Hydraulics Research
Wallingford

A MACRO-REVIEW OF THE COASTLINE OF ENGLAND AND WALES

1 The North East. St Abb's Head To The Tees

J M Motyka BSc (Eng)
S M Beven BSc PGCE

Report No SR 90
March 1986

Registered Office: Hydraulics Research Limited,
Wallingford, Oxfordshire OX10 8BA.
Telephone: 0491 35381. Telex: 848552

This report describes work carried out by Hydraulics Research into a review of the coastline of England and Wales. It has been funded by the Ministry of Agriculture, Fisheries and Food under contract number CSA 1033, the nominated officer being Mr A Allison. At the time of reporting the Hydraulics Research nominated project officer was Dr S W Huntington.

ABSTRACT

This report is a review of the coastline between St Abb's Head, Berwickshire and Tees Bay, Cleveland. In it are described the various natural and man-made processes which affect the behaviour of this particular stretch of Britain's shoreline. The report includes a description of the major coastal defences, areas of erosion and accretion and various other aspects of beach behaviour. Information is given about winds, waves and tidal currents and how these affect the formation of the coast and its future behaviour. Various stretches of coastline which for coastal engineering purposes can be treated as independent or semi-dependent cells are also identified. This report is the first of a series covering the whole coastline of England and Wales which Hydraulics Research are carrying out for the Ministry of Agriculture Fisheries and Food.

This report was written by Mr J M Motyka and Mrs S M Beven of the Coastal Processes Section of the Maritime Engineering Department, Hydraulics Research Limited, who should be contacted for further information.

CONTENTS

		Page
1	BACKGROUND TO THE MACRO-REVIEW	1
2	EXECUTIVE SUMMARY	3
3	COASTAL GEOLOGY AND TOPOGRAPHY	5
	3.1 Geological framework	5
	3.2 Regional geology	5
	3.3 Recent geological processes and sea level changes	9
4	WINDS, WAVES AND TIDES	11
	4.1 Wind-wave climate	11
	4.2 Inshore and offshore wave records	12
	4.3 Tides and tidal currents	15
	4.4 Extreme water levels and surges	16
5	COASTAL PROCESSES	18
	5.1 Beach behaviour and geomorphology	18
	5.2 Sediment budget for the North East coast	21
6	REVIEW OF COASTAL DEFENCES	28
	6.1 St Abb's Head to the River Tyne	28
	6.2 The River Tyne to the River Wear	34
	6.3 The River Wear to the Tees Bay	36
7	CONCLUSIONS	40
8	ACKNOWLEDGEMENTS	45
9	REFERENCES	46
10	BIBLIOGRAPHY	49

CONTENTS (CONT'D)

TABLES:

1. Proposed division of coastline for the Macro-review

FIGURES:

1. Location map

2. Proposed division of coastline for the Macro-review

3. Simplified geology of the North East coast

4. Summary of divisions of geological time in the North East

5. St Abb's Head to Cheswick Sands

6. Cheswick Sands to Bamburgh

7. Bamburgh to Howick Haven

8. Howick Haven to Snab Point

9. Snab Point to Tynemouth

10. Tynemouth to Seaham

11. Seaham to Tees Bay

12. Tees Bay to Saltburn

CONTENTS (CONT'D)

PLATES:

1. View north from Berwick Harbour
2. Low cliff line between Berwick and Cheswick
3. Cliffs and wave cut platform between Bamburgh and Seahouses
4. Peat exposures and eroding dune face at Druridge Bay
5. The effects of overgrazing at Druridge Bay
6. The accumulation of coal south of Newbiggin breakwater
7. Cliff erosion at Newbiggin Moor holiday camp site
8. Erosion of the spit north of the Alcan Co. frontage, Blyth
9. Cliff erosion and boulder clay pebbles on beach north of Seaham Hall
10. Cliffs isolated by colliery waste south of Seaham
11. Wide shingle beach trapped north of Blackhall Rocks
12. View south of Crimdon showing sand beach and dunes
13. Coastal defences at Redcar
14. Erosion of boulder clay cliffs east of Redcar
15. Weathering of boulder clay cliffs by rainfall at Saltburn
16. Termination of sand beach at Hunt Cliff east of Saltburn

1 BACKGROUND TO THE MACRO REVIEW

In 1985 the Ministry of Agriculture, Fisheries and Food commissioned Hydraulics Research, Wallingford to carry out an overall review of the beaches and coastal defences of England and Wales. The principal aim of the report is to provide those involved in or having responsibility for coastal protection with information relevant to coastal engineering. Inevitably, because of the scale of such a project, it has been necessary to divide the coastline into regions in some way. Thus this volume is the first in a series and covers the coastline of the North East from St Abb's Head in Berwickshire to Tees Bay, Cleveland (Fig 1).

When coastal defence attracts attention, it is only too often focussed on the immediate locality where the problem occurs, be it flooding, cliff falls, damage to and deterioration of existing defences or loss of beach material. These problems should really be viewed as the result of the dynamic interaction of a range of natural and man-made processes operating within the wider context of the coastal system. Any inbalance within this system may create new problems, exacerbate existing ones or merely transfer them along the coast. Such problems only become worse with time unless appropriate remedial 'defensive' action is taken.

Historically coastal defence has been approached in a 'piecemeal' fashion with little consideration for the consequent long term spatial or temporal effects. This has been made worse, even in recent times, by the lack of comprehensive planning strategies, partially due to the large number of organisations and agencies responsible for coastal defence and because of the location of sometimes ill-placed administrative boundaries.

It has been a fundamental objective of this review, therefore, to identify areas which can be considered as individual coastal units or cells on an environmental basis. Such cells are defined as stretches of coastline within which beach changes take place largely independently of changes in adjoining cells. As such, the cells may be considered 'self contained' and have defined the coastal units covered by this and subsequent volumes of this review (Fig 2, Table 1). Any one unit may in fact consist of several smaller sub-units. For example, a long stretch of sand coastline may be divided by a stretch of rocky cliff line. The two stretches of sand coast can be considered as sub-units with little in the way of sediment exchange between them. It is hoped that this 'global' view will enhance the growing awareness and understanding of the coastal system and ultimately lead to a more unified and sympathetic approach to the planning and design of coastal defence.

Coastal engineering has become an increasingly precise study, not only as a result of advances in technology but also necessitated by the very high cost of new coastal defences and the maintenance of existing systems. Thus, proposed schemes have to be carefully evaluated. This increasingly involves the collection of comprehensive field data and in some cases the use of predictive or physical models. A further purpose of these reports is thus to highlight sources of existing data and the availability of such techniques.

The major points derived from this study are summarised in Chapter 2. Here information is drawn together about the important features which characterise the North East, its geology and geomorphology, coastal development etc. From here onwards the various chapters of the report are broadly in sequence with respect to time, beginning with the evolution of the coast and ending with a description of present day coastal defences. Chapter 3 describes the geology of the coastline in detail and relates it to existing sea defence problems. Information about wind, waves and tidal phenomena are given in Chapter 4. In Chapter 5 the coastal processes are described, paying particular attention to areas of sediment supply (sources) and areas of accretion (sinks). An analysis of beach and sea bed sediment movement is given next and this is followed by a "sediment budget" for the coastline. A systematic regional survey of coastal features and defences follows in Chapter 6.

The conclusions are found in Chapter 7. Potential future problem areas for coastal defence are highlighted here, with emphasis being given to the definition of coastal cells in the North East. The report finishes with an extensive although presently not exhaustive bibliography, which we hope to update regularly, as and when fresh sources of information become available.

2 EXECUTIVE SUMMARY

This report attempts to draw together available knowledge and information about the coast of the North East in such a way as to be of practical use to coastal engineers in the area. Fundamental to the aims of this report is an understanding of the coastal system as the dynamic interaction of a range of natural and man-made processes. The beautiful and varied coastal scenery of Northumberland and Durham is a reflection of the geological structure of the region. Much of the underlying bedrock has been covered by thick deposits of relatively soft boulder clay deposited during the Ice Age. Differential erosion has resulted in the formation of a headland and bay coastline. Major coastal recession occurred during the postglacial sea level rise, and much of the available beach material is thought to have been accumulated in the near-shore zone during this time. Rates of sea level rise are currently slow and recent modifications to the coastline are small.

The North East is exposed to a very high energy wave climate dominated by north and north-easterly gales, and promoting a net transport of beach sediment southwards assisted by tidal currents. However, the rate is low and often limited to movement within individual embayments. The net volumes involved may be small compared with seasonal onshore/offshore movements of beach material within the littoral zone, and short term variations in longshore drift due to the action of waves from different directions in individual events. Fresh supplies of beach material are currently limited to localised cliff erosion along the open coast. The marked indentations at Holy Island and the Tees act as major sinks for sand and finer sediment fractions.

Compared to some other parts of the British coastline, a relatively small proportion of the North East coast is at present protected from the sea by man-made defences. The majority of the defences are to be found south of Lynemouth (Fig 1). This is in part a reflection of the urban and industrial expansion of this area, largely based on 19th Century development of the coal and steel industry. Coastal engineering works are concentrated along urban frontages such as Whitley Bay, Tynemouth, Seaham, Sunderland and Hartlepool. Recent coastal defence schemes have been implemented at Blyth and Redcar. The remaining sea defences are relatively small and fragmentary.

There are a number of factors related to man's activities that have in the past or may currently be contributing to coastal problems. The extensive tipping of colliery waste on the foreshore over a period of decades has resulted in widespread despoliation and pollution at Lynemouth and Cambois Bays and south of Seaham for example. While cessation of tipping and the introduction of reclamation schemes have resulted in some marked improvements, there has been undoubted amenity loss to some stretches of coastline.

The large sand dune and sand link features that are characteristic of this coastline should be regarded as a valuable resource both in terms of supply of beach material and as an effective natural sea defence. Dune systems will erode rapidly if misused, either by overgrazing or trampling. Sand extraction is also known to take place. Even small quantities of sand removal, if allowed to continue unrestrained, may create weaknesses in the dunes and increase the likelihood of breaching and flooding under severe wave conditions. The dune systems suffer additional pressures as a result of tourism and recreational use. Dune conservation and management schemes should be considered where problems arise.

St. Abb's Head acts as a point of divergence for sediment movement under the north-easterly wave climate. At the southern boundary of the area considered in this report, Tees Bay acts as a large sink for sediments and it is unlikely that beach material moves south of Saltburn. Thus the length of coast from St. Abb's Head to Tees Bay forms a large coastal unit some 175km in length in which coastal changes are likely to take place independently of the adjacent coast to north or south. This report has distinguised a number of sub-cells, namely:

(1) St. Abb's Head to the Tyne;
(2) The Tyne to the Wear;
(3) The Wear to Seaham;
(4) Seaham to Hartlepool;
(5) Hartlepool and Tees Bay.

These divisions are based on local variations in sediment movement. The river mouths of the Tyne and Wear and associated harbour installations create partial barriers to sediment movement and almost total barriers to drift within the littoral zone ie. with the 10m isobath. For the most part the drift is uni-directional along the North East coast, in both the littoral zone and on the near-shore sea bed and therefore any effects of coastal works are likely to be found to the south. These effects should be considered at the planning and design stage of coastal structures. Thus while these cells are not themselves independent of the larger unit, they can be considered as fundamental units in coastal engineering terms.

3 COASTAL GEOLOGY AND TOPOGRAPHY

3.1 Geological framework

The varying resistance of different rocks to wave action is fundamental to the evolution of the shoreline and gives rise to the sequence of wide bays separated by rocky stretches of cliff line along the North East coast. The coastal geology is very complex and is covered in detail in other sources (Refs 1, 2, 3).
A simplified geology of the North East is shown in Fig 3. The rocks are predominantly sedimentary, laid down between 435 and 135 million years Before Present (see Fig 4). The older rocks outcropping in the north are overlain by successively 'younger' rocks towards the south and the strata dip away in a south-easterly direction. However, the occurrence of igneous rocks, both intrusive and extrusive in origin, gives rise to distinctive local coastal features.

From St Abb's Head to Burnmouth, Silurian and Devonian (or Old Red Sandstone) rocks predominate. From Burnmouth to Alnmouth, Carboniferous Limestones outcrop with many igneous intrusions. Carboniferous Millstone Grits and Coal Measure Series extend from Alnmouth to the Tyne. Permian rocks, mainly sandstones and Magnesian Limestones, form the cliffs South of the Tyne to Hartlepool. The Triassic (or New Red Sandstone) underlies the Tees estuary area and is replaced by cliffs of Lias further south.

However, in many places these rocks are covered by thick superficial deposits of more recent origin. The Tees estuary area is filled by fluvial and estuarine deposits. The North East coastline may have been covered by ice up to four times (from 1.8 million to 10,000 years Before Present), scouring the bedrock and in places depositing thick sheets of glacial drift. Glacial drift, till or boulder clay are general terms given to the heterogeneous mixture of materials deposited either directly by ice or subsequently redistributed by meltwater. Where this unconsolidated material outcrops at sea level, it has been subject to fairly rapid erosion, and is a major source of beach and dune material on the North East coast.

3.2 Regional geology

At St Abb's Head the fine rugged cliffs, up to 100m high, are formed of resistant igneous rock of extrusive origin. The cliffs are precipitous, deeply fissured and dissected by ravines. There are numerous stacks and reefs offshore. Between St Abb's Head and Burnmouth (Fig 5), rocks of Silurian and Devonian age predominate and alternate in exposure at sea level as a result of folding in this area. Lower Old Red Sandstone forms the cliffs south of St Abb's Head to Coldingham Bay. Between Coldingham Bay and Cullercove, Silurian shales outcrop at the coast together with locally resistant felstone intrusions which form stacks. The Lower Old Red Sandstones reappear between Cullercove and Eyemouth forming cliffs up to 30m in height. The bay at Eyemouth corresponds with a fault line and shales appear once more and extend south to Burnmouth. Here, the folded strata are evident in the cliffs and the coast is diversified by igneous intrusions or dykes providing differential resistance to erosion. For example, Scout Cave (near Scout Point) has formed where the lower part of a dyke has been hollowed out, while at Breeches Rock similar action has created an arch form. All along this part of the coast the shore platform is well developed.

The deep ravine at Burnmouth is associated with a fault line which brings down Lower Carboniferous rocks mainly sandstones, shales and limestones to the coastline. These strata predominate along the whole coastal stretch from Burnmouth to Alnmouth, with a number of Whin Sill intrusions south of Holy Island. From Burnmouth to Holy Island these Carboniferous rocks form low cliffs. At Berwick these cliffs are cut through by the River Tweed to form a deeply incised valley. A wide rocky wave cut platform is exposed at low tide and clearly shows the geological structure. This rock platform gradually disappears as one reaches Cheswick Sands due to the increasing volume of beach deposits (Fig 6). In the area from Cheswick Rocks to Budle Bay, the underlying Carboniferous Limestone is covered by thick glacial drift.

Resistant sandstone outcrops form Holy Island, which is in fact a group of islands covered by glacial drift and linked by shingle beaches. The sand and shingle banks enclose an extensive area of active accumulation of marine silt, mud and fine sand, which, when exposed at low water, allows winds to blow the sands into sizeable dune systems 10 or more metres high. Dunes are also extensive on the mainland from Cheswick Rocks to Ross Links and from Budle Bay as far south as Seahouses. At Ross Links, south of Holy Island, the dunes reach a height of 18m and protect the low lying land behind which is susceptible to flooding.

To the south of Budle Bay, the Whin Sill makes a dramatic impact on the coastal landscape, intruding through the predominantly Carboniferous rocks. The igneous coarse grained doleritic sill is approximately 30m thick with a characteristic columnar structure. It is relatively resistant to wave action and thus forms the headlands flanking Embleton and Beadnell Bays (Fig 7), where more rapid erosion of the Carboniferous Limestones has created marked embayments. Offshore outcrops of the Whin Sill form the Farne Islands. Between Embleton and Cullernose Point the sill outcrops almost continuously at the coastline, forming a landward west facing scarp. Both Bamburgh Castle, just south of Budle Bay and Dunstanburgh Castle, near Embleton are sited on the Whin Sill because of its natural commanding position. Some faulting associated with the formation of the sill has provided local points of weakness that have been exploited by wave action to form the harbour at Craster, Boulmer Haven and the small bay south of Seaton Point (Fig 8).

South of Alnmouth, the cliffs generally become lower. Millstone Grit is exposed between the mouths of the Aln and Amble, and the Coal Measure Series predominate south of Amble to the Tyne (Fig 9). The Coal Measures consist of a variety of strata including shales, sandstones and productive coal seams. The Coal Measure rock may be buried in places by a considerable depth of boulder clay. Where this unconsolidated material is exposed at sea level it has been eroded to form a series of wide sweeping sandy bays, e.g. Alnmouth Bay and Druridge Bay, fringed with wind blown dunes up to 15m high (Fig 8). Some of the dune belts are large, as between Blyth and Seaton Sluice where they reach ¼km in width. The dune systems, which are so characteristic of the Northumberland coast, have been formed since the Pleistocene glaciations. i.e. in the last 10,000 years. Their extensive development at Alnmouth, has left the former cliff line 'stranded' behind the links. The mouths of the rivers Aln, Coquet, Lyne, Wansbeck and Blyth are all deflected to the south by sandy spits, indicating the net movement of beach material southwards (see Chapter 5). Local outcrops of more resistant strata within the Coal Measures form promontories and reefs, for example Newbiggin Point, Spital Point and Snab Point. The offshore islands, Coquet Island, Hadstone Carrs and Cresswell Scars for example, are of similar origin. From the River Coquet to the Tyne, the economic exploitation of the local geology is apparent. Along this coast the productive Coal Measures are mined by open-cast and shaft methods and the waste is tipped directly onto the beach in the intertidal zone as at Lynemouth and formerly at Cambois (Fig 9).

Just north of the River Tyne, the Coal Measure rocks give way to Permian strata which extend south to Hartlepool. This transition can be seen as a marked unconformity in the cliffs to the south of Cullercoats Bay (Fig 9) where Permian sandstone overlies Coal Measures. The thickest strata of the Permian period are the Magnesian Limestones. These form flat-topped and often vertical cliffs, 15 to 45m high behind rocky wave cut platforms and sandy beaches. The boulder clay overburden is often clearly seen above the white limestone cliffs. These cliffs were formed under higher tidal levels than at present and are now only reached by high spring tides. Hence stacks, upstanding rocks, sea caves and arches are frequent along this section of the coast. Notable examples are the Marsden Rocks, Parsons Rocks and Blackhall Rocks (Figs 10 and 11). Between Seaham and Hartlepool, deeply cut valleys or 'denes' eg at Horden, Ryhope, Seaham, Hawthorne, Foxhole, Castle Eden, Hesledene and Crimdon, dissect the cliff line. These are incised into boulder clay which fill deeper preglacial valleys. The presence of coal mining from the underlying Coal Measures is evident by the large waste tips as at Horden and formerly at Blackhall. At Easington the cliff face is in part made up of coal waste. The cliffs become less pronounced south of Blackhall, at which point the beach widens and the accumulation of wind blown sand forms links extending to Hartlepool.

Hartlepool, to the north of the River Tees, is situated on a limestone mass called the Heugh and joined to the mainland by the accumulation of sand from the north-west. The Heugh is fronted by limestone scars (reefs). Hartlepool Bay forms a sweeping indentation and marks the transition from the Permian Magnesian Limestones to the generally less resistant sandstones and marls of the Triassic period. These form low cliffs fronted by sandy beaches between Hartlepool and the Tees. However, within Tees Bay itself there are few surface rock exposures. The rocks have been covered by glacial boulder clays and alluvial deposits up to a thickness of 30m. Estuarine deposits have accumulated partly because of the constriction of the river mouth by sand accumulation from the north at Seaton Sands and from the south by Coatham Sands (Fig 12). Within the estuary itself there is extensive salt marsh development and land reclamation.

The extensive sands backed by links south of the Tees extend to Redcar. Resistant sandstones form reefs at Coatham and Redcar Rocks. The land behind is relatively low lying in this region. Between Redcar and Saltburn, boulder clay forms low cliffs in places capped by wind blown sand and fronted by a good beach. To the east of Saltburn, the cliffs increase in height denoting the appearance of Lower Lias rocks of the Jurassic age. Although not in themselves very resistant rocks, the clays and shales are nevertheless more resistant than the boulder clay to the west and therefore Hunt Cliff forms a distinct promontory with cliffs of 120m behind a rocky wave cut platform.

3.3 Recent geological processes and sea level changes

The shoreline of the British Isles as we know it has been formed relatively recently in geological history, during and after the Pleistocene Ice Ages (1.8million to 10,000 years BP). Current coastal processes, which are of most interest to the coastal engineer, reflect this recent geological history and the prevailing wave climate. A full account of marine processes is given by King (Ref 4) but the following points are worth noting in the context of the North East coastline.

The operation of coastal processes has been affected by changes in sea level. These have occurred during and after the Pleistocene as the result of the complex interaction of isostatic and eustatic processes initiated by the melting of the ice sheets. A eustatic rise in sea level results directly from the volume of water added to the oceans following melting. Isostatic uplift of the land results from a re-adjustment of the Earth's crust following release from the weight of ice. Evidence suggests that sea levels may have varied by as much as 100m or more, but the rate of change is presently low (see later).

During periods of relatively high sea levels, coastal recession proceeded rapidly, forming much of the cliff outline we see today. Many of these cliffs are now not subject to present day wave action excepting at the major promontories along the coastline. Further evidence of higher sea levels is provided by fossil or raised beach deposits such as those found at Saltburn. Shell deposits found at Easington raised beach (27m) are interglacial in date. Evidence for lower sea levels than present is provided by submerged fossil forest and peat deposits which are frequently exposed at low tides in Druridge Bay, Hartlepool Bay and Tees Bay. During the major post glacial rise in sea level, very large volumes of glacial sediments from the bed of the North Sea were delivered to what is now the near-shore zone, making up much of the present day beach material. Little is known about the mechanisms involved in this process, but it is thought to be largely complete under present rates of sea level rise and there is now little transfer of potential beach material from the sea bed to the coastline. Current rates of supply to the beach system therefore depend on rates of erosion at the coastline and rates of drift (see Chapter 5).

Sea level is rising today at a relatively slow rate. An analysis of mean sea level variation at North

Shields for the years 1895 to 1982 shows an annual rise of 2.8mm/yr (Ref 5). This may in part be due to a sustained decrease in atmospheric pressure over the last 20 years, a trend that may or may not continue (Ref 6). While very small, such a secular rise in sea level must ultimately contribute to coastal recession in the future, albeit very slowly. This should be considered in the planning and design of coastal defences and in particular where coastal installations of a long operational life are involved, such as power stations.

4 WINDS, WAVES AND TIDES

4.1 Wind-wave climate

Much of the coastline of the North East is not strongly indented and is thus exposed to wind generated wave action from a large sector, typically from the north clockwise to the south-east. The prevailing winds from the south-west are offshore. However, high onshore wind speeds occur especially during winter gales. These winds have long fetches across the North Sea and into the Arctic. The severity of these storms can be judged by the fact that in certain areas, submerged rock platforms are free of sediment to a depth of 30m. The strong onshore winds also result in the development of wide belts of sand dunes within the bays where beach sediment is plentiful. Swell conditions generated by the passage of low pressure weather systems to the north may persist even during prevailing offshore winds, thus helping to reinforce the net southward drift of beach material.

While it is not essential to describe the wind climate of the North East in detail, it is worthwhile outlining a number of sources of wind data for this area. Wind records for South Shields, for example, have been analysed for the period 1950-59 and are published in tabulated form in the Meteorological Office publication 792 (Ref 7). In this publication the percentage frequency of hourly mean wind speed versus direction is plotted both on a monthly and on a yearly basis. The tables show that the most frequently occurring onshore winds are from the north and from the south-east directions. However, the highest onshore wind speeds are associated with northerly gales and this together with the large wind fetch in the northern part of the North Sea generate the highest waves from this direction. This applies for the whole of the coast from St Abb's Head to the River Tees.

However, the anemometer stations at which the winds are recorded are affected by the topography of the adjacent land masses. Thus, while there are anemometer stations at a number of coastal sites, eg Boulmer, Lynemouth, Blyth, South Shields and South Gare, care needs to be exercised in converting coastal wind speed values to "over the sea surface" winds. Correction of wind speed values depends upon the local topography at the site, the orientation of adjacent land masses, elevation of the wind recording station etc. No standard method is applicable for each situation and a certain degree of experience is needed in the "extrapolation" of land based wind records. A simplified guide as to how much wind speeds need to be increased to estimate offshore values has been produced by the Climatological Services Branch of the Met Office (Ref 8).

Such information is widely used by coastal engineers and scientists to forecast wave conditions from wind data. For predicting probable maximum heights for a particular storm, wind speed values need to be averaged for durations of time equal to the time over which the wind is adding energy to the sea surface. Analysis of many storms has produced wind speed factors allowing mean wind speeds to be estimated over considerably longer durations than the 1 hour wind recording interval. Each storm, will of course have its own particular characteristics. The following factors can be used to give an "average" storm profile:-

Vt	$0.96V_1$	$0.93V_1$	$0.87V_1$	$0.80V_1$
t	3	6	12	24

where Vt is the approximate wind speed during t hrs and V_1 is the mean hourly wind speed value. Strictly speaking the ratios have been calculated for a storm with an average recurrence period of 50 years (Ref 9).

4.2 Inshore and Offshore wave records

Actual wave records in this area are rather sparse and much of the offshore wave information has been collected at oil and gas fields and is thus of a confidential nature. The readily available data which has been recorded instrumentally is mainly derived from ship-borne recorders installed and analysed by the Institute of Oceanographic Sciences. The wave recorders are installed on light vessels, typically for periods of one year. Additionally, some vessels also have visual observations which cover a longer timespan.

Wave recordings off the North East are restricted to just the North Carr Light Vessel, situated off the Fife coast to the north of Berwick. Here instrumental records were begun in June 1969 and continued to June 1973. Analysis based on the first year of data has been published by the Institute of Oceanographic Sciences (Ref 10).

There is also much information in the form of visual observations of wave height and period and this data is held at the Meteorological Office, Bracknell (Ref 11). These estimates are made from passing ships and as such are somewhat subjective. The values of wave period in particular should only be treated as order of magnitude estimates. However, the number of readings are high (tens of thousands) and they therefore provide a good data base from which to predict offshore wave heights. Existing data have also been analysed to give predictions of the 50 year storm event around the coastline of the United Kingdom. The results have been presented by Noble and Denton for the Department of Energy in the form of a contoured chart (Ref 12). This is an update (including a wider use of wave observations) of the Department of Energy Guidelines for offshore installations (Ref 9).

Off the North East coast those wave height contours which are relatively close inshore tend to be nearly parallel to the general configuration of the coastline. Between St Abb's Head and Tees Bay the offshore 50 year maximum wave height is likely to be about 20 metres. This value corresponds to a significant wave of the order of 10 metres. The "crest to crest" period associated with the extreme wave height value is about 15 to 16 seconds. The corresponding inshore wave conditions have much greater variation than the offshore contours would suggest. Waves are strongly influenced by sea bed topography (wave refraction and energy loss due to bed friction) and also by the presence of offshore islands, large headlands, submerged reefs etc (diffraction and wave breaking). Features such as headlands will also tend to focus wave energy. It is not surprising, therefore, that areas such as Blyth harbour entrance are subject to strong wave activity while areas such as Budle Bay are almost devoid of wave action. Estimating inshore wave heights on the North East (as elsewhere) is therefore a complex and costly exercise.

Inshore wave observations are also notable by their scarcity. In order to calculate wave conditions within the littoral zone one therefore has to transform measured waves from offshore using refraction models (Refs 13 and 14), or one can use one of the number of inshore wind prediction techniques that are now available (Ref 15). The few records that are in existence tend to be based on visual observations taken at the entrances to ports. Since this coastline is largely unpopulated such observations are too few and far apart to allow reliable "interpolation" to be made.

One of the best wave data sets to be found is based on measurements at the entrance to the Port of Tyne (Ref 16). Here daily recordings were made of the vertical movement of buoys covering the period 1908 to 1929, but excluding the war years 1914-1919. These were analysed by the Port of Tyne Authority and a Weibull probability distribution plotted so as to allow extrapolation of extremes to be made. From this data it can be estimated, for example, that a wave height of 5 metres will be exceeded on average, on one day per year. L Draper of the Institute of Oceanographic Sciences has examined the Port of Tyne data and has statistically estimated the nearshore significant wave height with a 50 year return period to be of the order of 8m. Care should be taken in the interpretation of such extrapolated values which do not allow for any wave height limiting factors such as wave breaking and wave energy losses by friction over the sea bed. For the case of the Tyne entrance the theoretically highest individual wave height in a 50 year storm is about 15m. Since the depth of water at the wave measurement position is only about 10 metres below Chart Datum, the maximum wave height would in fact be limited by depth to a value of approximately 10-13 metres depending upon the tidal stage. One can see, therefore that even inshore measurements, when extrapolated to give extreme values may require modification to take wave energy losses over the sea bed into account.

It is not recommended that such information should be used other than locally to the Port of Tyne. Although records also exist at the South Gare breakwater at the mouth of the Tees, the observed values have not been treated statistically. The wave height values have been crudely grouped together and a long term statistical analysis would probably not be very accurate. For example, the data is quoted in an early HR report (Ref 17) where it states that:-

(i) less than 0.3m for 70% of the time
(ii) between 0.3m and 0.9m for 18% of the time
(iii) between 0.9m and 1.5m for 9% of the time
(iv) greater than 1.5m for 3% of the time.

Apart from these two sets of visually observed inshore data some instrumental records were also obtained at Seahouses, North Sunderland in 1969 (Ref 18). The precise duration of recording is not known but is certainly less than one year. The mean water depth at the recording site is also not recorded hence the records as they stand are also of dubious value.

In summary inshore wave records off the North East coast are so sparse that we would recommend that a two stage approach be used for estimating near-shore wave heights. Firstly the waves should be predicted using wind-wave numerical models or forecasting curves (Refs 15, 19, 20, 21). Swell should be taken into account by means of examining existing ship observations. If the scatter in the data between the various hindcasts is large then it may be necessary to work from offshore wave conditions and to translate them to the point of interest. This latter approach is somewhat costly in that a model such as the Meterological Office wind-wave model would need to be run to obtain the offshore wave climate, possibly for a number of storms. A refraction/bed friction model would then have to translate the waves, possibly over a wide sea bed area to the inshore position.

4.3 Tides and tidal currents

Off the East coast of Britain the tide is semi-diurnal, flooding southwards and ebbing northwards twice daily. As each tidal wave propagates southwards so it increases in height. This is partly due to the constriction produced by the land masses converging in a southward direction and partly because of wave attenuation in shallower water. Thus the mean spring tidal range increases from just over 4 metres off St Abb's Head to over 4½ metres off the mouth of the Tees.

Currents associated with tidal motion flow in a southward direction during the flood and in a northward direction during the ebb (Ref 22). These currents are proportional to the size of the tidal range so that one finds that maximum current speeds also increase in a southward direction. At any point tidal currents also increase as the range increases from neap tides to spring tides.

From the view point of sediment transport it is the spring tides which are most important. Off St Abb's Head nearshore maximum tidal currents during mean spring tides are of the order of 0.4m/s increasing to about 0.7m/s off Tees Bay. Because of the assymetrical nature of the tidal wave the maximum flood flow is generally higher than the maximum ebb flow and this has been found to produce a net movement of sediment in a southward direction. Thus, off the North East coast not only is there a net littoral drift in a southward direction but also a net southward movement of sea bed material. This pattern of movement has been confirmed by sea bed surveys and a map of net sand transport direction, around the British Isles has been inferred from sand ripples on the sea bed and the tidal current assymetry referred to above (Ref 23). This assymetry also explains why fine particles of colliery waste which are transported seawards in suspension then diffuse southwards from the waste tipping points of the coastline of Northumberland and Durham (Ref 24).

While tidal current flow offshore is more or less northward and southward, that close inshore is affected by the coastal topography. For example, tidal currents are stronger locally as they flow past prominent headlands, giving rise to eddies within embayments. Off Druridge Bay, for example, the offshore residual currents are southerly because of the tidal assymetry, but within the bay a weak clockwise circulation is developed (Ref 6). This circulation is not sufficiently strong to affect the pattern of near-shore material movement, ie beach sand. A similar situation exists in Hartlepool where a clockwise circulation is so strong that it is believed to cause a circulation of sediment within the bay. In general, however, the movement of material within the littoral zone is dominated by wave activity and tidal streams are thought to be of less significance on straight open coastlines. In river mouths and estuaries, on the other hand, currents can attain sufficient speed to enable them to transport fine sands, silts and muds.

In summary, tidal current activity undoubtedly affects the movement of sediment within the mouths of estuaries and within large bays such as Hartlepool Bay and Tees Bay. On the open coast of the North East, however, beach movement is dominated by wave activity.

4.4 Extreme water levels and surges

While tidal variations in sea level are well predicted, there are additional and cumulative variations due to the fluctuation of atmospheric pressure. This may, under certain weather conditions, have the effect of raising and lowering the water level over and above variations due to the tidal cycle but can only be effectively forecasted a few hours in advance. Extremely high levels or surges are of importance to the coastal engineer. For each mb reduction in atmospheric pressure, there may be a corresponding increase in water level of 1cm or above. With the pressure related weather systems of these mid-latitudes, this can have a dramatic effect especially when associated with wind stress on the water surface. Surges occur relatively frequently along the North Sea coasts, increasing in height towards the south. Typically surges occur when an intense, fairly static, low pressure area is situated to the north of Scotland and strong northerly winds persist over the North Sea. The combined effect of atmospheric pressure and wind stress cause the build up of water in the south of the North Sea. Extreme wave conditions arise if these coincide with high water spring tides as in 1953 (Ref 25).

Results of research and data collection at IOS, Bidston indicates a maximum likely 50 year storm surge residual elevation for the North East coast of the order of 1.5m over and above predicted tidal levels, increasing from north to south (Refs 12, 26). Mean high water spring tides at the Tees and Tyne are 5.5m and 5.0m above Chart Datum respectively. These elevations do not, however, represent the joint probability of highest surge, tide level and wave set up. Thus, taking these into account sea levels may well be in excess of 7m. Such extremes are clearly important in the planning and design of coastal engineering structures and require careful study.

5 COASTAL PROCESSES

5.1 Beach behaviour and geomorphology

The dominant factor controlling beach processes on the North East coast is wave action. Rates of erosion, transport and eventual deposition of beach sediments are all interrelated and dependent on the available wave energy.

Erosion over a long timespan has formed low but rugged cliffs, headlands and reefs, alternating with wide sandy bays backed by dunes. However, the supply of beach material from cliff erosion is now limited. Many of the cliff lines are now "fossil" and not reached by wave action. The cliffs of Millstone Grit which back the sand dunes south of Alnmouth are an example of this. South of Seaham, Magnesian limestone cliffs are also stranded, landwards of a wide beach of colliery waste pebbles. Headland cliffs which are subject to wave action are usually formed of more resistant rocks, thus yielding little beach material. The erosion of red sandstone cliffs and stacks at St Abb's Head, for example, does not give rise to the large sandy beaches in this area. However, where there are boulder clay cliffs some material is still added to the beaches. Boulder clay is a heterogeneous mixture of rock fragments varying greatly in size and set in a sandy/clay matrix. Thus many of the pebbles strewn on the beaches between Sunderland and Seaham are derived from weathering of the boulder clay which overlies the Magnesian limestone cliffs.

A large proportion of present day beach deposits was derived from changes brought about by a dramatic rise in sea level after the last Ice Age. As the sea level rose so wave action pushed large quantities of glacial debris in a landward direction. Now that the rise has been greatly reduced this process has slowed down. Where the land is low lying some rolling back of beach deposits continues to take place, but this occurs at a very slow rate. Thus, the shingle spit at North Blyth has a tendency to move in a landward direction, giving rise to erosion problems along the frontage of Alcan Co (see Chapter 6).

The supply of sand and shingle from offshore deposits on the open coast is now finite for all intents and purposes. However, siltation by fines continues to take place in estuaries and sheltered embayments and the 1911 Royal Commission on Coast Erosion Afforestation (Ref 27) suggests that more land is being won than lost in this manner. The most extensive zone of siltation along the North East coast is in the shelter of Holy Island and its associated offshore barriers and spits. The marked coastline indentation encloses shoaling waters and the refraction of waves around the island creates a convergence of longshore drift. Thus the area has developed wide sand spits recently (on a geological timescale). Within the spits the embayment acts as a "sink" for fine sediments, with associated growth of salt marsh. Likewise Tees Bay and the mouth of the Tees estuary have sand, silt and mud accretion on a large scale.

St Abb's Head by contrast, is a point of divergence for both beach and seabed sediments. The orientation of this promontory to predominantly north-easterly waves is such that material is transported away from the head, both north-westwards and southwards. St Abb's is also a point of divergence for seabed sediment transported by tidal currents (Ref 23). The fact that the beaches in this area are not eroding rapidly suggests that the net rate of littoral drift is very low. South of St Abb's to the Tees the general net drift is from north to south. This is confirmed by the southerly direction of river mouths over a long timespan in the Aln and the Blyth.

Tidal currents are weak inshore, especially where the coast is indented, and they contribute little to the movement of beach sand. Offshore tidal currents carry fine particles southwards in suspension because of the dominance of the flood tide along this coast. Such currents do help siltation to take place within the areas such as Holy Island. In studies of the dispersal of colliery waste, coal particles dumped on the beaches and offshore have provided useful tracer, confirming the net southward movement both on the beaches and on the sea bed (Ref 24).

Although the North East coast is exposed to a high energy wave environment (giving a high potential for sediment transport), actual volumes of material moved in an alongshore direction are small. This lack of movement is verified by the relatively small recent accumulations of sand on the beaches north of the harbour entrances at Tynemouth, Wearmouth and Seaham. The beaches in these areas are substantial, but as far as it has been able to ascertain, are not accreting. Alongshore movement is thus mainly confined to individual embayments, where extensive rock platforms at headlands provide a partial barrier to the transfer of material from one bay to another. Thus, there is likely to be little exchange of material between, for example, the bays at South Shields, Marsden and Whitburn. There is, of course, much transfer of beach material between Hartlepool and Tees Bays which clearly should be viewed as one geomorphologic unit. Both are part of one large embayment, stretching from Hartlepool to Redcar.

Actual alongshore movements in any particular storm will vary in direction depending on the direction of wave approach. Both northward and southward transport of beach material can take place although as has been said earlier the net drift is southwards. Where there is shelter from notherly waves there may in fact be a local reversal in net drift direction. The northward extension of Spittal beach into the entrance of the river Tweed is a case in point.

Apart from alongshore movement, large volumes of sediment may be transferred in an onshore/offshore direction between a series of temporary storage 'units' eg, dunes, backshore storm deposits, the intertidal zone and the near-shore littoral zone. Such responses occur on different time scales and are highly correlated with wave characteristics as shown by King in studies undertaken at Marsden Bay and in related model studies (Ref 27). In the short term, changes may be related to the tidal cycle or to a particular storm event while seasonal fluctuations reflect seasonal changes in wave climate. The formation and migration of ridge and runnel features found on some sandy beaches in the North East, as at Druridge Bay, are a result of such variations in wave climate. Longer term changes, however, may only be detected with confidence by the analysis of beach profile data collected over a period of several years. Such data can now be rapidly processed by computer methods to evaluate trends over time statistically (Ref 28). For the coastal engineer such information is particularly useful in planning decisions relating to the siting of outfalls, the renourishment of beaches or in the design of groyne systems.

There is unfortunately very little information on volumetric beach changes along the North East coast or rates of erosion or accretion. Traditionally, long term changes in beach plan shape have been identified by the comparison of various editions of Ordnance Survey maps. In view of what has been said earlier about the variability of beach profiles, such an analysis can only give order of magnitude of shoreline advance or retreat.

Beach sediments are broken down by attrition and abrasion and sorted by the action of waves. Analyses of beach samples from a number of Northumbrian beaches show a high degree of sorting and a similar particle size composition with modal values in the medium sand range (0.25-0.4mm) (Ref 24). This testifies to the harsh hydro-dynamic environment and implies the intense and long-term reworking of sediments within the bays. Beach sediments have thus been worked on by waves for a very long timespan and it is therefore not surprising they are in dynamic equilibrium with the offshore wave climate and that the net littoral drift is now generally low.

The breaker zone forms a barrier to the offshore transport of sediments too coarse to move in suspension (0.2 mm). Under the maximum wave heights experienced along the North East coast, beach sediments are effectively trapped inshore of the 10m isobath. This is the reason why we consider that movement of beach material around the entrances to the Tyne and Wear and Seaham harbour is negligible. The harbour arms at these ports extend a long distance seawards and into water depths of 10 metres or greater. Under less severe waves and with a breaker zone at smaller depths, a break point bar with a marked landward trough may develop where sand moving landwards outside the breakpoint meets with sand moving seawards from the upper beach. Thus short groynes on wide sand foreshores are rarely affective in arresting littoral drift while often contributing to "downdrift" erosion of the upper parts of the beach.

The occurrence of sand dunes and links is a particular feature of this coastline especially near the Holy Island and Tees Bay. These have resulted from the action of wind in the transporting and redeposition of fine sand-sized material (0.2mm). The dunes are a very important component of the beach system since they act as 'reservoirs' for beach material, being built up during periods of onshore winds but returning sand to the foreshore under offshore conditions. They therefore provide beach material as well as acting as a natural coastal defence which is resistant to and able to conform to long term coastal erosion. However, sand removal may lead to the eventual deterioration of the dunes and increase the likelihood beaching and flooding.

5.2 Sediment budget for the North East coast

Having described the various processes affecting the evolution of the shoreline it is necessary to determine their relative importance in shaping present day beach changes. This can be made by a so called budget of sediments, in other words considering all the various inputs and losses of beach material. These inputs and losses can be bracketed as follows:-

(i) supply of sediments from coastline erosion
(ii) losses or gains as a result of change in the volume of littoral drift in a particular area
(iii) input of sediments from rivers and estuaries
(iv) supply of sediments from the offshore sea bed

(v) artificial nourishment
(vi) sand extraction
(vii) addition of spoil to the beaches
(viii) inland loss by wind action over dunes

(i) Supply of sediments from coastline erosion

As has been mentioned earlier, erosion of hard cliffs and near-shore reefs produces little beach building material. Thus on the rocky coastline to the north of Amble there is little input of fresh sediments from the cliffs to the beaches. This is evident from the rocky shoreline platforms, many of which have only small beaches at their toe. There is, of course, interchange of sand between the beaches and the dunes in areas such as Holy Island, Beadnell, Embleton and Alnmouth Bays. In so far as one can tell there is a dynamic balance between the movement of sand from the beaches to the dunes and vice versa. However, should erosion be caused due to overuse or mismanagement of the dunes, this would undoubtedly have an impact on the beaches also.

South of Amble the wide sand beaches are backed by dune sytems which themselves are underlain by boulder clay. Only in local areas of erosion, such as the south end of Druridge Bay, are the underlying strata exposed during severe storms. The erosion of the underlying boulder clays and peat deposits under such conditions is spasmodic and does not contribute much material to the beach. (The boulder clays in this area contain mostly fines and these are carried offshore, as described earlier.) The dune systems between Amble and Seaton Sluice have been interfered with to varying degrees. As a result blow outs in the sand dunes carry sand landwards by onshore winds and seawards by offshore ones. The offshore winds return sand to the beach but onshore winds tend to "strand" it inland thus removing it from the coastal zone. Since there is little in the way of documentary evidence it is difficult to assess the impact of the damage to these dunes.

From Seaton Sluice south to Sunderland most of the coastline is cliffed and large stretches are protected by sea walls. South of the Tyne the cliffs are of Magnesian Limestone and contribute very little material to the beaches.

Between Sunderland and Crimdon the rocks are overlain by thick deposits of boulder clay. Weathering of the clay brings pebbles as well as fines down to the beach. The largest accumulation of material derived from erosion of the boulder clay can be found to the north of Seaham harbour. Here pebbles form a significant portion of the beach material.

The cliffs between Seaham and Blackhall Rocks are stranded landwards of a very large accumulation of mine waste. The high water line does not reach the toe of these cliffs. Any material which is eroded from these cliffs is stranded at their toe and is not strictly speaking, incorporated into the active beach zone. Between Blackhall and Crimdon the sea washes the cliff toe, but lack of significant quantities of pebbles attests to their relative unimportance as a source of beach material. Monitoring by Hydraulics Research over a 15 year period has shown no noticeable change in beach character (Ref 29).

There are extensive sand beaches, in places backed by dune systems, between Crimdon and the Tees. There is no input of fresh sediment from erosion of the hinterland much of which is protected by sea walls.

Between Redcar and Saltburn wide sand beaches are backed by boulder clay cliffs. The clays contain not only sands and gravels but also boulders. Their continued erosion undoubtedly adds significant quantities of material to the beach locally. Since no measurements have been made of their rate of erosion it is not possible to estimate the volume of material added.

(ii) Littoral drift

As mentioned earlier St Abb's Head is a divide as far as the net direction of littoral drift is concerned. From St Abb's Head there is a tendency for beach material to be transported northwestwards into the Firth of Forth and southwards along the North East coastline.

The coastline is rocky and has small pocket beaches, thus the net volume of sand and pebbles transported southwards from St Abb's Head to Berwick upon Tweed is very small, of the order of several thousand cubic metres per annum. Lack of continuing beach build up to the north of Berwick harbour attests to this fact.

There are increasing quantities of sand as well as small volumes of pebbles southwards from Berwick to Holy Island. Beyond here sand beaches and links extend south to Budle Bay. Holy Island projects out to sea so that beaches to the north are exposed to northerly waves while those to the south are exposed to easterly waves. There is thus a net movement of beach material from both north and south towards Holy Island. The net littoral movement in this area is small but the gross movement of sand may be several hundred thousand cubic metres per annum.

From Budle Bay south to the Tyne there are sand bays interspersed with stretches of rocky coastline. There is a net north to south littoral drift which is not large due to the natural groyning effect of the headlands and the nearshore rock platforms. The harbour arms at Seahouses, Amble, Blyth and at Tynemouth also act as barriers to beach movement. An order of magnitude estimate of the volume of littoral drift can be derived from the dredging records at Blyth. Here, as part of a study into the causes of beach erosion HR analysed dredging returns for the period 1966 to 1972 (Ref 30). While dredgings from the entrance channel are normally dumped at sea, during this period some 91,500 cubic metres of sand were pumped ashore onto the south beach. Undoubtedly some of this material found its way back into the harbour entrance. However, the figures do suggest that the gross littoral drift rate (more strictly bypassing material trapped in the entrance) during this period was about 15,000m^3pa. There is no significant build up of material at large barriers such as the Port of Tyne harbour arms, hence our estimate is that the net rate of littoral drift is considerably less than this figure; of the order of several thousand cubic metres per annum.

There is a pocket beach at South Shields which is situated immediately south of the harbour. Beach movement is restricted by the headland called Trow Point further southward. The interchange between this beach and Marsden Sands is small (Ref 31). At South Shields the loss of material from the beach during the period 1962 to 1979 has been estimated as being almost 150,000m^3. Some two thirds of this loss can be accounted for by sand extraction from the south end of the beach. The remainder, some 3,000m^3pa, can be taken as an order of magnitude estimate of the net littoral drift out of this area.

The net southward drift between the Tyne and the Wear we believe is also of this order of magnitude. Further south between Sunderland and Seaham the coastline is more open but the net drift southwards is probably no greater than 10,000m^3pa. The lack of large scale beach accretion north of Seaham indicates that the rate of littoral drift must be modest. The beach material consists of a mixture of sand and pebbles. Such a mixture is transported by waves less rapidly than a beach consisting purely of sand. On the other hand there is less obstruction to movement along this coast than at Blyth or South Shields.

Between Seaham and Blackhall Rocks the beach surface now consists of a mixture of pebbles, grit and sand as a result of large scale tipping of colliery waste. The net rate of littoral drift is modest, as attested by the relatively small volumes of material bypassing the Blackhall Rocks headland. The material is coarser than on the beaches to the north but the specific gravity of the sediments is lower. The transport rate is no greater than that of a sand material and is probably less than 10,000m^3pa. Most of the colliery waste dumped on these beaches is ground down and carried offshore.

South of Blackhall to Tees Bay there are wide sand beaches and a coastline open to wave action. With a once plentiful supply of sand and few major littoral barriers the drift in this area was probably of an order of magnitude greater than that further north. Certainly in the recent past the movement of sand was very high. Calculations based on the analysis of charts dated 1891 and 1930 indicate that the beaches adjacent to the mouth of the Tees accreted very rapidly following the construction of the North Gare and South Gare breakwaters. Accretion of the north beach averaged at 130,000m^3pa and that of the south beach at 107,000m^3pa (Ref 32). Thus, accretion on the north side would have been caused by northerly waves, with the breakwaters sheltering the area from southerly waves. On the south side there would be a dominance of southerly waves due to the shelter of the breakwaters. Accretion at Seaton Sands to the north and at Coatham Sands to the south is believed to be taking place now more slowly than before. However, drift still continues with the southward movement of sand increasing the problems of coastal erosion in Hartlepool Bay. The net southward drift is probably about 50,000m^3pa and that northwards somewhat less (erosion at Redcar being less serious than that in Hartlepool Bay).

(iii) Estuarine and river input of sediment

Input of material due to river flow consists mainly of silts and muds. These are transported offshore, and with the exception of very sheltered area such as Holy Island Sands and Budle Bay, fine materials contribute little to shoreline development. However, they do present problems of harbour siltation, particularly where approach channels are "over dredged" to allow access for shipping. It is outside the scope of this study to assess the sediment budget other than in terms of beach material, ie sand and shingle. However there are a number of reports by Hydraulics Research which deal with this aspect in detail (see Bibliography).

(iv) Offshore sea bed supply

The supply of sediments from offshore is limited. Fine material stirred up from the sea bed during exceptionally severe wave activity may stay in suspension over a period of typically a tidal cycle. With the tidal flow carrying such material into and out of estuaries and very sheltered embayments mud deposition may take place. There is, however, no evidence that material from the offshore sea bed (beyond the 10m isobath) is likely to have anything but a very short residence time on the open coastline. In fact, with the slow rise in sea levels a readjustment of the beach and seabed profile may take place, resulting in some cut back of the beach and accretion of the near-shore sea bed (Ref 33). Such changes while slow and relatively modest, have implications with regard to the siting of structures such as power stations which generally have a very long design life. Certainly, there is little likelihood of beaches being fed from offshore, but rather the reverse may occur.

(v) Artificial nourishment

Artificial beach nourishment is very rare on the North East coast and has as far as one can ascertain been only carried out at Blyth and at Redcar. At Blyth beach erosion is being combatted by an experimental scheme involving the construction of two groynes and beach feeding on a small scale. The situation at Redcar is less clear, with sporadic nourishment having been made over a period of years (Ref 34).

(vi) Sand extraction

Beach sand removal has been fairly intensive and widespread. Extraction for commercial purposes has been taking place in Druridge Bay for many years. No details have been found about the rate of sand extraction from this area. To the south of Blyth large scale sand extraction has also taken place since the early part of the twentieth century. There has been a net loss of some 170,000m^3 of sand from south of the harbour entrance and some 500,000m^3 have also been extracted from the beach further south, towards Seaton Sluice (Ref 30). Erosion has been serious enough to warrant beach protection measures in the form of the groynes and nourishment mentioned above. At South Shields extraction has also been on a large scale in past years; some 150,000m^3 of sand was removed from the south end of the beach between 1962 and 1979 (Ref 31). Erosion of the upper foreshore has proved to be troublesome from an amenity viewpoint. Protection measures have included the use of Maccaferri gabion mattresses to stabilise the upper beach where it adjoins the promenade.

(vii) Colliery waste disposal

Finally, one must take into account the very large input of sediments to the beach and sea bed from coal mining activities. Disposal of colliery shale onto the beaches at Lynemouth, Cambois and between Seaham and Hartlepool over the last century has added many millions of cubic metre of material to the near-shore system. Lynemouth beach now consists almost entirely of colliery waste, as does the coastline between Seaham and Blackhall Rocks. Dispersal of this material by the grinding action of waves takes place rapidly. Within several decades after the cessation of tipping the beach at Cambois has largely been restored. However, the pollution of the seabed is much more permanent since this is where the ground down fractions finally come to rest. During exceptionally severe storms this waste is resuspended and can be found on many of the Durham beaches as trashlines. Pollution in this manner will continue for many decades but once tipping ceases it will gradually become diluted and become more of an amenity nuisance than a health hazard.

6 REVIEW OF COASTAL DEFENCES

6.1 The border to the River Tyne

The rocky, indented coast from St Abb's Head to Berwick upon Tweed (Fig 5) is undeveloped and scenically attractive. From St Abb's south to Burnmouth the cliffs are some of the most spectacular in Scotland. The coastline has rock platforms and is strongly indented; sand beaches are found locally within areas such as Coldingham Bay and Eyemouth Bay. In more open parts, such as Burnmouth, there are rocky beaches. Although accretion of sand at Eyemouth Harbour poses navigational problems this is not due to any strong influx of sand into the bay. The formation of sand bars within the harbour is linked to the suspension of sand from the sea bed within the bay itself and its redeposition in the entrance channel (Ref 35).

From the border southwards the coast forms the northern most part of the North Northumberland Heritage coast. The high cliffs of Carboniferous Limestone extend seawards as wide rock ledges and have small pocket sand beaches at their base. The Department of the Environment's Coast Protection Survey (Ref 36) shows a very old concrete wall at Fisherman's Haven to the north of Berwick Pier. At the time of the survey this was the only sea defence between the border and the River Tweed. The net littoral drift along this stretch of coast, as elsewhere in the North East is generally from north to south. However, the lack of significant beach build up north of the pier and the general sparseness of the beaches, points to a low volume of littoral drift, (Plate 1).

The market town of Berwick is centred around the old bridge over the Tweed, a short distance upstream of the river mouth. Coastal development is absent, except for some industrial and recreational facilities at Spittal south of the River Tweed entrance. There is some accretion within the mouth of the Tweed. Calot Shad is an area of shingle deposition on the inside of the last bend before the river flows into the sea. There is also sand accretion at Sandstell Point on the south bank of the Tweed. This is derived from the net drift of sand from south to north. This local reversal in drift is produced by the sheltering effect of the pier, which cuts down wave activity from the north and gives a local dominance of waves from the south. At Spittal the beach is sandy and considerably wider than those to the north and hence the rock platforms are less conspicuous. Spittal is situated on relatively low lying land subject to erosion. At the mouth of the river some derelict land has been "reclaimed" and is protected by a short length of rock armouring and gabion work, plus some old groynes. The gabions have suffered considerable damage in the past and will continue to be affected by weathering in the future. The lifespan of most gabion work is only 10 years or so (Ref 37). The cliffs south of the reclamation area are also Carboniferous Limestone and at their foot is a 1km length of sea wall and promenade, approximately 85 years old but still in satisfactory condition (Ref 36).

South of Spittal the cliffs lose height and the coast becomes a level plain, with "sea cliffs" being intermittent and localised (Plate 2). There are wide sand beaches banked by extensive dune systems, beach material being transported in a net southward direction. The coast is unspoilt and there are no sea defences. The coast from Spittal south to Amble is an area of outstanding natural beauty (AONB) and is part of the North Northumberland Heritage coast.

Holy Island (Fig 6) lies to the seaward of a very strong coastline indentation and within this area enormous quantities of sand, silt and mud have accumulated. Massive sand spits have been formed by wave action and the wind has blown sand landward to form extensive links at Cheswick to the west and at Ross to the south of the island. Much of Holy Island itself is covered by superficial deposits of wind blown sand, boulder clay and alluvium. The peninsula at its west end is called The Snook; it consists of sand dunes resting on a base of boulder clay. Mud has tended to accumulate in the shelter of the island, and also in Budle Bay to the south of Ross Links. There has been extensive saltmarsh development and natural reclamation of the foreshore, particularly in Budle Bay. Most of this area is in a virgin state and has the status of a Nature Reserve and a site of Special Scientific Interest (SSSI). The only sea defences are a short length of flood bank and sluices at South Low, near Holy Island Sands.

From Holy Island south as far as Amble the coastline is unspoilt. Large stretches are owned by the National Trust and there are numerous SSSI's. An update of the latter has recently been prepared by the Nature Conservancy (Ref 38). Most of the cliff line is overlain by wind blown sand, forming extensive sand links. There are also extensive sand beaches backed by dunes within a series of strongly indented bays between Beadnell and Amble. Both the cliffed stretches of coast and the embayments are characterised by extensive offshore reefs, in places extending nearly a kilometre seawards at low water. Predominance of northerly winds results in a net southward movement of beach sand. However the lack of large scale accumulation against groynes, jetties, headlands etc indicates that the rate of littoral drift along this stretch of coast is low. The coastal plain is mainly devoted to farming and most of the developments consist of small fishing and farming communities. Holiday development is on a small scale, the largest being at Seahouses, a village which has become commercialised in recent years.

From Bamburgh to Beadnell (Fig 7) there are few coast protection works, except for the harbour of Seahouses. There are sand dunes on both sides of the promontory on which the harbour is situated but no strong accretion of sand to the north or erosion to the south, which would indicate significant littoral drift in this area. The coastline is low lying and backed by dunes (Plate 3) and there are wide rock platforms outcropping nearly ½km seawards at low tide. At Beadnell there is a short stretch of coastal defences supporting a road.

Beadnell is a small village with a high density of holiday development. At present beach erosion is limited, but could be exacerbated by overuse. In particular the sand dunes, as at Bamburgh, are susceptible to damage.

Between Beadnell and Dunstanburgh the strongly embayed coast has wide sand beaches backed by links and the rock platforms and offshore reefs outcrop generally between the embayments. Much of this stretch of coast is owned by the National Trust. The offshore reefs in this area are very prominent and protude seawards in a north-easterly direction. Sea defences along this fine stretch of coast are very fragmentary and are mostly in private ownership. The embayed nature of the coastline restricts the littoral drift of sand in this area.

Between Dunstanburgh and Cullernose Point the Whin Sill intrusion forms a coastal plateau which is raised prominently above the surrounding coastal plain, the whole stretch being designated an SSSI. The plateau is unusual in having a distinct escarpment which slopes downwards in a landward direction. The foreshore is rocky and the cliffs and reefs are geologically very interesting. The igneous intrusion has, for example, columnar jointing whose top surface resembles crazy paving. The rock platform is almost free of sediment, with the exception of small pebble beaches lodged within the most strongly incised coves. The net southward drift of beach material is weak. The Coast Protection Survey indicates that there are no sea defences in this area.

From Cullernose to Howick (Figs 7 and 8) the cliffs are again of Carboniferous Limestone, but from Howick to Alnmouth they are of Millstone Grit and boulder clay. Along this stretch there are very wide rock ledges some of which outcrop offshore as reef like islands, especially in the vicinity of Boulmer. The beaches are sandy and backed by sand dunes. Erosion is taking place in several areas but only chalets and beach huts are at risk. Sea defences are fragmentary but with some concentration of coast protection works at Alnmouth. The largest protected frontage is at Marden, about 1km north of Alnmouth. Here stone and concrete block revetments protect the edge of the golf course. The Coast Protection Survey indicates that there are some dilapidated groynes in this area. There is also a low gabion retaining wall protecting the road edge on the north shore of the river Aln. The wall is of flimsy construction and unlikely to have any serious consequences on the coastal regime. The town of Alnwick is essentially a medieval settlement in which little subsequent growth has taken place. Sea defences consist essentially of bank protection and are of very modest scale and as such, unobtrusive.

South of the Aln the sand links form a flat area in front of the former sea cliffs of Millstone Grit. The wide sand beach and dunes extend south to Warkworth Harbour at Amble. Behind the dunes runs the river Coquet, having been deflected southward by the movement of beach material in that direction. It now exits through Warkworth harbour. The beach and dune system appears to have stabilised and there is no evidence of strong southward littoral drift taking place presently. This harbour is somewhat dilapidated and is subject to infilling by beach sand which is carried over the north breakwater by overtopping waves and by wind blown sand during storms. The foreshore north of the harbour is relatively stable but the base of the dunes adjoining the north breakwater do need protection against wave attack (Ref 39). The fact that erosion is taking place on the north side of the harbour testifies to a lack of strong southward beach drift.

Amble, immediately south of Warkworth Harbour is predominantly a mining town and the coastline for several miles to the south is despoiled by former mine workings. Sea defences are fragmentary, consisting of short stretches of concrete and rock revetments.

From Amble southwards to the Tyne, cliffs are of Coal Measures capped by drift. The dip of the rocks results in the exposure of the drift (mainly boulder clay) in many of the embayments. Thus from Amble south to Seaton Sluice the cliffs form rocky promontories and offshore reefs separated by wide, open sandy bays which are backed by sand dunes. The bays having a very open aspect are subject to wave attack from a wide sector. At the south end of Druridge Bay, for example, fossilised trees embedded in clay and peat are regularly uncovered during storms (Plate 4). The south part of the bay has an SSSI which encompasses part of the coastal dune system. Further southwards the Coal Measure rocks are of geological interest and stretches of cliffed coast at Seaton sluice in Whitley Bay and at Tynemouth Castle are also SSSI's.

The coast from Amble to Lynemouth (Fig 9) has little in the way of "traditional" coast protection works. Beach and dune erosion is taking place in Druridge Bay and the situation, though not serious, is not helped by the practice of sand extraction from the foreshore. The sand dunes at the southern end of the bay are also overgrazed (Plate 5). The scale of the erosion is such that dune management needs to be implemented. Deflection of stream mouths in a southward direction indicates a net north to south littoral drift. However the rate of drift is relatively low and the transfer of beach material between adjacent bays is very limited.

At Lynemouth Bay the beach and dune system is largely unrecognisable as a result of industrial development. Despoliation due to the tipping of mine waste onto the foreshore has transformed the once sand beach into a pebble one. Lynemouth Power Station is in fact built on reclaimed land. Were it not for the continued tipping of waste, the seaward boundary of the Power Station would be at risk from "beach" erosion.

Newbiggin Bay, to the south of Lynemouth Bay has a sand beach which is spoilt by fine coal particles derived from tipping of waste at Lynemouth Power Station. The coal particles are transported southwards by waves and tidal currents and tend to collect in the shelter of the old breakwater at the north end of the beach (Plate 6). The frontage at Newbiggin has a sea wall and promenade which has had to be extended southwards in recent years. Erosion is taking place at Newbiggin Moor, the promontory north of the town. Only holiday camps are believed to be at risk (Plate 7). South of Newbiggin, erosion extends to the mouth of the river Wansbeck. The scale of erosion, as far as one can tell, has not been determined. Recession of the upper foreshore could lead to the need for extending the promenade in a southward direction in the long term. The town frontage has experienced flooding by the sea in recent years and investigations are underway into the feasibility of protecting it by offshore breakwaters (Ref 40).

The southward deflection of spits at the entrance to the river Wansbeck is an indication of a net north to south drift. Similarly the deflection of the river Blyth also indicates a dominant southward drift of beach material by wave action along the stretch of coast from Newbiggin to Blyth.

At Cambois, south of the Wansbeck, a spoil tip abutting onto the foreshore has been levelled and grassed over. This "reclaimed land" is eroding slowly and its seaward face has had to be protected by a rock revetment. This is not a serious problem except that erosion of the cliff of waste pollutes the beach with small quantities of colliery waste. The beach at Cambois is wide and sandy and the base of the revetment has a carpet of pebbles of coal measure stone, the finer particles of waste being transported offshore.

The end of the sand spit running to the entrance of Blyth harbour, is protected by a rock revetment, a short length of old timber breastwork and an old concrete sea wall. The concrete wall is necessary to prevent the spit, which is very narrow at this point, from breaching. The same spit just to the north of the Alcan frontage is also eroding (Plate 8) and the situation ought to be monitored in future years. These defences are in the ownership of the Alcan Co. The wall, built in the 1900's is occasionally overtopped by wave action. The Coast Protection Survey maps show that the foreshore in front of the sea wall is groyned. In view of the scarcity of beach material this groyning would appear to be largely redundant.

There is a wide sand beach and dune system between Blyth and Seaton sluice. Serious erosion has been taking place south of Blyth Harbour and this has been causing concern for some years. Mechanical removal of sand from the approach channel to the harbour, while necessary, has not helped matters. The beach has also been used for sand extraction for many years. Erosion of this stretch of coast was studied by Hydraulics Research and a trial scheme recommended, consisting of beach feeding and the construction of groynes (Ref 30). The recently constructured system consists of three 150 metre long groynes set out at a spacing of 120 metres. Some 71 cubic metres of sand per metre run of beach were also deposited here between January 1981 and January 1984 (Ref 34).

The scheme has now been implemented and the beach has subsequently improved dramatically although erosion has occurred down drift of the groyne system. There is a local northerly drift of sand in the shelter of the Blyth piers, but along the main frontage the drift is in a southward direction. Little material appears to be transported round the rocky promontory at Seaton Sluice and we believe that the net southward drift is small.

Seaton Sluice harbour lies on a promontory at the south end of Blyth Bay. The former village has expanded and is now a dormitory for Newcastle. Residential development here extends close to the cliff edge, which needs protection. Sea walls are intermittent and erosion of soft slaty cliffs within Collywell Bay immediately south of the harbour is posing problems.

From Seaton southwards to the river Tyne the headlands consist mostly of massive beds of sandstone, often extending seawards as offshore reefs. Within the bays the rocks are covered by boulder clay and wind blown sand and the low clay cliffs in Whitley Bay are particularly susceptible to erosion. The coast is very heavily built up, with residential development almost to the cliff edge. With the exception of a gap at its north end the coastline in Whitley Bay is protected by concrete walls, with the cliffs graded to stabilise them. The erosion of the cliffs at the north end of the bay poses no immediate threat since at the cliff top there is presently amenity land (Ref 35). At the south end of the bay there are two areas of sand beach. Cullercoats bay is surrounded by steep cliffs and protected by piers to the north and south. Long Sands is a considerably wider, more open sand beach bordered by steep clay banks which are graded and at its northern part fronted by a concrete promenade. King Edwards Bay, just to the north of the North Pier, Tynemouth is a small sand beach surrounded by steep cliffs. Accretion here is very limited and this suggests that the net southward littoral drift towards the harbour arm is very weak. The sea defences between Whitley Bay and the North Pier are fragmentary. They consist of sea walls of various ages and some concrete facing to the cliffs around Tynemouth Castle. There are also extensive sea walls and a short length of rock revetment in the outer harbour area at Tynemouth, these lying mainly to the north of the river mouth.

6.2 The River Tyne to the River Wear

The heavily developed area at South Shields does not extend to the coastal fringe, which has a wide sand beach backed by sand dunes. The beach is heavily used and has required protection, which has taken the form of gabion mattresses. The gabions are by no means immune to general wear and tear, or vandalism. Sand extraction from the south end of the beach has resulted in beach erosion thus aggravating the situation. The beach at South Shields is contained by the very large south pier of Tynemouth and by a rocky promontory at Trow Point (Fig 10). The net littoral drift is therefore small and beach losses must be attributable to man's activities. Erosion has had a deletrious effect on the beaches fron an amenity viewpoint but no development is at threat.

The coast to the south of Trow Rocks has exceptionally fine cliffs of Magnesian Limestone which extend to Whitburn. Between South Shields and Marsden the cliffs are fronted by a narrow rock platform with little on it in the way of beach material. In Marsden Bay there are deep caverns incised at the cliff base by wave action. The beach is fine, wide and sandy and on it there are a number of stacks. The best known of these is Marsden Rock, whose base is pierced by a large arch. There are no coastal defences in this area. The cliffs between Trow Point and Lizard Point are of geological interest and the area is an SSSI. There is also a nature reserve at Mardsden Rock.

Between Marsden Bay and Whitburn Bay the Magnesian Limestone cliffs are fronted by a rock platform which is almost free of beach material. There is little residential development near the cliff edge but there is much evidence of mining activity. Although the collieries at Whitburn and Ryhope are closed, former tipping of waste mars the cliff top scenery south of Whitburn colliery. The slow spread of waste in a southward direction indicates a small net north to south drift. The cliffs decrease in height southwards and are capped by an increasingly thick overburden of boulder clay. Erosion of these cliffs is not giving rise to problems and there are no coastal defences in this area.

Between Whitburn and the River Wear the coast has much residential development. Whitburn bay has wide sand beaches which are interspersed with isolated rock platforms. The beaches continue to Roker on the north side of the Wear. They are backed by old sea walls some of which are in need of repair; however, as far as one can ascertain there are no serious beach erosion problems within the bay. The piers at the entrance to Sunderland harbour extend about ¾km seawards and as at Tynemouth they greatly restrict the transfer of beach material from north to south. The bay appears to be largely in equilibrium with the wave climate in this area and the net southward drift of sand as at South Shields is low.

6.3 The River Wear to to Tees Bay

Immediately to the south of the Wear there are dock installations and beyond that to Hendon heavy industrial development encroaches upon the cliff line. The Hendon frontage is protected by concrete walls, short stretches of rock revetment and groynes. The beach is sandy but spoilt by pollution from Sunderland docks. In the past large concrete breakwaters were constructed in an effort to stabilise the beach but these gave rise to serious erosion to the south of each one. This has resulted in the development of the zig-zag coastal plan shape which can be seen on large scale maps. Cliff recession to the south of the "breakwaters" is an indication of a net southward drift. Pebbles are derived from the erosion of the cliff overburden. This source of beach material has now been reduced with the construction of sea walls at Hendon.

The Magnesian Limestone cliffs south of Hendon are overlain by a thick cover of drift, which is unstable. Erosion of this has added pebbles to the beach at the foot of the cliffs (Plate 9). There has been much differential cliff erosion. For example, at Saltfern Rocks there is a hard point but to the south the cliffs have eroded fairly rapidly. These cliffs are unprotected as far south as Seaham Hall. Erosion poses no serious threat since the coast has mostly farmland with some amenity areas, the chief one being at Seaham Hall. The coast is intersected by a number of deeply incised valleys or denes ie. at Hendon, Ryhope, and at Seaham Hall. There is some accumulation of pebbles at Seaham Hall, derived from erosion of cliffs to the north. The accumulation is not large and the net southward drift is on a modest scale.

From Seaham Hall south to the harbour there is a concrete wall at the base of the cliffs and the sand and shingle beach is groyned. Differential erosion has taken place between the south end of the wall and the north pier, Seaham. The embayment thus formed has "outflanked" the north pier and the root of it is protected by a rubble revetment. Had the southward drift been high then the gap between the north pier and the promenade would have had large scale build up of beach material.

The whole stretch of coastline between Hendon and Seaham is subject to erosion (because of the softness of the cliffs) and this needs to be taken into account in future coast protection works in this area.

South of Seaham the strength and durability of the Magnesian limestone rocks and the thickness of the boulder clay cover is variable, resulting in some dramatic scenery, not withstanding the despoliation of the beaches by colliery waste. The coast is not heavily developed except at Seaham but the cliffs and beach are heavily despoiled by coal heaps, tips, etc at Dawdon, Easington, Horden and Blackhall (Fig 11). The tipping at Blackhall has now ended but the coastal despoliation remains. However, the deeply incised valleys such as Castle Eden Dene, Hawthorn Dene and Crimdon Dene still retain much of their original charm. The dene at Hawthorn Hive is a Nature Reserve and an SSSI. The Magnesian limestone cliffs are geologically very interesting and a great portion of the cliff line to Crimdon and the dune system south to North Sands, Hartlepool are designated as SSSI's. There is a marked southward net drift of material from the waste tipping points. However monitoring of this stretch of coast indicates that when tipping ceases equilibrium conditions are soon reached and the net southward drift is reduced to a low value. There are no major sea defence works south of Seaham to Hartlepool. Indeed, the continuous tipping of colliery waste for more than a century has led to the development of very wide "pebble" beaches leaving the original sea cliffs isolated landwards (Plate 10). In several places the coastal railway embankment runs close to the cliff edge, as at Shippersea Bay. Here the boulder clay slips give rise to some embankment instability but as the cliffs are stranded well to the landward of high water these cannot be deemed to be a coastal erosion problem.

The headland at Blackhall Rocks traps much of the net southward drift of colliery waste pebbles (Plate 11) and the coves on either side of this headland act as stilling areas to trap the lighter fraction of the tipped waste. The despoliation south of Blackhall gradually decreases until at Crimdon the wide sand beach and dunes are relatively free of waste. However, the light, small particles of coal continue to pollute the beaches intermittently as far south as Tees Bay. There is a southward transport of material both by waves and tidal currents.

South of Crimdon the cliffs give way to low lying land covered by a belt of sand dunes stretching to Hartlepool (Plate 12). Some erosion of the dunes has taken place but there has been no noticeable loss of beach material from the beach as a whole.

Industrial development begins at Hartlepool and affects most of the low lying coastline south to the Tees. Old Hartlepool is built on a rocky outcrop of Magnesian Limestone, called the Heugh. This promontory is exposed to wave action and the residential frontage is protected by concrete sea walls. At Middleton Sands between the two dock systems the backshore is protected by a massive gabion wall which looks sufficiently robust to have a relatively long lifespan.

South of Hartlepool docks there is low lying land which is heavily drift covered. The underlying sandstones and mudstones outcrop as offshore reefs, such as Long Scar, in Hartlepool Bay. The Bay acts as a stilling basin, trapping much of the southward moving fine particles of colliery waste. Dredging of the entrance to the harbour helps to remove these but also removes muds and sand from the system. However a proportion of the waste reappears on the beaches to the south being left stranded as "tide lines". Some of this sea coal is "reclaimed" for domestic use and the rest eventually disappears seaward under wave action. The coastline between Hartlepool and Seaton Sands is undergoing erosion and this could well be associated with the dredging at the harbour entrance. Almost all the stretch of coast from Hartlepool to Seaton Carew is protected by concrete and masonry walls. Those to the north are very old and partly reconstructed and the situation is now made worse by the lowering of beach levels at their toe. From Seaton Carew to the North Gare breakwater at the mouth of the Tees there is a wide sand beach backed by extensive dunes. The drift of sand in Hartlepool Bays and in the north part of Tees Bay is in a southward direction. The sand dunes north of the Tees entrance are of botanical interest and the area is designated SSSI.

Tees Bay acts as a vast trap for sands, muds and silts and there is interchange between the beaches and the nearshore sea bed. This is evident from the intermittent pollution of the beaches by colliery waste which also acts as a good tracer material. Both the beaches to the west and to the east of the Tees entrance are thus affected and for this reason it is necessary to consider the coast from Hartlepool to Saltburn as part of the same coastal cell.

Accretion of sand has also taken place to the east of the Tees entrance at Coatham (Fig 12), as a result of local reversal in the general southward direction of littoral drift. Here also there is a wide sand beach and an estensive dune system which is designated an SSSI. Further east, towards Redcar, the general north to south net drift is again established. The Coast Protection Survey indicates that the sand beach at Redcar has periods of accretion and erosion. This is probably linked to the presence of large offshore reefs. Under normal wave and tidal activity these dampen wave energy and produce conditions conducive to accretion. During storms coincident with exceptionally high tidal levels their damping effect is nullified and erosion may then take place. The land from the Tees entrance to Redcar is low lying and this undeveloped stretch of coast is protected by the wide belt of sand dunes mentioned earlier, though these have suffered considerable damage by holidaymakers. The town frontage at the west end of Redcar is protected by concrete sea walls backing a very wide sand foreshore. The defences are old and somewhat piecemeal, with some buildings abutting onto the upper beach (Plate 13). The beach thins out at the centre of the frontage where the offshore reefs (Redcar Rocks) run close in to the seawall. The east part of the town is protected by a concrete sea wall and a groyne system. The groyne system was built following erosion in the 1950's. The groynes have been fairly successful in maintaining existing beach levels but have not increased beach volumes dramatically. It is considered that longshore drift is too low to allow the groynes to fulfill their potential. Some $70m^3$ of sand and shingle per meter length of frontage have therefore been added artifically to the beach between 1973 and 1983 (Ref 34).

East of Redcar, low cliffs of shale and clay gradually increase in height towards Marske and Saltburn. Cliff erosion is evident to the east of the Redcar groyne system (Plate 14). Erosion of the boulder clay has produced a carpet of pebbles at the cliff toe on an otherwise wide, sand beach. At present there are few houses at risk on the unprotected coast between Redcar and Saltburn. However, there is high density urban development at Marske not far from the cliff edge.

The coastline is unprotected eastwards as far as Saltburn. Wave induced erosion is not serious but there is considerable cliff weathering by the action of rain, forming gullies in the cliff face (Plate 15). The town frontage is protected by concrete sea walls. The wide sand beach continues in front of these defences and terminates abruptly at Hunt Cliff; there is clearly very little material transported southwards round this headland (Plate 16).

7 CONCLUSIONS

There are several prominent boundaries along the North East coastline which allow one to subdivide it into a number of independent cells with regard to sediment transport and coastal engineering problems.

St Abb's Head, north of the border, acts as a point of divergence for sediment transport. North of it both sea bed and beach material tend to be carried north-westwards into the Firth of Forth. South of St Abb's Head the movement of sediments is in a southward direction. The fact that the pocket beaches in the St Abb's area are not eroding rapidly indicates that the coastline has a low rate of littoral drift. St Abb's thus forms a natural boundary where coastal processes north-west of it take place independently to those south of it.

The whole stretch of coast from St Abb's Head to the River Tyne could be considered as one unit in terms of coastal engineering policy. The harbour arms at the mouth of the River Tyne act as huge groynes and restrict the net southward movement of beach material. Hence coastal defences north of the Tyne have no significant effect on those to the south and vice versa.

Berwick harbour which lies south of St Abb's Head traps a portion of the southward drift of beach material. In the shelter of the north harbour arm there is a local reversal in drift direction and sand is transported northwards from Spittal into the mouth of the Tweed. The harbour entrance acts as a trap for both beach material and fine sediments. The drift divide at Spittal is an area of erosion and reclaimed land here is protected by a gabion sea wall; further erosion is taking place here. Further south there is a 1km stretch of sea wall. This wall constitutes the major coastal defense work between St Abb's Head and Berwick upon Tweed.

South of Berwick the coastline is open and unprotected as far as Holy Island and has few erosion problems. The wide sand beaches are backed by dunes and the rock outcrops diminish in a southward direction. The net littoral drift is in a southward direction.

At Holy Island the coast is strongly embayed and the area is a trap for sand and fine sediments. Many of the sand and gravel beach deposits were formed by the reworking of glacial debris after the last Ice Age. The sheltered areas within the lee of Holy Island and in Budle Bay still act as very effective silt traps. Fine material suspended by wave action and brought in by the rapidly moving tidal streams tends to settle out here, resulting in continuing mudflat and salt marsh development. The large sand spits adjoining Holy Island merge in with adjacent beaches. Because of their exposed position there is a great deal of interchange between foreshore and backshore areas by wind action. The sand links project well seawards of the original coastline and are also well exposed to wave activity from a large offshore sector. The gross movements of beach material are therefore large but the net southward drift is probably on a modest scale. This area, like Berwick harbour entrance, should not be treated in isolation from adjacent areas from a coast protection point of view. There are, however, few erosion problems.

From Holy Island to Amble there are a series of sand bays bounded by rock platforms and offshore reefs. There are also rocky stretches of coast largely free of beach material. Urban development is very sparse and is centred around a number of small fishing harbours. Littoral movement of beach material is largely contained within each bay and the net southward drift is low. Coastal defences along this undeveloped stretch of coast are few and far between and erosion problems are not serious. There is a local concentration of coastal defences fronting the sand links north of Alnmouth and some gabion walls at the river entrance. The erosion in this area is not serious. South of Alnmouth there is a large sand beach and dune system which has deflected the mouth of the river Coquet in a southward direction. The Coquet now exits through Warkworth harbour at Amble. there is no evidence of further, more recent deflection of this river in a southward direction.

Amble is a small mining town and coastal defences are centred on the promontory on which it is situated. Coastal erosion problems are not serious.

South of Amble the bays are more open than those to the north. Rock promontories and reefs are less well developed, hence there is more interchange of beach material between adjacent bays. For example, dispersion of colliery waste from the disposal point in Lynemouth Bay pollutes the beaches south to Blyth and beyond. Sand winning at the south end of Druridge Bay is taking place despite the damage which the adjacent dune system has suffered. Continued future extraction and overgrazing of the mature dunes by cattle may pose serious erosion problems in the future.

From Lynemouth south to the river Tyne the coast becomes increasingly industrialised and there is a heavy concentration of urban development. There are substantial stretches of coastal defences at the towns of Newbiggin, Blyth, Seaton Sluice and Whitley Bay.

Both beach and backshore erosion is widespread, particularly at the southern ends of each "defended" stretch of coast. For example, beach and dune erosion is currently taking place south of the promenade at Blyth and along the protected frontage at Newbiggin. In both areas coastal defences have either recently been completed or are under design. While littoral drift is generally low there is clearly interchange of beach material between adjacent bays. Thus the coast between Amble and the Tyne should be treated as an interdependent unit.

The piers at the entrance to the river Tyne extend to a depth of abouth 10 metres below Chart Datum, that is well beyond the limit of onshore/offshore beach movement. Hence littoral drift across the harbour entrance is minimal, though fine seabed material is probably transported southwards in suspension. Coastal defences north of the Tyne will have negligible effect on the beaches south of the Tyne, and vice versa. The drift divide at St Abb's Head and the "zero drift boundary" at the Tyne make it practical to consider the coastline between as one cell from a coastal engineering viewpoint.

The coastline between the rivers Tyne and Wear should also be considered as a single unit. Little beach material is likely to be transported across the entrance to the Wear since the harbour arms extend $\frac{3}{4}$km seawards and to a depth of nearly 10m relative to Chart Datum. The three major sand beaches are effectively seperated by rocky stretches of coast and can therefore be considered as self contained. Erosion problems along this stretch of coast are not serious. This is largely due to the fact that urban development in the north part is well away from the cliff edge. In the south part urban development within Whitburn Bay is protected by sea walls. Erosion has been taking place at South Shields beach for many years. This is believed to be due to the practice of extracting sand for industrial use at its southern end, near Trow Point. Beach lowering has had a deletrious effect from an amenity viewpoint but at present no housing or industrial development is at risk. There is little development at Marsden and the beach is backed by high erosion resistant cliffs. The beach at Whitburn Bay is bounded by a rocky coast to the north and by the harbour piers to the south and is also believed to be relatively stable.

The Magnesian limestone cliffs between Sunderland and Seaham are capped by boulder clay which is easily eroded. Immediately south of the Wear there is heavy industrial development and the cliffs have sea walls at their foot. The beaches are generally thin and consist of a mixture of sand and of pebbles derived from former cliff erosion. Erosion prior to construction of sea defences is evident from the zig zag plan shape of the coast in the vicinity of Hendon. South of this a groyne system in recent years with the intention of retaining the existing beach as far as this is practicable. Further south the hard outcrop at Saltfern Rocks acts as a natural groyne so that the coast to the south has tended to recede faster than that to the north. Thus coastal defences and natural hard points between Sunderland and Seaham have tended to accelerate erosion to the south of them. This stretch of coast should clearly be treated as one unit. The harbour arm at Seaham has some accretion to the north of it though this on a modest scale. The net rate of southward drift is therefore moderate to low.

The harbour arms at Seaham extend well seawards and prevent any major transfer of beach material across the harbour entrance. From Seaham to Blackhall the coastline is heavily despoiled by the dumping of very large quantities of colliery waste into the intertidal zone. It would appear that the rate of tipping is now in balance with the "digestion" of the colliery waste by waves and tidal currents. There is very little in the form of coastal defence works and indeed past tipping practices have led to the development of very wide pebble beaches over a once sand foreshore. The beach now extends seawards to such an extent that wave action can continually work on the colliery waste and disperse it rapidly in a southward direction. However, the original cliff line lies stranded well to the landward of the intertidal zone. It is likely to remain so until the rate of tipping is reduced significantly. The southward transport of colliery waste poses a potential threat to the relatively clean beaches to the south of Blackhall Rocks. Colliery waste can in fact be found on the beaches as far south as Hartlepool Bay and in smaller quantities within Tees Bay. The whole of the coastline from Seaham to Hartlepool should therefore be treated as one coastal unit. There are few erosion problems in this area with the exception of some dune erosion at the mouth of Crimdon beck.

Hartlepool and Tees Bays act as a major sink for sediments. Following the construction of the breakwaters at the mouth of Tees, vast quantities of sand accumulated both to the north and to the south of the Gare breakwaters. This pattern of accretion indicates very large <u>gross</u> movements of beach material in opposing directions. The beaches adjacent to the Tees have now largely stabilised and the scale of beach transport is much more modest. There is a net southward drift of material in both Hartlepool and Tees Bays. Dredging in the approaches to Hartlepool harbour intercepts much of the southward moving colliery waste as well as beach material. There is reason to suspect that beaches in Hartlepool Bay are being deprived of material as a result of dredging in the approaches to the port. The beaches at Middleton have been affected particularly seriously and here the sea walls are likely to be undermined if present trends continue. Accretion continues to take place at the mouth of the river Tees though the rate of build up has now slowed down, as has the rate of littoral transport into the area. East of the entrance there is seasonal erosion which is causing some concern at the east end of Redcar. The sand beaches at Redcar are protected by sea walls and a groyne system, though this has failed to build up beach levels as much as was hoped. Further east the beach is unprotected and boulder clay cliffs at Marske are eroding. However, no development is immediately at risk. The sand beach extends to Saltburn and further movement of beach material is prevented by the large promontory of Hunts Cliff. The beach from the Tees entrance to Saltburn is continuous and for the purposes of coastal engineering management should be considered as part of the Hartlepool and Tees Bay coastal unit.

Summarising therefore our survey indicates that the stretch of coast from St Abb's Head to the river Tees can be considered as one large coastal cell. Within this there are a number of sub cells which can be considered almost independent of each other namely:-

St Abb's to the Tyne;
The Tyne to the Wear;
The Wear to Seaham;
Seaham to Hartlepool;
Hartlepool to Tees Bay.

8 ACKNOWLEDGEMENTS

The assistance of Mrs W D Duddell is gratefully acknowledged and we would like to thank Mr Alan McKirdy of the Nature Conservancy Council for his survey of the locations of SSSI's and GCR's in England and Wales.

9 REFERENCES

1. Steers J A. The coastline of England and Wales, 2nd Edition. Cambridge University Press, 1969.

2. Steers J A. The coastline of England and Wales in pictures. Cambridge University Press, 1960.

3. Steers J A. The coastline of Scotland. Cambridge University Press, 1973.

4. King C A M. Beaches and Coasts, 2nd Edition. Edward Arnold, 1972.

5. Marine Information and Advisory Service. Sea level variability and extremes. MIAS News Bulleting No 3, 1980.

6. Hydraulics Research Ltd. Druridge Bay Power Station Study : Report on beach and sea bed stability. Report No EX 1285, April 1985.

7. Meteorological Office. Tables of surface wind speed and direction over the United Kingdom. MO 792, HMSO, 1968.

8. White P A. The offshore wind-energy resource around the United Kingdom. BWEA International Symposium on Offshore Wind Energy Systems. Royal Aeronautical Society, London, 21 October 1983.

9. Department of Energy. Offshore installations : Guidance on design and construction. HMSO April 1984.

10. Draper L. Waves at North Carr Light Vessel, off Fife Ness. National Institute of Oceanography, Internal Report No A50, 1971.

11. Meteorological Office. Marine climatology, Observation count (World distribution of wind and visual wave observations). Meteorological Office, Bracknell, August 1985.

12. Department of Energy. Environmental parameters on the United Kingdom Continental Shelf. HMSO, 1985.

13. Abernethy C L and Gilbert G. Refraction of wave spectra. Hydraulics Research Ltd, Report INT 117, May 1975.

14. Brampton A H. A computer method for wave refraction. Hydraulics Research Ltd, Report IT 272, December 1977.

15. Hydraulics Research Ltd. Hindwave. A wave hindcasting method. Report IT 288, August 1985.

16. Hagger P. Wave heights at the Tyne Piers. Port of Tyne Authority, 1979.

17. Hydraulics Research Ltd. Coastal erosion of the beaches at Hartlepool, Co. Durham. Report No EX 387, February 1968.

18. Marine Information and Advisory Service. The MIAS catalogue of wave data, second edition. Institutue of Oceanographic Sciences, 1982.

19. Seymour R J. Estimating wave generation on restricted fetches. Journal of the American Society of Civil Engineers, Vol 103, No WW2, May 1977.

20. Darbyshire M and Draper L. Forecasting wind-generated sea waves. Engineering, Vol 195, 1963.

21. Shore Protection Manual. US Army Coastal Engineering Research Center, Vol 1, 1984.

22. Hydrographer of the Navy. North Sea, Flamborough Head to the Pentland Firth. Tidal Stream Atlas, 1963.

23. Lee A J and Ramster J W. Atlas of the seas around the British Isles, Fisheries Research Technical Report No 20, Ministry of Agriculture, Fisheries and Food, 1979.

24. Nunny R S. A survey of the dispersal of colliery waste from Lynemouth beach, Northumberland. Fisheries Research Technical Reort No 43. Ministry of Agriculture, Fisheries and Food, 1978.

25. Institution of Civil Engineers. Conference on the North Sea floods of 31 January - 1 February 1953. Published ICE, 1954.

26. Marine Information and Advisory Service. Extreme Surge Heights in the North Sea. MIAS News Bulletin, No 6, 1983.

27. King C A M. The relationship between wave incidence, wind direction and beach changes at Marsden Bay, Co. Durham. Institute of British Geographers Transactions and Papers. Publication 19, 1953.

28. Brampton A H and Jelliman C E. Beach data analysis system (BDAS). Hydraulics Research Ltd. Report No DE 62, April 1983.

29. Hydraulics Research Ltd. Monitoring of South Durham beaches, analysis of beach samples, 1974 - 1985. Report No EX 1341, September 1985.

30. Hydraulics Research Limited. Blyth, coast erosion south beach. Report No EX 803, December 1977.

31. Hydraulics Research Limited. South Shields foreshore. Report No EX 910, February 1980.

32. Hydraulics Research Limited. Tees Estuary. Report on Tees Bay model investigation. Report No EX 166, November 1961.

33. Bruun P. Sea-level rise as a cause of shore erosion. Journal of the American Society of Civil Engineers. Vol 88, WW1, 1962.

34. CIRIA. Research project 310. Effectiveness of groyne systems, Phase JF, Final Report - Volume 2. Sir William Halcrow and Partners, October 1985.

35. Reid W J. Eyemouth Harbour. A tidal model investigation. Permanent International Association of Navigation Congresses. Bulletin 48, 1958.

36. Department of the Environment. Coast Protection Survey 1980. Summary of coastal defences.

37. Welsby J and Motyka J M. A review of novel shore protection methods. Volume 3 - Gabions. Hydraulics Research Ltd. Report No IT 260, March 1984.

38. National Conservancy Council. Coastal Survey 1985 (Survey of SSSI's and GCR's).

39. Hydraulics Research Limited. FDGR Amble investigation. Studies of the proposed Dock Approach Channel in Warkworth harbour, Northumberland. Report No DE 35, April 1976.

40. New Civil Engineer. Data base selects best sea defence. 12 December 1985.

10 BIBLIOGRAPHY

Coastline topography, geology etc.

1. Steers J A. The Coastline of England and Wales, 2nd Edition. Cambridge University Press, 1969.

2. Robinson A and Millward R. The Shell book of the British coast. David and Charles, 1983.

3. King C A M. Beaches and coasts, 2nd Edition. Edward Arnold, 1972.

4. Atkinson J R. A policy for the Durham coast. Durham County Council, 1966.

5. Bird E C F and May V J. Shoreline changes in the British Isles during the past century. Division of geography. Bournemouth College of Technology, 1976.

6. National Parks Commission. The coasts of North East England. HMSO, 1968.

7. Steers J A. The coast of England and Wales in pictures. Cambridge University Press, 1960.

8. National Environment Research Council, Institute of Geological Sciences. British regional geology, Northern England. HMSO, 1971.

9. National Conservancy Council. Coastal survey 1985 (Survey of SSSI's and GCR's).

Wind data

1. Meteorological Office. Tables of surface wind speed and direction over the United Kingdom, MO 792. HMSO, 1968.

2. Department of Energy. Offshore installations : Guidance on design and construction. HMSO, April, 1984.

3. Meteorological Office. Frequency of observations of visually estimated wind speeds and non coarse-code wave heights in the Main Marine Data Bank. Marine Climatology, 1985.

4. Department of Energy. Environmental prameters on the United Kingdom continental shelf. HMSO, 1985.

5. White P A. The Offshore wind-energy resource around the United Kingdom. BWEA International Symposium on Offshore Wind Energy Systems. Royal Aeronautical Society, London, 21 October 1983.

6. Meteorological Office. Observation count (world distribution of wind and visual wave observations). Meteorological Office, Bracknell, August 1985.

7. Department of Energy. Environmental parameters on the United Kingdom Continental Shelf. HMSO, 1985.

Wave data

1. Hagger P. Wave heights at the Tyne Piers. Port of Tyne Authority, 1979.

2. Shellard H C and Draper L. Wind and wave relationships in United Kingdon coastal waters. Estuary and Coastal Marine Sciences, 1975.

3. Department of Energy. Environmental considerations for the design of offshore structures. HMSO, 1977.

4. Meteorological Office. Frequency of observations of visually estimated wind speeds and non coarse-code wave heights in the Main Marine Data Bank. Marine Climatology, 1985.

5. Department of Energy. Environmental parameters on the United Kingdon continental shelf. HMSO, 1985.

6. Hogben N and Lumb F E. Ocean wave statistics. HMSO, 1967.

7. Darbyshire M. Waves in the North Sea. Dock and Harbour Authority, Volume XLI, No 481, 1960.

8. Draper L. North Sea wave data 'Norspec 70'. Thomas Reed, 1970.

9. Draper L and Driver J S. Winter waves in the northern North Sea at 57 30'N 3 00'E. Recorded by M V Famita. National Institute of Oceanography (now Institute of Oceanographic Sciences). Internal report No A48, 1971.

10. Fortnum B C H. Waves recorded by M V Famita in the northern North Sea (winters 1969-76). Institute of Oceanographic Sciences, report No 59, 1978.

11. Saetre H J. On high wave conditions in the northern North Sea. Institute of Oceanographic Sciences, Report No 3, 1974.

12. Marine Information and Advisory Service. The MIAS catalogue of wave data, Second edition. Institute of Oceanographic Sciences, 1982.

13. Meteorological Office. Marine climatology, Observation count (world distribution of wind and visual wave observations). Meteorological Office, Bracknell, August 1985.

14. Draper L. Waves at North Carr Light Vessel, off Fife Ness. National Institute of Oceanography, Internal Report No A50, 1971.

15. Hydraulics Research Limited. Tees Estuary, Report on Tees Bay model investigation. Report No EX 166, 1961.

Tides, tidal currents and seabed topography

1. Hydrographic Department. North Sea (West) Pilot, first edition. Hydrographer of the Navy, 1973.

2. Hydrographic Department. North Sea, Flamborough Head to Pentland Firth, tidal stream atlas, revised edition 1965. Hydrographer of the Navy.

3. Hydrograhic Department. Admiralty tide tables, volume 1, European Waters. Hydrograher of the Navy.

4. Harvey J G. Atmosphere and ocean, our fluid environments, first edition. The Artemis Press, 1976.

5. Hydrographic Department. Admiralty Chart 1192, St Abb's Head to the river Tyne, natural scale 1:200000. Hydrographer of the Navy, May 1978.

6. Hydrographic Department. Admiralty Chart 1191, river Tyne to Flamborough head, natural scale 1:200000. Hydrographer of the Navy, October 1977.

7. Hydrographic Department. Admiralty Chart 1612, harbours and anchorages on the east coast of England and Scotland:
Eyemouth and North Sunderland harbours, natural scale 1:7500;
Whitby harbour: Scarborough bay, natural scale 1:10000;
Berwick and Holy Island harbours, natural scale 1:12500;
Runswick Bay, natural scale 1:20000.
Hydrographer of the Navy, May 1978.

8. Hydrographic Department. Admiralty Chart 111, Berwick to the Farne Islands, natural scale 1:35000. Hydrographer of the Navy, May 1978.

9. Hydrographic Department. Admiralty Chart 160, St Abb's Head to the Farne Islands, natural scale 1:75000. Hydrographer of the Navy, August 1975.

10. Hydrographic Department. Admiralty Chart 156, Farne Islands to the river Tyne, natural scale 1:75000. Hydrographer of the Navy, May 1978.

11. Hydrographic Department. Admiralty Chart 152, river Tyne to river Tees, natural scale 1:75000. Hydrographer of the Navy, May 1978.

12. Hydrographic Department. Admiralty Chart 1627, harbours on the east coast of England:
Sunderland harbour, natural scale 1:10000;
Seaham harbour, natural scale 1:12500;
Warkworth harbour, natural scale 1:15000,
Hydrographer of the Navy, May 1978.

13. Hydrographic Department. Admiralty Chart 1626, Blyth harbour, natural scale 1:6250. Hydrographer of the Navy, May 1978.

14. Hydrographic Department. Admiralty Chart 1934, entrance to the river Tyne, natural scale 1:7500. Hydrographer of the Navy, June 1978.

15. Hydrographic Department. Admiralty Chart 2567, approaches to Tees bay, natural scale 1:30000. Hydrographer of the Navy, May 1978.

16. Hydrographic Department. Admiralty Chart 2566, Tees and Hartlepool bays:
Hartlepool bay, natural scale 1:10000;
Tees bay, natural scale 1:20000. Hydrographer of the Navy, May 1978.

17. Hydrographic Department. Admiralty Chart 134, river Tees to Scarborough, natural scale 1:75000. Hydrographer of the Navy, December 1975.

18. Sparks B and West R G. The Ice Age in Britain. Methuen, 1972.

19. Lee A J and Ramster J W. Atlas of the seas around the British Isles, Fisheries Research Technical Report No 20. Ministry of Agriculture Fisheries and Food, 1979.

20. Department of Energy. Environmental parameters on the United Kingdom Continental Shelf. HMSO, 1984.

21. Hydraulics Research Limited. Tyneside sea outfalls investigation. Report No EX236, May 1964.

22. Evans F. Wind currents, tidal streams and plankton off the Northumberland coast. Journal of the Marine Biological Association (UK), Volume 38, 1959.

23. Graff J. An investigation of the frequency distributions of annual sea level maxima at ports around Great Britain. Estuarine, Coastal and Shelf Science, Volume 12, 1981.

24. Institution of Civil Engineers. Conference on the North Sea floods of 31 January-1 February 1953. Published ICE, 1954.

Coastal Engineering studies

1. Hydraulics Research Limited. South Shields forshore, Report No EX 910, February 1980.

2. Nunny R S. A survey of the dispersal of colliery waste from Lynemouth beach, Northumberland. MAFF Fisheries Research Techical Report No 43, 1978.

3. Hydraulics Research Limited. Dredging for waste coal off the Durham coast, an assessment of the effects on the adjacent shoreline. Report EX 1136, July 1983.

4. Hydraulics Research Limited. Colliery waste disposal on the Durham coast. Beach changes near Blackhall - a continuation study. Report No EX 765, February 1977.

5. Hydraulics Research Limited. Colliery waste on the Durham coast, a study of the effect of tipping colliery waste on the coastal processes. Report No EX 521, November 1970.

6. Hydraulics Research Limited. Colliery waste on the Durham coast, a follow up study of the despoliation of Crimdon Beach. Report No DE 19, April, 1974.

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

8. Department of the Environment. Coast protection Survey 1980. Summary of coastal defences.

9. Hydraulics Research Limited. Druridge Bay Power Station Study. Report on beach and sea bed stability. Report No EX 1285, April, 1985.

10. Reid W J. Eyemouth Harbour. A tidal model investigation. Permanent International Association of Navigation Congress. Bulletin 48, 1958.

11. Hydraulics Research Limited. Tees Estuary, report on Tees Bay model investigation. Report No EX 166, November 1961.

12. Hydraulics Research Limited. Dredging for waste coal off the Durham coast. Report No EX 1136, July 1983.

13. Hydraulics Research Limited. Blyth, coast erosion south beach. Report No EX 803, December 1977.

14. Hydraulics Research. Monitoring of south Durham beaches, analysis of beach samples 1974-85. Report No EX 1341, September 1985.

15. Nunny R S. The dispersal of colliery waste away from the South Durham beaches. Horden pipeline survey 1, October 1977.

16. Hydraulics Research. West harbour redevelopment, Hartlepool. Report No EX 1202, January 1985.

17. Fisheries Laboratory, Burnham on Crouch. The dispersal of colliery waste away from the south Durham beaches: Interim report on a survey of the effects of the disposal of colliery waste by pipeline at Horden, Co Durham. January 1978 (Confidential report prepared for the Working Party on colliery waste tipping on Durham beaches).

18. Hydraulics Research. Tees-side outfalls. Report No EX 393, April 1968.

19. Hydraulics Research. Tyneside sea outfalls investigation. Report EX 236, May 1964.

20. Hydraulics Research. North Sunderland Harbour, Seahouses, Northumberland. Model investigation of proposed improvements. Report No EX 437, March 1969.

21. Department of the Environment. Coast Protection Survey, 1980.

22. Hydraulics Research. Jarrow Slake, Estuary of the river Tyne, Report on hydrographical survey. Report No EX 206, August 1962.

23. Hydraulics Research. FDGR Amble investigation, studies of the proposed Dock Approach Channel in Warkworth harbour, Northumberland. Report DE 35, April 1976.

24. Hydraulics Research. River Tyne, proposed deepening of the entrance reach and Shields Harbour reach of the river Tyne. Report No EX 389 February 1968.

25. King C A M. The relationship between wave incidence, wind direction and beach changes at Marsden Bay, Co Durham. Transactions of the Institute of British Geographers Vol 9, 1953.

26. Hydraulics Research. Coastal erosion of the beaches at Hartlepool. Co Durham. Report No EX 387, February 1968.

27. Tomlinson K W. Coastal erosion of the beaches at Hartlepool, Co Cleveland. March 1977.

28. Tees Conservancy Commission. The development of a modern river. Centenary Report 1852-1952, published 1952.

29. Hydraulics Research Limited. Seaton Sluice harbour restoration scheme. Report No EX 593, March 1972.

30. Hydraulics Research Limited. Seaton Sluice harbour entrance, recommendations to improve navigation. Report No EX 1037, December 1981.

31. New Civil Engineer. Data base selects best sea defence. 12 December 1985.

32. Institution of Civil Engineers. Shoreline Protection Proceedings of a conference held at the University of Southampton, 14-15 September 1982. Thomas Telford, London, 1983.

33. CIRIA. Research project 310, effectiveness of groyne systems, phase II, final report - volume 2. Sir William Halcrow and Partners, October 1985.

34. Hydraulics Research Limited. South Shields foreshore. Report EX 910, February 1980.

TABLE

TABLE 1 Proposed division of coastline for the Macro-review

1. St Abb's Head to Tees Bay
2. Tees Bay to the Wash
3. Wash to the North Foreland
4. North Foreland to Solent
5. Solent to Portland Bill including Isle of Wight
6. Portland Bill to Lands End
7. Lands End to Bristol Channel
8. Bristol Channel to St Davids Head
9. St Davids Head to Great Ormes Head
10. Great Ormes Head to the Solway

FIGURES

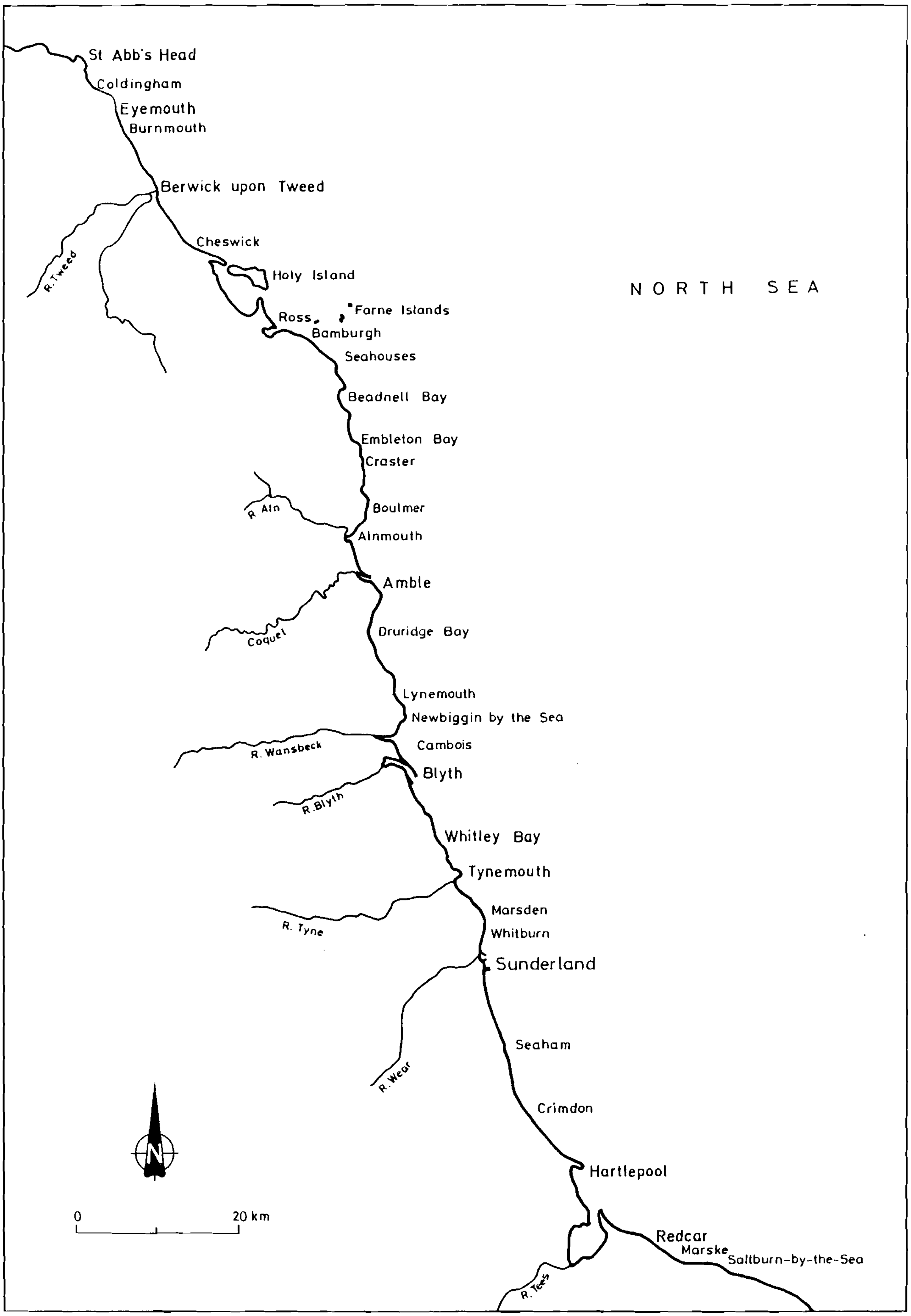

Fig 1 Location map

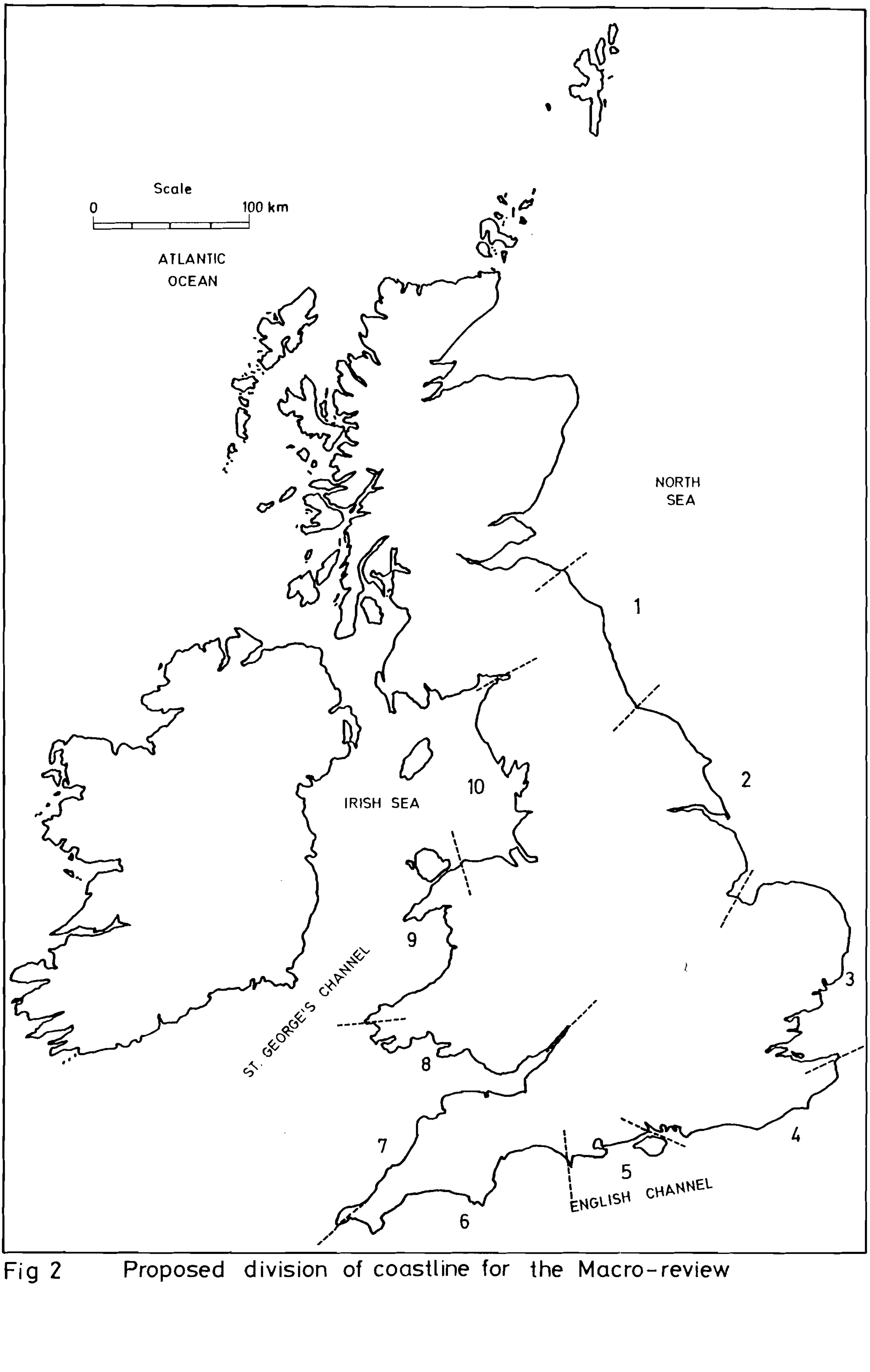

Fig 2 Proposed division of coastline for the Macro-review

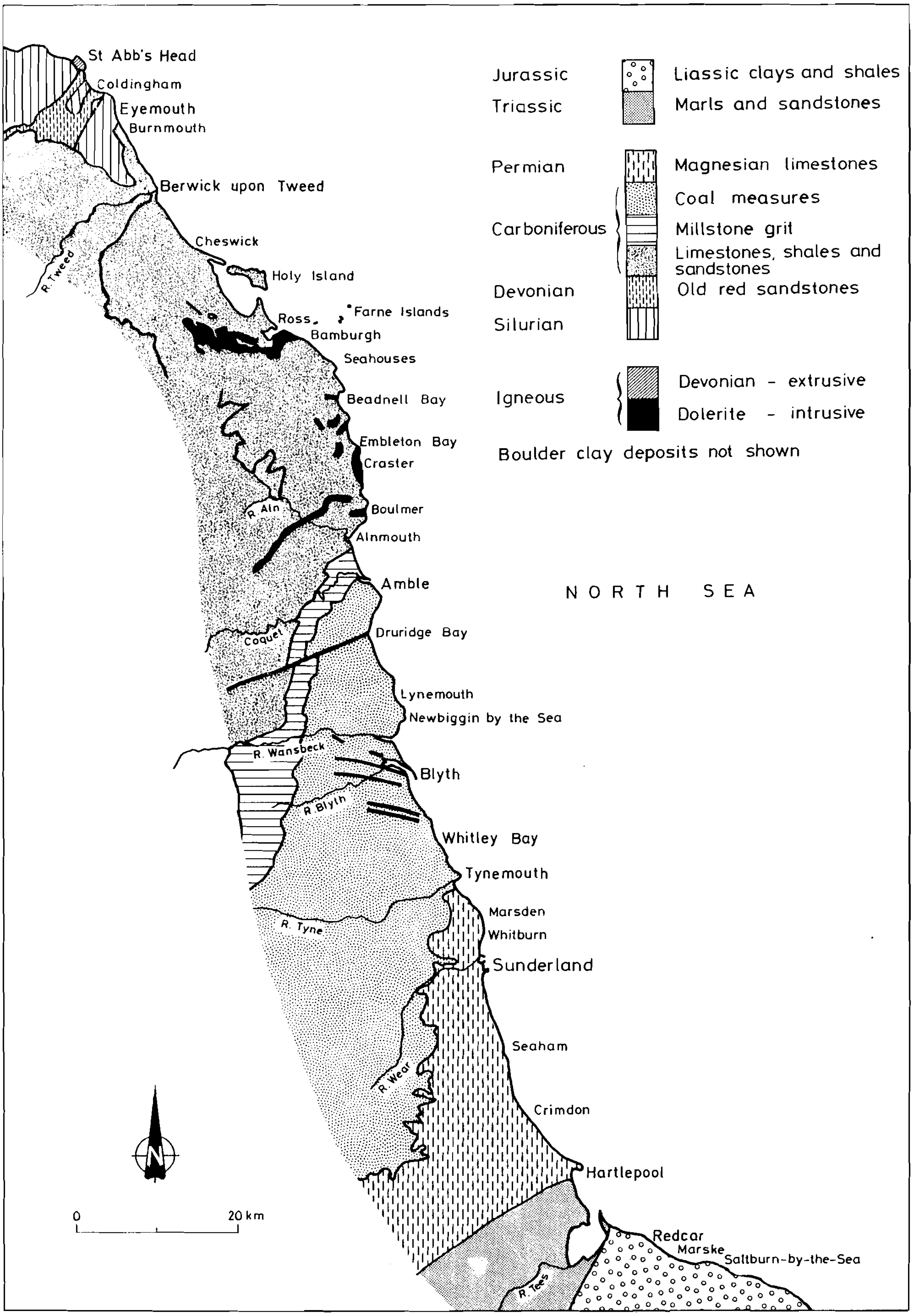

Fig 3 Simplified geology of the North East coast

Million years before present (not to scale)	Geological period		Duration million years
Today			
	Quaternary	Holocene	10000 yrs
1·8		Pleistocene	about 1·8
135			
	Jurassic		70
205			
	Triassic		45
250			
	Permian		40
290			
	Carboniferous		65
355			
	Devonian		50
405			
	Silurian		30
435			

Fig 4 Summary of divisions of geological time in the North East

Legend for figures 5 to 12

These figures show the coastline in sections from St Abb's Head in the north to Tees Bay in the south.

——————→	Direction of longshore drift
←– – – – – –	Reversal of longshore drift
●●●●●●●●●●●●●	Coastal defences
– – – – – – –	Boundary of Sites of Special Scientific Interest

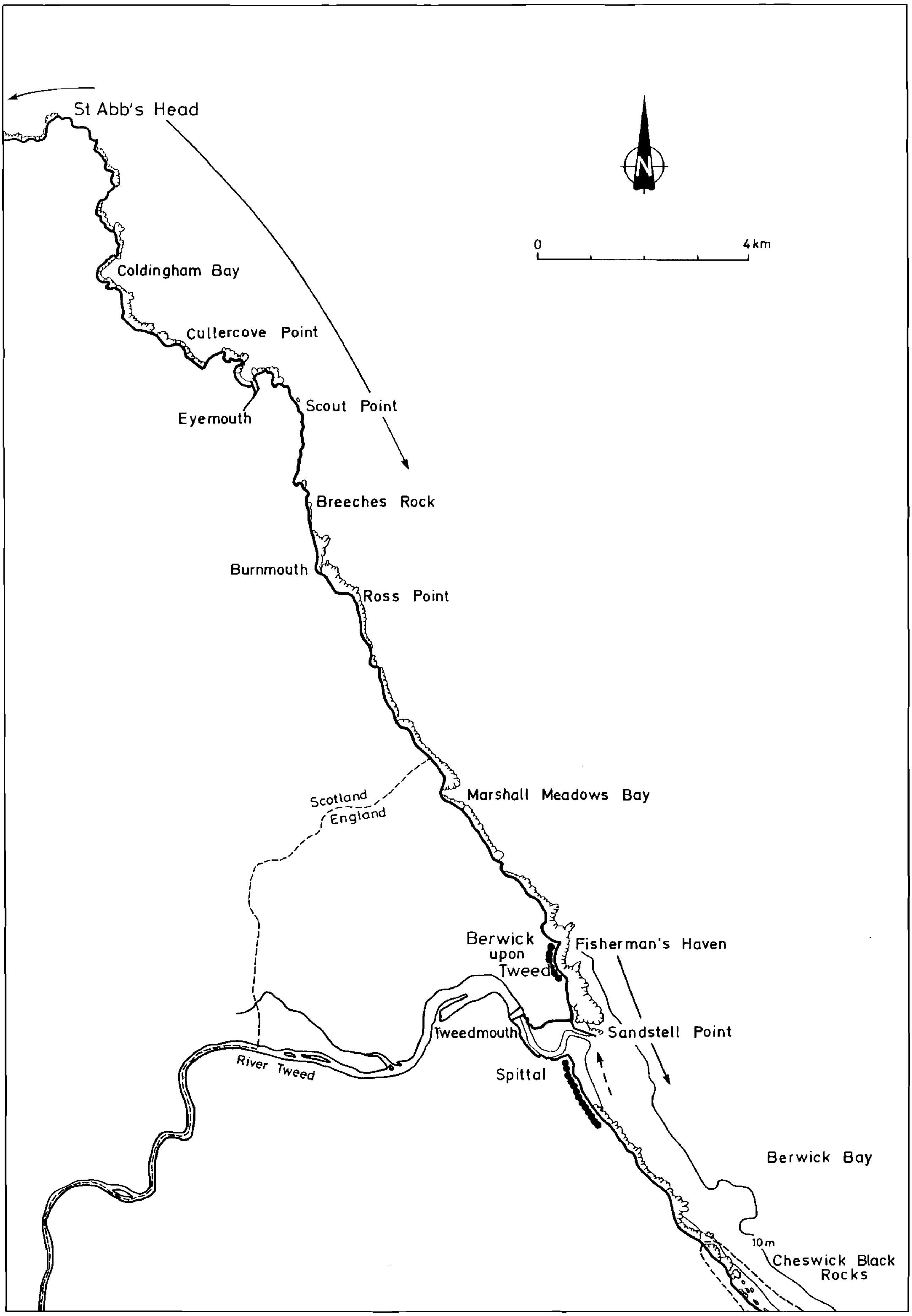

Fig 5 St. Abbs Head to Cheswick Sands

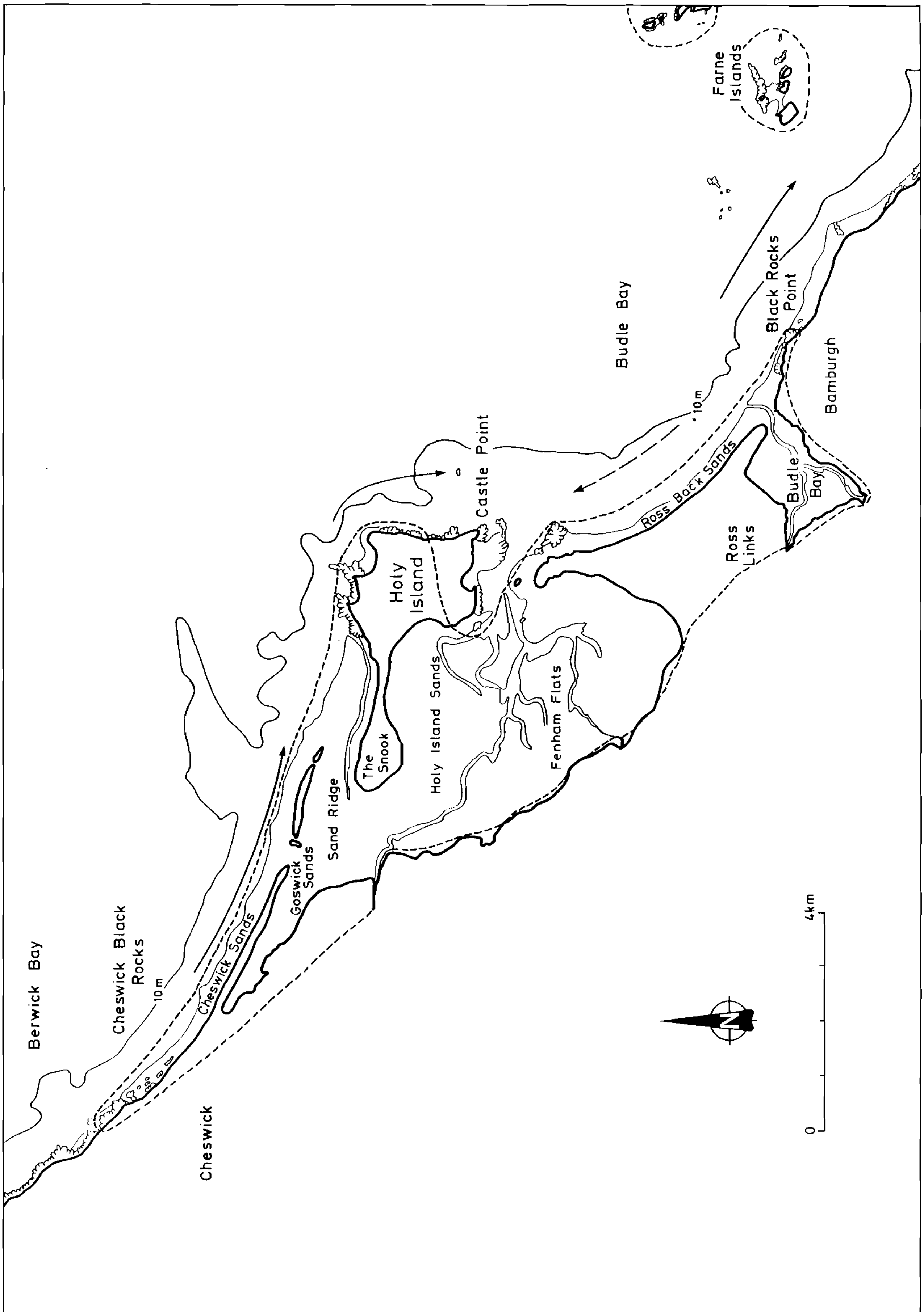

Fig 6 Cheswick Sands to Bamburgh

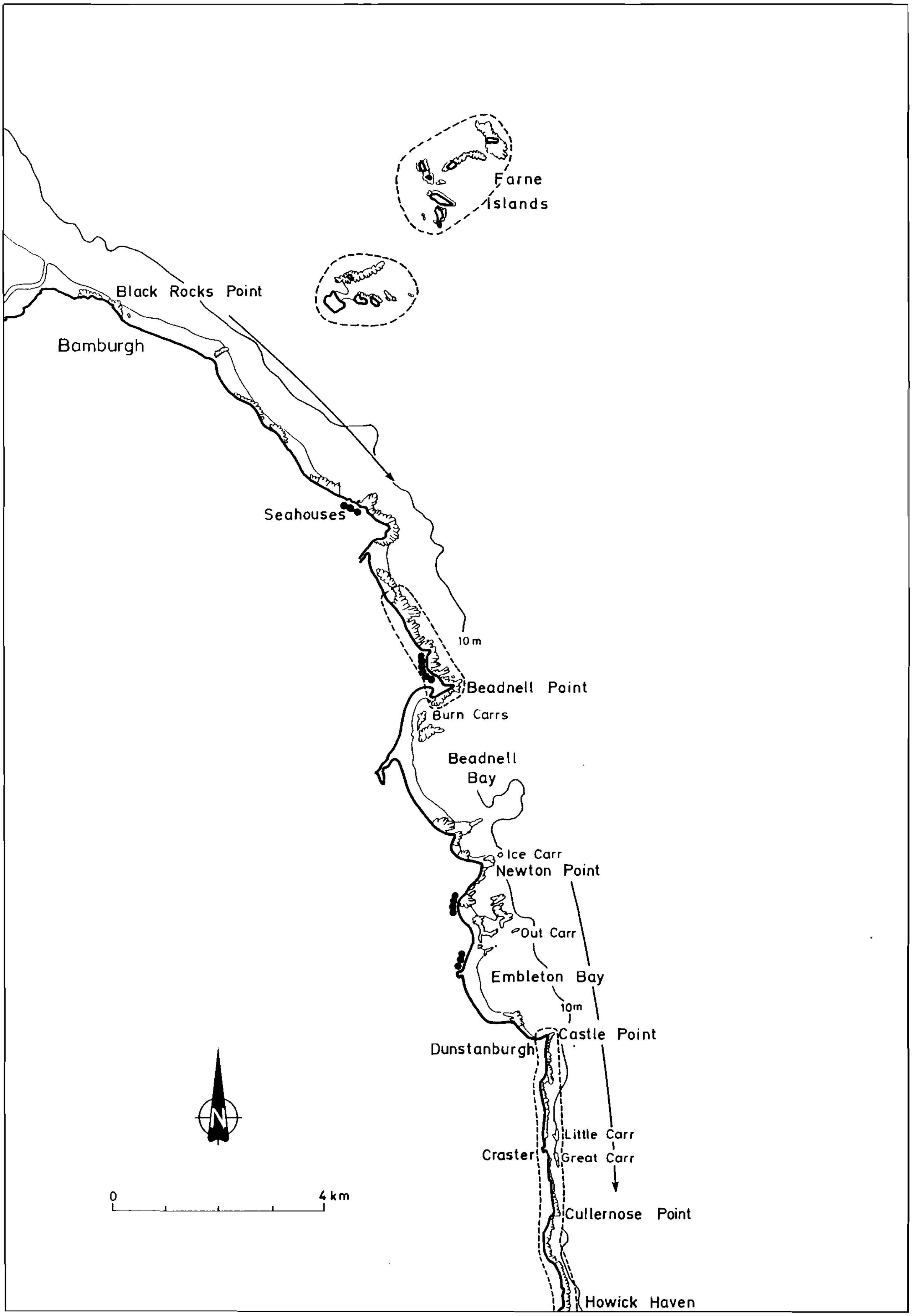

Fig 7 Bamburgh to Howick Haven

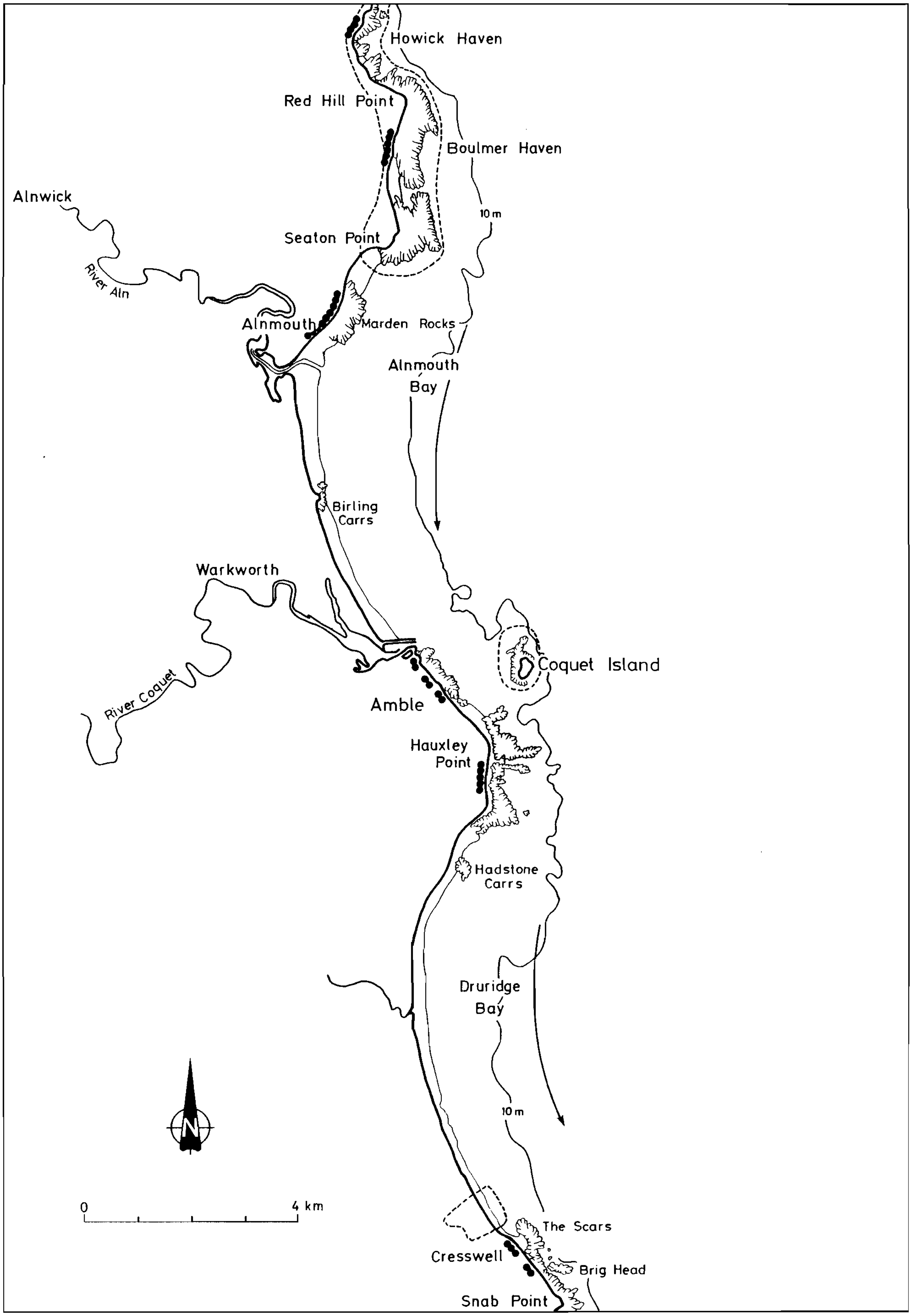

Fig 8 Howick Haven to Snab Point

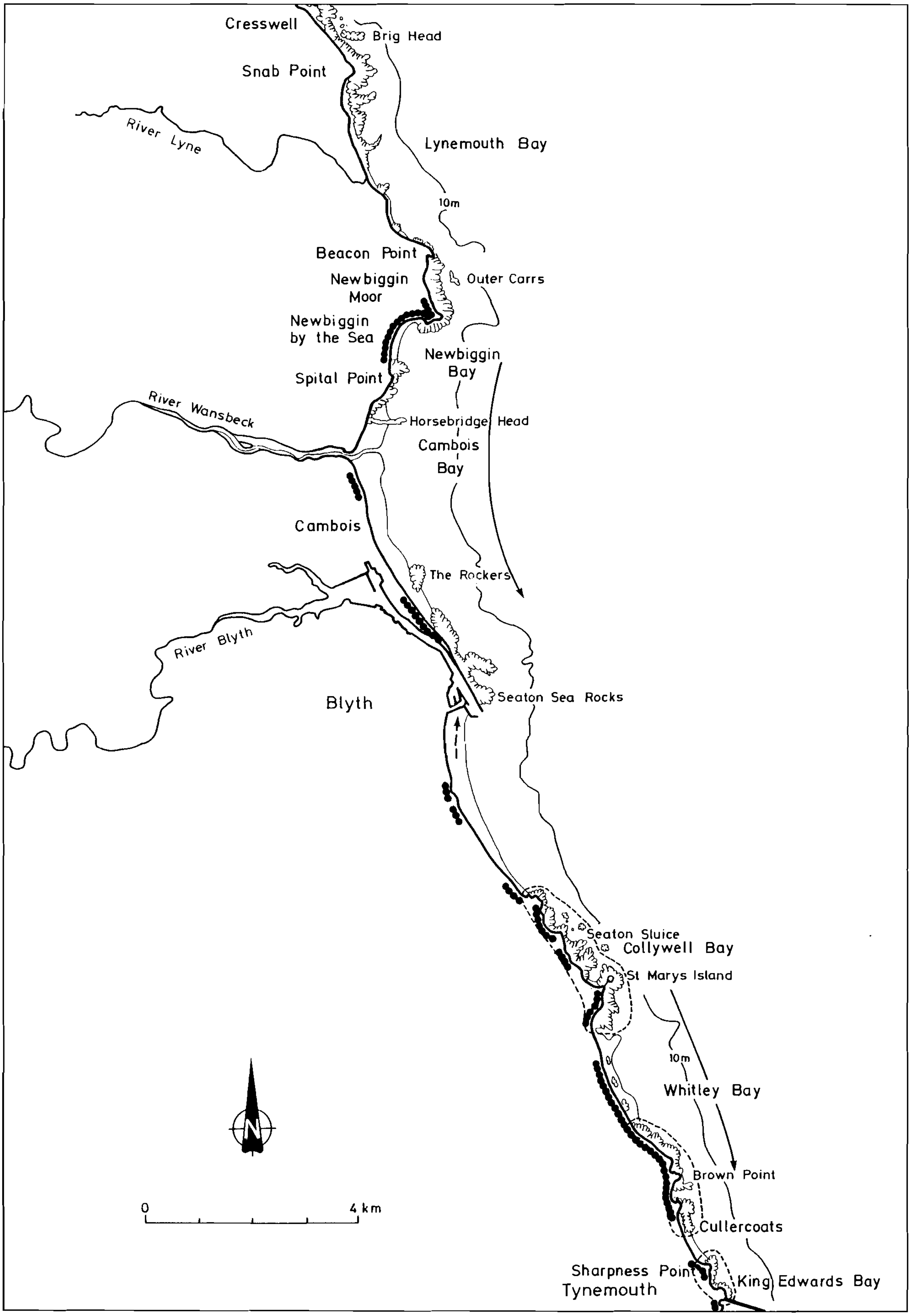

Fig 9 Snab Point to Tynemouth

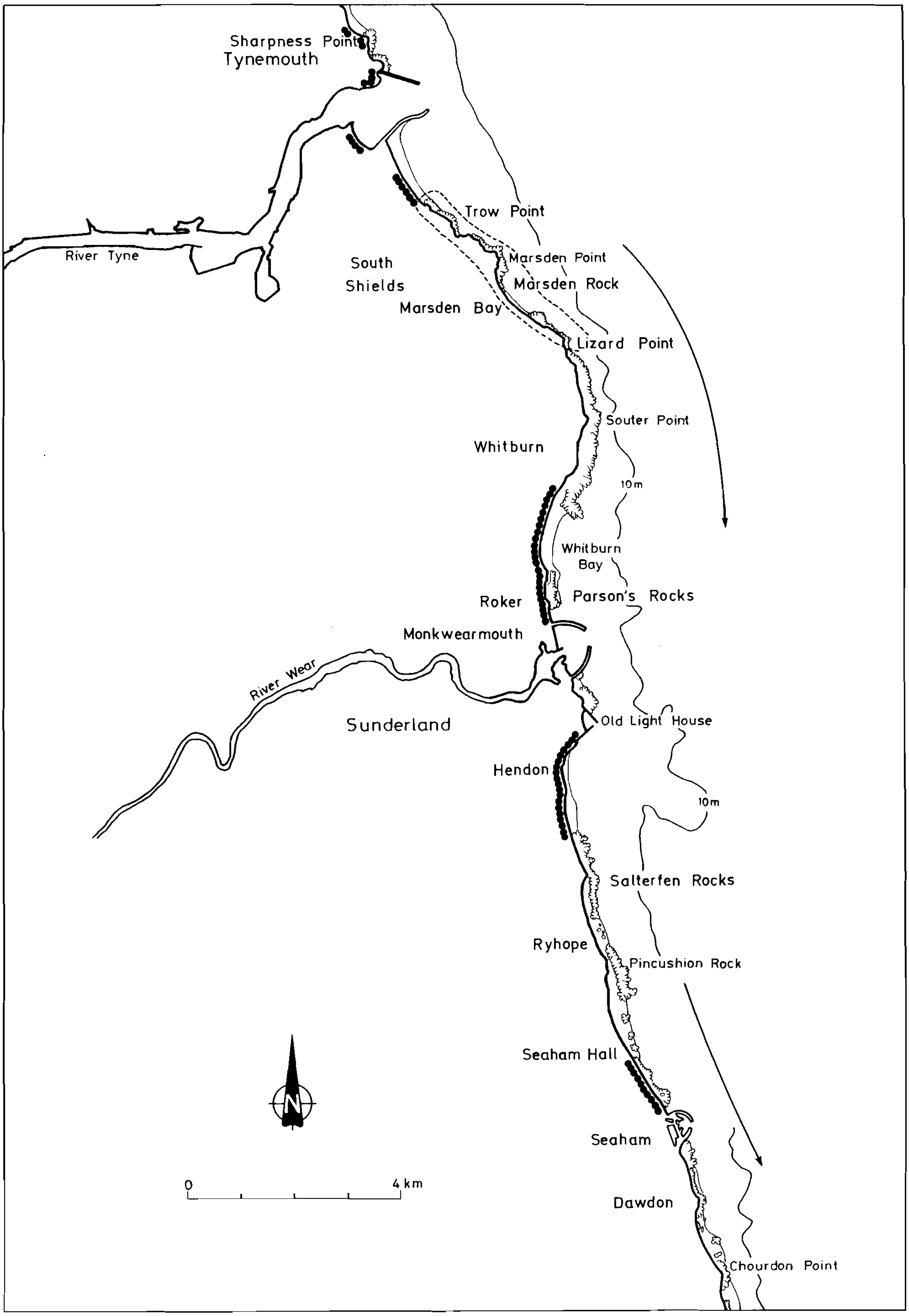

Fig 10 Tynemouth to Seaham

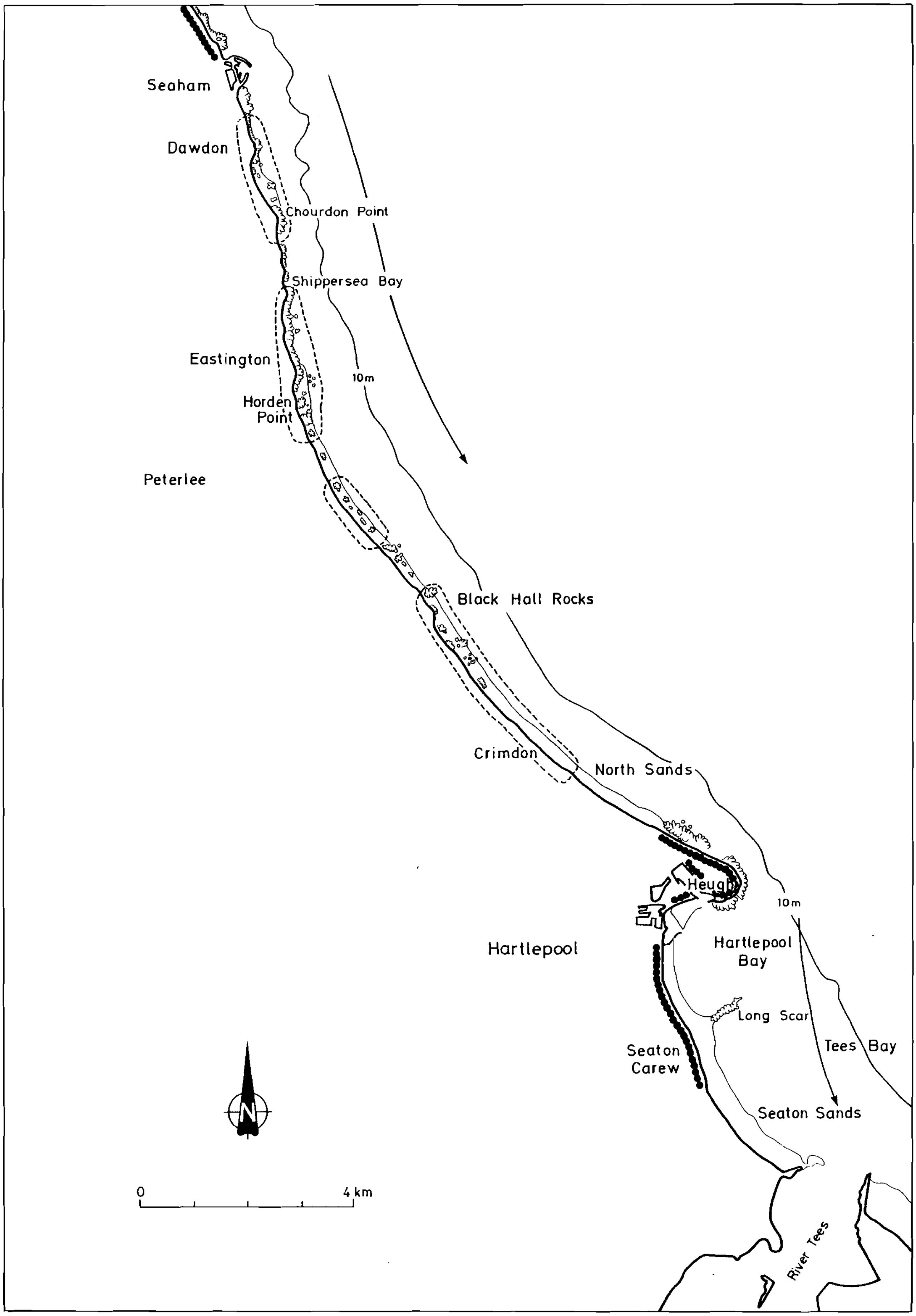

Fig 11 Seaham to Tees Bay

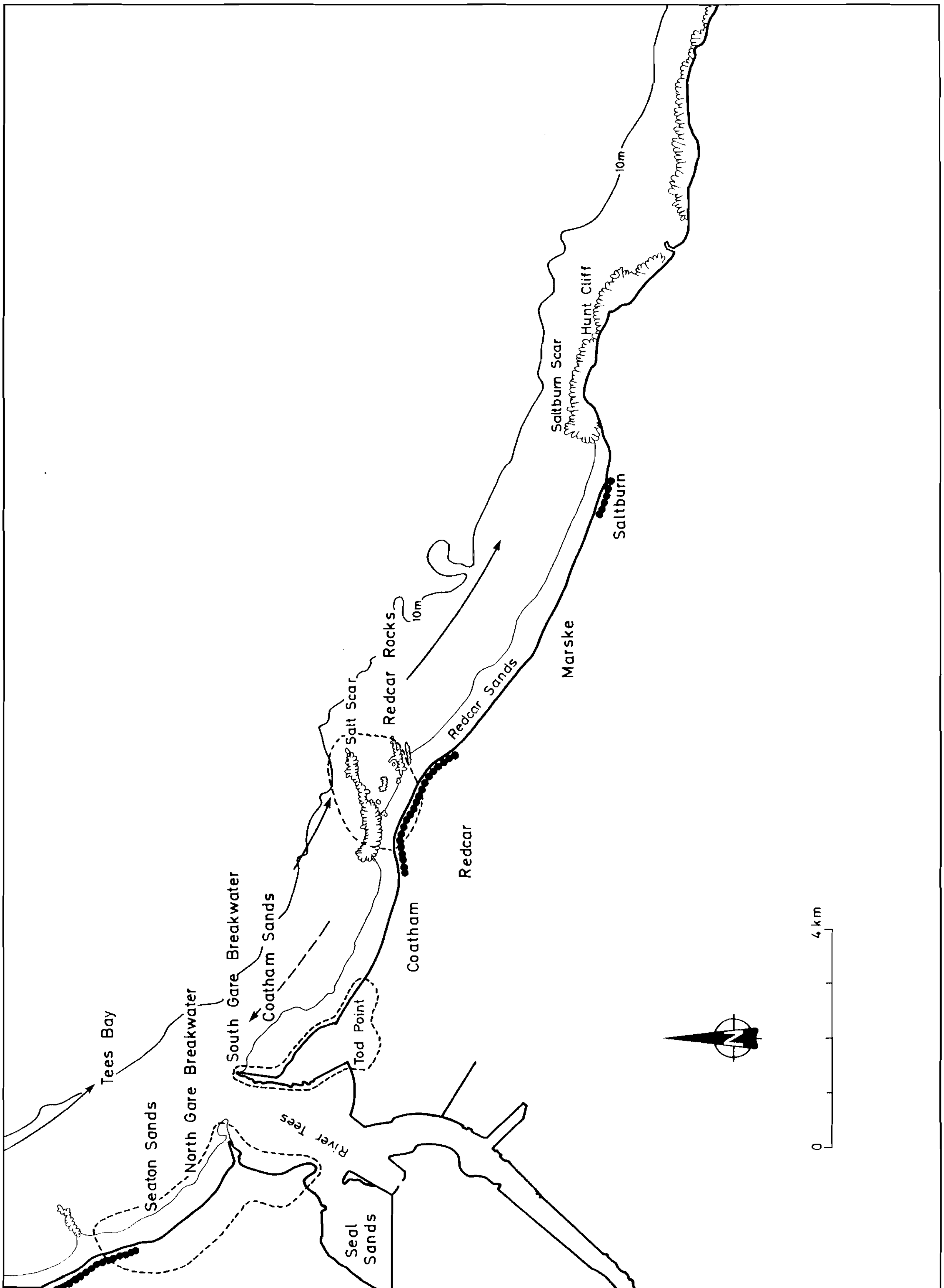

Fig 12 Tees Bay to Saltburn

PLATES.

Plate 1 View north from Berwick Harbour

Plate 2 Low cliff line between Berwick and Cheswick

Plate 3 Cliffs and wave cut platform between Bamburgh and Seahouses

Plate 4 Peat exposures and eroding dune face at Druridge Bay

Plate 5 The effects of overgrazing at Druridge Bay

Plate 6 The accumulation of coal south of Newbiggin breakwater

Plate 7 Cliff erosion at Newbiggin Moor holiday camp site

Plate 8 Erosion of the spit north of the Alcan Co. frontage, Blyth

Plate 9 Cliff erosion and boulder clay pebbles on beach north of Seaham Hall

Plate 10 Cliffs isolated by colliery waste south of Seaham

Plate 11 Wide shingle beach trapped north of Blackhall Rocks

Plate 12 View south of Crimdon showing sand beach and dunes

Plate 13 Coastal defences at Redcar

Plate 14 Erosion of boulder clay cliffs east of Redcar

Plate 15 Weathering of boulder clay cliffs by rainfall at Saltburn

Plate 16 Termination of sand beach at Hunt Cliff east of Saltburn