of Hartlepool the coal extends seawards beyond the 10 fathom contour and hard ground frequently occurs on the inshore sea bed. It is interesting to note that offshore from Crimdon beach the quantity of fine coal material on the sea bed is relatively small.

(ii) Core samples of material on the sea bed.

As part of the present investigation 33 cores, 2 inches diameter and up to 2.5 ft. long, were taken from the sea bed within the surface sampling area, see Fig. 9. The object of the coring was to determine the concentration of coal material with depth below the sea bed surface. The results of the analysis of the cores can be seen in Table 2. In general, the results of the core analysis confirmed the results of the surface samples. In the forementioned northern and southern areas of high concentration large deposits of coal material were found more than 2 ft below the surface. The core near Easington Colliery had 65% of coal material 2 ft to 2.5 ft below the surface and in Hartlepool Bay, core number 23 had 83% of coal material between 0.5 ft and 1.5 ft below the surface. This latter figure is similar to the analysis of a sample of material dredged from the navigation channel to Hartlepool Docks in 1968; 50% of the sample was coal material.

The mean size of coal waste particles was found to be about 1.2mm on the sea bed near Easington tipping point and 0.5mm near Blackhall, further away from the tipping points it was found to be 0.17mm except for Hartlepool Bay where the mean size was 0.48 mm.

It would be unrealistic to attempt to use the sea bed sample and coring data to calculate the total quantity of coal material that is present on the offshore sea bed, however, it is apparent from the study that the quantity is very large indeed.

(iii) Sediment in suspension.

Samples of sea water were collected at the tidal current measuring stations, see Fig. 1 , on 6 occasions during a full tidal cycle at 1, 5 and 10 ft above the sea bed, mid-depth and 1 ft below the surface. The average concentrations of solids in suspension during the flood and ebb tides are shown in Table 3 . These concentrations are very small, the maximum, 15 parts per million (p.p.m.) occurred 1 ft above the sea bed at the offshore site during the ebb tide. These concentrations are comparable with other samples that have been collected on open coastlines around the British Isles.

Within the breaker zone, near the tipping points suspended sediment concentrations are very much higher. The breaking waves are "grey" with suspended waste particles, in addition several streams of washery effluent discharge their waste on the foreshore. However, it appears that most of the waste particles settle out of suspension in the calmer conditions just seawards of the breaking waves.

(iv) Tidal current data.

Tidal current measurements were taken at two sites, see Fig 1 , during a full tidal cycle at the following depths 2, 5 and 10 ft above the sea bed, mid-depth and 1 ft below the surface. The measurements were taken on successive days, the inshore site on 30/6/69 and the offshore site on 1/7/69, the tidal ranges were 14 ft and 16 ft respectively. The tidal currents 2 ft above the sea bed and 1 ft below the surface can be seen in Figs. 10 to 13, they have been resolved along a line 333^{o} to true north.

The tide floods in a southerly direction and ebbs in a northerly direction. There is little difference in flow 2 ft above the sea bed at either inshore or offshore sites, the maximum flood flow being 1.0 ft/sec and ebb flow 0.8 ft/sec. The surface currents are higher at the offshore site, maximum flood and ebb being 2.1 and 1.1 ft/sec respectively compared to 1.5 and 1.0 ft/sec at the inshore site. The difference in area under the tidal velocity curve between the flood and ebb flows is the net tidal drift, these have been calculated as follows:

Inshore site 2 ft above the sea bed 5,450 ft/tide southwards
Inshore site 1 ft below the surface 7,960 ft/tide southwards
Offshore site 2 ft above the sea bed 5,300 ft/tide southwards
Offshore site 1 ft below the surface 19,800 ft/tide southwards

The effect of these tidal currents producing a southerly net drift together with the wave orbital velocities on the sea bed has been to transport coal waste away from the tipping points in a southerly direction. It is impossible to make a realistic calculation for the net southerly rate of transport of coal material on the offshore sea bed, this could only be determined by tracking the movement of marked coal waste.

Summary of the transport of colliery waste on the offshore sea bed:

Colliery waste is transported southwards by wave action on the beaches until it has been broken down to a small size, it is then transported to the offshore sea bed by wave action. It has been estimated that 85% of the waste deposited on the beaches has been transported to sea in this way. Large quantities of coal material have collected on the offshore sea bed within the 10 fathom contour. The areas of highest concentration are near the Easington tipping point and in Hartlepool Bay. High coal material concentrations have been found in these two areas down to 2.5 ft below the sea bed surface. Except for Hartlepool Bay, the size of coal material particles decreased with distance from the tipping points. The colliery waste is transported southwards on the offshore sea bed by the high flood tide currents, resulting in a southerly net drift and wave action. The coal material is transported to the southern beaches by wave action usually during storms. The small particles of colliery waste material present in the breaking waves soon settle out on the offshore sea bed and it is likely that further transport takes place mainly on the sea bed.

It is probable that the net southerly transport of coal material on the offshore sea bed will continue to take place and that coal will be washed-up on the southern beaches for many years after tipping has been terminated. It is not possible to determine whether a balance has been reached between new coal material supplies arriving from recently tipped waste and the final grinding and removal from the "system" by wave and tidal current action.

REMEDIAL MEASURES

It appears from the present investigation that the continued tipping of colliery waste on the Durham coast will increase the despoliation at Crimdon and on beaches to the south. Even with the termination of tipping a very large quantity of waste will remain in the "system", both on the beaches and offshore, and this material will be transported towards Crimdon and the southern beaches. It is not possible to predict the natural rate of removal of the waste on the beaches if tipping was terminated, but a large proportion of the waste would probably be removed within 10 to 20 years, due to natural erosion. Therefore, the solution to the despoliation by the larger fraction of waste on the beaches would be to terminate tipping and remove the existing waste mechanically. This would, of course, still leave the reservoir of coal material on the offshore sea bed causing the intermittent pollution of beaches to the south.

The despoliation of Crimdon beach by the larger fraction of colliery waste could be reduced by the construction of a breakwater extending seawards from the coastline between Blackhall Rocks and the small headland between Limekiln Gill and the Caravan Steps. Its object would be to slow down the southerly transport of the waste and allow the wave action to grind it to a small enough size to be transported out to sea. Initially the breakwater would have to extend seawards for about 400 ft and be further extended as colliery waste accumulates on the northern side. The disadvantages of this breakwater from a coastal engineering view point would be, firstly, its interference with sand transport along the coast resulting in some erosion on the beach immediately to the south and, secondly, the rate of build-up of waste may be so great that frequent extensions would be required. Alternatively, the waste may be trapped by a series of groynes, extending from the cliff face to about mean water. A study has been made of the advantages and disadvantages of constructing a breakwater and/or groyne installation to intercept the waste, see Appendix 1. The existing colliery waste between the proposed breakwater or groyne installation site and Crimdon beach would have to be removed mechanically in order to prevent its transport to Crimdon by wave action along the beaches.

The termination of tipping at the Blackhall Colliery flight would probably have little effect on the quantity of coal material arriving at Crimdon, particularly in the short term, as there is already a large quantity of waste on the beaches. Even in the long term it is doubtful if the termination at this one colliery would result in a significant decrease in the quantity of coal material reaching Crimdon beach.

It is probable that a significant reduction could be made in the present level of despoliation near the Pavilion, i.e. the popular area of Crimdon beach, by removing the waste by mechanical plant and this should be considered as a temporary remedial solution. It would be particularly effective in the late spring or early summer during a spring to neap tidal cycle.

The following alternative methods of colliery waste disposal were outlined in the M.H.L.G. report of 1966.

(i) Underground stowage.

(ii) Extension of overhead system.

(iii) Groynes.

(iv) Sea wall.

(v) Crushing and pumping to sea as a slurry.

(vi) Crushing before dumping on the beach.

(vii) Barging to sea.

(viii) Additional disposal points.

(ix) Selective tipping.

It was suggested that the most attractive of the above methods were as follows:

(i) Barging all waste to sea (with some new and special equipment but retaining much equipment already in use).

(ii) Crushing before dumping on the beaches, and possibly, at a greater number of disposal points than at present.

(iii) Tipping reduced to amounts which the sea could "handle", the rest being barged out to sea.

It is apparent from the present investigation that there is no short term solution. The long term solution would be (i), barging to sea; methods (ii) and (iii) would probably have serious hydraulic and amenity disadvantages. Crushing before dumping on the beaches would probably result in local despoliation along the coast and at the same time produce large quantities of coal material for increasing the offshore "reservoir" with additional depoliation on the southern beaches in future years. It is unlikely that the sea could adequately handle more than a very small proportion of the waste now being tipped on the foreshore without creating unsightly areas.

Summing up this section. The investigation has shown that the despoliation by colliery waste at Crimdon and beaches to the south is unlikely to diminish,

unless action is taken; in fact the tendency at Crimdon could be towards a further deterioration. A breakwater or groyne installation could be constructed to the north of Crimdon to intercept the waste, irrespective of the cessation of tipping, but it would also probibit sand transport along the coast and could thereby result in some erosion on the beach immediately to the south. The solution to the problem of despoliation along the whole coastline would be to terminate tipping and barge the waste to sea. However, the "reservoir" of coal material on the sea bed would still remain and cause intermittent pollution on the beaches to the south of Crimdon for many years to come. Other possible solutions could have serious hydraulic or amenity difficulties. The existing waste on the beaches could be removed mechanically but this would be a very difficult task ; alternatively natural wave action would probably remove the bulk in about 10 to 20 years.

PROGRAMME FOR FURTHER RESEARCH AT CRIMDON

The following research programme would provide information to illustrate future changes in the degree of despoliation on Crimdon beach:

1. Record beach cross sections and collect samples every month along the following lines:

   (i) Caravan Steps.
   (ii) The Pavilion.

2. Take photographs every month at sites A, B, C and D.

3. Carry out a daily beach inspection.

This programme should be continued until a definite trend in the rate of despoliation of Crimdon beach has been determined.

It would be possible to undertake a research programme to illustrate the average rate of transport of colliery waste on the beaches and coal material on the offshore sea bed, but these studies would be elaborate, expensive and probably not add very much to the existing knowledge of the problem.

If it is decided to barge the colliery waste to sea then a study should be undertaken to ensure that the correct choice of spoil ground area is made.

REFERENCES

1. ARMISTEAD, H. Tipping of colliery waste on beaches in North-East England. May 1966. Ministry of Housing and Local Government.

2. Crimdon Park Benefit Study. Durham County Council 1970.

3. GREEN, J.W. Notes on Inspections made of the Area of Foreshore between Crimdon Burn and Blackhall Rocks covering the period July 1964 - April 1970. National Coal Board, South Durham Area.

APPENDIX 1

A further visit was made to Crimdon to study the merits of a breakwater or groyne installation to restrict the movement of colliery waste on the beaches. A meeting was held on the site between officials of the Ministry of Housing and Local Government, Durham County Council, Easington Rural District Council, the National Coal Board and the Hydraulics Research Station.

It was apparent after discussing the problem and examining the beaches that a breakwater would be less expensive to construct than a groyne installation. It is probable that the effect on the beaches of both types of construction would be similar, therefore discussion of the groyne installation was discontinued.

The construction of a breakwater was considered in the area bounded to the north by Blackhall Rocks and to the south by a small headland between Limekiln Gill and Caravan Steps. The benefits to be derived from a breakwater in this area would be twofold. Firstly, it would cause a temporary halt in the transport of colliery waste towards Crimdon and secondly, it would allow more time for natural wave action to grind the waste to a small size. The small particles could then be transported out to sea by wave action. Unfortunately the rates of both transport and grinding are unknown, it is therefore not possible to estimate the length of time that would elapse before colliery waste completely fills the catchment area created by the breakwater. Once the area was filled, material would pass round the end of the breakwater and travel south. Extensions to the structure could be added to create additional storage as required. Due to the unknown factors mentioned above, the construction of a breakwater would be to some extent conjectural, however, in the light of present knowledge, it forms the most attractive short term remedial measure.

The most suitable site for the breakwater is on either of the two small headlands immediately to the north of Limekiln Gill, see photograph 1. Here the nature of the beach changes in response to changes in wave action, but in general it consists of a more steeply sloping upper beach and a flatter sandy and boulder strewn lower beach. The upper beach consists almost entirely of colliery waste with some sand. In order to provide a reasonably large area, to the north, for the waste to accumulate the breakwater should extend from the face of the cliffs to about 150 ft beyond the most seaward limit of the upper beach, i.e. about 400 ft overall. The crest of the breakwater should be about 10 ft above high water springs in order to minimise waste being thrown over the breakwater during storms.

One disadvantage of the breakwater from a coastal engineering point of view would be its interference with sand transport along the coast resulting in some erosion of the beach immediately to the south. However, this effect should be small as the proposed site of the breakwater is near the northern limit of the sandy upper beach, further north the upper beach is mainly colliery waste. The cliffs immediately to the south of the proposed breakwater are partly protected by waste deposits, a reduction in future supplies could lead to their attack by wave action during storms, but it is thought that the resulting erosion would be slight.

There is already a large quantity of waste on the beaches to the south of the proposed breakwater site and this will be transported to Crimdon by wave action unless it is removed by mechanical plant.

ACKNOWLEDGEMENT

We would like to acknowledge the assistance rendered by the Easington Rural District Council and the National Coal Board Scientific Department during the present investigation.

The investigation, of which this report is the official Hydraulics Research Station account, was carried out in Mr. Price's division by Mr. Tomlinson's section.

TABLES

TABLE 1

Analysis of sea bed samples

Location	Mean size of sea bed material in mm	Percentage of coal by weight	Remarks
1	0.13	31	
2	0.13	45	
3	0.10	<10	
4	0.10	<10	
5	0.10	<10	
6	-	-	hard ground no sample
7	0.13	14	
8	0.10	36	
9	0.10	<10	
10	0.10	<10	
11	0.10	<10	
12	-	-	mud
13	-	-	hard ground no sample
14	0.13	39	
15	0.10	32	
16	0.13	19	
17	0.13	<10	
18	-	-	mud
19	0.10	<10	
20	0.13	<10	
21	0.10	<10	
22	0.13	<10	
23	0.30	<10	
24	-	-	hard ground no sample
25	0.13	<10	
26	0.13	<10	
27	0.13	<10	
28	-	-	mud
29	-	-	hard ground no sample
30	0.13	<10	
31	0.13	<10	
32	0.10	<10	
33	0.10	<10	
34	-	-	mud
35	-	-	small stone and broken shell
36	0.13	<10	
37	0.21	<10	
38	0.13	<10	
39	0.10	<10	
40	-	-	hard ground no sample
41	0.21	<10	
42	0.13	<10	
43	0.13	<10	
44	-	-	hard ground no sample
45	-	-	hard ground no sample
46	0.29	10	

TABLE 1 (cont')

Analysis of sea bed samples

Location	Mean size of sea bed material in mm	Percentage of coal by weight	Remarks
47	0.21	<10	
48	0.13	<10	
49	-	-	hard ground no sample
50	-	-	small stones
51	-	-	hard ground no sample
52	0.21	<10	
53	0.13	<10	
54	0.13	<10	
55	-	-	mud
56	-	-	hard ground no sample
57	0.21	<10	
58	0.13	<10	
59	0.10	<10	
60	0.10	56	
61	-	-	mud
62	0.21	<10	
63	0.13	<10	
64	-	-	mud
65	-	-	mud
66	-	-	mud
67	0.13	<10	
68	0.13	<10	
69	0.10	20	
70	0.10	30	
71	0.13	<10	
72	0.21	<10	
73	-	25	
74	0.13	<10	
75	0.10	<10	
76	-	-	hard ground no sample
77	-	-	hard ground no sample
78	0.13	<10	
79	0.10	<10	
80	-	-	hard ground no sample
81	0.10	<10	
82	0.10	<10	
83	0.10	<10	
84	0.10	<10	
85	-	-	hard ground no sample
86	0.13	<10	
87	-		hard ground no sample
88	0.13	<10	
89	-	-	hard ground no sample
90	-	-	hard ground no sample
91	0.10	<10	

TABLE 2

Analysis of core samples

Location	Depth below sea bed, ft	Mean size of sample mm	Mean size of coal in sample mm	Percentage of coal by weight
C_1	0 - 0.5	0.31	0.80	20.9
	0.5 - 1.0	0.34	0.80	21.5
	1.0 - 1.5	0.32	0.80	8.6
	1.5 - 2.0	0.31	0.94	25.7
	2.0 - 2.33	0.32	0.94	5.9
C_2	0 - 0.5	0.11	0.33	22.5
	0.5 - 1.0	0.10	0.42	16.0
	1.0 - 1.5	0.10	0.29	12.2
	1.5 - 2.0	0.11	0.29	7.4
C_3	0 - 0.5	0.16	0.95	32.5
	0.5 - 1.0	0.22	1.30	58.5
	1.0 - 1.5	0.22	1.20	37.5
	1.5 - 2.0	0.26	1.14	51.8
	2.0 - 2.5	0.25	1.43	64.8
C_4	0 - 0.5	0.15	0.63	34.0
	0.5 - 1.0	0.15	0.42	14.0
	1.0 - 1.5	0.14	0.42	7.0
	1.5 - 2.0	0.13	-	0
	2.0 - 2.5	0.13	-	0
C_5	0 - 0.5	0.21	0.56	11.3
	0.5 - 1.0	0.24	1.00	25.3
	1.0 - 1.5	0.22	1.09	22.8
	1.5 - 2.0	0.23	1.30	23.8
	2.0 - 2.5	0.23	0.78	22.3
C_6	0 - 0.5	0.15	0.59	30.0
	0.5 - 1.0	0.15	0.59	7.4
	1.0 - 1.5	0.14	-	0
	1.5 - 2.0	0.13	-	0
	2.0 - 2.5	0.13	-	0
C_7	0.- 0.5	0.15	0.32	6.2
	0.5 - 1.5	0.13	0.32	8.6
	1.5 - 2.0	0.14	0.32	18.8
C_8	0 - 0.5	0.12	-	1.0
	0.5 - 1.0	0.12	-	1.0
	1.0 - 1.5	0.12	-	1.0
	1.5 - 2.0	0.12	-	1.0
	2.0 - 2.5	0.13	-	0

TABLE 2 (cont')
Analysis of core samples

Location	Depth below sea bed, ft	Mean size of sample mm	Mean size of coal in sample mm	Percentage of coal by weight
C_9	0 - 0.5	0.18	0.53	13.5
	0.5 - 1.0	0.16	0.53	7.4
	1.0 - 1.66	0.17	0.53	4.7
C_{10}	0 - 0.5	0.12	-	0
	0.5 - 1.0	0.11	-	0
	1.0 - 1.5	0.12	-	0
	1.5 - 2.0	0.12	-	0
	2.0 - 2.5	0.12	-	0
C_{11}	0 - 2.0	0.21	-	3.0
C_{12}	0 - 0.5	0.11	0.17	11.0
	0.5 - 1.0	0.12	0.17	6.0
	1.0 - 1.5	0.12	0.17	1.0
	1.5 - 2.0	0.11	0.17	6.0
	2.0 - 2.5	0.12	0.17	1.0
C_{13}	0 - 0.5	0.22	-	3.9
	0.5 - 1.0	0.23	-	1.0
	1.0 - 1.5	0.23	-	1.0
	1.5 - 2.o	0.23	-	1.0
C_{14}	0 - 0.5	0.11	-	0
	0.5 - 1.0	0.12	-	0
	1.0 - 1.5	0.12	-	0
	1.5 - 2.0	0.12	-	0
C_{15}	0 - 0.5	0.35	-	0
	0.5 - 1.0	0.35	-	0
	1.0 - 1.5	0.35	-	0
	1.5 - 2.0	0.24	-	3.8
	2.0 - 2.66	0.26	-	5.9
C_{16}	0 - 0.5			4.2
C_{17}	0 - 2.5			3.6
C_{18}	0 - 0.5	0.12	-	0
	0.5 - 1.0	0.11	-	<1
	1.0 - 1.5	0.11	-	<1
	1.5 - 2.0	0.11	-	<1
	2.0 - 2.5	0.11	-	<1
C_{19}	0 - 2.5	0.21	-	4.0
C_{20}	0 - 2.5	0.13	-	2.0
C_{21}				34.8

TABLE 2 (cont')

Analysis of core samples

Location	Depth below sea bed, ft	Mean size of sample mm	Mean size of coal in sample mm	Percentage of coal by weight
C_{22}	LIME STONE			
C_{23}	0 - 0.5	0.10	0.37	20
	0.5 1.0	0.21	0.42	83.7
	1.0 - 1.5	0.19	0.48	83.6
	1.5 - 2.0	0.19	0.40	48.5
	2.0 - 2.5	0.21	0.40	2.4
C_{24}	0 - 0.5	0.21	-	<1
	0.5 - 1.0	0.21	-	<1
	1.0 - 1.5	0.21	-	<1
	1.5 - 2.0	0.21	-	<1
	2.0 - 2.5	0.21	-	<1
C_{25}	0 - 0.5	0.16	-	5.2
	0.5 - 1.5	0.17	0.37	21.4
	1.5 - 2.5	0.15	0.37	5.3
C_{26}	0 - 1.0	0.14	0.42	10.1
	1.0 - 2.33	0.14	0.42	4.0
C_{27}	0 - 0.5	0.15	0.45	13.7
	0.5 - 1.0	0.15	0.45	9.8
	1.0 - 1.5	0.15	0.45	3.9
	1.5 - 2.0	0.14	-	<1
C_{28}	0 - 1.5	0.13	-	<1
	1.5 - 2.66	0.13	-	<1
C_{29}	0 - 0.5	0.11	-	0
	0.5 - 1.0	0.14	0.30	10.1
	1.0 - 1.5	0.13	0.15	33.3
C_{30}	0 - 1.0	0.18	-	1.0
	1.0 - 2.0	0.19	-	6.2
	2.0 - 2.66	0.51	-	10.0
C_{31}	0 - 0.5	0.16	-	<1
	0.5 - 1.0	0.16	-	<1
	1.0 - 1.5	0.14	-	<1
	1.5 - 2.0	0.15	-	<1
C_{32}	0 - 0.5	0.12	-	<1
	0.5 - 1.0	0.12	-	<1
	1.0 - 1.5	0.11	-	<1
	1.5 - 2.0	0.11	-	<1
	2.0 - 2.5	0.11	-	<1
C_{33}	0.- 0.5	<0.1	-	<1
	0.5 - 1.0	<0.1	-	3.2
	1.0 - 1.5	<0.1	-	<1
	1.5 - 2.0	<0.1	-	<1
	2.0 - 2.5	<0.1	-	<1

TABLE 3

Analysis of suspended solids

Site A

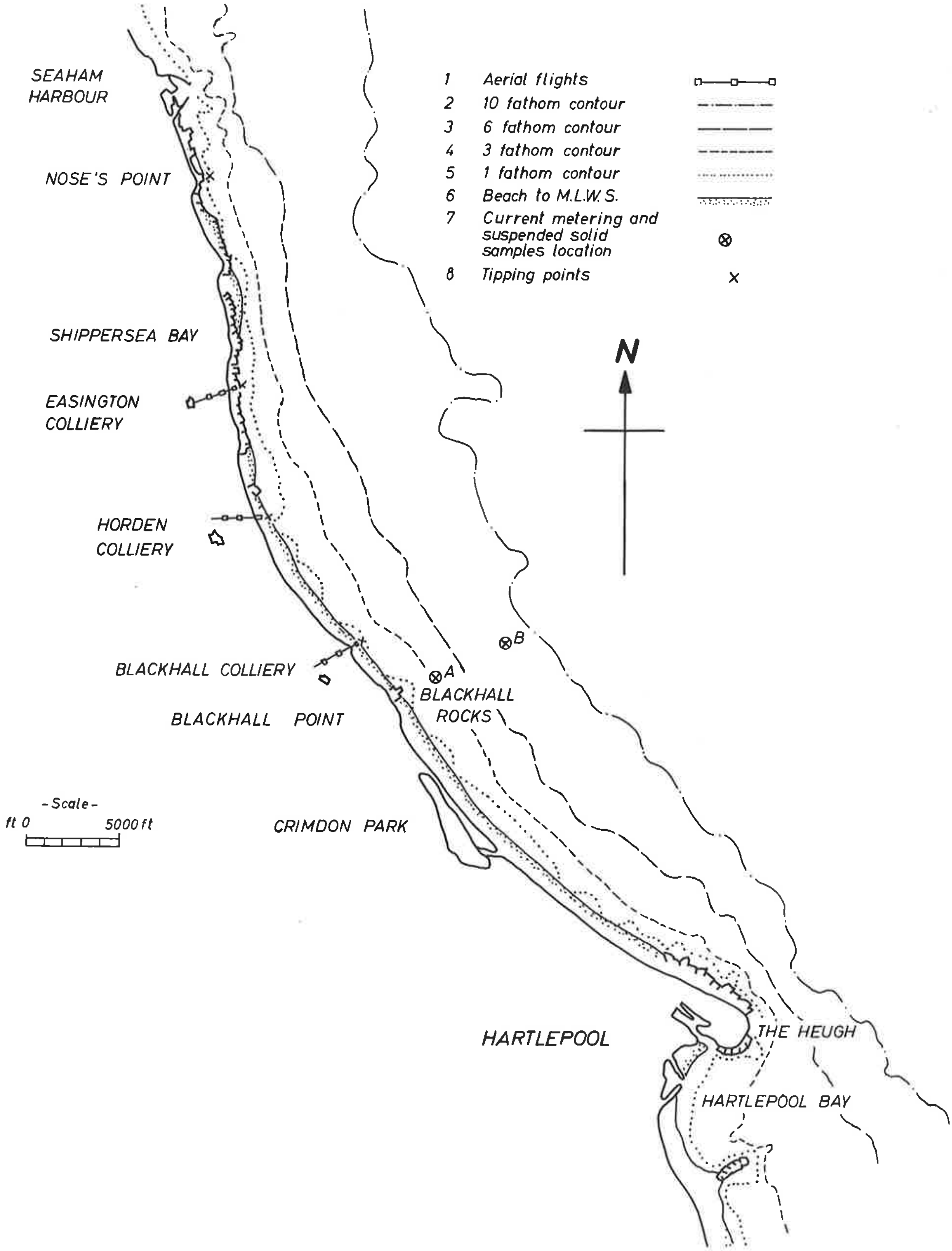
Sample location	Flood tide No. of Samples	Flood tide Average concentration p.p.m.	Ebb tide No. of Samples	Ebb tide Average concentration p.p.m.
2 ft above bed	6	5	7	12
5 ft above bed	6	3	7	4
10ft above bed	6	4	7	7
Mid-depth	6	4	7	6
1 ft below surface	6	3	7	7

Site B

Sample location	Flood tide No. of Samples	Flood tide Average concentration p.p.m.	Ebb tide No. of Samples	Ebb tide Average concentration p.p.m.
2 ft above bed	5	12	6	15
5 ft above bed	6	14	7	10
10ft above bed	6	9	7	12
Mid-depth	6	9	7	8
1 ft below surface	6	12	7	13

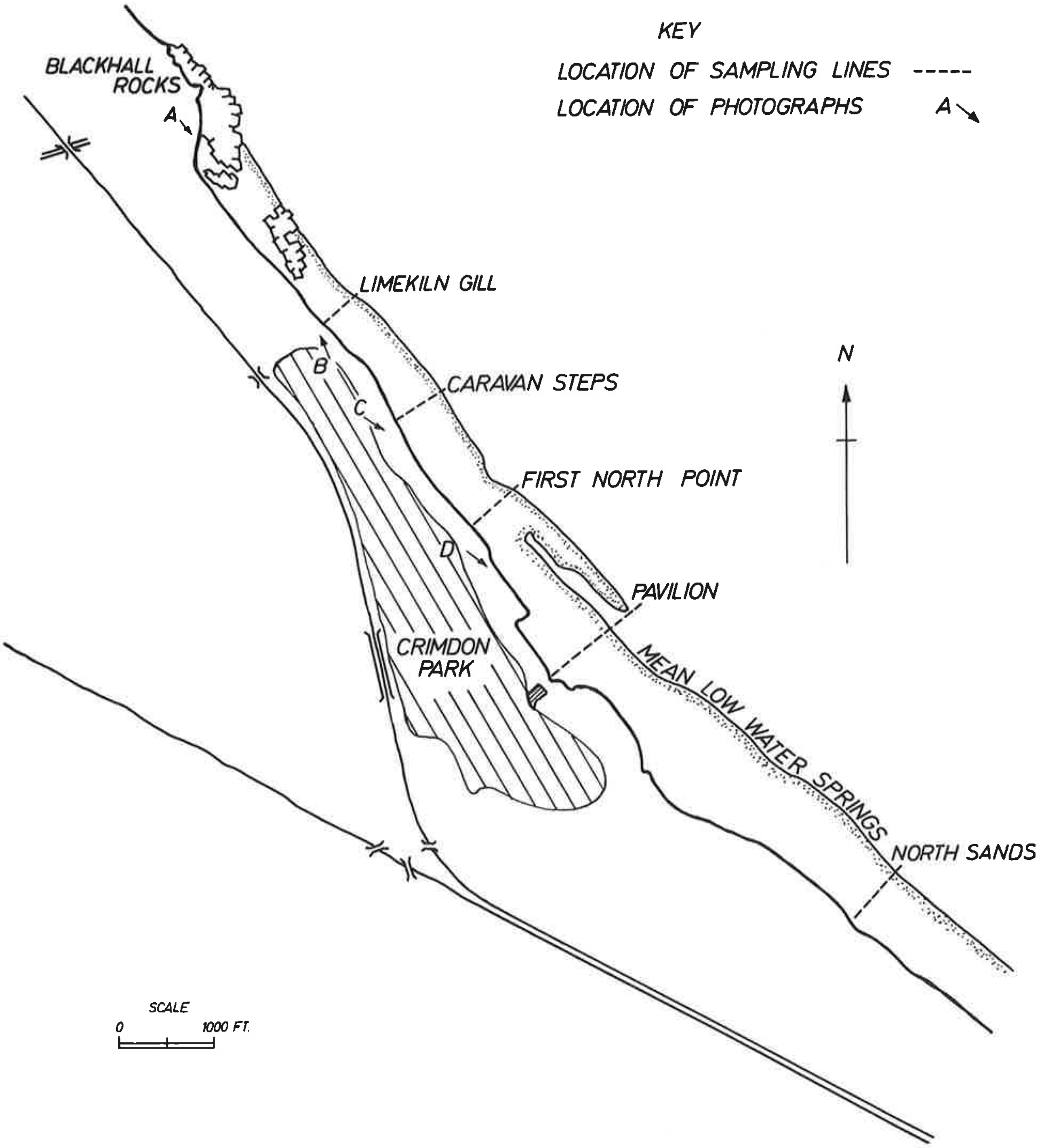
for sampling sites see Fig. 1

FIGURES



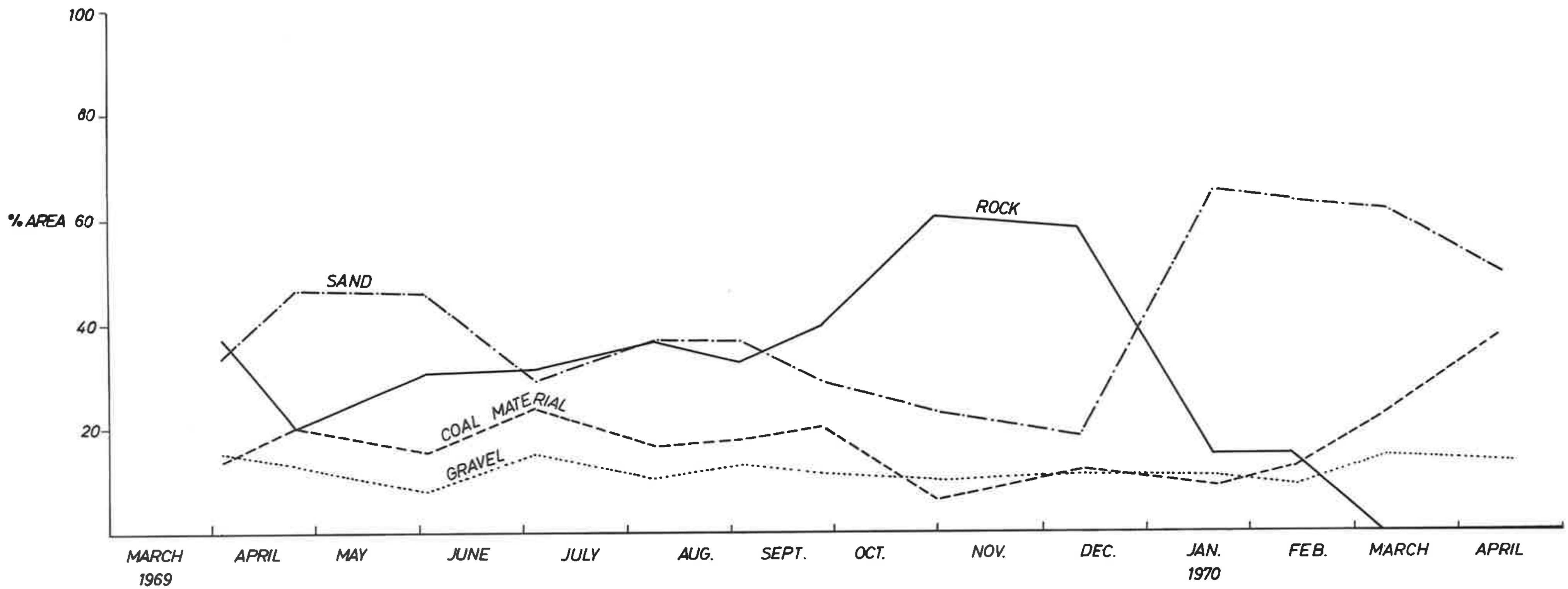
LOCATION OF TIPPING POINTS

FIG 1



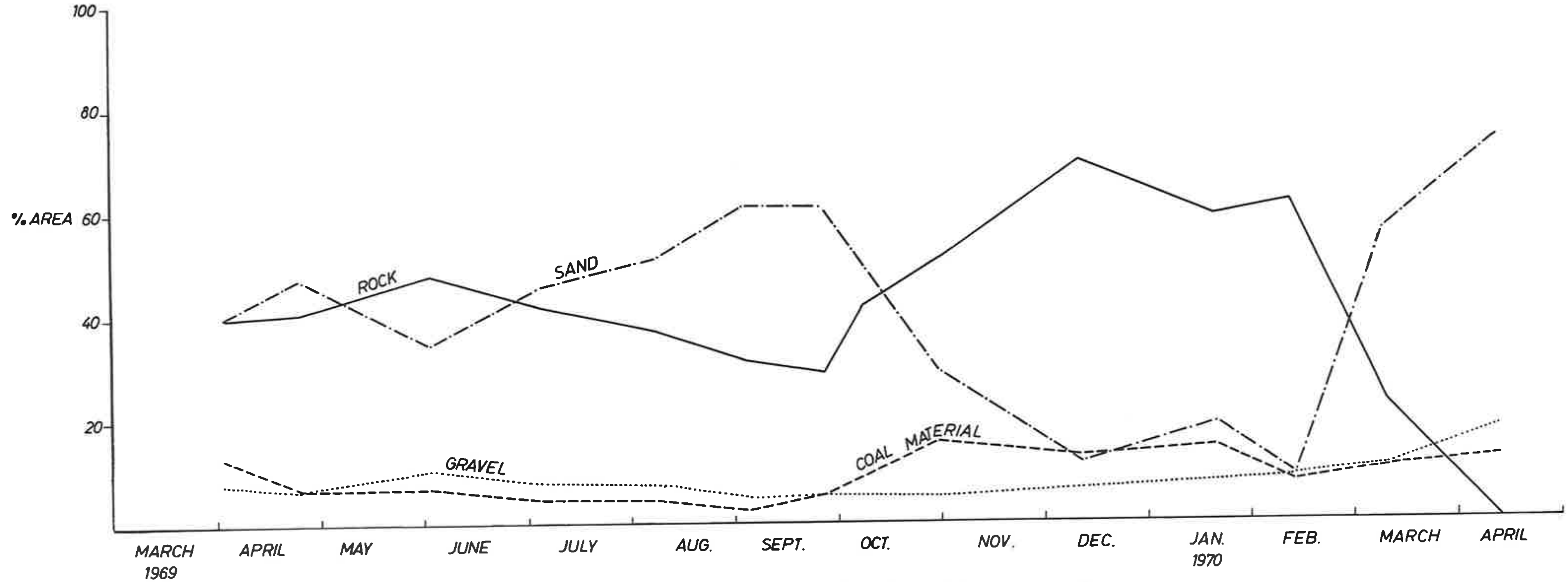
LOCATION OF PHOTOGRAPHS AND BEACH SAMPLING LINES

FIG 2



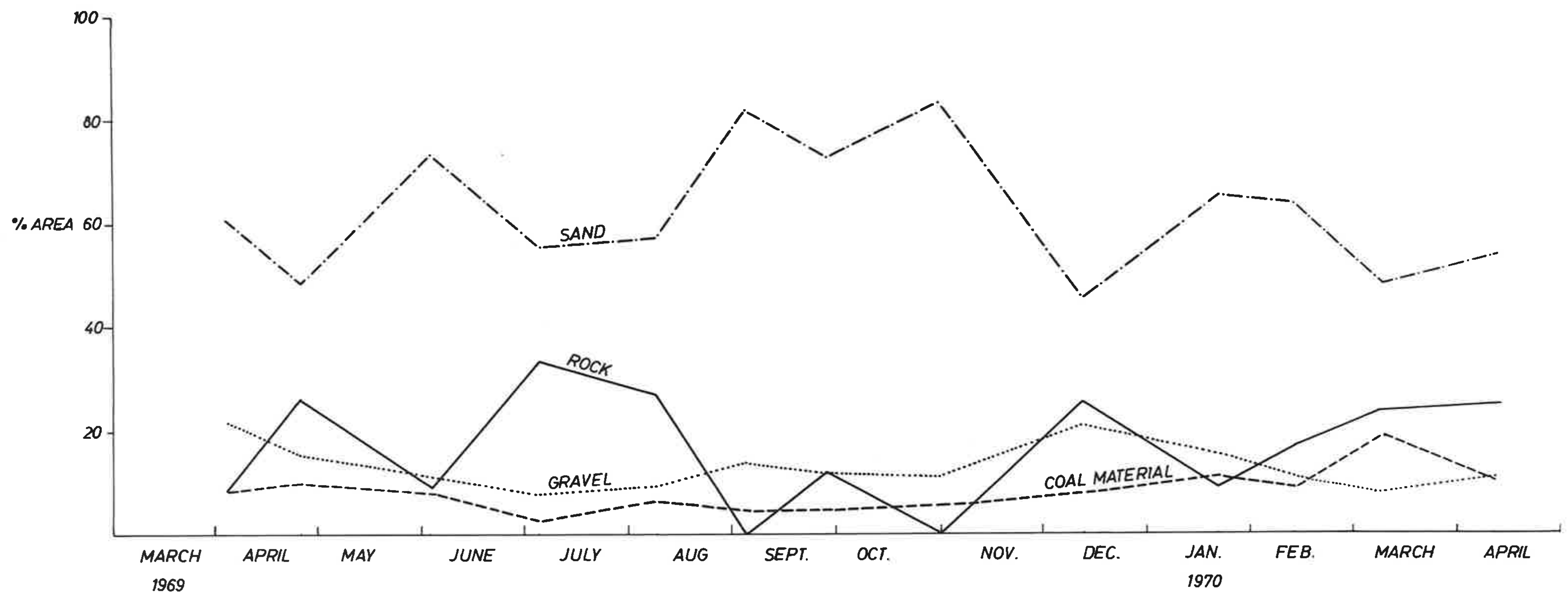
ANALYSIS OF BEACH SAMPLES, LIMEKILN GILL

FIG 3



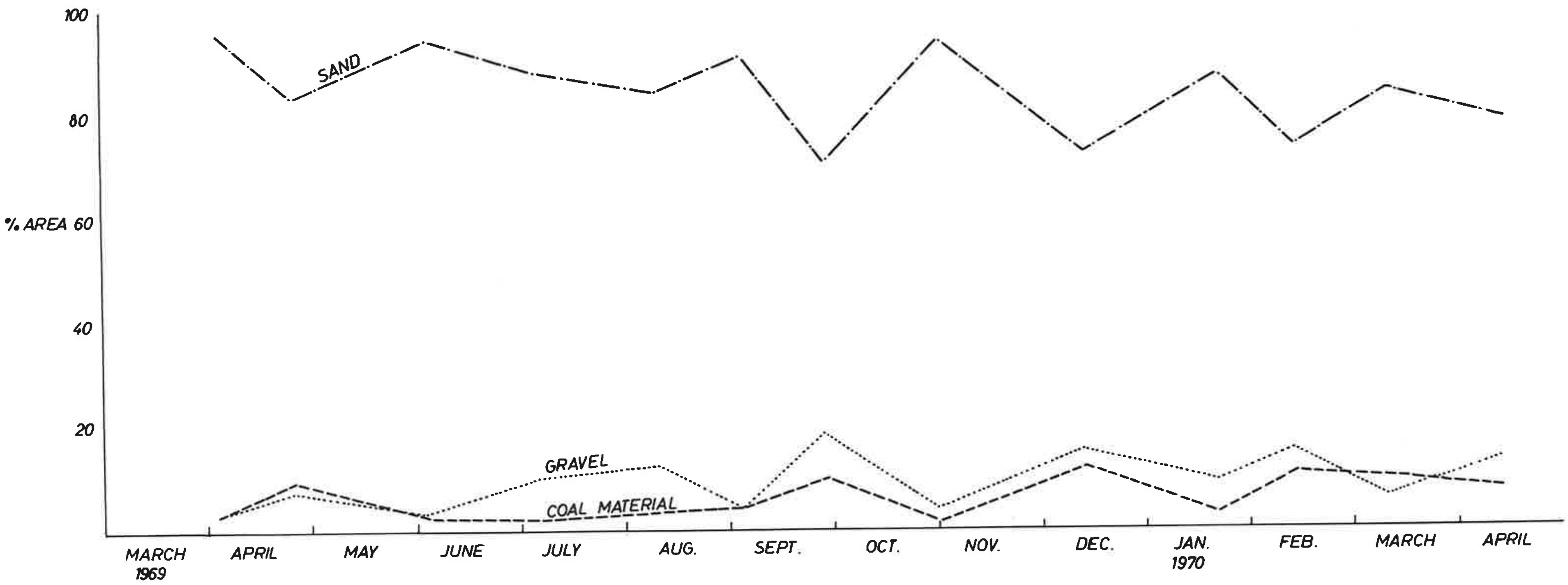
ANALYSIS OF BEACH SAMPLES, CARAVAN STEPS

FIG 4



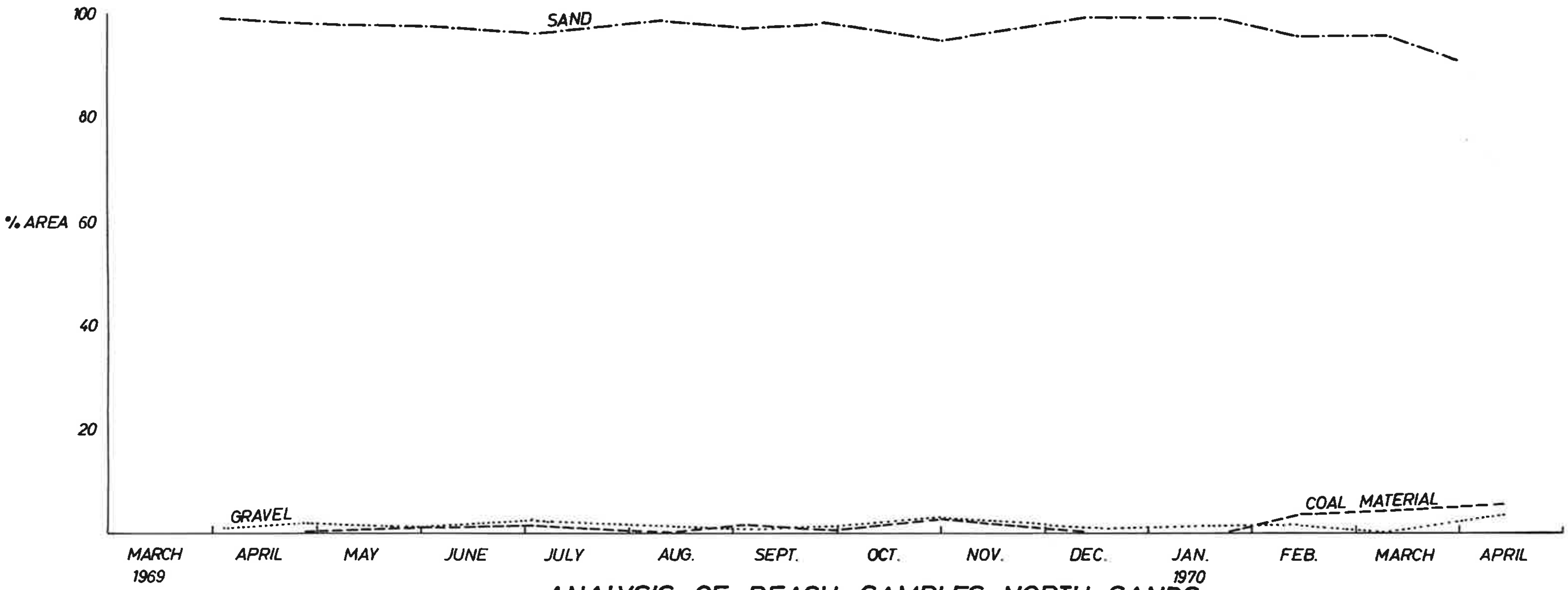
ANALYSIS OF BEACH SAMPLES, FIRST NORTH POINT

FIG 5



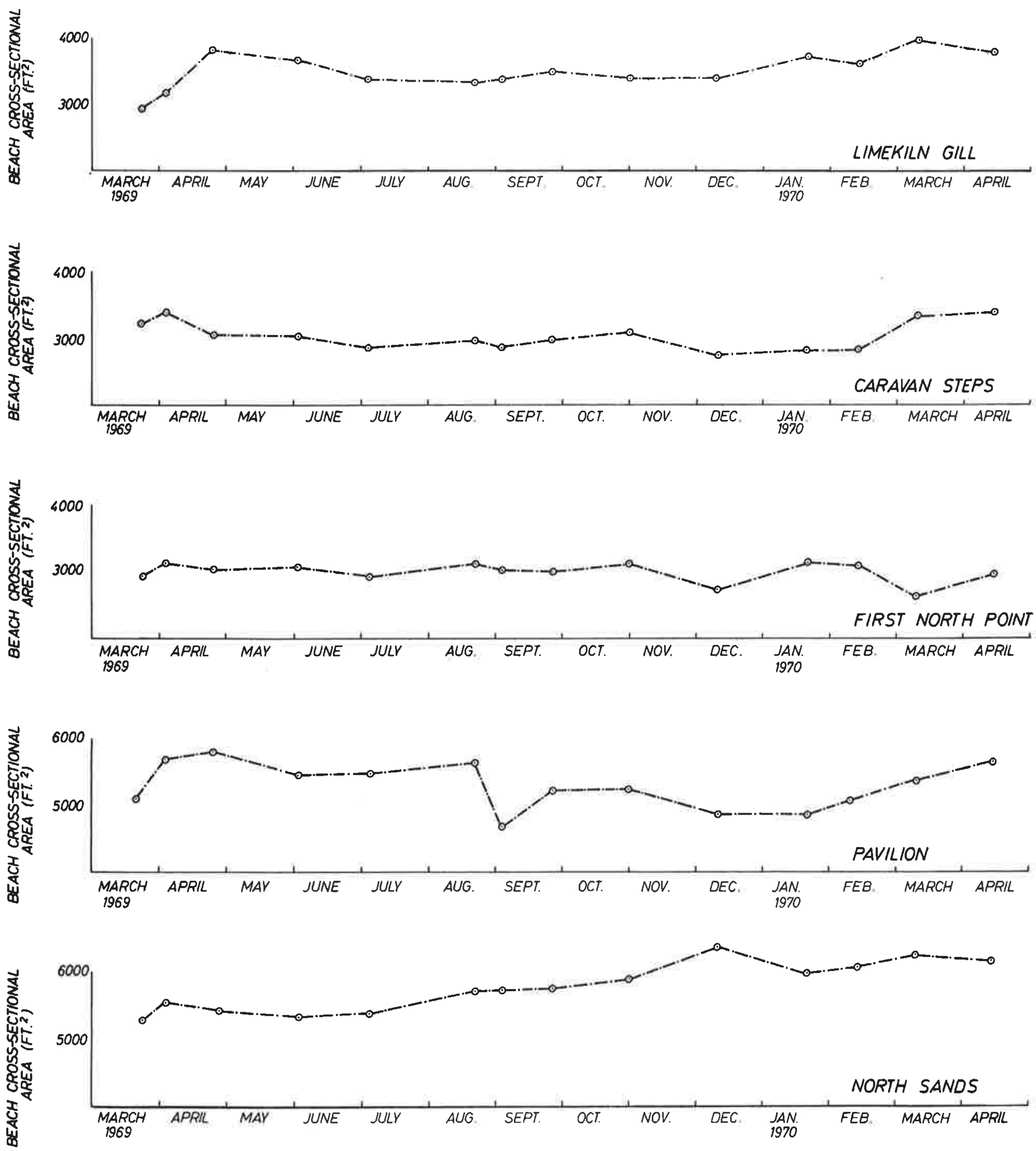
ANALYSIS OF BEACH SAMPLES, PAVILION

FIG 6



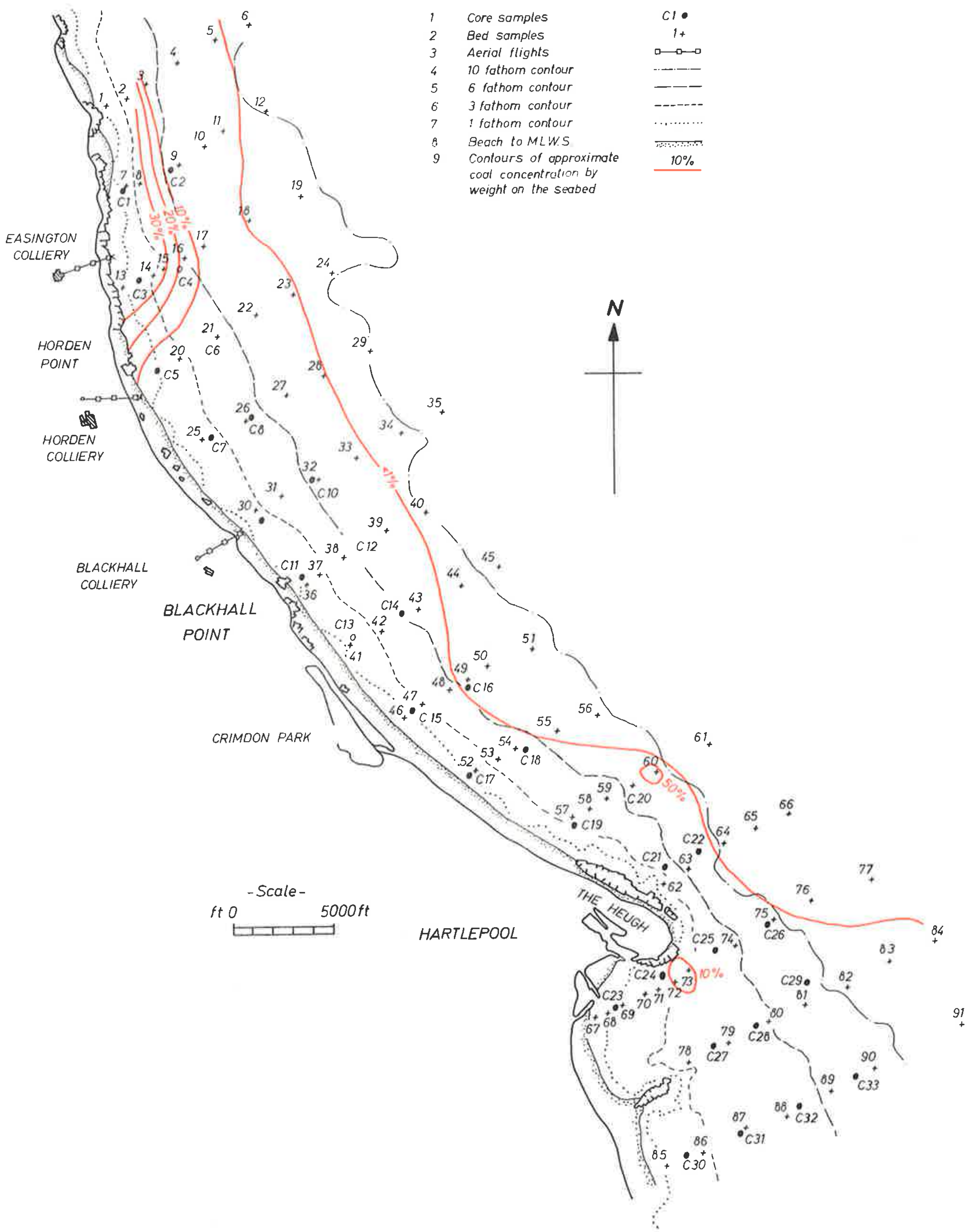
ANALYSIS OF BEACH SAMPLES, NORTH SANDS

FIG 7



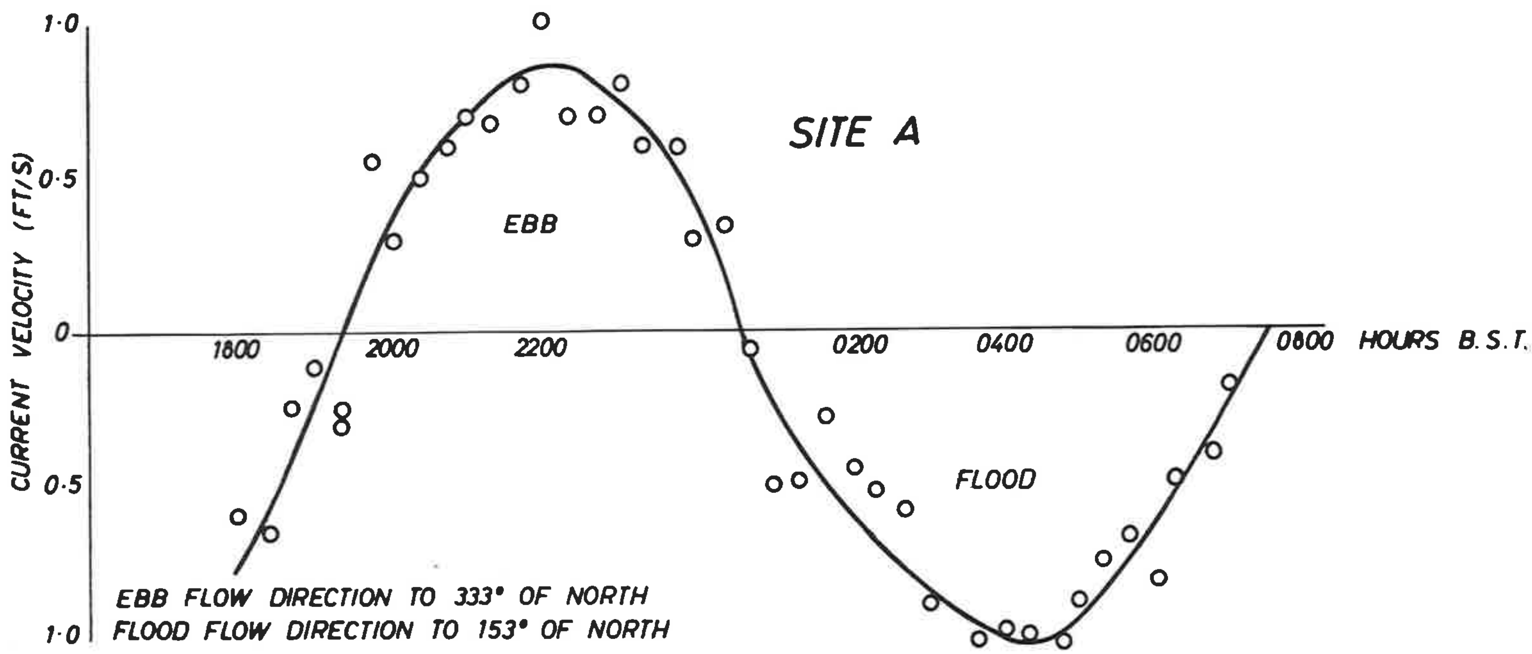
CHANGES OF CROSS-SECTIONAL AREA OF CRIMDON BEACH

FIG 8



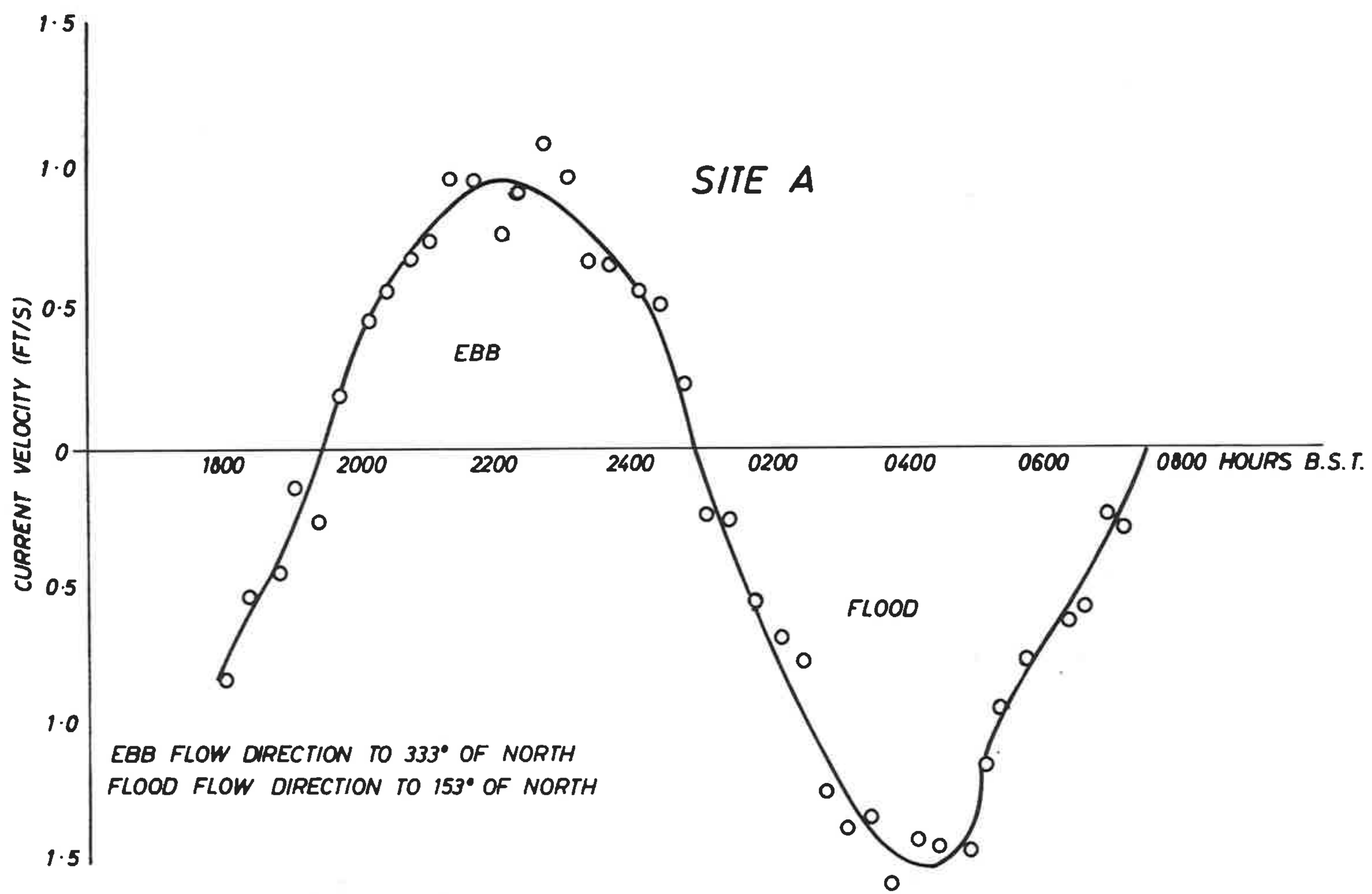
LOCATION OF CORE AND SEABED SAMPLES

FIG 9



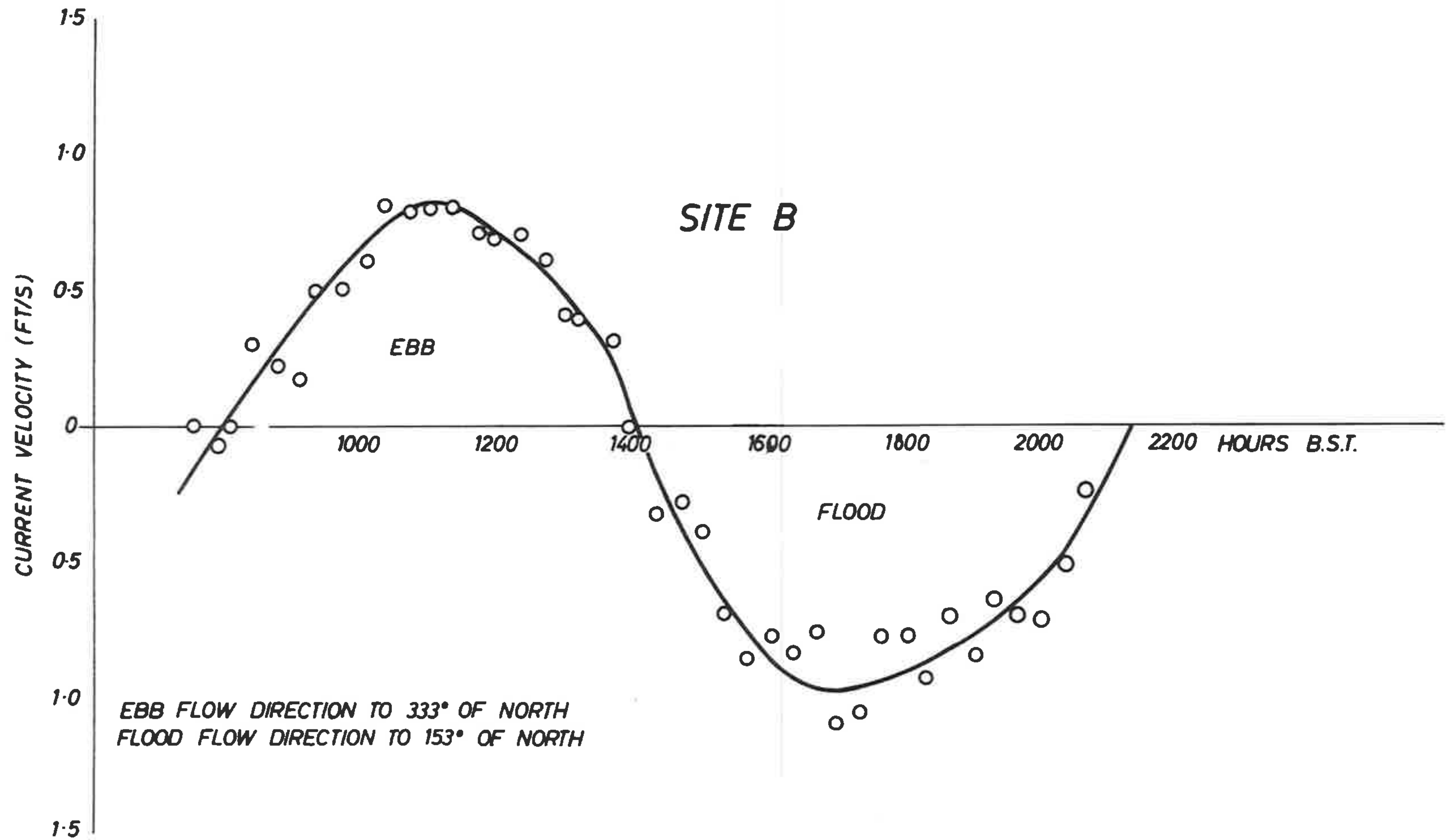
TIDAL CURRENTS 2 FT. ABOVE THE SEA BED
(Survey dated 30-6-1969)

FIG. 10



TIDAL CURRENTS 1 FT. BELOW THE SURFACE
(Survey dated 30-6-1969)

FIG. 11



TIDAL CURRENTS 2 FT. ABOVE THE SEA BED
(Survey dated 1-7-1969)

FIG. 12


Headlands
1
2