BEACH DEVELOPMENT ALONG THE HOLDERNESS COAST, NORTH HUMBERSIDE, WITH SPECIAL REFERENCE TO ORDS.

by

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Anne Scott 1976

ABSTRACT

The main aim of this work is to study features found on the Holderness beach known as Ords. Ords are sections of low beach at the cliff foot, separated from each other by built-up sections of beach. Three major questions are asked: What form do the ords take, and where are they found? How do they move? How do they originate? A period of field study was undertaken during 1974/1975, including surveys of three selected ords. The results were analysed with the corresponding wind, wave and tidal data.

Two types of ord were found, northern and southern. The changes to the ords can be divided into short and long term changes. In the short term the changes are confined to the small scale movements within the ord and include the week-to-week fluctuations of the lower beach ridge and the upper beach. The long term changes are on a larger scale and include the southward movement of the whole ord feature during severe northerly storms.

In a review of similar features around the world, it is established that no feature of the same type has yet been identified. The mechanism of ord formation is discussed in the light of recent work and the most likely theory is the sheltering effect of Flamborough Head during northerly storms. The effects of ord movement on the rate of cliff erosion is also discussed.

C H A P T E R   O N E

INTRODUCTION

The till cliffs of the Holderness coast, North Humberside, between Flamborough Head and Spurn Head (figure 11), have generated interest by their rapid rate of retreat, which has been in progress throughout the Flandrion rise in sea level. Valentin (1954) reviewed the rates of erosion during the previous century in detail, but he, along with many other research workers on this coast, concentrated on the cliffs themselves and little attention was paid to the beach.

Of the few exceptions to this, Thompson (1824) was one of the earliest writers to describe the Holderness beach in some detail, and for the first time the beach features he calls "Hords" are mentioned:-

> "The sand banks ... are frequently changed in shape and position; but generally tending southwards, and leaving between them large hollow places, here by a perversion of meaning, called hords, running southwards from the cliff to the sea.
>
> "Where the hords, or hollow places in the sand are, the cliff is cut down the fastest, as the sea has constant and uninterrupted access to it. When sand and small gravel lie against the cliff, the cliff is preserved until a powerful sweeping tide comes and changes the whole face of the sands on the coast, and carries southward all before it."
>
> Thompson, 1824.

These features are not referred to again in the literature until Phillips (1962, 1964), when they appear as "Ords". The word here, describing similar features to those of Thompson, was not derived from Thompson but from conversations with local fishermen. Therefore during the 140 years between the two papers, no mention was given to these often large, conspicuous features on the Holderness beach. The ords' importance to the local fishermen (much diminished in numbers this century), for beaching boats on the gentler beach slope found within the ords is of note.

Reid (1885) notes a strange deficiency of the beach at many points on the Holderness coast where no artificial abstraction takes place, and he concludes:-

> "What beach there is consists principally of shifting banks of sand, which unless fixed by groynes, are of little use in protecting the coast during storms."

The only other references to the Holderness beach are of a general nature. Dossor (1955) recognises the protection value of a well built up beach to the unconsolidated Holderness cliffs.

The use of the word ORD is taken from Phillips (1962). Ords are features found along the Holderness coast from Skipsea in the north to the tip of Spurn Head in the south. The low area of beach, the ord, migrates southward during times of northerly storms. The length of the features varies considerably (see table 2.1), but on average they are between one and two kilometres long. Figure 1.2 shows a generalised plan of the form of an ord. To the north and south of the feature the typical Holderness beach formation is found. This consists of two units, the upper and lower beach. Nearer the cliff is a dry, often convex upper beach which slopes relatively steeply seawards. It is formed of coarse sand and shingle, the latter often concentrated on the lower slopes. Most of the upper beach is above the beach water table at low water. The water table is found on the surface of the upper beach usually slightly above the break of slope between the upper and lower beaches. The lower beach has a very gentle gradient and consists solely of medium and fine-grained sand. As it usually lies below the beach water table, at times of low water it has a thin layer of water on the surface, and is therefore described as a wet lower beach.

As an ord is approached from the north the upper beach becomes lower and narrower. The break of slope between the upper and lower beaches, instead of running parallel to the cliff line, swings in towards the cliff foot, causing the upper beach to disappear gradually. The lower beach at this point is slightly raised above the beach water table and its surface is therefore dry. Sand on the beach often completely disappears at the cliff foot at this point, exposing the shore platform of till. This part of the ord is the "centre" and is the lowest part of the beach at the cliff foot. It is not uncommon for an ord to have more than one centre, but this will depend on the configuration of the upper beach at the cliff foot south of the northern centre. Some ords do not display any well-defined centre, as will be illustrated in Chapter Two, Section D. The centre of an ord may be quite short, only a few metres in length at the cliff foot, or over ten metres long.

South of the centre the upper beach begins to reform gradually at the cliff foot, and increases in height and width southwards. The till platform is usually continuous from the cliff foot at the centre of the ord southwards along the seaward edge of the southern upper beach. The till platform often becomes weathered and uneven towards the southern end of the ord, and there it is often associated with large rock boulder erratics on its surface.

The lower beach within the boundaries of the ord develops into a high, dry asymmetrical ridge, with a short steep landward slope and a long gentle seaward slope, separated by a ridge crest. This lower beach ridge may trap water between the ridge and the till platform in a water-filled runnel, at low water. This runnel may have outlets across the lower beach of the ord but the main outlet of the runnel is at the southern end of the ords.

The sand sizes within the ord vary little from those in the non-ord parts of the Holderness beach, the coarser material being incorporated into the upper beach and the finer sands in the lower beach.

The north and south boundaries of an ord are not always easy to define. In the north the upper beach may fade out very gradually at the cliff foot or end in a sweeping curve. The southern end is usually marked by the high water mark once more appearing on the well built up beach near the cliff foot, and the disappearance of the till platform beneath the widening upper beach. The line of the water table across the lower beach, separating wet and dry sections of the lower beaches, marks the boundary of the ord.

For the purposes of simplicity in this thesis, the Holderness beach, which has a general alignment north-west, south-east, will be referred to as north and south. The actual alignment of this curving coastline can be seen in figure 1.1, the location map. As some of the terms used here are new, a glossary is added, after the bibliography.

During the field research, two types of observations were made. The general observations included photographic surveys from the cliff top, recording of the beach details on sketch maps, and the plotting of the positions of each ord on a 1 : 25,000 map. The second type of observation made on the coast was the survey observation. This included a complete survey of an ord by levelling techniques, often with a sand sampling programme. The beach plans produced from the second type of observation include precisely measured details.

It is the aim of this thesis to investigate the ord system of the Holderness coast, both on the overall scale and in detail on specific ords. Three main questions are asked. Firstly, what is an ord, and where are they positioned at present on the Holderness coast? What are the topographical features most typical within an ord? Secondly, in what manner and by what mechanisms do ords move and under what conditions do the features within an ord change? Does a particular ord retain its own characteristics during and after it moves to another position? Thirdly, where and how do the ords originate? If they move southwards, it appears that they will originate somewhere in the northern part of Holderness. If this is so, what is the mechanism which causes such features to be formed and why are they not destroyed again until they reach the tip of Spurn Head?

To answer the questions outlined above, this thesis has been devided into five chapters, plus the introduction and the conclusion. Chapter Two discusses the Holderness beach in general and the history of the ords before the present study period. A classification of the ords present in 1974 follows and then the general changes over the study period 1974 to 1976 are outlines.

Chapter Three is composed of two parts. The first deals with a general description of the three ords selected for detailed study. The second part of this chapter discusses the methods of study both in the field and in the laboratory, with a criticism of these methods in relation both to work on the Holderness coast and the relevant literature.

Chapter Four consists of the presentation of the results obtained from the detailed study of the three ords outlined in Chapter Three. These results of surveys and sampling programmes are related to the changing wind, wave and tidal characteristics. Much of the detail of the surveys are reproduced in the figures in Volume Two.

Chapter Five discusses the short term beach changes. These include the week to week changes of the upper and lower beach as well as short term variations in sediment distribution.

Chapter Six deals with the long term beach changes. The major movements of the ords are discussed together with the mechanisms of ord movement. The effects of the presence of the ords on the erosion of the cliffs is outlined. Finally, in Chapter Six, the mode of ord formation is discussed.

Chapter Seven, the conclusion, summarises the findings of each chapter and assesses the overall results of the study in the light of the original problems posed in this introduction.

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C H A P T E R   T W O

THE HOLDERNESS BEACH AND ITS ORDS

A. The Holderness beach.

B. Ords in the past - A. W. Phillips.

C. Ords in the past - Aerial photographs.

C. Ords in the present - A classification.

D. Ords in the present - General changes 1974 - 1976.

A. THE HOLDERNESS BEACH

The Holderness coast is 64 kilometres in length, from Bridlington harbour in the north to Kilnsea in the south, and another 8 kilometres from Kilnsea to the tip of Spurn Head. The beach is uninterrupted the whole length of the coast and can be classified into three sections. The boundaries between these sections are very approximate.

The first section, in the north, lies between Bridlington and Fraisthorpe (4 kilometres in length). Here the beach is wide (over 300 metres at mean low water), with a gentle gradient between the cliff foot and low water mark of approximately 1·5 degrees. A well-formed ridge and runnel system is present with three or four ridge/runnel units across the beach. Most of the runnels are water filled at low water and at intervals runnels cross through the ridges, draining the low sections of the beach. Figure 2.1 shows a typical profile across the beach on the South Sands at Bridlington. This system of dry ridges, crossed only occasionally by a transverse runnel sweeps southwards around Bridlington bay.

The beach material in this section is almost completely sand, characterised by its shelly and chalky nature. The small amount of shingle that is present is concentrated at the cliff foot. This wide flat beach offers moderate protection to the cliffs south of Bridlington which are low and in many places topped by low, well-vegetated sand dunes. Mean high water is at, or just below the cliff foot.

The second section of beach, like the first is quite short, $2\frac{1}{2}$ kilometres, and continues from Fraisthorpe to Barmston. This part of the beach forms a zone of transition between one beach form, the ridge and runnel system, and the next. Here the ridges and runnels become less important and the beach near low water mark is lower and often covered by a thin sheet of water at low water. The beach gradually builds up near the cliff, and this becomes recognisable as a separate unit in the area of Barmston, with a smooth but steeper face than the wetter lower beach near low water mark. This upper beach has not a very great depth - less than half a metre - and is removed quite quickly by rough seas, disclosing a smooth shore platform of till, continuous with the material in the cliff. The beach material here displays a more varied character than the northern section. The main beach material is sand, still slightly shelly but not as noticeably so as in the north. Sorting of the sand is evident, the coarser material lying nearer the cliff. There is more shingle in this section, scattered over all the beach, but also occasionally in cusps, often elongated, perpendicular to the cliff, on the lower slope of the upper beach.

The third section includes all the remaining beach of Holderness and the seaward side of Spurn Head. The beach displays a well-developed form, divided into two distinct parts, an upper beach and a lower beach. The upper beach, adjacent to the cliff, has a convex form in profile and is composed of coarse sand and shingle of all sizes. The shingle is often continuous on the lower slope of the upper beach, sometimes worked by the waves into cusps, and is only thinly scattered over the sand nearer the cliff foot. Surface water is absent on the upper beach at low water and the water table frequently comes to the surface along the lower edge. The lower beach extends from the bottom of the upper beach to low water mark. This is characterised by a more gentle even slope and is covered by surface water at low water. Only occasionally a small area of dry sand rises slightly above the general level. The material of the lower beach is almost always fine sand. An occasional small pebble may be seen, but rarely except after exceptionally rough sea conditions. The division between the upper and lower beach may be sharp both in slope and beach material or in places may be a zone of more gentle transition.

Material is supplied to the Holderness beach as a whole solely from the sand and gravel lenses in the cliffs, the promontory of Flamborough Head impeding any sediment movement from the north. The volume of sand in the beach increases southwards as a result of longshore drift. This has quite a marked effect on the beach width and general shape, as will be shown in detail in succeeding chapters. The Till shore platform is visible, not only in the north, as outlined above, but also in the third section of the beach. It is seen at or about the low water spring tide mark in many places where the lower beach thins out completely. Often associated with the platform are large rock boulders, erratics from the till which are too large to be moved by the waves and lie in the position in which they fell from the eroding cliffs.

Another quite noticeable beach and offshore feature is the locally named "Skerrie", similar to the "scars" of Morecambe Bay. A skerrie is a small area, up to approximately 100 metres in diameter, of assorted rock boulders (from 10 centimetres to over half a metre in diameter) embedded in a till surface. The skerries are either incorporated into the beach system, for example at Nevills, south of Withernsea, or occur as an offshore feature, only visible at low water spring tides. They may, on a well built up beach, become covered by the sand and shingle and thus be hidden from view.

Unlike most of the Norfolk and Suffolk coastline the Holderness cliffs have no man-made protection from wave action for much of their length. Concrete revetments with adjoining wooden groyne systems are present at Bridlington, Hornsea and Withernsea. At Kilnsea and Spurn there are the less strong wooden and concrete revetments and also groynes, severely damaged in places by marine attack. At Bridlington the groynes, which reach halfway to the low water mark, date from 1877 (Wheeler, 1902), and the sea wall south of the harbour from 1896. A stronger extension was added to this in 1974.

Groynes at Hornsea were originally constructed in 1869 by a private landowner, and as early as 1885 the effect of their presence was recorded by Reid (1885) who notes that although the beach at Hornsea was well built up:-

> "South of Hornsea the effect of the groynes is now being felt in the deficiency of the beach and consequently more rapid wasting of the cliff; but

the present groynes being very modern, the cutting back is not yet sufficient to endanger the defences."

The defences at Hornsea were practically destroyed by severe gales in 1906 (Douglass 1911) and it is after this that the main part of the sea wall in existence today was built.

The groynes at Withernsea date from 1870 and the first revetment probably from about the same period. Reid notes the protective influence of these defences extending up to two miles northward but also records an extra beach deficiency for two miles south of the town.

On Spurn Head the first groynes were erected in 1864 at the narrow reach of the spit. The revetment of wood with concrete behind was added later with the rest of the groynes.

The beach system has been discussed and attention will now be given to the ord system within it. Ords, in the form outlined in the introduction, are not found in either the first or second sections of the beach just discussed. They first appear in a zone south of Skipsea but north of Hornsea, and southwards from there can be found as part of the beach system all the way to the south end of Spurn Head.

B. ORDS IN THE PAST - A. W. PHILLIPS

It was noted in the introduction that no published references had been made to the ords before the work of A. W. Phillips, at Spurn Head and south Holderness. Neither have similar features been reported from any other world coast, the nearest related features being certain crescentic beaches in the eastern U.S.A. (Dolan, 1971, 1974), and some ridge and runnel beaches (King and Williams, 1949, King and

Barnes, 1964). These similarities will be discussed in more detail in Chapters IV and VI. Therefore to study the ords which existed before the study period of 1973/1976, in any detail, we can refer only to two sources. One is the work of Ada W. Phillips at Spurn Head and Kilnsea in the late 1950's and early 1960's (Phillips, 1962, 1964), and the other is the aerial photograph collection at the department of Geography, University of Hull.

Phillips' brief definition of ords is as follows:-

> "Along much of the Holderness coast features which in dialect are known as "ords" form part of the pattern of changes in the beaches. These features result from the removal of a vast quantity of sand and shingle from the upper part of the beach which may reduce its height by about 10 feet and sometimes exposes the boulder clay beach platform. Ords vary in length along the coast, but are commonly between 50 and 60 yards long. Severe storms do not fill them in, but move them about one mile per year."
>
> Phillips 1964

Phillips recorded the movement and changes within one ord on Spurn Head during 1959 and 1960. In the autumn of 1959 this ord was positioned at the narrowest section of the spit, as it swings from a north-west to south-east alignment towards a north-east to south-west trend. This point was called point X.

> "From September 1959 to early January 1960 this feature varied but little. At the narrow section of the spit the upper beach was completely missing, and the large pebbles which form the base of the beach were exposed near several of the groynes. Elsewhere the beach was composed of fine sand, sloping gently and evenly to the low water mark. The beach reached its lowest level beneath the groynes, which had been excavated below the lowest cross-plank."

In the middle of January 1960 more rapid changes took place as serious damage occurred to a groyne and part of the revetment, allowing a large semi-circular bite to be taken out of the dunes behind. This occurred again between 26th and 29th of January.

> "At the same time as this destruction occurred the beach was beginning to build up again. A tongue of sand and shingle of assorted sizes began to extend from the upper beach north of the ord and penetrated south of the broken groyne by 2nd February. As this feature extended southwards it was at the same time being pushed up the beach. This formed the core of a new upper beach which was built up rapidly during February and March."

The ord continued to move southwards during severe storms between March and September 1960. At point Y, 2 kilometres south of point X, beach changes brought about by the approaching ord were monitored by transverse profiles across the beach at that point. After storms in early October the ord became centred on Y. During late March 1961 strong northerly gales caused the ord to move south from Y and in quieter conditions the upper beach re-formed as a separate entity from the lower beach. Figure 2.2 (after Phillips, 1964) shows how the beach profiles changed at X and Y over the period of observation. Another ord was also observed by Phillips at Kilnsea, against the till cliffs. In 1961 this ord showed a pattern of southward movement similar to that of the ord on Spurn Head the previous year.

A detailed study of the relationship between wind direction and velocity, and beach change at Spurn Head, established that only when winds of over 15 knots blow from a northerly quarter for at least several hours does a major breakdown in the form of the beach occur. Under most other wind conditions the beach tends to become built up in form.

From the beach surveys and the study of wind data Phillips reached three main conclusions on ords. These will be quoted in full as they formed the basis for much of the research for this thesis, and, as such, are unique in the study of the Holderness ords:-

> "1. During a severe storm with strong winds from a northerly quarter, an ord is moved southwards into a new position. The upper beach is swept away and therefore no division of the beach into upper and lower sections is possible. The bottom part is raised slightly in height with some of the sand and small pebble components of the former upper beach. It is probable that some of the remainder of the material is swept southwards to form a well developed series of sand and shingle rises on the lower beach south of the ord.
>
> "2. The presence of an ord enables most high waters to reach the back of the beach causing the cliffing of dunes, the erosion of boulder clay cliffs and the undermining of groynes and revetments. If strong winds from the north occur when an ord is established, and the winds are not strong enough to produce waves capable of moving it, they nevertheless cause rapid erosion of the sand or boulder clay cliff and smash groynes and revetments. Because of the nature of the material, a sand cliff will retreat immediately it is attacked, whereas a boulder clay cliff may need to be considerably undermined before parts will collapse.
>
> "3. The movement of an ord southwards during a severe storm is inseperably linked with the movement of material from the north. The building up of the beach where an ord has been present is commonly by the pushing up-beach of a tongue of sand and shingle which has extended from the upper beach to the north. Once the upper beach is re-established its build-up is likely to be rapid, but at the same time the lower beach will be reduced slightly in height."

C. ORDS IN THE PAST - AERIAL PHOTOGRAPHS

There are six sets of aerial photographs which give stereoscopic cover of the Holderness coast. These are not all on the same scale but comparison between one set and another is not difficult. The six sets are dated as follows:-

5 - 9 - 59	(1 : 5,000)	
16 - 3 - 61	(1 : 15,000)	(A)
23 - 3 - 61	(1 : 15,000)	(B)
15 - 9 - 62	(1 : 15,000)	
7 - 5 - 66	(1 : 5,000)	
11 - 5 - 72	(1 : 15,000)	

The sets for 1959, 1961B and 1962 are incomplete north of Hornsea. The second March 1961 set was taken immediately after a storm, thus producing a useful before and after sequence. Unfortunately the second run was taken in the afternoon when the cliffs cast a shadow over the beach. This very dark zone on the photographs makes them difficult to interpret. The 1966 set is also rather poor, for despite the larger scale it was taken at mid-tide with much of the lower beach below water and therefore the form of the beach is again difficult to interpret from these photographs.

The period between each set (except for the 1961 sets) is too long for any particular ord to be followed from one set to the next with any certainty, but they are useful in establishing basic positioning. It is unfortunate, due to economic pressures, that a run could not be undertaken during the period of the present study, for a more detailed comparison to be made. The mechanisms of ord movement cannot be established from these aerial photographs with such a long period between each set. No details of the ords on Spurn Head have been recorded from these photographs. Table 2.1 shows the lengths and approximate positions of the ords in each set of aerial photographs.

In 1959, with no data available north of Hornsea, there were eight ords present on the Holderness coast. Five of these were situated between Hornsea and Withernsea, and they varied in length between 3.8 and 0.8 kilometres. They all had a centre which was less than half a kilometre from the northern end of the ord, except for the ord near Waxholme which had no centre visible from the photographs.

The first set in 1961, with data available north of Hornsea, shows ten ords on the Holderness coast. This included one ord north of Atwick and five between Hornsea and Withernsea. Seven of the ords had centres less than half a kilometre from their northern ends, three others showing no visible signs of a centre. These were the relatively short ords at Tunstall, Waxholme and the feature around the fort at Kilnsea. The second set for 1961 is not complete north of Hornsea. There were eight ords visible on this set, all with centres less than half a kilometre from the northern end, except for the ord near the Runnel and again the feature at Kilnsea. Both of these were relatively short.

In 1962, with no data north of Hornsea, nine ords were visible, five of these between Hornsea and Withernsea. All of these ords were over a kilometre in length and all, except the ord at Out Newton, had centres less than two thirds of a kilometre from the northern end of the ord.

In 1966, with full but rather poor aerial coverage of the whole Holderness coast, eight ords were visible. One of these was north of Hornsea and four between Hornsea and

and Withernsea. Only two had visible centres and these were the largest ords. The lack of visible centres in the other ords may be due to either the wind, wave and tidal conditions leading up to the time of the aerial run, or to the poor photographs, which are indistinct and therefore difficult to interpret details from. As will be seen later, certain physical conditions can obscure the centre of an ord for a time, without obliterating the whole feature.

In 1972 there were nine ords visible. One of these was north of Hornsea and five between Hornsea and Withernsea. The northern five ords and the ord near Easington had centres less than 0.2 kilometres from the north end. The other three had no visible centres. The first ord south of Hornsea appeared to have more than one centre within its boundaries. This phenomenon will be investigated in more detail in Chapter IV.

From table 2.1 it can be established that an ord can be generally positioned from one of ten points along the coast. North of Hornsea this point is the road end at Atwick (grid ref. TA 197512). From here there is a good view north along the beach to Skipsea and south to Hornsea. On the aerial photographs no ord is positioned more than three kilometres north of here, but in all the available photographs there is always an ord in this area north of Hornsea. There has been an ord positioned at Rolston on each set of photographs except 1966. In 1961B this was a particularly large ord extending both north and south, overlapping into the next area, at Cowden. South of the road end at Cowden there has been an ord in each set of photographs, with the northern end north of Cowden on two occasions. Between here and Aldbrough is a Ministry of Defence firing range for aircraft and the only beach data available for this zone is from these photographs.

The ords on the photographs are found north and south of the cliff top form at Ringbrough, south of Aldbrough, and also around the Hilston road end. The other site north of Withernsea is between Sand-le-Mere and Waxholme. It is possible that some of the shorter features visible around Sand-le-Mere are not ords but are areas of exposed peat, near the groyne at low water, mistaken for such. Sand dunes in the place of the till cliffs at Sand-le-Mere give the beach a different form on the aerial photographs.

South of Withernsea ords are found on the photographs north and south of the Runnel, a small stream with an outlet on the beach one kilometre north of Holmpton. Further south ords are found around the hamlet of Out Newton and Dimlington Highland (the highest cliffs on the Holderness coast - over 30 metres in height). On the photographs ords are also positioned around the North Sea Gas Station at Easington. The last point on the Holderness coast around which the ords appear is the old fort at Kilnsea. Only in 1962 was the ord seen here of substantial size, two kilometres in length.

The storm in 1961 did not affect each ord in the same way, some grew longer and some shorter. Only the feature at Kilnsea remained the same length. The absence of an ord at Out Newton in the second set is most likely due to the poor quality of this set of photographs, although the possibility of the feature being obliterated by the storm cannot be dismissed at this stage. As interesting as the change in the length of the ords is the direction in which this change occurred. At Rolston there was a small movement south of both ends of the ord. At Cowden the ord became smaller from both ends. The ords at Ringborough and Hilston both grew larger to the north. At Waxholme the feature was enlarged considerably both north and south, but especially in the latter direction. South of Withernsea, the ord north of the Runnel, at Intack, enlarged a little in both directions. This was only a short feature (one kilometre in length). Figure 2.3 shows the configuration of the beach within the ord before and after the storm. On 16th March the ord is short, ending immediately south of the skerrie where the upper beach builds up quite quickly to the south. North of the ord the upper beach is only poorly built up. There is no till platform visible but the upper beach is absent within the ord. The lower beach is well developed into high, dry rises with occasional outlet runnels between. On 23rd March, after the storm, till platform was exposed at the cliff foot for 600 metres. The seaward edge of the platform was covered by a line of till boulders which extended slightly to the north of the platform and also along the edge of the widening upper beach to the south. The lower beach was still dry but there were more runnels across and it was generally flatter and lower.

The ord at Easington moved slightly northwards at both ends.

Many of the ords had no visible centre before the storm but had after. Perhaps, as with the ord outlined in more detail above, the effect of this storm was not to generally move or lengthen the ords in either direction, but to deepen them, and it was found therefore to have followed a period of calmer weather conditions when the features within the ords had become obscured (wind data from Phillips, 1962).

One or two basic conclusions can be drawn from this short study of the available aerial photographs. At any one time there were not less than eight ords present on the Holderness beach. These were fairly evenly spaced along the coast between Skipsea and Kilnsea. The lengths vary considerably; the average length of the 52 ords listed in table 2.1 is 2.0 kilometres, but generally the lengths were greater in the northern ords (excluding those north of Hornsea). No ords were found further north than Skipsea, but they were well-established north of Hornsea. Therefore we can trace the presence of ords on the Holderness beach back into the 1950's and there is no reason to believe they have not been in existence long before this period although overlooked by geomorphologists and taken for granted by local fishermen and others living by the sea on the Holderness coast.

D. ORDS IN THE PRESENT - A CLASSIFICATION

At the beginning of the present study in January 1974 there were seven ords present on the Holderness beach (figure 6.1). The northernmost of these was situated between

Atwick road end and the North Cliff sailing club, Hornsea, (grid ref. TA 201502). This was named the Atwick ord. In January 1974 it was 1400 metres long. The northern end was 300 metres north of the road end and the beach built up to mean high water mark at the cliff foot 350 metres south of the sailing club.

The second ord, between the children's camp at Rolston and the road end at Mappleton (grid ref. TA 228438) was 1500 metres long. This was called the Rolston ord. The third ord was the longest of all, 3,000 metres, and extended between the road ends at Cowden and Aldbrough. It was named the Cowden/Aldbrough ord. The fourth ord was situated around the cliff top farm at Ringbrough, south of Aldbrough. It was 1200 metres long extending from 100 metres north of the farm to Beacon Hill in the south, and called the Ringbrough ord. The fifth ord was found between Hooks farm and the Hilston road end, 1300 metres in length. This was called the Hilston ord.

The upper beach was well built up between Tunstall and Withernsea, with no sign of till platform on the beach. There was an outcrop of peat near the low water mark adjacent to the groyne at Sand-le-Mere.

South of Withernsea there was a complex double ord feature between Nevills farm and the Old Hive stream outlet, south of Holmpton. This feature was 2,400 metres in length. It was named the Holmpton ord, but when split into two the north section will be called the Runnel ord and the south section the Old Hive ord. The seventh and most southerly of the ords on the Holderness beach at this time was the

Easington ord between Dimlington farm and Easington road end. This ord was 2,200 metres long. South of Easington the upper beach was well built up all the way to the tip of Spurn Head and a detailed examination of the Spurn beach did not reveal any signs of an ord present at the time.

The ords can be classified into two groups on the basis of their surface features. The first group includes the five northernmost ords, Atwick to Hilston. The second group includes the remaining two ords. Figure 2.4 illustrates a generalised ord in group A. To the north of the ord the upper beach becomes lower and narrower as the ord is approached, and it eventually disappears altogether. When the till platform is exposed it is usually confined to an area very close to the cliff foot (less than 10 metres from the cliff foot). The till platform has a smooth surface and is often continuous with the cliff from which it gently slopes away. Except after times of exceptionally calm weather, when there has been little or no cliff erosion in the zone of the ord, the seaward edge of the till platform is covered by a line of till boulders. These range in size from nearly a metre to less than 10 centimetres in diameter, and are all in the process of being quickly broken up and washed away in suspension in the sea. To the south of the till platform the upper beach builds up again at the cliff foot, often quite abruptly, and within the space of 100 metres reaches its maximum width and height. The till platform may extend for a short length away from the cliff at the foot of the upper beach in the south. The lower beach is free of surface water within the boundaries of the ord and extends from the till platform, or the line of till boulders to the low water mark. Although the lower beach is dry it is raised little above the height of the adjacent wet lower beach and is almost flat. There are few drainage channels across the lower beach although low wet patches within it are common, separating it into sections.

The ords of Holmpton and Easington form the second group of ords, group B. Figure 2.4 illustrates the main features of this group. The upper beach becomes lower and narrower to the north of the ord and fades out much in the same way as the feature in group A ords. Till platform is exposed at the cliff foot just south of this. The platform is found at the cliff foot for a varied distance between 10 and 200 metres,but then lies at an angle to the cliff and is separated from it by the gradual build up of the upper beach to the south. Unlike the ords in group A this build up in height and width of the upper beach in the southern part of the ord is very gradual. The till platform extends along the seaward edge of the upper beach until the upper beach reaches its maximum width and height when the till platform is covered and out of sight. The till platform retains an almost constant width for the length of the ord until it is covered by the upper beach at the south end. This width may vary between 5 and 30 metres at different times of the year. As in the group A ords the lower parts of the platform may be covered by till boulders. The till platform does not always have a smooth surface in Group B ords. It is often quite deeply grooved and the surface weathered to disclose structures in the till.

The lower beach is free from surface water within the boundaries of the ord. Unlike group A ords the lower beach in group B ords is usually raised into a high unsymmetrical ridge. This has a steep short slope at the landward edge and a longer, gentle slope to low water mark. This ridge often traps water as the tide ebbs and this is left as a water-filled runnel at the junction of the till platform and the lower beach. This runnel is drained by one or two channels crossing the lower beach and at the southern end of the ord where the raised lower beach becomes lower. When the tide floods, this runnel becomes filled with water very quickly and cuts off the lower beach ridge from the till platform and upper beach.

The presence of a water-filled runnel in an ord at low water indicates to the observer the degree of build up of the lower beach. Therefore where the lower beach is low, as in the ords of group A, there is rarely a water-filled runnel present, but it is a common feature in the ords of group B.

The beach materials in the ords are similar in both groups. The upper beach is formed of coarse and medium sand, with shingle on the lower slopes of both the northern and southern upper beaches within the ord. The lower beach is solely of medium and fine sand. Shingle is only present on the lower beach in exceptional circumstances (Chapter 4). The beach material within an ord will be discussed in more detail in Chapter Four.

E. ORDS IN THE PRESENT - GENERAL CHANGES 1974-1976

Between January 1974 and February 1976 general observations were made of the beach all along the Holderness coast, at regular time intervals. Wind observations at three-hourly intervals have been obtained from the Kilnsea Meteorological Station and these are plotted in figure 2.5, for each interval between the relevant observations discussed below. For this initial analysis of the wind data a simple scheme has been devised. Each observation has been placed in one of four quarterly directional groups. These are as follows:-

the northerly quarter	315° - 45°
the easterly quarter	45° - 135°
the southerly quarter	135° - 225°
the westerly quarter	225° - 315°

Each of these is divided into three sub-groups for wind speeds of 1 - 10 knots, 11 - 20 knots and more than 20 knots.

The period of observation has been divided into 16 shorter periods, and the changes in the features of the ords, and the corresponding wind records during each period, will now be outlined. Detailed diagrams of the changes in the ords at Atwick and Holmpton are found in Figures 4.22 to 4.33. original position of the ords in January 1974 has been discussed above.

The first period started on 8.1.74 and ended on 8.3.74, and the changes to the ords were as follows. All the ords were slightly shorter from one or both ends. An upper beach, narrow but continuous had developed along the length of all the ords. The area of till platform in each ord was much reduced. In the group A ords the till platform had been confined to very small areas, less than 10 metres in length, at the cliff foot. In group B ords the platform was also much smaller in area and confined to a strip at the base of the narrow but continuous upper beach. The lower beach was slightly lower, especially in the southern part of the ords, although the water-filled runnel was still present in a shortened form. In both groups where till boulders were present these were in a line very close to the cliff foot. The dominant winds during this period were from the west and south, and of all strengths. Winds from the norther quarter only blew for a short time and can be discounted as far as having any effect on the beach is concerned. Therefore the winds of any duration were from offshore or alongshore from the south.

The second observations were on 26.4.74. Since the previous observations most of the ords were slightly shortened from the southern end. The amount of till platform uncovered varied from ord to ord. At Atwick and Hilston, in group A, where there was very little till platform present in March, there was none visible in April. At the Cowden/Aldbrough ord (group A) and the Holmpton ord (Group B) there was more till platform visible along the cliff foot in the former but only at the seaward side of the upper beach at Holmpton. The upper beach was still much in evidence along the whole length of most of the ords. The lower beach in the group B ords was still not as high as it had been in January and therefore the runnel was poorly developed. The dominant winds for this period blew from the northern quarter with a moderate strength. The only direction with any duration of strong winds was from the east, the direction of the shortest fetch (figure 2.6). During this period the westerly and southerly winds were poorly represented.

The next observations were carried out on 22.5.74. There was very little change during this period. The area of till platform visible altered little, but the continuous narrow upper beach present in most of the ords in April was absent in May. It was replaced by the lower beach, low, flat and dry continuous from low water mark right up to the cliff foot. The dominant winds during this period blew from the south and east with a moderate strength (11-20 knots).

Further observations were made on 20.7.74. Since the observations in May the ords had again altered only in minor details. The dominating feature in the ords of both groups was still the lower beach, all the way from low water mark to the cliff foot. In most ords in group A the till platform was not exposed and the absence of an upper beach was the main evidence for the presence of an ord. In the group B ords the till platform was exposed in places near the cliff foot, but not joining with it. The dominant winds during the period were westerlies, although there were also a significant number of light and moderate northerlies. In comparison with the previous period the number of calms recorded was high.

The next observations were made on 24.9.74 and again only small minor changes had occurred since the last observations. Till platform was only present in small areas at the cliff foot in the group A ords. In the group B ords the till platform was much as it had been in July, just a small area near the cliff foot, only separated by a narrow upper beach. In these ords the lower beach was raised slightly above the July level, trapping short water-filled runnels between the till platform and the lower beach. Light and moderate strength winds were dominant from both western and southern quarters and there was also a fair proportion of light northerly winds. Very few strong winds of over 20 knots were recorded, none from the northern quarter.

The next observations were made on 17.10.74. There were quite marked changes within the ords since 24.9.74. In all the ords the area of till platform visible was very much greater. In them all it extended from the north of the ord along the cliff foot almost to the southern end. In all cases the build up of the upper beach in the south was abrupt. The till platform was well covered by till boulders and the cliffs showed signs of recent erosion, in the form of slips and falls, and were almost vertical in places. For the first time since the beginning of the study the lower beach of the ords in group A was slightly ridged in places, and trapped narrow water-filled runnels. In the group B ords the lower beach was lower than it had been previously, although still dry in most places. The water-filled runnels here were confined to the southern ends of the ords. The northern ends of all the ords were re-exposed and for the first time since January the centre of each ord could be established easily by the observer. This was in comparison with the rather blurred forms noted during the summer months. Therefore, at this time the ords from both groups displayed very similar characteristics. The wind data records light and moderate winds blowing for much of the period from the north and west, but strong northerlies (more than 20 knots) blew constantly on the 3rd and 4th of October and again on the 7th. Moderate north and westerly winds blew on the intervening and following days. Therefore for almost a week, at the beginning of October 1974, there were constant strong and moderate winds, mostly from the northern quarter.

Further observations were made on 28.11.74. At this time it was noted that the ords in group A displayed certain constant characteristics. There was no till platform at the cliff foot and therefore the centre of the ords was difficult to establish. The platform was less extensive than at the time of the previous observations, especially in the northern part of the ord, and it was found on the seaward side of a low upper beach which was continuous the length of the ord. The upper beach between ords was also quite low and the mean high water mark reached the cliff foot at most places along the coast. The lower beach was not as well built up as it was in October, but it was still dry within the boundaries of the ord. The till boulders were not as numerous as before. The ords in group B displayed a similar distribution of till platform, most platform in the north of the ords being covered by a thin layer of upper beach. Till platform adjacent to the cliff foot was much in evidence in the south of the ord. The lower beach was built up into a ridge, higher than in October. As in the group A ords there were less till boulders on the beach. The wind records show a dominance of winds of all speeds from the south and west, but strong northerly winds blew for a few days in October - 21st, 22nd, 23rd, 29th and 30th.

The next series of observations took place on 11.1.75. Very little change had occurred in the group A ords since the last observations. Till platform was present in a narrow line parallel to the cliff foot, but separated from it by a narrow upper beach. Only at Hilston was there any connection between the cliff foot and the till platform. In the group B ords till platform again emerged in the northern parts of the ords, but the platform in the south had diminished in area. The lower beach was in a similar condition to that of November. The north and south ends of all the ords were in a similar position in January 1975 to those in January 1974. The only noticeable feature at this time was on extension of the northern upper beach, at Holmpton, south into the lower beach zone. This will be discussed in more detail in Chapter IV. The winds during this period were solely from the west and south, westerlies being the most common.

At the next observations on 4.3.75 the till platform was absent from all the ords in group B and most of the ords in group A. Where it was visible it only occurred in small patches at the cliff foot. Ords in both groups were dominated by the dry lower beach which in most places extended from the low water mark to the cliff foot. In the group B ords this was raised into one or two gentle ridges with water-filled runnels between, most parallel to the cliff foot. The north and south ends of all the ords were quite clearly defined and a line of till boulders was common along the length of the ords, at the cliff foot. The wind records for this period show almost no northerly winds, but many from the three other quarters. For the first time in many months easterly winds form a fair proportion of the data.

Further observations were carried out on 16.5.75. In the period since the last observations were made quite marked changes had taken place in ords of both groups, but especially in the group B ords. In group A there was more till platform visible but this was separated from the cliff foot by a narrow but continuous upper beach. Till platform was found further south, at the base of the upper beach, than had been previously reported. The lower beach was dry but not raised into a ridge. In the group B ords the amount of visible till platform was the greatest yet seen. The ord at Holmpton was again split into two by a bank of upper beach south of Holmpton farm (TA374239).The till platform in the south covered only a small area, but the northern section of platform extended for over one kilometre. The northern ends of the ords in group B were clearly marked by a sharp decline in the width of the upper beach at 100 metres north of the till platform. The lower beach was well raised into the characteristic asymmetrical ridge, and this trapped a water-filled runnel against the till platform. Winds during the preceding period were mostly from the northern quarter. These blew continuously on 19th, 20th March, 2nd, 3rd, 4th, 5th April, and 5th, 6th, 7th May, at strengths over 20 knots.

The next observations were made on 22.7.75. The ords in group A had a greater area of till platform visible. In the north this formed a centre at the cliff foot. The northern end of the ords was sharply defined as the northern upper beach ended. To the south the build up of the upper beach was more gradual. The lower beach was in a typical group A form, dry, but not excessively raised. The ords in group B had less till platform visible than at the last observation. This was concentrated around what was the middle section of these ords in May. The upper beach was present at the cliff foot all along the ord. The lower beach was again well built up, especially in the north and opposite the till platform. Strong northerly winds blew on 27th and 28th May and moderate northerlies at the end of May and the end of June. Moderate winds from the other quarters were common although strong winds infrequent.

At the time of the next observations on 27.9.75 there was no till platform at the cliff foot in group A. The platform visible was reduced in area since the last observations. The low dry lower beach extended up to the cliff foot in the northern parts of the ords, the upper beach building up gradually to the south, as in July. The northern ends of the ords were quite clearly established where the upper beach ended abruptly. In the group B ords the pattern of shrinking till platform was similar, especially in the north of the ords. The northern ends of these ords were sited further south than in July, the wide upper beach gradually fading out into the lower beach near the cliff foot. Very few strong winds blew during this period, and the wind records show an even distribution between all quarters, with a slight emphasis on westerlies.

The next observations took place on 17.10.75. The ords in group A were in a very similar form to those in the last observations. The ords in group B show another movement south of the upper beach in the north, and as in January 1975 the northern upper beach extends on to the lower beach for a short distance. There is more till platform visible in the south of the ords. Westerly and southerly winds dominated the previous period.

The next observations were carried out on 18.12.75. In the group A ords the upper beach was wider to the north of the ords. The area of till platform exposed in the south of the ords was much greater than in October, and extended most of the way along the ord at the cliff foot, often 30 to 35 metres wide. The ords in group B were dominated by two main features at this time. Firstly there was a large area of till platform exposed in the southern part of the ord. This was adjacent to the cliff for most of the length of the ord and was up to 50 metres in width from the cliff foot. Secondly, north of this was a well built up upper beach, extending seawards and southwards on to the raised lower beach of the ord. Therefore these ords were shorter from their northern ends than in October. The upper beach to the south of the ords was built up within a short distance of the till platform, although not to the exceptional width of the upper beach in the north. The lower beach was high and asymmetrically ridged, trapping a water-filled runnel the whole length of the till platform. The winds during this period blew from all quarters, especially moderate winds from the south and west. On 16th, 17th, 18th and 23rd November, strong northerly winds blew constantly.

The next observations were made on 5.1.76. In the group A ords the northern upper beach, which had been built up at the time of the previous observations, had been lowered in all the ords of this group. It was positioned slightly further south. A large area of till platform was exposed at the cliff foot and the lower beach was raised above the previous level, almost into a ridge form. In the group B ords there was still a large area of till platform exposed, although this was narrower than on the 18.12.75, as the lower beach had widened and covered the seaward edge of the platform. The northern upper beach had moved slightly southwards and the southern upper beach was lowered.

The winds during the previous fortnight mainly blew from the westerly quarter. During the severe storm on 2nd and 3rd January, wind speeds reached 55 knots from the north-west. There were no winds from the northerly or easterly quarters over 20 knots.

The last observations were made on 16.2.76. All the ords, of both groups, displayed subdued features after a period of calmer weather after the storm in January. The northern and southern upper beaches had become built up and the lower beach of each ord had moved landwards, covering much of the till platform exposed in January. There were no till boulders on the beach.

The winds blew most constantly from the westerly quarter but winds from the southerly and easterly quarters were also common. Winds over 20 knots were experienced from all three quarters. Northerlies were infrequent.

A few basic conclusions can be drawn at this point, and will form the basis for later chapters, to be verified in full by more detailed study in those chapters.

When winds blow from a westerly or southerly direction at any strength, the features within an ord become subdued. An upper beach may form along the cliff foot and the area of till platform visible becomes less. The ends of the ord are difficult to distinguish because of the presence of the upper beach within the ord.

After a sustained period of easterly winds of all strengths, the lower beach is usually flattened, still dry at low water, and stretching from low water mark right up to the cliff foot. This completely obscures all the till platform. There is no upper beach at the cliff foot between each end of the ord.

Northerly winds of light and moderate strength do not cause much alteration on the beach within an ord. Some lower beach material may move nearer the cliff and cover part of the till platform.

During periods of strong northerly winds, the most marked changes take place. Large areas of till platform are re-exposed in the north of the ords after a long period of filling-in processes, and in the south where the upper beach narrows, fresh areas of platform are exposed. Between ords the upper beach is often lowered and much damage occurs to the cliffs all along the coast.

REFERENCES - CHAPTER TWO

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C H A P T E R   T H R E E

ORDS SELECTED FOR DETAILED STUDY
AND A DISCUSSION OF THE METHODS OF STUDY

A. The Ords
1. Atwick
2. Holmpton
3. Easington

B. Methods of Study
1. The process variables.
2. The response variables.

A. THE ORDS

Three of the seven ords present were selected for a more detailed study over the fieldwork period. These were at Atwick, Holmpton and Easington.

1. Atwick

The Atwick ord was chosen because it is the most northerly of the ords, and, as such, not only represents the group A ords but also reveals information of beach movements in this critical northern zone of the Holderness beach. The ord's position in January 1974 has been given in Chapter Two, Section D. The northern end of the ord was positioned immediately north of the Atwick road end (map ref. TA 197512). Two cottages on the cliff top, 100 metres north of the road end are the only datum points in this area visible from the beach. At the southern end of the ord is a gap in the cliffs for a track down to the beach from the North Cliff Sailing Club (map ref. TA 201502), and 500 metres south of the gap is the northern fence of a caravan site. Datum points on the beach consist solely of concrete blocks, the relics of second world war coastal defences. A line of blocks extend 50 metres from the cliff foot towards the low water mark at the Sailing Club gap. There is a very large block 400 metres to the north of these, lying 20 metres from the cliff foot. These blocks are very useful as temporary datum points for levelling heights provided care is taken in selecting the block, which must rest on the till platform and not on sand, for the sake of its stability between times of survey.

Opposite the Atwick road end the upper beach at the cliff foot is reduced in height and width at the northern end of the Atwick ord. It is usual within an ord for the upper beach to disappear completely but occasionally it may be present in a very narrow and low form the whole length of the ord. Where the upper beach is absent till platform is not always present at the cliff foot. The lower beach often extends right across the beach from the cliff foot to the low water mark. It is only slightly ridged and usually slopes gently, at an angle of 2^{o}, to the low water mark. The lower beach declines in height southwards after its initial build up in the north (figure 4.23, profiles for 23.1.74). The area of till platform visible varies from observation to observation but at all times it has a smooth, unweathered surface, and is often only a few metres wide. It is very rarely visible the whole length of the ord, either at the cliff foot or separated from it by the upper beach. The numbers of till boulders on the beach, usually at the cliff foot or on the till platform, is a function of the rate of erosion of the cliffs during the preceding days. A plan of the ord when first surveyed on 23.1.74 can be seen in figure 4.17. In the figure are marked the sample points, taken along the levelled transverse profiles. The mean grain size of these samples can be found in table 4.4 These will be discussed in detail in the next chapter but it can be seen that generally the sand is much coarser on the upper beach than on the lower beach, especially at low water. The shingle-size beach sediment is not included in this table. This accounts for some of the gaps in the sample grid and the reasons for this are given later in this chapter.

The Atwick ord was first surveyed and sampled on 23.1.74. During the rest of 1974 general observations were made at regular ihtervals (see introduction). In February 1975 the ord was again surveyed and sampled. Another 15 surveys, with frequent samplings, were made over the next 13 months.

2. Holmpton

The ord at Holmpton was chosen for closer study because of its well-developed ord form and also because it displayed a complex double ord feature, not seen in any of the other ords. At the time of the first survey (27.12.73, figure 4.12) the ord was almost two separate ords in very close proximity to each other. The northern end of the ord was south of the skerrie on the beach opposite Nevills Farm (grid ref.TA36325). The upper beach was fully built up again in the south just north of the Old Hive stream outlet (grid ref.TA381232). Useful datum points on the cliff top for the survey work included the Runnel stream outlet, 500 metres south of Nevills Farm, the Holmpton road end, 700 metres south of the Runnel, Holmpton Farm just south of the road end, and also a few field fences reaching the cliff top. On the beach there is a line of concrete blocks near the low water mark opposite the Runnel stream, and another line of blocks 35 metres from the cliff foot at Old Hive. A large erratic, 25 metres from the cliff foot, is found on the beach 260 metres north of the Holmpton road end. Most of these points are included on the plan diagrams (figures 4.12-4.16).

This ord was first surveyed on 27.12.73 when it appeared as a double ord feature. When it is a double ord the northern ord within the Holmpton system will be called the Runnel ord, and the southern part will be called the Old Hive ord. Separating the low areas of beach at the cliff foot (the two separate ords) at this first survey was a bank of upper beach 400 metres in length. The upper beach in the north declined in height and width very gradually. Where it ended at the cliff foot, till platform took its place. The till platform was fairly extensive in the Runnel ord along the cliff foot and up to 60 metres wide before the upper beach began to form again to the south. The till platform continued for a short way on the seaward edge of this upper beach, which itself ended quite abruptly into the Old Hive ord, where till platform was exposed again at the cliff foot. This platform was not as wide as in the northern ord. As the southern upper beach gradually built up, the till platform continued once more on its lower seaward edge. The platform, except for that adjacent to the cliff foot, was deeply grooved and often weathered to such an extent that structures in the till were easily seen picked out on its surface. The lower beach was moderately well developed into an asymmetrical ridge, but only in the northern of these two ords was a trapped water-filled runnel present. A plan of the ord on 27.12.73 is shown in figure 4.12 and the transverse profiles are marked on this plan. The Holmpton ord was surveyed on 27.12.73 and 3.5.74, and during the rest of 1974 regular general observations were made. Between February 1975 and

February 1976, 12 surveys were carried out on this ord. In 1974 only a minor sampling programme was attempted and none was taken on 27.12.73 to compare with the Atwick samples. During 1975 regular samples were taken (Table 4.3).

3. Easington

The ord at Easington was chosen for further investigation because it was the southernmost of all the Holderness ords present at the time of the fieldwork. It was a well-developed ord, and in January 1974 its northern end was at Dimlington Farm (grid ref. TA397208), north of the Easington Gas Station. The southern end was positioned north of the Easington road end. There are very few noticeable datum points on the cliff top, except field fences, on which to co-ordinate beach profiles. On the beach there is a mass of collapsed concrete at the southern end of the Gas Station where the first natural gas pipeline was placed through the cliffs. Also, near the road end is a large, partially-buried concrete gun emplacement.

In January 1974 the upper beach in the north declined very slowly in height and width southwards (figure 4.4) and where it ended till platform was exposed at the cliff foot for 60 metres. At this point the till platform was 35 metres wide. South of this, the upper beach built up very gradually at the cliff foot. It was composed of coarse sand, and shingle of all sizes. Till platform was exposed at the foot of this upper beach the whole length of the ord, only disappearing south of the Easington road end. Towards the south of the ord the till platform was reduced to 10 - 20 metres wide. Like the till platform found towards the south of the Holmpton ord, this platform was often grooved and well weathered. Rock boulders were common on the southern parts of the platform, too large to be removed by the sea, and probably lying where they originally were eroded out of the till cliffs. The most outstanding feature of the Easington ord at this time was the extremely well built up lower beach. This took the form of an asymmetrical ridge, very high and wide, compared with the lower beach ridge in many of the other ords, especially those in group A (see Chapter Two). At low water Spring tide, weathered till platform was exposed at the seaward edge of the lower beach in the northern part of the ord. Samples of beach material were also taken at the time of the survey and the mean grain sizes of the sand are given in table 4.2.

This ord was surveyed on eight occasions between 8.4.74 and 3.6.74. Sand samples were also taken during this period. It was intended to continue the surveys of the Easington ord throughout the period of the fieldwork but this plan was abandoned after the commencement of excavations to place two new natural gas pipelines across the beach and through the cliffs, in July 1974. The disturbance of the sand, the positioning of metal piles across most of the beach, and the presence of earth-moving machinery disturbed and altered the form around the centre and north of the ord. Therefore, only general observations (see Introduction) have been carried out since that time.

B. A DISCUSSION OF THE METHODS OF STUDY USED IN THE FIELD AND THE LABORATORY.

The beach environment is a complex interaction of many variables. These can be divided into two groups: the process variables operating on the beach, the wind, the waves and the tidal conditions; and the response variables, the characteristics of the beach on which the process variables are operating.

1. The Process Variables.

THE WIND

The speed and direction of the wind greatly affect the waves operating in the inshore zone, even when the waves themselves are generated in another sea area by winds with different characteristics. It is possible, with the knowledge of the wind characteristics, to predict the wave energy and the longshore drift potential of such waves.

Wind data, comprising of direction (to the nearest ten degrees), and speed, in knots, has been obtained from the Meteorological Station at Kilnsea, for three-hourly intervals. The results of a primary analysis of this data have been given in Chapter Two (figure 2.5). This involved grouping the information into four directional quarters: the northerly quarter 315°-45°; the easterly quarter 45°-135°; the southerly quarter 135°-225°; the westerly quarter 225°-315°. The winds in each quarter were divided into three groups for wind speed: 1-10 knots; 11-20 knots; more than 20 knots. This is only intended to be a basic division of the data. In the following chapters a closer breakdown of the details of the wind regime, related to wave and tidal conditions, and the changes on the beach, will be carried out. The conclusions of Phillips (1962) concerning beack breakdown during a period of northerly winds of over 15 knots will be investigated in the light of the present findings.

THE WAVES

It was not possible to establish a wave recorder gauge for any part of the study period off the Holderness coast. Therefore the only wave information collected during this period was from observations at the shore during times of surveys (Table 3.1). The direction of the waves was obtained by taking a compass bearing along the wave crests and calculating the direction of approach from this. The wave period was calculated from the number of waves passing a given point in two minutes. The period, T (in seconds), is the time taken for one wave form to move the distance of one wave length. The wave length is proportionally related to the wave velocity, and can therefore be easily calculated from the wave period. Many of the survey points do not possess structures seaward of the breaker zone from which wave heights can be measured, therefore these could only be estimated. For this three classes were employed: waves of less than half a metre in height were classed as small; between half and one and a half metres in height the waves were classed as moderate; and waves of more than one and a half metres were classed as large. The absence of absolute wave heights makes calculation of the steepness parameter of the waves impossible.

Wave refraction diagrams (figure 6.8) have been constructed for the following deep water periods and directions:

12 seconds	N and NNE
10 seconds	N and NNE
8 seconds	N, NNE, and NE
6 seconds	NNW, N, NNE, NE and E
4 seconds	NE and E

The refraction diagrams show the orthogonals, or wave rays, which run at right angles to the wave crests. If the orthogonals are equally spaced in deep water, it is assumed that the energy between any two remains equal. As they are traced towards the shore they diverge or converge, as the wave crests are refracted (by the waves coming into contact with the uneven seabed) and the distribution of wave energy reaching the coast becomes uneven. It is not theoretically possible for the following waves to be generated because of insufficient length of fetch to depth:

12 seconds	NE and E
10 seconds	NNW, NE and E
8 seconds	E

The wave refraction diagrams were constructed geometrically by the method outlined by Arthur et al (1952), on to the most recently printed Admiralty charts. An example of the method is given in figure 3.1. Waves begin to refract when they come into contact with the sea bed at a water depth of half the wave length. The refraction of the waves between two arbitrary contours can be constructed for each orthogonal. The ratio of the wave velocity at two successive contours is calculated relative to the deep water value (figure 3.2). The mean contour between the two depth contours is drawn by eye. The orthogonal cutting the deeper contour at A is produced to cut the mean contour at B. BC is then drawn perpendicular to AB with a length of one unit (on any convenient scale). Then C1/C2 (the ratio of the wave velocities over the contours) is drawn on the same scale from C to cut the mean contour at D. The new direction of the orthogonal is drawn perpendicular to CD so that the length of the original orthogonal is equal to the new orthogonal within the two contours, meeting at E. The new orthogonal crosses the shallower contour at F. Therefore AE = EF in length.

This method of construction of the orthogonals does have its drawbacks. For example, it is not always certain that the complex wave pattern over troughs and bars can be drawn to produce a likeness with reality. The offshore topography of the Holderness coast is relatively simple and uniform (figure 1.1). Only around the southern tip of Spurn Head does the influence of troughs and bars affect the track of the orthogonals. The wave refraction diagrams will be discussed in Chapter Six, when the influence of wave direction on the beach morphology is considered.

THE TIDES

Tidal data for the Holderness coast was obtained from the Admiralty Tide Tables for the years concerned. All tides were taken from the secondary port of Bridlington, which were calculated from the River Tees entrance to the north. The correcting factors for time and height were applied as supplied in the Tide Tables. The high and low waters are 10 minutes later at Hornsea, and 15 minutes later at Withernsea than Bridlington. There is only a small time lag along the Holderness coast. The actual recorded tide levels are superimposed upon the predicted tides in figures 6.3 and 6.5, for two particular periods. The differences between the two sets of tides will be discussed in a later chapter, in connection with other factors of meteorological and morphologic natures; why a tide is higher or lower than predicted and the effect this may have upon the beach.

The high water mark of the preceding tide is marked on each surveyed profile where it appears below the cliff foot. At the time of each survey the position of that day in the Spring/neap cycle is also noted.

2. The Response Variables.

The response of the beach to the processes operating on it was studied in three main ways, each looking at a different aspect of beach change.

PLAN RECORDING AND PHOTOGRAPHIC RECORD

At each observation, plans of the whole Holderness beach, accompanied by detailed notes, were taken. The plans of the ords under detailed study were transferred from the field notebook to the 1 : 10,000 Ordnance Survey map. Details of the remainder of the beach were stored for later comparison. To make the plans taken in the field as uniform as possible, certain guidelines were devised. Fixed points on the cliff top were always included, for example, field boundaries, road ends and farm buildings. Large stable objects on the beach were also marked, such as the concrete gun emplacements left on the beach as the cliff has receded, and very large erratics. These were only considered stable when carrying a good growth of undisturbed barnacles, and sometimes also mussels. The following beach features were then positioned on the plan if they were present on the beach: the upper beach; the lower beach, marked dry, wet or raised; exposed tillplatform; a water-filled runnel at the time of low water; the position of rock and till boulders. In the notes accompanying the plan was included the sediment size and distribution, the condition of the till platform surface and any other unusual features present, such as exceptional ripple patterns. The state of the cliffs was also noted, whether they were sloping and well vegetated, unvegetated but temporally stable, almost vertical with evidence of recent cliff falls, dominated by mudflows or rapidly retreating by crescentic shaped landslides from the cliff top.

The plans drawn in conjunction with beach surveys are obviously more accurate than those drawn only at times of more general observation.. The ord plans in figures 4.3-4.6 and 4.12-4.21 are marked to show from which type of fieldwork they were made. Despite this lower degree of accuracy, it is believed that the value of the non-survey plans is only slightly less, as their value lies in providing a record of the beach morphological changes between the periods of the surveys. Major changes can be depicted quite clearly.

To supplement the plans, photographs were taken at regular intervals looking north and south from 16 positions on the cliff top, all along the Holderness coast. Obviously distances cannot be judged accurately from the photographs and this is one drawback to this method of recording topography, but they are most important as a record of over-all beach change at particular locations. These photographs, taken in colour, and made into transparencies initially, show well the presence of till platform on a sandy beach. Their importance is as a record of beach change. Not all the photographs taken form plates in this thesis, as they are far too numerous, but those included show particularly striking series of beach changes.

BEACH PROFILING AND OFFSHORE ECHO SOUNDING

The ords under detailed study were surveyed, by levelling at low water, a longitudinal profile along the beach from north to south connecting four or five transverse profiles between the cliff foot and the low water mark. The positions of the transverse profiles were decided by the form of the ord and were not placed at regular intervals along the beach, for the first survey at least. For example, the most northern profile would be positioned where the upper beach was completely built up, and high water mark appeared on the beach. The second profile may be placed where the upper beach was no longer in evidence, the "centre", the third transverse profile may be placed across an area of till platform near the cliff foot. The fourth and fifth profiles would be positioned towards the southern end of the ord showing the gradual build up of the upper beach to the south. The same profile positions were used for successive surveys. Only the early 1974 surveys of the ords were made in different positions from those finally determined, and varied from survey to survey as the ord features changed.

Using this method of profile positioning, the movement of the different facets of the ords can be monitored well. The profiles have been plotted in various ways (for example figure 4.8). Firstly, all the transverse profiles for a particular ord on one day are shown together from north to south. This method displays the form of the ord. Secondly, each transverse profile on successive weeks has been superimposed to produce the overall changes for each profile of a survey period. Thirdly, the gain and loss on each profile from survey to survey has been plotted using the first of two successive profiles as a straight zero baseline.

This method of producing profiles was found successful, especially in 1975. The surveys were made weekly over periods of four to eight weeks. It was not possible to survey and observe the beach constantly all the year round.

Each transverse profile has been classified by its form into one of five groups (figure 3.3). Group 1 profiles are typical of the beach at the north of the ords. The upper beach is present but not built up very high. High water mark may be at or above, but never far from the cliff foot. The lower beach is flat, low and wet. The profiles in group 2 are characteristic of the beach at the centre of the ord. There is usually, but not always, till platform at the cliff foot. There may be a slight runnel present, trapped by a lower beach that is moderately well built up into the asymmetrical ridge discussed in Chapter Two. The profiles in group 3 are typical of those found further south from the centre of the ord. The upper beach is beginning to build up again at the cliff foot and may vary in width. Seaward of this is a section of till platform. The lower beach is extremely well built up into a high asymmetrical ridge which usually traps a substantial runnel even at low water. The beach reaches its maximum width within the ord system, at low water, at this point. Group 4 profiles are found in a similar position to group 3 (south of the centre). They are found in ords that are not so well developed, where the limited sediment availability limits the height of the lower beach ridge. The upper part of the profile is very similar to that in group 3 profiles but the lower beach is much lower with a less exaggerated ridge although still dry. There is often only a small, or no water-filled runnel present. The group 5 profiles are found at the southern end of the ord where the upper beach is fully built up once more and it is often higher than the upper beach to the north of the ord in the group 1 profiles. The high water mark is almost always below the cliff foot. The upper beach has a steeply convex slope and often a sharp break of slope at its foot where the low, flat and wet lower beach begins. The lower beach is often narrow at times of low water owing to the large width of the upper beach at this point.

An experimental extension was made to the profiling programme in the form of offshore profiling by echo sounding.

Two tests were made, in August 1974 and August 1975. The tests were carried out in a small 15-foot open boat with an outboard motor. This boat was fitted with a Seascribe depth finder producing a paper trace profile. The results were recorded in feet but also shown in figures 4.10 and 4.34, with a metre scale added, for comparison with the beach profiles. The sounding transducers were fitted into a wooden shell on a steel frame and the whole fitted on to the side of the boat so that the transducers were below the water level at all times. The control box and batteries were placed in the boat.

In August 1974, echo-sounding profiles were made at Easington. These were made at low water and an overlap with the beach profiles was not possible. They form an extension to the beach transverse profiles. In addition, a longitudinal profile from north to south was made 100 metres seaward of the low water mark.

In August 1975 a similar programme was carried out at Atwick. This was undertaken at high water. Each of the four transverse beach profiles levelled during 1975 was extended half a mile offshore, perpendicular to the cliff line. A longitudinal profile was also made 200 metres seaward of the cliff foot. The results of the findings of both series of profile soundings will be discussed in Chapter Six.

SEDIMENT SAMPLING AND ANALYSIS

The distribution of the grain sizes of a beach sediment is controlled by the wave energy. The beach sediment within the three ords under detailed study was sampled at the same time as certain surveys were made, and the scheme for this sampling was planned as follows:-

1. Samples were taken along the transverse profiles levelled within an ord.
2. These samples were not taken at regular distances from the cliff foot or low water mark but at certain morphological points along the transverse profiles. Each sample position can be classified on to the profile classification discussed above (figure 3.3). There are six sample position classification types: (1) is at the cliff foot where this is below the high water mark; (2) is the high water mark where this appears below the cliff foot; (3) is taken on the lower part of the upper beach above the landward edge of the till platform; (4) is the landward edge of the lower beach; (5) is taken on the lower beach halfway (MID lower beach) between (4) and the low water mark; (6) is on the lower beach at the low water mark.

   Therefore, combining this classification with the profile classification, a sample taken at the low water mark on the centre profile of an ord is labelled 26, the profile classification being placed before the sample position.
3. Only sand-sized sediment was sampled for collection. Larger sizes were measured in the field and placed on the recorded plan. Sand is the dominant sediment on the Holderness beach, the larger material being most abundant on the lower slope of the upper beach. Measurement in the field was considered sufficient for the larger material; taking into consideration the laboratory analysis of these sizes would have required a large sample (up to 2 kilograms) which would have been very

difficult to collect. The larger material was therefore placed into one of three size groups based on the lengths of their long axes. These groups, small (s), medium (m), and large (l) are noted on the plans of the ords with the prefix P, denoting sediment of the pebble size:

P_s - less than 4 centimetres

P_m - 4-10 centimetres

P_l - more than 10 centimetres

Sizes greater than 20 centimetres are classed as rock boulders.

4. Only the top centimetre of sand was collected at each sample point, reflecting, it was hoped, the depth of disturbance and movement of only the latest tides. King (1951), after experiments into the depth of disturbance of sand on beaches by the waves, concluded:-

> "... the depth to which sand is disturbed by the waves is very small under normal conditions on a relatively fine sand beach. The approximate value of 1 centimetre disturbance depth for 1 foot of wave height. The relationship is nearly linear and can therefore be extended."

The sampling grid employed in this study is not random but by choosing particular beach forms as sampling points it is hoped more useful results will be obtained.

The samples of sand-sized sediment were analysed by dry sieving in the laboratory. Each sample was dried in an oven heated to 105°-110° for 24 hours. It was then ensured that all the aggregates were crushed by pounding with a pestle and mortar (not ground, as this would destroy the grain sizes). The sample was divided using a riffle box to obtain a sample of convenient size, which was 100 grams. Twenty-one British Standard sieves were used at $\frac{1}{4}$ phi unit (ϕ) intervals (phi = $-\log_2$ [diameter in millimetres]), from -1·25 phi (2.38 mm.) to 3·75 phi (0·074 mm.), and each sample was sieved for 20 minutes on the Ro-tap mechanical shaker. A larger sieve interval than $\frac{1}{4}$ phi was considered too large for such research work as this. The sand retained in each sieve was weighed and the percentage passing through each sieve calculated. The cumulative percentages were then obtained. Figure 3.4 is an example of one of the data forms used for the sieve analysis in the laboratory.

One of the major advantages of the phi scale is that the cumulative plot of the sediment size distribution on arithmetic probability paper gives a straight line if the size distribution is logarithmically normal, which is a characteristic of many beach sediments. Another advantage is that the phi scale is now universally accepted. From the cumulative percentage frequency curve, percentage values can be read off on the phi scale and various properties of the sample obtained by simple calculations. Folk (1966) reviews the parameters developed to study the size distributions in sand. The Folk and Ward (1957) measures have been adopted here to calculate four descriptive measures:-

1. A measure of the central tendency, the mean

$$\text{Mean} = (\phi 16 + \phi 50 + \phi 84) / 3$$

The efficiency of the method according to McCammon (1962) is 88%.

2. The sorting or standard deviation

Standard deviation =

$$(\phi 84 - \phi 16)/4 \quad + \quad (\phi 95 - \phi 5)/6{\cdot}6$$

This has an efficiency of 79% (McCammon).

3. The skewness which describes the asymmetry of the distribution

$$SK = \frac{\phi 84 - \phi 16 + 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 95 - \phi 5 + 2\phi 50}{2(\phi 95 - \phi 5)}$$

4. The kurtosis, which defines the peakedness of the curve

$$k = \frac{\phi 75 - \phi 25}{2(\phi 90 - \phi 10)}$$

A curve that is more peaked than normal is leptokurtic, while a less peaked one is platykurtic.

The median value of central tendency (ϕ50%) is also recorded for comparison with the mean. (Median 64% efficiency - McCammon). In a perfectly normal distribution the mean and the median will be identical. It was found possible to take the values from the cumulative percentage curve to two decimal places which were retained during calculations.

The mean diameter size of beach sediments has been used to classify the sediments. Table 3.2 gives Wentworth's classification in millimetres and Krumbein's (1934) corresponding phi units. The mean therefore reflects the overall average size of the sediment.

The standard deviation measure as outlined by Folk and Ward (1957) takes in a reasonable part of the distribution and is most efficient when applied to sand. The relationship between mean values (in phi units) and sorting shows that for sands the two values increase together, finer sands being better sorted. A normal distribution has a standard deviation of 1.

The measures of skewness and kurtoses give an indication of the non-normality of the sediment and therefore in most beach sediments are of less importance than the first two mentioned measures. The skewness measures the asymmetry of the curve and therefore the difference between the medium and the mean. Folk and Ward measure has values ranging from -1 to +1, the negative values indicating a tail of coarser particles, and the positive values indicating a tail of finer material. It is rare in nature to find a sediment with a greater skewness value than 0·8. Skewness is useful where comparisons are made between beach and dune sediments, but this is not of great importance in the present study. The kurtosis value indicates the ratio between the spread in the central part of the distribution and that in the tails. Folk and Ward's graphic kurtosis value is 1·0 for a normal curve. Kurtosis can also be used to distinguish between different sedimentary environments.

Five measures of the beach sediment characteristics, the median, mean, standard deviation, skewness, and kurtosis are available from the sediment samples collected on the Holderness beach.

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C H A P T E R F O U R

RESULTS FROM THE ORD SURVEYS

A. Easington. January to June 1974.

B. Atwick and Holmpton.
January 1974 to January 1976.

The three ords at Atwick, Holmpton and Easington were observed, surveyed and sampled in detail during 1974 and 1975. During the first six months of 1974 the work was concentrated on the Easington ord, until it was halted by commercial excavations on the beach by the North Sea gas project. The Atwick and Holmpton ords were initially surveyed and sampled in 1974, and both surveyed in detail during 1975.

At the beginning of the study in the winter of 1973/1974 all three ords were surveyed for the first time to establish their position and form. The Easington ord was surveyed again in April 1974 and it was then realised that the intervening period of two months was too long to monitor each change in the ords position and form. To achieve this a series of weekly surveys was undertaken on the Easington ord. These were brought to an end by the excavations on the beach by the Gas Board. In 1975 weekly surveys of both the Atwick and Holmpton ords were undertaken and five periods of fieldwork, table 4.1, were carried out during the year. It was considered at the time of these weekly surveys, and later in the light of the results, that weekly surveys were much more profitable from the point of view of ord changes than the less frequent surveys which could not separate the many facets of ord movement.

In this chapter it is proposed to discuss first the beach form and changes at Easington during the period between January and June 1974. The second part of the chapter will be concerned with the beach changes at Atwick and Holmpton during

1975, but introduced by the initial surveys in 1974. The results from the two sections will then be compared.

EASINGTON. JANUARY TO JUNE, 1974.

Beach plans of the Easington ord, drawn from the field observations and the surveys are given in figures 4.3 to 4.6. The rest of the survey details are shown in figures 4.7 to 4.9.

27.1.74

The Easington ord was first surveyed on 27.1.74 (see figure 4.4 for the plan of the ord). At this time the ord displayed the well-developed features of the south Holderness ords, namely a large area of exposed till shore platform, connecting with the cliff foot in the north of the ord (the ord centre), and separated from the cliff foot south of this by an upper beach of sand and mixed size shingle which increased in width southwards. Seawards of the till platform was a very well-established lower beach in the form of an asymmetrical ridge, which was often over 100 metres wide at low water. This trapped a water-filled runnel between itself and the till platform. To the north and south of the ord the upper beach built up in height and the high water mark was seen on the beach below the cliff foot. In the northern part of the ord the till platform was exposed at the low water mark of a spring tide. Seawards of this an offshore bar, running parallel to the lower beach ridge of the ord, was marked out by a line of surf.

By levelling, a longitudinal profile was surveyed the length of the ord 15 metres from the cliff foot. This was 2270 metres long (figure 4.7). It formed the link for five transverse profiles between the cliff foot and the low water mark. The positions of these are marked on the longitudinal profile. One was placed at the northern end of the ord (profile E) where the upper beach was completely built up, with the high water mark below the cliff foot. This profile had an upper beach of sand and shingle of small and medium sizes (see Chapter 3), and a lower beach of finer sand below the beach water table and therefore covered by a thin sheet of water (a wet lower beach). The next transverse profile to the south was placed at the centre of the ord (i.e. where the beach is at its lowest at the cliff foot, and in this case where the till platform joins the till of the cliffs). This profile, profile D, crossed 35 metres of seaward sloping till platform and 120 metres of lower beach ridge which was formed of fine sand. The lower beach here was completely dry to the low water mark. The third profile, profile C, was placed where the upper beach started to form at the cliff foot again. Here it was about 15 metres wide. The profile then crossed 22 metres of till platform, a narrow water-filled runnel and then the dry lower beach ridge. The upper beach on profile C was mainly of coarse sand and small and medium-sized shingle, with a few large pebbles and till boulders scattered over the surface. The fourth transverse profile from the north of the ord, profile B, was placed where the upper beach was much wider, 70 metres, and the till platform was narrower in width, only 13 metres. The landward, steeper slope of the asymmetrical lower beach ridge was at its most pronounced here, at an angle of between 4° and $4 \cdot 5^{\circ}$ and reaching a height of over 1 metre above the water-filled runnel. The southern-most profile, profile A, was positioned at the southern end of the ord, 1,500 metres south of the ord centre where the high water mark was 30 metres from the cliff foot. Here the upper beach was very well formed, high and wide and over 4·5 metres O.D. at the cliff foot. The high water mark as the spring tide was approached cut a small cliff or notch into the upper beach. The upper beach was mainly of sand and PSM (see Chapter 3, B.1) at the top, and PSML on the lower slopes. The water-table came to the surface towards the base of the upper beach. There was neither a till platform nor a lower beach visible above the low water mark on profile A.

On the longitudinal profile the gradual lowering of the upper beach in the north and its gentle, but irregular rise again in the south can be seen. There was little upper beach build up between profiles D (the centre) and C, 450 metres further south. This, then, was the position and form of the ord in January 1974.

8.4.74

The ord was surveyed again on 8.4.74, ten weeks later. During this time the feature had altered considerably, as can be seen from the plans (figure 4.4). Once again a longitudinal profile was surveyed. Four transverse profiles were surveyed, only the southernmost, A, coinciding with any of the January profiles. The longitudinal profile on 8.4.74 (figure 4.7) was much more irregular than in January. The upper beach to the north was not as well built up as before and the high water mark was not seen below the cliff foot, even 1 kilometre north of the centre of the ord. The till platform was not visible at the cliff foot anywhere along the length of the ord. But there was a slight depression in the low upper beach which was called the centre of the ord. This was 400 metres further south than on the previous survey. From this point the upper beach gradually and irregularly built up towards the south.

On the most northern transverse profile, E, which was 300 metres further south than the northernmost profile in January, the low upper beach at the cliff foot was accompanied by a lower beach below the water table (seen at the foot of the upper beach). Once again at the low water mark (Spring tide - 1 day) there was till platform exposed, but only in this northern section of the ord.

The second profile from the northern end of the ord, profile D, was positioned 100 metres north of the centre of the ord and 730 metres south of profile E. The upper beach was 37 metres wide, with a depression at the foot. This was created by the landward face of the lower beach ridge which was 0·4 metre above the foot of the upper beach. The seaward slope of the lower beach ran 110 metres from the crest of the ridge to the low water mark at the gentle angle of 0·4°.

Profile C was positioned 200 metres south of the centre. The upper beach was very similar in form to the upper beach in profile D, concave and 38 metres wide, but here there was exposed a 6 metre strip of till platform at the base. The lower beach ridge was at its most highly developed at this point in the ord, higher and steeper than on the other profiles. A water-filled runnel was trapped between the lower beach and the till platform.

The upper beach slope of profile A, in the south, was in a very similar position to January. A high Spring tide had removed much of the top part of the beach but the height at the cliff foot was the same. A little beach material had been added to the lower slope of the upper beach. No till platform or lower beach was visible.

The changes in the ord between 27.1.74 and 8.4.74 are threefold:

1. In April the upper beach was lower in the north but it was continuous the length of the ord along the cliff foot, whereas in January it faded out at the Runnel stream outlet.
2. The amount of till platform exposed along the whole length of the ord was much reduced in April and confined to the southern part of the ord. By comparing the plans much of this can be attributed to the greater extent of upper beach at the cliff foot, as the lower beach ridge was in a very similar position in April to that in January.
3. Finally the centre, the lowest part of the ord at the cliff foot, was 400 metres further south in April.

The external conditions acting directly and indirectly on the beach in the intervening ten weeks will now be reviewed. Both surveys were made two days after a Spring tide. The January Spring range was 4·8 metres, the April Spring range 5·4 metres, but the high waters only varied by 0·1 metre, and this would not have affected the beach profile. The wind reached speeds of over 20 knots for periods of a day or more on 8 occasions, between 27.1.74 and 8.4.74. On 6 of these the wind direction was westerly and southerly, and the remaining 2 easterly. At this stage, and with such a long period between the surveys it is difficult to isolate particular directions and speeds of the wind affecting different movement of the beach material through the generation of certain waves.

22.4.74

The next Easington survey was on 22.4.74 (see figure 4.4 for the ord plan). Only four transverse profiles were levelled. Three of these, A, C and D were on the same lines as the 8.4.74 survey. Profile B was positioned 470 metres north of profile A. These four profiles were then resurveyed every week until 3.6.74. The results of these surveys and the beach changes the surveys show over this period are plotted in figures 4.8 and 4.9. Each survey has a corresponding beach plan (figures 4.4, 4.5 and 4.6).

On 22.4.74 the ord at Easington had resumed much of its January form. For example, it had a centre with till platform exposed at the cliff foot, a large exposure of till platform at the base of the widening upper beach to the south, and a high lower beach ridge. But one major difference in the ord on the 22.4.74 from the ord on 27.1.74 was its size and position. The ord on 22.4.74 was only 1,200 metres in length, whereas in January it had been over 2,200 metres long. Most of the change in the size was due to the movement of the northern end southwards, while the southern end had moved very little (see Profile A). The whole feature at the end of April was much more compact than it was in January.

The northernmost transverse profile, D (see figure 4.8), was positioned where the upper beach began to decline in height and width. It was still quite low at the cliff foot, but had been raised half a metre since the last survey on 8.4.74, two weeks previously. The lower beach was slightly convex, marking the beginning of the lower beach ridge, and it was above the beach water table and therefore dry. The beach here was higher all along the profile, except at the low water mark, than it was at the last survey. The depression between the upper beach and the lower beach was less emphasised and 10 metres landwards than on 8.4.74. The seaward slope of the lower beach ridge was steeper at $1 \cdot 2^{\circ}$.

Profile C, south of the centre of the ord was very similar in form to the last survey. At the foot of the upper beach there was 20 metres of till platform, slightly covered by a thin veneer of sand. The whole beach profile was fractionally higher than it was on 8.4.74, except where the till platform was exposed and also on the crest of the well formed lower beach ridge which had moved landwards by 7 metres, steepening the landward side of the ridge from $1 \cdot 4^{\circ}$ to $3 \cdot 6^{\circ}$.

Profile B, surveyed on 22.4.74 for the first time, displayed a well built up upper beach with the high water mark 1 metre below the cliff foot. At the foot of the upper beach the till platform extended for over 30 metres seawards and a water-filled runnel was trapped by the lower beach ridge. The lower beach had declined in height here from its highest point at profile C.

Profile A in the south displayed a very wide and well built up upper beach. Since the survey on 8.4.74 it had built up slightly near the high water mark but had steepened on the lower upper beach slope by the loss of over half a metre of material. The upper beach had therefore become narrower. Till platform was exposed for the first time at the foot of the upper beach. There was also a lower beach ridge exposed above the low water mark, and this had trapped a water-filled runnel. From an examination of these four profiles for 22.4.74 superimposed (figure 4.8), it becomes clear that the crest of the lower beach ridge declined in height the further it was from the cliff foot, or, in other words, declined in height southwards. From the superimposed profiles it can be seen that the lower beach ridge crest on profiles D and C was at approximately the same height, 0·20 metre OD. The profile D ridge crest was 53 metres from the cliff foot, the profile C crest 56 metres from the cliff foot. The lower beach ridge crest of profile B was - 0·50 metre OD in height, and 98 metres from the cliff foot, in profile A - 1·10 metres OD and 132 metres from the cliff foot.

Looking at the profile changes over the preceding fortnight (8.4.74 to 22.4.74), it was profile D in the north that had shown the most significant change. There had been a considerable build up of both the upper and lower beach on this profile, and a loss of material only at the low water mark. Both profiles C and D had shown a landwards movement of the lower beach asymmetrical ridge.

The survey was taken two days before a Spring tide, the range on the day of the survey being 4·6 metres. The build up of the high water mark towards the Spring can account for the swash bar feature seen on the upper beach of profile D, seawards of the high water mark. The direction of the winds since the last survey were all between 350° and 90°, but only on three occasions were these slightly over 15 knots, the average speed being between 10 and 15 knots.

29.4.74

The next survey of the Easington ord was on 29.4.74. On the plan the ord (figure 4.5) was in a very similar form and position to the week before. The upper beach in the north was approximately the same width, ending at the same point at the cliff foot, and the centre of the ord was in the same position. The southern upper beach was also in the same approximate position. The area of till platform exposed was slightly less and the lower beach had extended further south past profile A.

In the north, profile D was again higher along all of the profile line. At the cliff foot the upper beach was 0·35 metre higher than at the time of the last survey. The width and slope of the upper beach remained the same but the lower beach was much flatter and did not exhibit the slightly raised form it had the week before. At the low water mark, over 1 metre of material had been gained. From the break of slope, at the base of the upper beach to the low water mark, the lower beach fell only 0·4 metre in height (a $0{\cdot}2^{\circ}$ slope).

Profile C, just south of the centre had lost up to 0·4 metre of material over most of its width, 0·3 metre at the cliff foot and 0·4 metre on the lower beach ridge crest. The slope of the upper beach remained approximately the same, $4{\cdot}2^{\circ}$, except where some coarser material had covered the till platform exposed a week earlier. The main changes in the profile were the decline in height of the lower beach ridge, the movement seawards by 15 metres of the ridge crest and the accompanying decline in the landward slope. The ridge at this time appeared almost symmetrical in profile.

On profile B the upper beach slope was approximately in the same position as it was in at the time of the last survey. The lower beach ridge crest was at the same height but 5 metres seawards of its earlier position. The lower beach extended 13 metres further landwards than it did on 22.4.74, thus covering some of the till platform. The landward slope of the lower beach ridge, as in profile C, was longer and therefore less steep.

Profile A again showed a narrowing of the upper beach by 1 metre at its base where fresh till platform had been exposed. The face of the upper beach had also been steepened by the loss of beach material from the lower slopes of the upper beach. The high water mark was still well below the cliff foot. The crest of the lower beach ridge was 8 metres further seaward, but unlike the ridge crest on the other profiles it was 0·2 metre higher.

The water-filled runnel on 29.4.74 was smaller than it had been the week before, mainly because of the lowering of the lower beach in the northern part of the ord. The survey was made 5 days after a Spring tide (the range on the day of the survey was 3·2 metres). The Spring high water mark had not reached the cliff foot on profiles A and B. The overall changes on the four profiles were dominated by the flattening out of the lower beach ridge. This had been achieved by a movement of the ridge crest seawards and in the north this movement had been accompanied by a decrease in height of the ridge crest. The northern profile continued to build up over all its width.

The winds during the preceding week were again between 350° and 90°, but this time most were between 15 and 20 knots, and on 28.4.74 they reached speeds of over 25 knots.

5.5.74

The ord was next surveyed on 5.5.74. From the plan (figure 4.5) the ord was in a very similar condition to the week before. In the north, on profile D, the upper beach was lower at the cliff foot by 0·2 metre, and it was also 5 metres narrower. But the break of slope at the base of the upper beach was 0·1 metre higher than the week before. The lower beach was all below the water table, which came to the surface at the base of the upper beach. The top part of the lower beach was flat and separated from the more gently sloping (0·5°) seaward part of the lower beach by a break of slope 63 metres from the cliff foot. The top part of the lower beach had gained material whereas the lower part of the lower beach had suffered a low of 0·3 metre over the previous seven days.

The upper beach on profile C had the same width and slope as it had a week earlier. The till platform had been lowered at the landward edge and it had also been extended a metre further seawards. The lower beach had resumed much of the asymmetrical ridge form which had disappeared the week before. This ridge had a short (15 metres), steep (2·2°), landward slope, a flat top for 30 metres, and then a slope of 1·4° to the low water mark. The gain of beach material on this profile had mostly been on the top of the present lower beach ridge and there had been a loss of material towards the low water mark.

Profile B showed similar changes to profile C, although they were not as marked. The upper beach was steeper, and narrower by 8 metres than the week before, and most of the loss had been from the lower slope. More till platform had been exposed at the foot of the upper beach. The lower beach was once again an asymmetrical ridge with a short landward slope of 10 metres, and a gentle (0·6°) seaward slope from the ridge crest to the low water mark. The largest gain of material had been at the new crest on the lower beach, which had moved the lower beach landwards.

Profile A had not altered very much. Unlike the other profiles the upper beach had widened and the slope become less steep. This had covered some of the till platform that was exposed at the last survey. The upper beach was 85 metres wide. There was a very wide water-filled runnel trapped by the lower beach. The lower beach was not higher than the week before but the crest had moved 11 metres landwards, creating a steeper, shorter landward slope.

The survey was made one day before a Spring tide and the tidal range on the day of the survey was 4·6 metres. Therefore any sand lost or gained on the southern profiles above the high water marks on the beach was attributed to wind action, as there had not been a higher tide since the last survey.

The overall features of change since the last survey on 29.4.74 are twofold:

1. The narrowing of the upper beach on all the profiles except the southernmost. This had been achieved by

loss of beach material from the base of the upper beach, very little being removed from the top, thus resulting in a steepening of the upper beach profiles.

2. The lower beach ridge had again become asymmetrical by the addition of material on the landward side of the previous week's ridge crest. On profiles C and D there had been a loss of material near the low water mark, but a slight gain there on profiles A and B.

The winds over the previous week had been very changeable, with two periods of calm. On 3rd, 4th and 5th May, the winds were from between 360° and 90° and at speeds between 15 and 24 knots. During the first half of the week all the wind speeds were below 15 knots.

13.5.74

The plan of the beach from the next survey on 13.5.74 (figure 4.5) shows that there was only negligible change during the preceding week. A closer look at the survey profiles reveals that all the beach changes were indeed only on a very small scale.

In the north, profile D had an almost identical upper beach to the week before. The lower beach again appeared to be slightly ridged but this had been brought about, not by the gain of material at the crest of the ridge but by the loss of material on either side of it. This loss was greatest towards the low water mark where it was over 0·5 metre.

The upper beach on profile C, just south of the centre, was narrower and had suffered a loss of up to 0·5 metre. More till platform had been exposed at the base of the upper beach.

The lower beach was almost identical in its form to the week before; the crest was in the same position and at the same height.

On the upper beach of profile B the high water mark had cut a notch into the sand. The foot of the upper beach and the exposure of the till platform was in the same position on 13.5.74 as it was at the last survey. There had been a loss of material from the lower beach ridge crest and the lower beach was much less of a ridge form than it was the week before; the landward slope was longer and less steep. There had been a loss of up to 0·2 metre over the whole of the lower beach on this profile.

On Profile A in the south the upper beach and the till platform exposed were almost exactly in the same position as the previous week. The high water mark was also cut into a notch on the upper beach profile here. Wind action had redistributed the sand above this level. The lower beach ridge on profile A had moved 7 metres landwards and because of this the water-filled runnel was much narrower.

The overall changes within the ord between 5.5.74 and 13.5.74 had therefore been very minor, and only a continuation of the changes of the previous seven days. This latest survey was made seven days after a Spring tide. The winds during the intervening period all blew from between 140° and 200°. The wind speeds were quite variable, between 12 and 25 knots.

20.5.74

The next survey of the Easington ord was taken on 20.5.74. The beach plan (figure 4.6) shows only one main change, the exposure of till platform at the cliff foot at the centre of the ord was now covered by a narrow strip of upper beach which was continuous the whole length of the ord.

Profile D in the north (figure 4.9) had altered little during the past week, except for the seaward part of the lower beach which had lost some material near the low water mark. The slight ridge form on the lower beach was still in evidence. Profile C had also changed only slightly. There had been a small gain at the cliff foot of 0·3 metre but this had not altered the overall slope of the upper beach. A loss of material from the landward edge of the lower beach had steepened the landward slope from $2{\cdot}5^{\circ}$ to 3°. The rest of the profile had not changed over the week.

The changes on profile B had been the greatest of all the profiles over the past week. The lower slope of the upper beach had gained up to a metre of beach material. The upper beach slope was therefore more convex and was 5 metres wider. This covered some of the till platform that was visible at its base the week before. The lower beach had also gained in height along the whole of its width, and both the point at which it met the till platform and the crest had advanced landwards by 5 metres. The angle of the landward-facing slope of the lower beach remained the same as on 13.5.74. Therefore the exposure of the till platform at this point in the ord had diminished in width.

The loss of material over much of profile A in the south had been almost in opposition to the gains on profile B. The high water mark notch still appeared in the slope of the upper beach, but below it the upper beach had suffered loss and the slope was distinctly concave. The till platform had also been lowered and more of it had been exposed at the expense of the lower slope of the upper beach. The lower beach ridge crest had moved landwards by 14 metres but it was no higher than it was a week ago. The water-filled runnel was narrower than before.

During the previous week there does not appear to have been any constant changes over the profiles, and the ord retained the basic shape it displayed the week before. The survey on 20.5.74 was made 4 days before a Spring tide. On the day of the survey the tidal range was 4·2 metres. The wind direction and speed were similar to those of the previous week. There was no wind over 20 knots, or less than 8, and most blew from between 90° and 160° (south-easterly).

26.5.74

The next survey of the ord was on 26.5.74. The beach plan remained very similar in its form to the week before (figure 4.6). The narrow strip of upper beach was still present at the cliff foot throughout the centre of the ord, still forming a continuous upper beach. On profile D, in the north, the upper beach continued to be low and narrow, and despite a slight gain of material at the cliff foot there had been a loss on the lower slope of the upper beach (figure 4.9). The lower beach had become slightly ridged once again by a gain of material on the present ridge top. The landward slope of this ridge sloped at half a degree for 20 metres towards the cliff. The seaward slope was the same as before, because the addition of material on this part of the beach had been uniform down to the low water mark.

The upper beach of profile C had also shown a gain of material over the whole of its width. At the base of the upper beach it had covered over some of the till platform exposed a week earlier, and the upper beach was therefore wider. The landward slope of the lower beach ridge had lost some material at its foot but gained at the crest. This had shortened and steepened the slope. A loss of material on the seaward slope of the lower beach had combined with the movement of the ridge crest landwards to move the whole of the lower beach ridge landwards.

The upper beach of profile B had become slightly narrower by 6 metres and had lost up to half a metre of material at its foot. This had exposed more till platform at the base. But despite this the width of the till platform exposed by the beach on the profile had decreased over the week because the crest of the lower beach ridge had moved landwards by the gaining of material on the landwards slope. This slope was now shorter by 10 metres and steeper by one degree. The crest was also higher by 0·2 metre. The seaward slope of the lower beach had suffered loss, except at the low water mark where there had been a slight gain. Overall the movement of the lower beach ridge on profile B had been very similar to the movement of that on profile C, that was a movement of the crest of the ridge landwards by a steepening and shortening of the landward slope due to a gain in material there and a loss of material seaward of the crest of the ridge.

The main change on profile A had been the large gain of material on the slope of the upper beach, up to 0·8 metre at one point. This gain had extended seawards the base of the upper beach and completely covered the till platform that was exposed at the last survey. The crest of the lower beach ridge had not moved landwards but had gained 0·2 metre in height and the whole of the seaward slope of the lower beach had gained in height.

Therefore, the upper beach during the previous week had suffered within the ord from both gain and loss, the most significant change being the large gains on profile A. The dominant change over the week had once again been on the lower beach. On the three profiles south of the ords centre there had been a gain in height, and on profiles B and C a landward movement of the ridge crest.

This survey was made two days after a Spring tide and the tidal range on the day of the survey was 4·6 metres. On the three days before the survey the winds blew from 360°, with speeds up to 20 knots; for the first half of the week the winds were interrupted by periods of calm.

3.6.74

The last survey of the profiles on the Easington ord was carried out on 3.6.74. The plan (figure 4.6) shows that the till platform was once again exposed at the cliff foot at the centre of the ord but it was still covered in the southern parts of the ord. In the north, profile D had a similar upper beach form to the previous in its width and slope. The lower beach, which was slightly ridged the week before, had flattened out and there was no longer a depression at the base of the upper beach (figure 4.9). This had been achieved by a loss of up to 0·3 metre of material from the crest of the lower beach. The seaward part of the lower beach had also lost 0·1 metre of material.

The upper beach on profile C had lost material from the base and had exposed a larger area of till platform just south of the ord centre. The lower beach on profile C had altered very little, except to gain 0·2 metre of material on the crest of the ridge. This had not caused the ridge to move seawards or landwards. There had been a slight loss of material from near the low water mark.

The upper beach and exposure of till platform on profile B were identical to the week before. The lower beach crest had been lowered by 0·2 metre but the seaward slope of the lower beach had been raised 0·3 metre near the low water mark. The had flattened the lower beach ridge somewhat, although it was still in evidence. There was no water-filled runnel present on this profile.

Profile A in the south had suffered a loss of material over all the upper beach. The depression between the upper beach and the lower beach had been almost completely filled, and the seaward part of the lower beach had lost material. Therefore the lower beach had lost its ridge crest by the infilling of the depression at the base of the upper beach. The till platform was still covered by this infill and there was no water-filled runnel. This profile had shown the most gain and loss of all the profiles over the past week. The changes on the other profiles that have been described had been very slight (see figure 4.9).

This survey was made 3 days before a Spring tide when the tidal range was 4·2 metres. The winds over the previous week were variable in direction and speed. The wind speed was between 15 and 20 knots, rarely less than 15 knots.

SEDIMENT SAMPLES OF THE EASINGTON ORD.

The sand within the ord was sampled on three occasions during the first six months of 1974. This was on 29.1.74, 26.4.74 and 22.5.74. The results of the statistical analysis (see Chapter Three) on these samples are given in the table 4.2. In this chapter the mean grain size (in phi units) will be evaluated, and the general distribution of the sediment over the surface of the ord outlined. Figure 4.11 shows the distribution of the mean sediment grain size within the ord.

Twelve samples were taken on 29.1.74. On each profile the mean grain size at the low water mark was smaller than that at the cliff foot, but this difference was not constant between the profiles.

On 26.4.74 there was a much larger difference between the grain sizes at the cliff foot and the low water mark. There was a much smaller grain size overall on the lower beach compared with the January samples. The cliff foot samples were also larger than the corresponding January samples. The samples taken a month later on 22.5.74 show the most distinct pattern across the ord. Again the samples from the cliff foot had the largest grain size. On three of the profiles the mid lower beach sample was coarser than either the top of the lower beach or the low water mark samples. The low water mark samples all had very small grain sizes and this feature was constant along the whole length of the ord. On the crest of the lower beach the grain sizes became smaller towards the south and this also applied to the top of the lower beach samples but not to those at the low water mark or at the cliff foot. It must be remembered that the top of the upper beach samples on profiles A and B in the south were from the high water mark and therefore are worked for only a short period each high tide. On the other hand the cliff foot samples of profiles C and D were taken on a beach which was considerably below the high water mark.

EASINGTON - A SUMMARY.

In figure 4.9, the 22.4.74 and 3.6.74 transverse profiles are superimposed to show the overall beach change during the period when the ord was surveyed every week. In the north, on profile D, it can be seen that the upper beach was narrower by 7 metres but also higher by 0·3 metre at the cliff foot. There had been little substantial build up of this upper beach north of the centre of the ord. The break of slope at the base of the upper beach, where it joined the lower beach, was 0·4 metre higher in June than it was in April. The lower beach was still slightly ridged in June and the seaward slope almost identical to its position on 22.4.74. The lower beach ridge crest had moved landwards by 17 metres.

Profile C, just south of the ord centre in April, was in almost the same position relative to the centre in June. The upper beach was approximately of the same width but overall was 0·3 metre lower than in April. The lower beach ridge crest remained in the same position but was 0·4 metre lower than before. This lowering trend was reflected over all the lower beach to the low water mark.

The upper beach on profile B, like that of D, remained approximately of the same slope except that it was 25 metres narrower. The break of slope between the till platform at the base of the upper beach and the lower beach was 0·5 metre higher than before. The lower beach, as was the case with profile C, was raised more than 0·4 metre over all its length, except at the low water mark where it attained its original height. The steep landward slope of the lower beach ridge was flattened out by the gain of material in the depression, and the lower beach ridge was much less noticeable than it was in April. It had been a feature of profile B since the beginning of May not to form a large depression between the upper and lower beaches. Instead it had been particularly well built up at that point, with an outlet runnel for the main water-filled runnel often across the lower beach ridge just to the north of profile B.

On profile A the greatest change had taken place. In early April this profile could still be said to mark the southern end of the ord. This was shown by the wide, well built up upper beach which reached almost to the low water mark, with very little lower beach in evidence at all. Over the weeks the slope of the upper beach was lowered and also retreated towards the cliff, by 38 metres at its base. But the top of the upper beach was not reduced in height below the high water mark of even the lowest tides by June 1974. The lower beach ridge gradually developed on this profile, continuing the lower beach of the ord from the north. By 3.6.74 the crest of the lower beach ridge had moved landwards as the upper beach narrowed and the whole lower beach was raised over 0·5 metre between 22.4.74 and 3.6.74.

The changes in this ord during the period of weekly surveys were only minor. No extremely strong wind or storm wave conditions occurred. When there was a short period of strong winds from the northerly quarter (on 23rd, 24th and 25th April) it was followed by an interrupted, calmer period during which the continued build up of the lower beach south of the centre of the ord continued. The most obvious change within the ord was the landward movement of the crest of the lower beach ridge. This occurred down the whole length of the ord south of the centre. There was also a gradual lowering of the upper beach, especially on profile C, just south of the centre, and on profile B as the influence of the ord began to affect the non-ord beach system to the south. Therefore, although the southern end of the ord was moving slowly southwards, there was not the evidence to show that there was any build up of the beach to the north of the ord, or any movement of the centre during April, May and June.

ATWICK AND HOLMPTON. 1974 and 1975.

HOLMPTON 27.12.73

The ord at Holmpton was first surveyed on 27.12.73. At this time it was a double ord (see Chapter 2) and was surveyed as such. The northern one, the Runnel ord, was 900 metres long. The southern one, the Old Hive ord, was 1100 metres long. The plans of the Holmpton ord over the period of fieldwork are given in figures 4.12 to 4.16. The details of the beach surveys can be found with those of the Atwick surveys in figures 4.22 onwards. To the north of the Runnel ord the upper beach was well built up. On profile K (figure 4.22) the upper beach was 66 metres wide and 4·20 metres OD at the cliff foot. The beach here was characteristic of a non-ord upper beach with its flat top and steep seaward slope. The break of slope between the upper and lower beaches was very gradual. The lower beach was below the beach water table which emerged at the surface on the lower slopes of the upper beach. The lower beach, therefore, had a wet surface, with water-filled depressions in places. Profile J, 200 metres to the south of profile K, had an upper beach that was reduced in width and height. It was 3·20 metres OD at the cliff foot and only 33 metres wide. The lower beach sloped seawards at the gentle gradient of 0·9°, from the break of slope at the base of the upper beach. The slope of the upper beach was reduced from 4·5° on the northern profile to 4·1° on profile J. The next profile south, H, was taken at the centre of the Runnel ord, 290 metres south of profile J. At the cliff foot there was 40 metres of till platform, sloping from the cliff foot at 2·9°. At the foot of this the lower beach began and sloped seawards at the much gentler slope of 0·5°. Halfway to the low water mark the lower beach was raised 0·2 metre into a slight ridge form. This trapped a shallow water-filled runnel to the landward side of the ridge. The lower beach ridge was dry.

The till platform continued at the cliff foot for 400 metres south of profile H. Profile G, 200 metres to the south of the centre profile, had a width of 59 metres of till platform at the cliff foot. This had an undulating and stepped surface down to a wide (40 metres) water-filled runnel.

This was trapped by the lower beach ridge which had developed to its greatest height on this profile, 0·4 metre above the runnel surface. Profile F was placed 200 metres south of profile G. Here the upper beach had begun to form again at the cliff foot. This upper beach was part of a short (500 metres) bank of sand at the cliff foot, separating the Runnel ord in the north from the Old Hive ord in the south. The upper beach on this profile was only 28 metres in width, with a very irregular slope down to till platform at its base. Just to the south of this profile the till platform was completely covered and did not join in any way with the till platform of the Old Hive ord. At the southern end of the Runnel ord a wide water-filled runnel ran between the till platform and the lower beach ridge to the low water mark. This completely separated the lower beaches of the two ords. The Old Hive ord lower beach never developed into the ridge form seen in the northern ord at the time of the survey. The Old Hive ord was surveyed on the following day and the longitudinal profile was begun at a lower point on profile F than the Runnel ord longitudinal profile. This point is marked on the plan by the erratic (figure 4.12). (During 1975 this marked the northernmost profile in the survey programme.)

The bank of upper beach at the cliff foot south of profile F was 500 metres long, only 50 metres in width, and at its highest point it was 4·20 metres OD. Profile E was placed at this point. It was 230 metres south of profile F. The height at the cliff foot was the same as profile K in the north, and the slope of the upper beach was also very similar.

Profile D was placed at the south end of the bank of sand where it had become very low again at the cliff foot, as the centre of the Old Hive ord was approached. The upper beach on profile D was only 15 metres wide, with a slope of 2^{o}. The lower beach then sloped more gently from the break of slope to the low water mark, 65 metres from the cliff foot.

The centre of the Old Hive ord was 350 metres south of profile D. Profile C, taken at the centre, had a continuous slope of $2{\cdot}2^{o}$ between the cliff foot and the low water mark. The upper 19 metres of the profile was exposed till platform, the remainder the fine sand of the lower beach. The next profile, B (330 metres south of C), was placed where the upper beach had begun to reform at the cliff foot. The till platform only extended 200 metres along the cliff foot south of the centre of the ord. At profile B the upper beach was 20 metres wide. At the foot of the upper beach was 14 metres of till platform and then the fine sand of the lower beach to the low water mark. The slope of all three facets of the beach was the same. The most southern profile of this ord, profile A, was taken where the upper beach was again well built up and reached to the low water mark 90 metres from the cliff foot. The high water mark was 30 metres from the cliff foot and the beach height was at 4·70 metres OD at the cliff foot.

This more southern of the two ords present on the Holmpton beach in December 1973 showed more subdued features than the northern ord. The amount of till platform exposed was not so great and it had a very smooth surface in comparison with the stepped profiles of the till platform in the Runnel ord. The lower beach of the Old Hive ord did not develop into a ridged form and therefore did not trap a water-filled runnel. The upper beach to the north and south of the ords was well built up and above the mean high water mark. The longitudinal profile for this survey at Holmpton (figure 4.22) shows well the two ord features and the bank of sand between them. This profile was taken 15 metres from the cliff foot. The build up of the upper beach in the south was rapid compared with the less steep rise of the upper beach to the south of the northern Runnel ord.

HOLMPTON 3.5.74

The Holmpton ord was surveyed once more in 1974, on 3.5.74. The overall size of the ord had changed (figure 4.12) as can be seen from the plans and therefore the transverse profiles were not surveyed along the same lines as 27.12.73 as they were to represent certain features found within the ord. There had been little change of great magnitude in the intervening period of four months. The double ord form was still evident, with a bank of sand between the two ords. The Runnel ord, in the north, no longer had till platform at the cliff foot. The upper beach in the north narrowed southwards, in the same position as on 27.12.73, but never completely faded out and the till platform was never exposed at the cliff foot. It was exposed in places at the base of the upper beach and seaward of this the lower beach was slightly ridged (figure 4.23 for the transverse profiles). The upper beach built up again to the south of the Runnel ord, opposite the Holmpton road end. This bank of upper beach extended further south than on 27.12.73.

This affected the position of the Old Hive ord to the south. The centre of this part of the ord had till platform exposed at the cliff foot where the upper beach camt to an abrupt end. South of the centre of the ord the upper beach began to build up almost at once, with a narrow strip of till platform exposed at its base almost as far south as the Old Hive stream outlet. As in December, the lower beach in this part of the Holmpton ord was not so well built up into a ridge as in the northern part of the ord.

HOLMPTON 28.2.75

In 1975 it was intended to make weekly surveys of both the Holmpton and Atwick ords during certain periods in the year. This started in February 1975. The Atwick ord was surveyed three times during February/March 1975, the Holmpton ord only once as bad weather prevented further surveys (see table 4.1 for the survey dates).

The Holmpton ord was next surveyed on 28.2.75. At the time of this survey the double ord feature had been obliterated, although it had still been in existence in January 1975 (figure 4.13). The Holmpton ord at this time was in a very unusual form with no visible till platform and more than one ridge form in evidence on the lower beach (see plan in figure 4.14). The upper beach in the north completely faded out 250 metres north of the Runnel stream outlet. South of here the ord was very uniform in feature. The lower beach reached right up to the cliff foot from the low water mark, with a gentle, if sometimes, irregular slope. There was no till platform exposed except one very small area at the cliff foot on profile B. There was a line of till boulders, up to half a metre in diameter, along the cliff foot. The distribution of these was very dense south of the Holmpton farm. In the south the upper beach built up very quickly and became over 100 metres wide in less than 500 metres. The survey was taken one day after the highest Spring tide of the year and the tidal range on the day of the survey was 6·1 metres. Therefore the four profiles levelled were much wider than is usual for the Holmpton beach and certain features were revealed that are usually submerged. One of these was a skerrie in the lower beach south of the Holmpton farm.

The longitudinal profile, 10 metres from the cliff foot (figure 4.22) emphasises the flat nature of the ord near the cliff foot. There was a slight rise on the beach near the erratic which is not brought out on the plan. This may be the foundation of the bank of sand seen previously. Profile D (figure 4.23) was surveyed at the erratic. There was a gentle break of slope 77 metres from the cliff foot; landward of this the beach sloped at $2{\cdot}7^{\circ}$ and seaward of this it was almost completely flat to the low water mark. The top part of the beach was concave. The beach slope on profile C, 530 metres south of the erratic profile, consisted of three distinct units. The top section from the cliff foot to a break of slope 94 metres seawards had a slope of $2{\cdot}4^{\circ}$. Seaward of this the beach sloped very gently for 73 metres at $0{\cdot}4^{\circ}$. Then there was a slight depression and a ridge 188 metres from the cliff foot. The beach then sloped at $0{\cdot}5^{\circ}$ to the low water mark. On profile B, 450 metres south of profile C, there was 3 metres of till platform exposed at the cliff foot. This could not really be called the centre of the ord on the day of the survey as the beach was almost as low at the cliff foot most of the way along the ord. The beach at profile B sloped at 1·7° for 107 metres, then there was a drop of 0·8 metre in 9 metres and the beach resumed an almost flat surface to the low water mark. Near the low water mark was a slight low water ridge.

The southernmost profile, A, was opposite the Old Hive stream outlet. Here the upper beach at the cliff foot was 2·4 metres above the high water mark and 5·8 metres OD. The beach sloped slightly convexly to the low water mark 121 metres from the cliff foot. The upper beach merged very gradually into the lower beach. Landward of the low ridge near low water mark was a depression running along most of the ord. This was water-filled south of the road end and it met the sea north of profile A in the south. This depression split the lower beach into two units. The Holmpton ord has now been considered up to February 1975. To bring the survey details of the Atwick ord up to that date the initial survey in January 1974 must be reviewed.

ATWICK 23.1.74

The ord at Atwick was first surveyed and sampled on 23.1.74. At this time the ord was well developed, and just over 1600 metres long (see figure 4.17 for plan). In the north the upper beach gradually lowered and narrowed towards the south, although it did not entirely disappear. At its narrowest till platform was exposed on the seaward edge of this upper beach and then followed the base of the upper beach for over 1,000 metres southwards before it eventually was covered by the widening upper beach. The upper beach gradually widened from its narrowest point at the centre of the ord southwards. The lower beach within the limits of the ord was dry, with a water outlet across it 600 metres south of the ord centre. It was not greatly ridged as was the case at Easington, and with the early surveys on the Holmpton ord.

A longitudinal profile 10 metres from the cliff foot was taken, connecting four transverse profiles (figure 4.23). The longitudinal profile shows the rapid break down of the upper beach from the north, the low centre region of the ord and the build up of the upper beach to the south. The longitudinal profile was interrupted near the gap in the cliffs at the sailing club where a stream crossed the beach and removed some of the beach material between each high tide.

Profile D in the north is typical of the beach profile north of an ord. The upper beach was 45 metres wide and 3·3 metres OD at the cliff foot. This sloped at $4{\cdot}3^{\circ}$ to the break of slope where the lower beach then sloped at a much gentler angle, $0{\cdot}6^{\circ}$, to the low water mark. Profile C is at the centre of the ord 480 metres south of profile D. The upper beach was only 13 metres wide with a slope of $4{\cdot}9^{\circ}$. The lower beach was quite steep and sloped at $1{\cdot}5^{\circ}$ to the low water mark. Profile B, 570 metres south of the centre of the ord, showed the upper beach once more widening to 30 metres and it was half a metre higher at the cliff foot than at the centre of the ord. This was not a very great rise in height over such a long distance. On profile B the lower beach sloped at $0{\cdot}7^{\circ}$ until 14 metres from the low water mark where a low water ridge rose 0·3 metre above the general beach level and then sloped steeply to the low water mark. In the south, profile A was completely upper beach. It had almost the same slope and height as profile D in the north.

FEBRUARY - MARCH 1975

ATWICK 26.2.75

The Atwick ord was not surveyed again until the field-work programme of 1975. It was then surveyed three times at the end of February and the beginning of March. A longitudinal profile was surveyed on the same line each survey, 30 metres from the cliff foot. There were four transverse profiles levelled off the longitudinal profile and these were also repeatedly surveyed. These four transverse profiles were positioned at distinct points along the ord and were not moved in later surveys, in order to record the movements of the beach material within the ord.

The Atwick ord was surveyed on 26.2.75. From the plan (figure 4.18) it can be seen that the ord at this time was dominated by a large exposure of till platform. The centre of the ord was in almost exactly the same position as it was in 13 months before. In fact, there had been very little movement of either end of the ord. In the north the upper beach declined in height and width north of the centre. Where it faded out at the cliff foot, till platform was exposed. It was then found for 850 metres along the cliff foot with an average width of 8 metres. The upper beach to the south began to reform at the sailing club gap and the till platform was gradually covered by it as it built up height and width quite rapidly to the south. The long profile, which was on the lower beach of the ord, was practically flat. It gained height south of the centre of the ord (figure 4.24).

In the north, profile D had an upper beach 30 metres wide with a slope of $3 \cdot 6^{\circ}$ (figure 4.26). From the base of the upper beach the lower beach sloped more gently to the low water mark. Profile C, 640 metres south of profile D, was 370 metres south of the centre of the ord. Till platform was present at the cliff foot for a width of 20 metres. Seaward of this the lower beach was raised half a metre in four metres to a crest and then fell at $1 \cdot 4^{\circ}$ with a slightly convex slope to the low water mark. Profile B, 340 metres south of profile C, also had 15 metres of till platform at the cliff foot. This had a very steeply sloping section at the cliff foot merging into the cliff itself. Seaward of the till platform the lower beach sloped to the low water mark at $1 \cdot 3^{\circ}$. In the south, profile A had an upper beach 65 metres wide which gradually merged into the lower beach near the low water mark. There was no real break of slope on this profile. The beach was higher at the cliff foot here than it was in the rest of the ord, and profile A could be said to mark the southern end of the ord.

The Atwick ord at this time did not have a well built up beach to the north, and in this respect was similar to the Easington ord. But the northern end of the Atwick ord had not moved southwards over the past few months and therefore the reasons for this feature at Atwick may be different.

ATWICK 5.3.75

The next survey of the Atwick ord was on 5.3.75 (see the beach plan, figure 4.18). The upper beach of the ord had again returned to the cliff foot covering most of the till platform that was exposed a week earlier. Otherwise the plan of the ord remained similar. The longitudinal profile was lower in the north. The northern profile, profile D, had gained 0·5 metre of beach material at the cliff foot, but undergone some loss on the lower slopes of the upper beach, making the upper beach slope convex (figure 4.26). There had been a gain of material on the lower beach which was already quite high. The overall slope of the profile remained the same. On profile C the upper beach had been steepend by a gain of 1·0 metre at the cliff foot. There had been a small loss at the foot of the upper beach, as on profile D, otherwise the profile had remained the same. Profile B was the only profile to have lost material at the cliff foot, but it had also gained material on the lower beach which had steepened its seaward slope. At the cliff foot on profile A in the south there had also been a gain of 0·3 metre. This had steepened the slope as the lower part of the upper beach had remained the same.

The general change over the preceding week had been one of build up at the cliff foot, both north and south of the ord centre. The lower beach had also been raised slightly on two profiles, B and D, but all the lower beach still sloped without interruption to the low water mark, and there was no beach ridge formed. The survey was made six days after a Spring tide when the tidal range was 4·0 metres. The winds during the preceding week (figure 4.2) were very uniform with speeds between 15 and 20 knots from a south-south-east direction.

ATWICK 12.3.75

The next survey of the Atwick ord was made on 12.3.75. The upper beach south of the centre of the ord was wider and there were two areas of till platform at the cliff foot (figure 4.18). Otherwise on the beach plan there had been little change. The centre of the ord was in the same position as 5.3.75, and the longitudinal profile unchanged in the north but 0·5 metre lower near the sailing club gap (figure 4.24). The changes on the transverse profiles had been a reversal of the changes of the previous week (figure 4.26).

In the north there had been a loss of 0·5 metre at the cliff foot on profile D, but a gain on the lower slope of the upper beach. This had therefore become less steep. The lower beach had suffered a loss of material where it was raised the week before. Profile C, to the south of the centre of the ord, had suffered a loss of 1·0 metre of material at the cliff foot, and a general lowering for 45 metres from the cliff foot. There had been a small gain of material on the lower beach which was slightly ridged. Profile B had suffered a loss of material over the whole profile. Profile A had undergone the greatest removal of beach material, 0·9 metre at the cliff foot and 0·5 metre 35 metres from the cliff foot. The lowering of the southernmost profile may be a sign of the ord moving south. The beach at the cliff foot on profile A on 12.3.75 was 2·90 metres OD.

The survey was taken two days before a Spring tide when the tidal range was 4·6 metres. During the preceding 7 days the wind speeds gradually increased to a peak of 28 knots on 9.3.75. All the winds were westerlies except when they blew at their strongest and then they veered to the northerly quarter.

This survey ended the first period of fieldwork on the Atwick ord for 1975. The overall movement of the ord over this period was as follows. Profile D (north) was lowered 0·5 metres at the cliff foot but the rest of the profile was unchanged. Profile C showed a general lowering of the profile over all its length except for a slight build up at the low water mark. Profile B displayed a slight lowering over all the profile, the greatest being at the cliff foot, 0·8 metre. In the south, profile A was also lowered over all the profile. Although the centre of the ord was clearly marked on 26.2.75, it was much less well defined on the following two surveys and here the end position of the northern upper beach was considered the centre of the ord.

MAY - JUNE 1975

ATWICK 14.5.75

The next series of surveys on the Atwick ord began on 14.5.75. The ord in plan at this time showed few major changes from March (figure 4.19, the ord plan). The end of the upper beach to the north of the centre had moved north

200 metres, and the centre of the ord had also moved northwards. The upper beach did not fade out completely at the cliff foot and remained 10 metres wide at the cliff foot to the sailing club gap, where it began to widen. The till platform was exposed intermittently at the base of the upper beach and at the cliff foot at the sailing club gap. The lower beach of the ord was raised above the beach water table, and therefore dry on the surface further south than on the previous survey.

The movement of the northern upper beach northwards had positioned the centre of the ord on profile D (figure 4.27). The upper beach here was very narrow, less than 10 metres wide, with a slope of $4\cdot3^{\circ}$. From this the lower beach sloped more gently to the low water mark. Between the upper and lower beaches was a 2 metre strip of till platform. Since 12.3.75 there had been a loss of material on the upper beach but a gain on the lower beach. Profile C had gained material on the upper beach and this was now 22 metres wider than its previous position. There was no distinct break of slope and the lower beach sloped gently to the low water mark. Profile B had also gained material on the upper beach. The till platform at the cliff foot was now covered. There had been a loss of material from the lower beach and the profile resembled very closely that of profile C. Profile A had suffered a loss of material on the middle section of the upper beach. At the base of the upper beach, 46 metres from the cliff foot, there was a narrow strip of till platform, 3 metres wide. The lower beach here was slightly raised into an asymmetrical ridge, uncommon on this ord.

This survey was taken one day after a Spring tide when the tidal range was 4·5 metres. The intervening period between the surveys had been too long to attribute any change to one set of conditions. At the end of March and the beginning of May there were periods of strong northerly winds, but between these had been intermittent calms and constant periods of westerlies. Both types of winds can change the form of the ord.

ATWICK 20.5.75

The next survey of the Atwick ord was on 20.5.75. The northern end of the ord was in a similar position to the previous week. The centre was still at profile D (figure 4.19). The major difference was on exposure of till platform at the cliff foot, interrupting the upper beach at profile C and for 200 metres south of this point. Profile D had lost some material from the base of the upper beach and the exposed till platform was only separated from the cliff foot by 5 metres of upper beach (figure 4.27). The lower beach on profile D had also suffered a loss at the low water mark. This had steepened the lower beach profile. Profile C had lost material from the upper beach and had now 14 metres of till platform exposed at the cliff foot. The lower beach had also suffered a slight loss. Profile B had lost beach material over most of the profile but this had been fairly uniform and the slope of the profile remained the same. In the south, profile A had lost 0·3 metre of material at the cliff foot but had gained 0·5 metre on the rest of the profile. The break of slope between the upper and lower beach was 45 metres from the cliff foot. Only on this southern profile had any gain been recorded over the past week.

This survey was taken 6 days before a Spring tide when the tidal range was 3·5 metres. During the preceding week the wind speeds fluctuated between 5 and 24 knots, with westerly and northerly directions. The northerly winds were the strongest on 17.5.75 (figure 4.2).

ATWICK 30.5.75

The next survey was carried out on 30.5.75 (figure 4.19 for the plan). The lower beach in the north had become narrower and the centre was 30 metres north of profile D. Once again till platform was exposed at the cliff foot at the centre and south of there for 250 metres. The upper beach gradually built up again south of this and the till platform was again exposed at the base of the upper beach between the sailing club gap and profile A. Profile D in the north had become lower at the cliff foot where till platform was now exposed, but had gained material seaward of this (figure 4.27). Profile C had gained up to 0·7 metre of material at the cliff foot which had covered the till platform exposed the week earlier. There was no till platform exposed on profile C on 30.5.75. There had also been a gain in the middle of the lower beach which was raised but did not form a ridge. Profile B again showed a similar change to profile C, and these two profiles were similar in slope except for the wider upper beach on profile B. Both profiles had a gradual break of slope between upper and lower beaches. Profile A had lost material at the top of the upper beach but gained material on the lower slope. This had changed the upper beach slope from a convex to a concave profile.

There had been a gain of material over all the ord except around the centre. Both upper and lower beaches had gained in height. This survey was taken 4 days after a Spring tide when the tidal range was 4·0 metres. The winds during the previous 10 days blew mainly from the northerly quarter. They were all over 10 knots and reached a peak of 25 knots on 26.5.75.

ATWICK 10.6.75

The next survey of the Atwick ord was taken on 10.6.75. The centre of the ord had moved southwards 150 metres and was 50 metres south of the road end (figure 4.19). The upper beach in the north faded out very gradually into the centre of the ord where till platform was still exposed. It was exposed at the cliff foot for 300 metres south of the centre. South of this the upper beach gradually built up again, with a strip of till platform at its base between profiles A and B.

Profile D in the north had gained 0·8 metre of material at the cliff foot (figure 4.27) as the ord centre had moved southward of this point. The upper beach was only 15 metres wide and merged gradually into the lower beach which had a slope of 1·4° to the low water mark. This was steeper than it had been over the past few weeks. Profile C showed a loss of material over all the profile. Profile B had lost up to 0·5 metre of material from the upper beach. This had exposed till platform at the base of the upper beach 21 metres from the cliff foot. This 8 metre strip of till platform merged without a break of slope into the lower beach which was unchanged. Profile A had lost a little beach material at the cliff foot but had gained up to 1·0 metre over the middle section of the upper beach. This had considerably built up the upper beach on this profile and it was wider and less steep.

The overall change in the ord during the previous 7 days was one of shortening, especially from the northern end, while the southern end had actually been raised in height. There was still a well-defined centre. The tide at the time of the survey was one day before a Spring tide and the tidal range was 4·3 metres. The wind data records a change from the northerlies during the week before,to south and south-easterlies with an average speed of 10 knots, until 9th and 10th June when they shifted again to the north but remained light.

Over the May/June 1975 period the Atwick ord had not changed very radically. Till platform was exposed at the end of the period in the north near the cliff foot and in the south of the ord at the base of the upper beach. In figure 4.27 the superimposed profiles for 14.5.75 and 10.6.75 are given. On profile D in the north the beach had gained slightly over all the profile. The upper beach was still quite narrow on 10.6.75. On profile C the beach had gained 0·6 metres on the upper beach but less at the break of slope and over the lower beach. Profile B had lost material over most of the profile, although this was only slight. Only at the break of slope had there been any gain. Profile A in the south had suffered a loss of 0·5 metre of material at the cliff foot but had gained over 1·0 metre of material over the rest of the upper beach. There had also been a small gain on the lower beach. Therefore, over the last period of fieldwork, the northerly winds which had been quite frequent had not caused any great change in the position or form of the ord, only exposing a little more till platform within the ord and moving the centre slightly further south to its original position on 12.3.75.

HOLMPTON 16.5.75

During the May/June period of 1975 the Holmpton ord was also surveyed in detail over 4 weeks. The first of these surveys was on 16.5.75 (figure 4.28). Since the last survey on 28.2.75 the ord had radically changed. As in 1974 it was again a double ord feature. On the plan of 16.5.75 (figure 4.14) there was much till platform exposed between the Runnel stream outlet and the Holmpton farm. The upper beach was reduced in height and width just to the north of this but it never disappeared completely at the cliff foot. Opposite the road end the upper beach at the cliff foot began to widen and gain in height, and 350 metres south of the highest point of this bank of sand at the cliff foot it faded out completely and till platform was exposed at the cliff foot in the southern part of the double ord feature, the Old Hive ord. The till platform here only extended for 230 metres at the cliff foot and this southern part of the Holmpton ord was much shorter than the northern part. South of here the upper beach quickly gained in height and was completely reformed at the Old Hive stream outlet. On the longitudinal profile the double ord feature was clearly seen separated by a bank of upper beach (figure 4.25).

Five transverse profiles were surveyed. The shape of the ord had changed considerably since February, and except for the north and south profiles (E and A), the others were positioned in different places to reflect the form of the ord on 16.5.75. Over the next few months these same profiles were surveyed to monitor the movement of the ord around fixed positions.

In the north, profile E (at the erratic) had a narrow upper beach, 14 metres wide, which had 26 metres of exposed till platform at its base (figure 4.28). The dry lower beach ridge was very well formed here with a $3{\cdot}7^{\circ}$ landward slope, a flat top over 40 metres wide and a $1{\cdot}4^{\circ}$ slope to the low water mark. This profile at the erratic was also surveyed on 28.2.75. In figure 4.28 the changes on the profiles since that period can be seen. There had been a loss of material, especially from the base of the upper beach, but there had been a considerable gain on the lower beach, up to 1·5 metres. The lower beach ridge was not in evidence at all on 28.2.75. Profile D was surveyed 360 metres south of profile E, north of the Holmpton farm. The form of the profile was very similar to profile E. The upper beach was wider, 26 metres, with 18 metres of till platform at its base. There was a well-formed, almost symmetrical lower beach ridge trapping a narrow water-filled runnel. There was no profile for comparison on 28.2.75.

Profile C, 450 metres south of profile D, was placed across the highest point of the upper beach separating the two sections of exposed till platform. There was no real break of slope between the upper and lower beaches. The whole profile was slightly concave between the cliff foot and the low water mark. The lower beach was below the beach water table which emerged on the lower slope of the upper beach, and therefore the lower beach was covered with a thin sheet of surface water.

Profile B was surveyed 330 metres south of profile C, where the till platform was exposed at the cliff foot. Here it was 16 metres wide and the lower beach seaward of this was less steeply sloping than the till platform and not ridged. As in 1974 the lower beach in this part of the Holmpton ord was not in a ridged form whereas the lower beach in the north was very well ridged. Profile A in the south, opposite the Old Hive stream outlet, had a very well-formed and wide upper beach, which merged with no definite break of slope into the lower beach near the low water mark. The slope of the upper beach was $4{\cdot}3^{\circ}$ and it was over 70 metres wide. In comparison with the same profile on 28.2.75, the upper 24 metres were very similar and much of this was above the mean high water mark. On the lower slope of the upper beach there had been a loss of beach material almost to the low water mark (figure 4.28).

The stage of the tidal cycle on the day of the survey was 3 days after a Spring tide, the tidal range 4·1 metres. This survey of the Holmpton ord was taken 2 days after the survey at Atwick. Therefore the wind conditions over the previous weeks can be found described on page

The main changes over this period can be summarised. The upper beach had reformed in the centre of the ord to separate it into two sections again. Till platform had been re-exposed both in the north and south of the ord. The lower beach in the northern section was once more well ridged. The ord had not moved either northwards or southwards and was approximately the same length. There had been more major changes in the Holmpton ord over the same period than in the Atwick ord (compare the plans in figure 4.14 with 4.18 and 4.19). The effect of the processes operating on the Holmpton ord had been to remove the vast area of lower beach which on 28.2.75 was covering most of the ord features.

HOLMPTON 23.5.75

The next survey of the Holmpton ord was on 23.5.75. The ord had only altered slightly since the previous week (fig. 4.14). The area of till platform exposed had been reduced in the northern section of the ord from both ends, but it was exposed at the cliff foot north of the road end. The bank of upper beach south of this was in a similar position to 16.5.75, and the till platform south of this had extended 100 metres further south towards the Old Hive stream outlet. The northern end of this till platform was in the same position. The longitudinal profile showed a slight lowering of the upper beach between the two exposures of till platform.

Profile E in the north had only changed slightly over the previous week (figure 4.28). The upper beach was only 10 metres wide and the till platform at its base 26 metres wide. There was no water-filled runnel trapped by the lower beach ridge which was slightly higher. The loss of material on the upper beach at the cliff foot had been counteracted by a gain of material over most of the lower beach. Profile D to the south had suffered less change than profile E. The upper beach was 3 metres narrower with till platform still at its base. The lower beach had gained a little in height.

Profile C, except at the cliff foot, had lost material over all its length, the slope of which was steeper at $3{\cdot}9^{\circ}$ compared with $2{\cdot}7^{\circ}$ on 16.5.75. There was still no real break of slope between the upper and lower beaches. On profile B there was still 10 metres of till platform at the cliff foot but the lower beach seaward of this had gained up to 0·6 metre of material. The profile of the lower beach was still not ridged but it was not as steeply sloping towards the low water mark as it was on 16.5.75. Profile A had again suffered a loss of material, this time mainly at the top of the upper beach. The slope was $4{\cdot}4^{\circ}$ and there was a more definite break of slope 55 metres from the cliff foot.

The overall changes during the previous week had been a gain of material on the lower beach of the whole ord, except on profile C where there had been a general lowering of the whole beach separating the two exposures of till platform. The tide on the day of the survey was 3 days before a Spring tide, and the range was 4·5 metres. The winds were mainly from a north and north-westerly direction with speeds fluctuating between 5 and 24 knots, mostly less than 15 knots.

HOLMPTON 29.5.75

The next survey of the Holmpton ord was on 29.5.75. In plan, figure 4.15, the ord had a similar form to the previous week except for the exposure of till platform in the north which had moved southwards from both ends. The northern end of the till platform was south of the erratic and there was 120 metres of exposed till platform at the cliff foot. South of this a tail of till platform was exposed at the base of the bank of upper beach between the two sections of the ord. The till platform exposed in the south remained in the same position as on 23.5.75.

Profile E in the north (figure 4.28) had gained material over most of the profile. Till platform was no longer exposed but there was still a deep depression between the upper and lower beaches and a highly asymmetrical lower beach ridge seawards of this. Profile D had suffered a loss of 1·3 metres of material at the cliff foot and the upper beach had narrowed to 14 metres with 24 metres of till platform at its base. There was a water-filled runnel trapped by the lower beach ridge which had gained 0·6 metre on its crest. Towards the low water mark the beach was lower than it was on the previous week.

Profile C, which had previously not been affected by the ord conditions was beginning to show the effects of the movement south of the northern part of the Holmpton ord. Although it was built up by 0·2 metre at the cliff foot, the lower parts of the upper beach lost 0·5 metre of material and for the first time during this period of fieldwork till platform was exposed at the base of the upper beach, which was only 23 metres wide. The lower beach was also developing into an asymmetrical ridge form, although its crest was only 0·3 metre above the till platform surface compared with 0·8 metre on profile D. This ridge had trapped a water-filled runnel.

Profile B had been lowered at the cliff foot where the till platform was exposed, but seawards of this, up to 0·5 metre of material had been gained. This had steepened the slope of the lower beach. Despite this it was still above the beach water-table. Profile A in the south had changed the least of all, losing only a little material from the upper beach which was the same width as 23.5.75. Therefore the main features of change over the previous week were: the movement of the upper beach between the two sections of the ord, the crest of which had moved southwards 80 metres (see figure 4.25 for the long profile); the movement of the northern section of the exposed till platform southwards. Despite this the upper beach in the north was not well built up until north of the Runnel stream outlet.

The survey was taken three days after a Spring tide and the tidal range was 4·4 metres. The winds during the previous week were northerlies with speeds between 10 and 25 knots.

HOLMPTON 9.6.75

The next survey of the Holmpton ord was on 9.6.75. During this survey a sea mist came over the beach and the survey had to be abandoned after profiles A and B in the south had been completed, but a plan of the beach was made before the mist came down, figure 4.15. The section of exposed till platform in the north was well established at the cliff foot between the erratic and the farm. A narrow strip of till platform extended north from the farm at the foot of the narrow upper beach to just south of the erratic. In the south the till platform extended at the foot of the upper beach south of profile A for the first time. The northern end of this southern till platform had also moved southwards as the upper beach to the north of this had shifted southwards.

Profile B (figure 4.28) had gained 1·3 metres of material at the cliff foot and the upper beach had built up to over 30 metres wide. The lower beach had suffered a slight loss and there was no sign of the slight ridge form seen a week earlier. Profile A had lost material from the upper beach but gained on the lower beach which was slightly ridged. At the foot of the upper beach 55 metres from the cliff foot was 4 metres of till platform.

This survey was taken 2 days before a Spring tide when the tidal range was 4·0 metres. The first part of the week had strong (over 20 knots) westerly winds blowing, which shifted to south-easterlies of less than 15 knots by the day of the survey.

The superimposed transverse profiles of Holmpton on 16.5.75 and 29.5.75 (also with profiles A and B for 9.6.75) can be seen in figure 4.28. In the north profile E had gained in height over all the profile, except near the low water mark where the height and slope had remained the same. The largest change had been on the lower beach ridge which had almost doubled in size and was now very asymmetrical and steep ($4 \cdot 9^{o}$) on the landward slope. Profile D had lost 1·0 metre at the cliff foot but gained 0·6 metre at the crest of the lower beach ridge. Profile C was slightly higher at the cliff foot but greatly reduced in height on the lower parts of the upper beach. A low lower beach ridge had begun to develop. Profile B, by 29.5.75, had begun to be raised 10 metres from the cliff foot. On 9.6.75 the till platform at the cliff foot was completely covered and the lower beach lowered. The whole profile took the form of the beach to the north of an ord where the upper beach was not fully built up and the lower beach was below the beach water table and sloped gently and smoothly to the low water mark. Profile A displayed a general lowering of the upper beach and a gradual rise of the lower beach.

The changes in the Holmpton ord over this May/June period had been a little more pronounced than in the Atwick ord over the same period. The dominant movement had been the movement of the bank of upper beach at the cliff foot, between the two sections of the ord, southwards. This was seen well in the longitudinal profiles (figure 4.25). This upper beach had a gently built up slope from the till platform exposed in the north, and a steeper decline to the till platform exposed in the south. Movement of both the upper and lower beaches had covered much of the northern section of the till platform which was exposed on 16.5.75. There had also been a general lowering of the upper beach to the south of the ord.

JULY 1975

ATWICK 22.7.75

Both the atwick and the Holmpton ords were surveyed twice at the end of July. The Atwick ord was surveyed on 22.7.75. The plan of the beach (figure 4.20) was not very different from the last survey 6 weeks before on 10.6.75. The areas of till platform exposed were in approximately the same positions, the centre was slightly further south than before. The upper beach was a little wider in the north and narrower in the south but the overall configuration of the beach was the same.

On the profiles the change over the previous 6 weeks is plotted in figure 4.29. Profile D in the north had gained material between the cliff foot and 55 metres seawards. The maximum gain was 0·5 metre. This had raised the general level of the beach near the cliff foot but it had remained the same near the low water mark. Therefore the profile was steeper but still smooth with no real break of slope between the upper and lower beaches. Profile C had changed very little and only lost material on the 10 metres nearest the cliff foot (less than 0·2 metre). The rest of the profile was unaltered. Profile B had a uniform loss over all the profile. The width of till platform exposed at the foot of the upper beach was 7 metres. The break of slope between this and the lower beach was not well marked. Profile A in the south had gained 0·2 metre at the cliff foot but 5 metres from this the upper beach had suffered a loss of material to its base. There had also been a loss at the low water mark.

The break of slope between the upper and lower beaches was 54 metres from the cliff foot.

This survey was taken 2 days before a Spring tide and the tidal range was 4·1 metres. There was a period between 21st and 30th June when the winds were all from a northerly direction but the wind speeds were below 15 knots. For the rest of the period the winds were westerly and southerly, speeds fluctuating between 3 and 16 knots, and only on two occasions were they over 20 knots. Therefore the weather during the preceding period was quite moderate with no storms.

ATWICK 28.7.75

The Atwick ord was next surveyed on 28.7.75 (figure 4.20). The ord was almost identical in plan to the previous week, except in the middle section of the ord where the upper beach was wider.

Profile D in the north (figure 4.29) had again gained material over most of its length, especially near the low water mark, and so it was very similar in profile to 22.7.75. Profile C also showed the same change, and also profile B to a larger degree. Even the upper beach on profile A had gained up to 0·2 metre of material except for a small loss at the cliff foot. Only profile B had an exposure of till platform, 20 metres from the cliff foot and 9 metres wide.

The survey was taken 4 days after a Spring tide and the tidal range was 4·1 metres. All the winds during the preceding week blew from a westerly direction and for the first 4 days the speeds were 17 to 27 knots and then fell to less than 12 knots.

HOLMPTON 23.7.75

The Holmpton ord was next surveyed on 23.7.75 (figure 4.15 for the beach plan). This ord had changed in plan more noticeably than the Atwick ord. The till platform exposed between the erratic and the farm was still present but centred further south between the road end and the farm. This was the only place in the whole ord where till platform was exposed at the cliff foot. North of the erratic there was a short section of till platform at the foot of the upper beach. Near Old Hive, where on 9.6.75 there was a large exposure of till platform, on 23.7.75 the upper beach had been established at the cliff foot and only a narrow strip of till platform was exposed between profiles A and B at the foot of the upper beach.

As can be seen on the longitudinal profile (figure 4.25) the bank of upper beach at the cliff foot south of the farm was still well established and it only narrowed slightly between profile C and profile A. In the north on profile E the upper beach had lost up to 0·5 metre of material during the previous 6 weeks, except at the cliff foot where there had been a slight gain (figure 4.30). The lower beach ridge had moved landwards and was 0·2 metre lower at its crest. On profile D there had been a gain of material over all the upper beach of approximately 0·3 metre and the lower beach ridge crest had also moved landwards. There had been a slight loss on the seaward slope of the lower beach. Profile C had again suffered a considerable loss on the upper beach, up to 1·0 metre and the break of slope was now

20 metres further landward. There had also been a loss of material near the low water mark. This had obliterated most of the lower beach ridge seen in June. Profile B had gained almost 2 metres over most of the upper beach except near the break of slope where some loss had occurred. This profile was a concave line from the cliff foot to the low water mark, with the break of slope 35 metres from the cliff foot and a gently sloping lower beach below the beach water table. Profile A in the south had changed very little over the previous 6 weeks. Only a little material had been gained at the foot of the upper beach which had covered the small area of till platform exposed on 9.6.76. This profile was now almost an even slope between the cliff foot and the low water mark.

Each profile appeared to have changed in a different way since the previous survey. This was to be expected if the ord form had moved at all. In the north the lower beach ridge, surveyed on profiles E and D, had moved landwards but was lower than before. Profile C reflected the movement of the bank of upper beach southwards, and whereas the crest of this beach was at profile C on 16.5.75, it was well to the south of there. This had affected the beach at profile B where the movement of this upper beach southwards had built up the profile and obliterated the centre of what was the southern section of the ord in May.

This survey was taken one day before a Spring tide and the tidal range was 4.5 metres. The wind data is outlined on page 117, and basically it was of moderate speeds with no storm conditions at all.

HOLMPTON 30.7.75

This ord was surveyed a week later on 30.7.75. The ord in plan was very similar to the previous week (figure 4.15). The changes on the profiles were almost the opposite of those of the previous week (figure 4.30). Profile E gained up to 0·7 metre on the upper beach, but much less (0·2 metre) on the lower beach. This had considerably built up the upper beach. Profile D had lost much material on the upper beach, up to 0·6 metre, and this was only 7 metres wide. Seaward of this was 33 metres of till platform. The crest of the lower beach had gained 0·5 metres of material. Profile C had gained 0·2 metre at the cliff foot and over the rest of the upper beach. There was still till platform exposed at the base of the upper beach. The lower beach had gained 0·9 metre and was in the form of an asymmetrical ridge, as high as the ridge on profile D. Profile B had only suffered a small gain over most of the profile. Profile A in the south had undergone the least change of all the profiles, only a very slight loss.

This survey was taken 6 days after the peak of the Springs and the tidal range was 3·2 metres. The wind conditions, which have been described more fully on page , were of variable speeds from the westerly quarter. During the months of June and July 1975 neither of these ords had undergone any major change. The north and south ends were in similar positions to those of May. The upper beach to the north of the ord at Holmpton was still not well built up south of the Runnel stream outlet. All the beach changes had been minor ones.

OCTOBER 1975

ATWICK 15.10.75

Both ords were surveyed again in October 1975. The Atwick ord was surveyed on 15.10.75. On the plan of the ord (figure 4.20), it can be seen that the centre of the ord had moved south by 300 metres but its place had not really been taken by the northern upper beach, therefore north of the centre was an area where the lower beach came right up to the cliff foot. At the centre a narrow strip of till platform was exposed at the cliff foot and this continued intermittently southwards at the foot of the upper beach which built up at the cliff foot south of the centre.

Profile D had gained up to 0·6 metre of material on the upper beach but 37 metres from the cliff foot this was reversed and the beach was lower than on 28.7.75 with a loss of 1.4 metres at the low water mark. The effect of these changes was to steepen the profile of the beach which did not have a distinct break of slope. Profile C had suffered a loss between the cliff foot and 36 metres seawards. This had re-exposed the till platform at the base of the narrow (16 metres) upper beach on this profile. There had been a slight gain of material seawards of this, but then, as on profile D, a loss at the low water mark. Profile B, also with till platform at the base of the upper beach, had suffered a loss of material over all the profile. This loss was 0·6 metre at the cliff foot and 0·1 metre at the low water mark. Profile A had shown the same change as profile B, a loss over all the profile.

The tidal range on the day of the survey, 6 days after a Spring tide, was very small, only 2·9 metres. Therefore since the end of July this ord was more built up in the north but lower at the cliff foot throughout the whole ord, and to the south of the ord. During August the winds were variable in direction and rarely over 15 knots. During most of September they blew from the west with speeds varying between 5 and 20 knots. These conditions persisted into October. Only on two occasions did strong winds combine with a northerly direction. The first of these was on 13th to 15th September, when wind speeds were over 20 knots, and 28 knots all day on 14th September. The second occasion of strong northerly winds was between 8th and 11th October when they blew slightly east of north with a maximum of 28 knots. If one studies the beach plan of the Atwick ord before and at the October survey, 5.10.75 and 15.10.75 (figure 4.20), it can be seen that there had only been a slight change caused by the northerly winds of 8th to 11th October. The changes over this same period were not quite so simple in the Holmpton ord.

HOLMPTON 16.10.75

The Holmpton ord was next surveyed on 16.10.75. Although the plan of the ord in the south has not changed to any great extent, the northernpart of the ord was greatly changed (figure 4.16). The centre of the ord was positioned at the road end. Till platform was exposed most of the length of the ord south of here. South of the road end the upper beach began to build up at the cliff foot and the till platform was exposed at its foot. In the northern part of the ord the upper beach,which had been reduced in height and width south of the Runnel stream outlet,was well established south of profile E, where it was extended on to the lower beach on 16.10.75.

Profile E (figure 4.29) had gained very little material (0·2 metre) at the cliff foot since July but the lower beach ridge had moved landwards by the addition of material over all the lower beach,but especially on the ridge crest 30 metres from the cliff foot where 1·4 metres of material had been gained. This had completely covered the erratic which had marked the profile earlier. The depression between the upper beach and lower beach ridge was now 3 metres landwards and 1·2 metres higher than in July. A similar pattern of change was found on profile D. The upper beach had been built up at the cliff foot and the lower beach ridge as on profile E was higher and further landwards. The build up of both upper and lower beaches had covered most of the till platform exposed in July, and it was only 10 metres wide on 16.10.75. Profile C also showed a gain of 0·5 metre over most of the profile except at the cliff foot where there had not been a change. Therefore the profile was in a very similar form to July. Profile B had gained 1·0 metre at the cliff foot. The lower slope of the upper beach and parts of the lower beach had suffered a loss. At the foot of the upper beach, 45 metres from the cliff foot, 13 metres of till platform were exposed. A slight gain of material near the low water mark had given this profile a slight lower beach ridge. Profile A had suffered a loss of 1·0 metre of material at the cliff foot, a gain mid way on the upper beach and a loss near the base. The profile showed a very similar slope to July, except at the cliff foot.

The longitudinal profile (figure 4.25) for the first time since February 1975 was not dominated by the bank of upper beach in the middle of the profile which separated the double ord form. The Holmpton ord was only a single ord feature on 16.10.75. The double ord began to disappear in July and by October it had gone. The longitudinal profile showed the fall of the northern upper beach to the centre and then the rapid rise of the upper beach again at the cliff foot to the south. The upper beach remained high at the cliff foot in the rest of the ord south of profile C.

If one looks at the ord plan for 3.10.75, it can be seen that considerable movement had occurred on the upper beach to the north since that date and the survey on 16.10.75 (figure 4.16). The upper beach on 3.10.75 was reduced in height and width in a sweeping curve which ended near the cliff foot mid way between the Runnel stream outlet and profile E at the erratic which was still visible. In July the upper beach ended at the Runnel. On 3.10.75 the upper beach consisted of a series of ridges which were parallel to the cliff foot and then swept round towards the cliff foot as the upper beach narrowed. The upper ridge, mainly of small and medium-sized shingle, met the cliff foot just south of the Runnel stream outlet and ponded up some of the stream water into a large pool. A second lower ridge of sand and some small shingle also swept round to meet the cliff foot further south than the first. Between the ridges there was a slight depression. These ridges were only a few metres across and could not be confused with the much larger form of the lower beach ridge of the ord. A slight merging of the upper beach and lower beach occurred at the base of the upper beach seaward of where the upper beach ended at the cliff foot. This in no way resembled the complete merging of these features 400 metres further south on 16.10.75. On this date, as was outlined above, the upper beach was well formed as far south as profile E, where it merged into the exceptionally high lower beach, its influence extending nearly as far south as profile D. The positioning of this tongue of material was recorded for the first time by the survey of 16.10.75.

DECEMBER 1975

The last period of fieldwork on the ords was carried out between 1st December 1975 and 7th January 1976. In some ways this has proved the most rewarding period as it took place after a severe storm in mid November and included another storm at the beginning of January.

ATWICK 3.12.75

The Atwick ord was next surveyed on 3.12.75, 7 weeks after the previous survey. In plan (figure 4.21), the ord had changed quite markedly. The end of the northern upper beach was 60 metres further south than October and the centre and northerly exposed till platform at the cliff foot was 170 metres further south, and 140 metres south of its July position. The most noticeable feature in the ord was the large exposure of till platform compared with October. It stretched for almost 200 metres at the cliff foot and where the upper beach gradually built up to the south at the cliff foot it was exposed at its base. The till platform was not completely covered until 100 metres south of profile A. The width of the exposure of till platform was greatest in the north, 30 metres, and reduced to 8 metres on profile A.

Profile D in the north was now typical of the beach north of an ord (figure 4.31). The upper beach was wide, high at the cliff foot, and convex in profile. The lower parts of the beach were below the beach water table and covered by a sheet of surface water to the low water mark. There was no distinct break of slope between the upper and lower beaches. This profile had gained 0·5 metre of material at the cliff foot, lost up to 0·3 metre between 10 and 70 metres from the cliff foot, and gained 0·7 metre at the low water mark. This alteration of gain and loss had smoothed out the profile and it was less steep. It was 170 metres north of the end of the upper beach, and the beginning of the ord. Profile C was just over 100 metres south of the centre of the ord. A narrow upper beach (11 metres wide) was present at the cliff foot. Seaward of this was 31 metres of till platform. The lower beach was slightly raised into a ridge with a steeper seaward than landward slope. On this profile there had been a loss of material at the cliff foot and also on the lower beach. The exposure of till platform had widened from both sides. Profile B had gained material at the cliff foot and the upper beach had become wider. Seaward of this was 20 metres of till platform. A loss of material on the lower beach had reduced it to an almost flat surface to the low water mark. Profile A had lost 0·3 metre of material over its whole length. The upper beach was only 29 metres wide with till platform exposed at its base.

This survey was taken on a Spring tide and the tidal range was 5·0 metres. Between the last survey and 5th November, the winds blew from a westerly direction with an average speed of 13 knots. After 5th November the winds fluctuated greatly with speeds of 15 to 20 knots from a north-north-easterly direction. Between 10th and midday of 16th November, low speeds and a variable direction were recorded. Between 16th and 18th November the winds veered northerly and built up in speed to a peak of 50 knots at midday on 17th. This was the highest speed recorded over the study period. After this the winds blew constantly from the west with speeds between 2 and 32 knots. The storm in mid-November was generated by a deep cyclonic low pressure cell moving across southern Scotland and into the North Sea from the west. It remained stationary in the North Sea for over a day, bringing strong northerly winds over all Great Britain (figure 6.2 , the cyclonic track).

ATWICK 10.12.75

The Atwick ord was next surveyed on 10.12.75. The northern upper beach remained in the same position as on 3.12.75 but the centre of the ord had moved southwards by 100 metres, see the plan (figure 4.21). The exposure of till platform at the cliff foot extended for 370 metres. The upper beach then built up quite quickly at the cliff foot with a wide (14 metres) strip of till platform at its base.

The longitudinal profile (figure 4.24) was surveyed nearer the cliff foot as the low water was exceptionally high on the day of the survey. In the north, profile D had gained up to 1·0 metre of material on the upper beach, 0·3 metre at the cliff foot (figure 4.31). Profile C had lost the upper beach between the cliff foot and the till platform and now the till platform was exposed at the cliff foot for 29 metres. A flat lower beach was found seaward of this where some addition of material had occurred. Profile B had gained 0·3 metre of material at the cliff foot but more till platform was exposed seaward of the upper beach. Profile A had suffered considerable loss near the cliff foot, up to 1·0 metre. The upper beach here was only 18 metres wide with till platform seaward of this. The overall change over the past week was the deepening of the ord with a southward movement of the ord south of the centre. This survey was taken 7 days after a Spring tide when the tidal range was 2·8 metres. The winds during the previous week were all westerlies and less than 15 knots.

ATWICK 17.12.75

The next survey of the Atwick ord was on 17.12.75. The upper beach to the north of the ord had moved 100 metres further south. The centre of the ord had also moved 100 metres south, but the previous centre had only been filled in by a thin veneer of sand. The rest of the ord was in a very similar form to the previous week, the till platform at the base of the upper beach ending further south (figure 4.21

for the plan). The longitudinal profile was surveyed on the same line as the previous week, nearer the cliff foot. In the north, Profile D had lost 1·0 metre of material over the whole profile (figure 4.31). Despite this reduction in height the upper beach was still quite wide and well established. The till platform at the cliff foot on profile C had been reduced in height since the previous week. It was now 34 metres wide. There had again been a small rise on the lower beach seaward of the till platform. Profile B was in a very similar form to the previous week. There had been a slight loss of material from the upper beach. Profile A could not be surveyed because of the worsening weather conditions. The main changes during the previous week had been in the north of the ord. The survey was taken 4 days before a Spring tide when the tidal range was 4·0 metres. Winds during the previous week fluctuated between the west and north with speeds between 4 and 36 knots, the highest on 13th and 17th December from the north.

ATWICK 22.12.75

The Atwick ord was next surveyed on 22.12.75 (figure 4.21). The greatest change had been the removal of most of the upper beach of the ord south of the centre. Only a little remained south of profile B as a narrow strip at the cliff foot. The centre of the ord was in the same position as before. The northern upper beach had moved 50 metres southwards. The high water mark was now present on the beach north of the road end. The longitudinal profile was surveyed on the original line.

On profile D (figure 4.32) there had been a gain over all the profile. The upper beach was now 64 metres wide and 3·80 metres OD at the cliff foot. Profile C had changed little. The lower beach had gained slightly and was now in the form of an asymmetrical ridge. Profile B had gained a little, 0·2 metre, at the cliff foot but the upper beach was only 15 metres wide. On profile A the upper beach was reduced to a thin veneer of sand at the cliff foot over the till platform and was only 7 metres wide. The till platform was 28 metres wide. The lower beach sloped gently from this to the low water mark. This survey was taken 1 day after a Spring tide and the tidal range was 4·6 metres. The winds were all westerlies from 5 to 24 knots.

ATWICK 6.1.76

The last survey of the Atwick ord was taken on 6.1.76. The upper beach to the north of the ord had moved 140 metres southwards (figure 4.21). The end of this upper beach was still in the characteristic form of the wide sweep towards the cliff foot. The centre of the ord was in almost the same position as the previous survey. The till platform was now exposed for 800 metres at the cliff foot, almost to profile A in the south. Profile D in the north had continued to gain material over all of its length, with a gain of 1·2 metres at the cliff foot (figure 4.32). The upper beach slope was now steeper at 4·3°. There was no visible lower beach above the low water mark. Profile C had changed only slightly. There was still 27 metres of till platform at the cliff foot but a gain of material on the lower beach had reduced the width of the till platform exposed. Profile B had suffered a loss of material from the cliff foot and till platform now extended from there for 22 metres. The lower beach had gained a little material but still sloped gently to the low water mark. Profile A had gained 0·3 metre of material on the upper beach which was 15 metres wide. The till platform seaward of this was 30 metres wide and a gain on the lower beach had raised it slightly. The main change since the previous survey on 22.12.75 had been the movement of the northern upper beach south and the slight build up of the upper beach south of profile A. This survey was taken 3 days after a Spring tide and the tidal range was 4·2 metres.

Since the previous survey the winds blew from a westerly direction with speeds between 7 and 22 knots for most of the time. But exceptional weather conditions were generated by the passage of a low pressure cell on 2nd and 3rd January. This low crossed southern Scotland from the west and moved into the north sea travelling towards Denmark, deepening as it moved. Speeds of up to and over 50 knots, with west-north-west and northerly directions, were recorded on the Holderness coast. The track of the centre of the low is shown in figure 6.4.

Figure 4.32 gives the superimposed transverse profiles for 3.12.75 and 6.1.76, covering the period of fieldwork described above. The upper beach on profile D had been built up while the lower beach had been gradually reduced in height.

The changes on the other profiles, all south of the centre of the ord on both surveys can be summarised as follows: there had been a general lowering of the upper beach, even as far as removing it completely on profiles B and C; the lower beach on each profile had been raised and the slight ridge form had moved landwards. This even appears in profile A in the south. Therefore, simply, there had been a pivoting of each profile around the break of slope between the upper and lower beaches. In the case of profile D the profile had been tilted up at the cliff foot and down at low water mark. The other three profiles show the opposite movement.

HOLMPTON 4.12.75

The Holmpton ord was next surveyed on 4.12.75 (figure 4.16 for the plan). As at Atwick the main change over the past 7 weeks was the much larger area of till platform exposed and the movement of the northern upper beach southwards. In the case of the till platform it was very similar in form to the Atwick ord. The till platform extended slightly further north than on 16.10.75 as well as for a very long distance at the cliff foot south of the ord centre, over 1000 metres. The upper beach in the south built up rapidly to a width of over 30 metres but the till platform was exposed at its base to the south of profile A. The second major change, the movement of the northern upper beach had not taken the same form as on the Atwick ord. On 16.10.75 it was observed that the northern upper beach was well formed north of profile E and southwards of this it merged with a tongue-like form into the lower beach of the ord north of profile D. On 4.12.75 this upper beach had extended even further south to merge with the high lower beach of profiles E and D.

Profile E had till platform almost at the cliff foot and seaward of this was a lower beach ridge of large dimensions. It had a steep landward slope but was symmetrical, as the seaward slope was very steep and showed the characteristics not of a lower beach seaward slope but of an upper beach seaward slope. The crest of the ridge had gained 1·6 metres of material since 16.10.74, whereas towards the low water mark almost a metre of material had been lost. Profile D had shown less change. The till platform at the cliff foot had been lowered. The lower beach ridge, well formed in October, was 0·6 metre higher and the crest slightly landwards. The seaward slope was not as steep as on profile E but it was steeper than before. There had not been a loss of material near the low water mark. Profile C had suffered a great loss on the upper beach, up to 2·2 metres, and now there was no upper beach remaining but 39 metres of till platform at the cliff foot, on what was originally the most well built up profile. The crest of the lower beach ridge was slightly landwards of its previous position and there had been a loss of material at the low water mark which had emphasised the ridge form. Profile B had also suffered a 1·5 metre loss over all the profile. Till platform was present 34 metres from the cliff foot. The slope of the upper beach remained the same. Profile A had lost material from both upper and lower beaches, most especially on the latter. There was no real lower beach ridge, but a wide exposure of till platform at the base of the upper beach.. This survey was made 1 day after a Spring tide and the tidal range was 4·9 metres. The winds during the preceding 7 weeks have been outlined on page 127.

HOLMPTON 19.12.75

The next survey of the Holmpton ord was on 19.12.75 (figure 4.16). The centre of the ord had moved southwards to between the road end and the farm. This had come about by the movement of the northern upper beach southwards and towards the cliff foot. The depression between the cliff foot and the crest of the lower beach on profile E had now been reduced in depth by the gain of material near the cliff foot. The lower beach ridge was still in existence but the loss of material from the seaward slope had increased the angle of the slope between the ridge crest and the low water mark to $4{\cdot}2^{\circ}$ compared with $3{\cdot}3^{\circ}$ on 4.12.75 (figure 4.33). Profile D had less till platform at the cliff foot but the lower beach ridge had been obliterated by the infilling of the depression landwards of the ridge. This profile marked the centre of the ord. Again there had been a loss of material on the seaward slope of the lower beach. Profile D now had a short steep section of beach near the cliff foot and then a more gentle slope to the low water mark.
Profile C had again suffered a loss over all the profile. The till platform exposed at the cliff foot was now 45 metres wide. Seaward of this was a reduced lower beach ridge.
Profile B had suffered a loss of 1·4 metres of material at

the cliff foot and the upper beach was also reduced in width. Till platform was exposed 16 metres from the cliff foot and was 25 metres wide. The lower beach ridge was 0·2 metre higher on its crest which had moved landwards. Profile A had also suffered a loss of material, mostly on the lower slopes of the upper beach. Till platform was exposed at the foot of the upper beach. A slight gain of material on the lower beach had reformed the ridge.

This survey was made 2 days before a Spring tide and the tidal range was 4·2 metres. Most of the winds since the preceding survey were moderate westerlies, except for two short periods of stronger northerlies on 13th and 17th December.

HOLMPTON 7.1.76

The next survey of the Holmpton ord was on 7.1.76. At this time the centre of the ord was in the same position as on 19.12.75, but the area of till platform exposed south of the centre was very much reduced (figure 4.16). Profile E, now well to the north of the ord showed characteristic upper beach features. It had gained material at the cliff foot, 1·0 metre, and lost material near the low water mark. The profile was now a smooth, quite steep slope from the cliff foot to the low water mark (figure 4.33). Profile D was also a smooth but less steep slope. There was a few metres of till platform at the cliff foot where the cliff had recently been eroded back. The beach had lost 0·8 metre of material towards the low water mark but a gain landwards of this had smoothed the profile which now was a gentle slope. Profile C had 45 metres of till platform at the cliff foot and a steep asymmetrical lower beach ridge seaward of this. The ridge crest had gained 0·8 metre since 19.12.76. Profile B now also had till platform at the cliff foot. This was 37 metres wide. The lower beach was only slightly raised and material had been lost from the ridge crest of the previous survey. Profile A had suffered a loss over the whole profile. The till platform was now exposed 41 metres from the cliff foot, 8 metres nearer than on 19.12.76. For the first time during the whole study of the Holmpton ord the beach was higher at the cliff foot on profile E in the north than profile A in the south.

The longitudinal profiles of the Holmpton ord during the December 1975/January 1976 period show a constant lowering of the central part of the ord south of the centre, and a raising of the northern upper beach (figure 4.25). The bank of upper beach sand between the two ord centres that was dominant throughout most of the year, began to decline in height in October and was completely obliterated by 4.12.75. Between 4.12.75 and 19.12.75 the profile between the transverse profiles B and D was lowered by 1·0 metre. The exceptional rise of the northern upper beach occurred between 19.12.75 and 7.1.76.

The survey on 7.1.76 was taken 4 days after a Spring tide when the tidal range was 3·8 metres. The storm that occurred on 2nd and 3rd January has been outlined on page 131

This ends the review of the results of the 1974 and 1975 fieldwork. No major changes occurred in the ords until the last quarter of 1975, when for the first time since the start of the study in December 1973 major northerly storms occurred associated with the passage of a deep low-pressure cell across the North Sea. In the following chapters these results will be analysed and the mechanisms of the ord movement studied in detail.

SEDIMENT SAMPLES OF THE HOLMPTON AND ATWICK ORDS.

The mean diameter of the sand samples, in phi units (see Chapter 3), taken on the ords are included on the beach plans in figures 4.12 to 4.21, when they were collected. The full results of the statistical analysis are given in tables 4.3 and 4.4.

A few preliminary samples were taken at Holmpton on 7.5.74. The most interesting of these were the four samples taken along the crest of the lower beach ridge on the southern section of the double ord, south of the Holmpton Farm. Here the sample means were reduced in size on the ridge crest the further south and seaward it went, from 1.37 in the north to 2.07 phi in the south. On 28.2.75, when the Holmpton ord displayed the double ridge feature on the very wide lower beach, the two ridges were distinguished by the mean grain sizes of the material on their crests. The upper ridge crest, the ridge nearest the cliff, had material sizes between 1.58 and 1.97 phi, and these were fairly constant the whole length of the ord. On the lower ridge crest the sand size varied between 2.26 and 2.32 phi, a very constant distribution of fine sand near the low water mark.

On 16.5.75 the ord was sampled again. The coarsest sand was found at the cliff foot on the upper beach. This varied between 0.83 phi on profile E to 0.93 phi at the Old

Hive stream outlet in the south. On profile C, on the top of the bank of upper beach separating the two sections of the ord, the mean grain size was slightly smaller at 1·40 phi. On the lower beach the same pattern of distribution was found as at the Easington ord the year before (see figure 4.11). The finest sand was at the low water mark and this became finer towards the south, where on profile A it was 2·29 phi. One exception was on profile C at the low water mark where the beach was below the beach water table. The mean sand size was as large as 1·42 phi and was probably affected by coarser material being washed down the beach by the film of water covering the lower beach at this point in the ord. The sample site was also very close to the overflow runnel crossing the lower beach ridge just to the north of profile C.

On 9.6.75 the sand at the cliff foot was slightly finer, 1·69 phi at profile E in the north, but the lower beach was coarser and the difference between the coarsest and the finest sand on the ord was reduced. On 30.7.75 a similar, but more pronounced pattern was found. The sand at the cliff foot was very fine, on average finer than that at the low water mark. On profile B at the cliff foot the average mean diameter of the samples was 2·17 phi. The material at the low water mark varied between 1·71 and 2.24. On 16.10.75 all the material within the ord was relatively fine, 2·17 at the cliff foot on profile B, and between 1·95 and 2·06 at the low water mark. The exception to this was where the tongue of upper beach in the north extended over the lower beach between profiles D and E. Here was found the coarsest beach material, between 1·44 and 1·65 phi. This area of the ord was even coarser on 19.12.75, 1·52 phi, when the tongue of upper beach had developed into a larger feature.

The Atwick ord was first sampled on 23.1.74. The sand at the cliff foot was coarsest at the centre of the ord, 1·62 phi, but remained fairly coarse at the cliff foot along the whole ord. On the lower beach the sand became finer towards the low water mark. The ord was sampled again on 26.2.75. At the cliff foot in the north there was much small chingle mixed with the sand and the mean grain size was very coarse at -0·05 phi. On this occasion the material at the low water mark was very fine, 2·06 phi in the north, 2·55 phi opposite the centre of the ord, and 2·10 phi in the south on profile A.

On 14.5.75 the material in the ord had become finer, 2·54 phi at low water mark on profile B. All of the samples on the lower beach were finer than 2·00 phi except on profile D at the low water mark where the sand was coarser at 1·82 phi. On 10.6.75 the beach material at the low water mark was still very fine but it was coarser over the rest of the lower beach. The sand at the cliff foot varied in size from 1·55 to 1·91 phi. The sample taken at the low water mark on profile D, 1·19 phi, has been influenced by the presence of surface water on this part of the beach, north of the ord.

On 28.7.75 the lower beach material was a little coarser but the sand of the upper beach at the cliff foot was very fine indeed, with mean diameter grain sizes varying between 2·11 phi on profile D in the north, to 2·22 phi on profile A in the south. This was the same distribution as was found on the Holmpton ord at the same date (30.7.75). A particular set of conditions must have been prevailing to produce such fine sand at the cliff foot on the upper beaches which were normally rather coarse. By 15.10.75 the distribution of the beach material was again rearranged and the coarsest sand was found at the cliff foot and the finest at the low water mark, especially opposite the centre of the ord.

C H A P T E R   F I V E

SHORT TERM BEACH CHANGES WITHIN THE ORD

A. The lower beach ridge.

B. The upper beach.

C. The till boulders.

D. Sediment size distribution.

In this chapter the short term beach changes will be considered, that is the changes occurring from week to week, and the effect these have on the overall form of the ords on the Holderness coast. Schwartz (1968) proposed a three tier scale of shoreline change:

Scale	Equilibrium Amplitude	Equilibrium Time
Micro (swash/backwash)	10^1 cm.	10^1 min.
Macro (neap/spring and seasonal)	10^2 cm.	10^4-10^5 min.
Mega (major sea level changes)	10^3-10^4 cm.	10^9-10^{10} min.

The mega changes occur on too large a scale to be considered in short term work of any kind. The short term changes discussed in this chapter will fall between the micro and the macro scales as defined by Schwartz. The weekly changes which include more than one full high water/low water cycle, but not the full spring/neap cycle, will be reviewed in this chapter.

Tanner (1958) defined a concept of a beach in equilibrium with the processes operating on it as follows:

> "The equilibrium beach has curvature and sand prism characteristics adjusted to each other so delicately that the potential littoral motion provides precisely the energy needed to transport the detritus supplied at the up-current end. The time element in this balance is long term rather than instantaneous. A beach which performs in any other way is not in equilibrium."

Therefore by this definition, the Holderness beach which is migrating landwards with the shoreline is not in equilibrium. There is more material leaving the beach on the down-current end than is supplied at the up-current end. It was discussed in Chapter Two how very little material was able to move around Flamborough Head into Bridlington Bay. The beach material on the Holderness beach is therefore derived from the many sand and gravel lenses in the till cliffs. The dominant waves on the Holderness coast refract from the north-east and it is accepted that these produce a drift of beach material southwards where it is eventually added to spit of Spurn Head. The basic instability in the beach is as material is moved southwards only further erosion of the unconsolidated cliffs can replenish the beach, and without the protection of a well built up beach these cliffs can be eroded by the waves at most high waters throughout the year. Therefore the Holderness shoreline is migrating landwards because there is not sufficient sediment introduced at the up-current end to absorb all the potential energy of the littoral drift and maintain a well-formed beach.

The Holderness beach, as discussed in Chapter Two, does not display the same characteristics along all its length. In the north in Bridlington bay it exhibits a ridge and runnel profile, incorporating a series of ridges and runnels between high and low water marks. Further south, south of Barmston, the upper beach/lower beach system is developed, in which the ords are found.

Ridge and runnel systems on the foreshore have interested geomorphologists since the last century. Gresswell (1937) made the first attempt to clarify the jumble of terms used for these features which he studied on the south-west coast of Lancashire. Gresswell defined them as follows:

> "Beaches often show marked undulations of considerable wave-length and low ampitude, lying parallel to each other but often at an angle to the coastline. These undulations which occur on the shoreface, i.e. below the low water mark, are termed "balls", those on the foreshore between high water mark and low water mark "fulls". There may be one or more of each of these features on a particular shore. Natural drainage channels which cross a full taking the tidal water from one low to the next seaward should be termed "cross-lows" . . . I have found that they (the fulls) attempt to face the dominant waves and are almost certainly formed by waves of moderate size rather than by storm waves."

Although the terms fulls and lows used by Gresswell have since been replaced by ridges and runnels (Gresswell defined a beach ridge as an undulation above the high water mark), Gresswell had recorded several interesting features of a ridge and runnel beach, especially the perpendicular alignment to the dominant waves. This work was followed up between 1943 and 1947 by King and Williams (1949) in research on the Blackpool beach in Lancashire. Like the beach studied by Gresswell the Blackpool beach is very wide at low water with a very large tidal range of 7·64 metres at Spring tides. King and Williams found the number of ridges on the beach varied from two to six, and they tended to increase in size towards the low water mark. Two of the most permanent ridges were found to be approximately at the levels of the mean high and low neap tides. The gradient of the whole beach was found to be very flat, 1 in 150, whereas the seaward-facing ridge slopes averaged 1 in 46. King and Williams discovered that the ridges altered considerably with changes in the weather:

> "It was observed that in rough weather the beach tended to become smoother. Ridge growth generally took place in calmer weather, the ridges developing in areas of very low gradient by the accretion of sand. This was usually a fairly slow process taking place over a period of weeks. There were occasions, however, usually following a stormy period, when ridges were built up in one or two days."

King and Williams found that the ridges did not move systematically landwards or seawards but maintained their positions for long periods on the beach. Like Gresswell they noted the drainage channels which cut across the ridges. The ridges were found to die out occasionally and another form elsewhere.

Ridge and runnel beaches are not found on coasts exposed to the open ocean. King (1972) notes the importance of the exposure of a beach on the development of ridges, which is related to the equilibrium gradient which the waves will attempt to establish on a beach. Long waves will produce flatter beach gradients than shorter waves. Thus a beach exposed to long swells will have a flatter equilibrium gradient than one which is only exposed to waves generated in the restricted fetch of a small sea, such as the Irish or North Seas.

On the wide, gentle gradient of the beach at the northern end of Walney Island, to the west of Morecambe Bay, there is a well-developed series of ridges and runnels. The height of the profiles across this beach may vary in places by up to six feet with the movement of the ridges and runnels. Following monthly profiles taken in 1964 and 1965 (Phillips and Rollinson, 1971), complete or partial smoothing of the profile was observed after a period when winds blew from the south-west sector (185°-265°). This is the direction of maximum fetch across the Irish Sea and therefore forming the longest waves. After periods of winds from other directions, either from over the mainland or with very short fetches, the ridges and runnels became re-established.

One factor which is commonly found in connection with the presence of ridges and runnels on a beach is a surplus of sand on the foreshore, on which the waves attempt to form an equilibrium swash slope gradient where the overall gradient of the beach is flatter. But even where the sand supply is not excessive, if the overall gradient of the foundation of the beach is flatter than the equilibrium swash slope gradient of the waves, the sand available will be built into ridges. King (1972) quotes the example of the beach at Walde, north of Calais:

> "The upper beach has a slope of 1 in 400 and is soft and muddy. On the lower part of the foreshore sand ridges and runnels have formed. The supply of sand is reduced here and the clay foundation of the flat beach is exposed in the runnels. The beach is suffering erosion at the present time."

Also associated with the ridge and runnel beach is the double berm feature outlined by Davies (1972). These occur on beaches where the tidal range is about 2 to 4 metres. A ridge forms above the high water mark (a normal berm), and anotner is found just above the low water mark, presumably because swash action is most prolonged at these levels. In between the two ridges is a runnel. As the tidal range gets bigger, and particularly if sediments are fine, and the overall beach gradient is low, multiple ridges develop and the typical ridge and runnel beach is produced. Around the British Isles the best examples of this double berm beach are in Norfolk where the tidal range is 4 to 5 metres. Davies also notes the importance of the interaction of sediment size and the waves:

> "It is clear that factors of sediment size and wave climate have to be taken into account, especially in so far as they affect beach slopes. At a critical tidal range it is possible for the same beach to show a single berm at one end and a double berm at the other if sand particle size changes enough along the beach."

Davis et al (1972) made a comparison of the ridge and runnel systems of Lake Michigan, a non-tidal environment, and the coast of Massachusetts with a spring tidal range of 4 metres. Only one ridge form was seen on the beach on the Massachusetts coast. The day after a storm this ridge was nearly symmetrical in profile but within a few tidal cycles after formation, the ridge began to migrate landwards and its shape modified. The slope became very asymmetrical with the landward-facing slope of the ridge quite steep (figure 5.1).

A. THE LOWER BEACH RIDGE

The Holderness beach displays two types of ridge and runnel beach. In the north in Bridlington Bay the beach is wide with a gentle gradient and a series of three or four long ridges and runnels between the high and low water marks (figure 2.1). The ridges are interrupted occasionally by a transverse drainage channel. The seaward runnel is often water-filled at low water. The ridges curve round the bay parallel to the cliffs and in every detail this beach resembles the ridge and runnel beach described by King and Williams (1949) at Blackpool. Bridlington Bay is protected from the waves of longest fetch, which come from the north, by Flamborough Head (see figure 6.8 for the wave refraction diagrams).

The beach in this northern part of the Holderness coast is adjusted to the short waves reaching it, and the slope of the ridges is close to the equilibrium gradient the energy content in these waves is capable of forming. Thus the beach with its flatter overall profile is adjusted to the short steep waves.

The second type of ridge and runnel beach on the Holderness coast is found on the lower beach within an ord. Here the upper beach, if present, is much narrower than on the ordinary upper beach/lower beach profile between the ords. This allows the lower beach to develop over a much wider zone between the foot of the upper beach or edge of the exposed till platform and the low water mark. On this lower beach it is usual for only one ridge to develop with a runnel landwards of it. Occasionally at low water Spring tides a second smaller ridge is seen on the beach and this will be discussed later. The main ridge, as described in the previous chapter, is usually asymmetrical in profile with a short steep landward slope and a more gentle longer slope from the ridge crest to the low water mark. The crest of the lower beach ridge may be well developed into a peak or flattened and not well defined as a ridge crest. The ridge is usually highest in the north of the ord opposite the ord centre at the cliff foot where the upper beach is absent or narrow and low. In the south the ridge declines in height and width as the upper beach at the cliff foot reforms. Here at the southern end of the ord it eventually merges into the low normal lower beach of the non ord system. The line of the lower beach ridge crest is inclined away from the cliffs at an angle perpendicular to the approach of the dominant waves. At Holmpton, the lower beach ridge is aligned at 131°, 12° from the line of the cliffs.

The lower beach in the Atwick ord will be discussed later as it does not develop into a well-defined ridge form. In figure 5.2 each profile for succeeding weeks in April, May and June, 1974, on the Easington ord are given. The movement of the lower beach ridge was as follows:

Profile D (north). Although this profile was in the north of the ord, north of the ord centre, the upper beach was poorly built up and narrow. This allowed the lower beach to develop over a wide zone and although it was in the north of the ord the lower beach was still formed into a slight ridge. On 22.4.74 this ridge was 0·35 metre higher than the runnel landwards of it. Both the landward and seaward slopes of the ridge were long and gentle and it was almost asymmetrical. By 29.4.74 it had flattened out. The winds during this period were all from the north with speeds at or over 15 knots. On 5.5.74 the lower beach was built up but not into a ridge form. It had a shallow step 64 metres from the cliff foot. The winds during the previous week had been variable in both speed and direction. On 13.5.74 the ridge form had developed once more. It was a very shallow feature with an almost non-existent runnel landwards of it and the ridge crest was flat. The dominant winds during the previous week had been southerly with speeds between 10 and 20 knots. On 20.5.75 the lower beach profile on profile D had altered little except the top of the low ridge was even flatter. The winds had been intermittent, but generally from the south-east with light speeds. On 26.5.74 the lower beach ridge had developed a slight crest, the highest it reached during the fieldwork. The winds were westerly to north-westerly with speeds between 10 and 20 knots. On 3.6.74 the ridge had flattened again and almost disappeared, the runnel was almost filled in. The winds during the previous week had been intermittent with variable directions and speeds.

Therefore during strong northerly winds the ridge became flattened and the lower beach much lower, while the upper beach was built up. During moderate easterlies and southerlies the lower beach ridge became built up again. This was flattened during a period of intermittent light winds. Moderate northerly winds built up the ridge crest.

Profile C (south of the ord centre). The upper beach here was 40 metres wide and the lower beach ridge at its highest in the ord on 8.4.74. The ridge was well built up into an asymmetrical form. The crest of the ridge was 0.8 metre above the runnel. On 22.4.74 the crest was much lower but so also was the runnel floor. The ridge crest had moved 11 metres landwards. During the previous fortnight the winds had been northerly with speeds between 10 and 25 knots. On 29.4.74

the ridge was the same height as the week before but had moved 5 metres landwards at its crest, steepening the landward slope after a week of intermittent light winds from a south-easterly direction. On 26.5.74 the ridge crest was slightly lower but again 6 metres landwards. The runnel was also less deep after a week of moderate westerlies and northerlies. On 3.6.74 the ridge was much lower with a quite insignificant crest slightly seawards of its previous position after a week of light intermittent and variable winds.

Profile B. On 22.4.74 the upper beach of this profile was over 50 metres wide and 1·2 metres higher at the cliff foot than profile C to the north. The lower beach was not so well developed into a ridge. The asymmetrical lower beach ridge was 0·3 metre high, and the ridge crest 98 metres from the cliff foot. On 29.4.74 after moderate to strong (10 to 25 knots) winds from the north,the ridge had filled in a little landwards of the crest which remained at the same height a few metres seawards of the previous position. The ridge at this time was symmetrical. On 5.5.74 after moderate northerly winds, the ridge was once more asymmetrical, the crest 22 metres landwards and 0·4 metre above the runnel. On 13.5.74 after a week of moderate east and southerly winds, the ridge crest was slightly lower and seawards of its former position. On 20.5.75 the lower beach had regained its 5.5.74 position but with the runnel slightly less deep, making the landward slope of the lower beach ridge less steep. Light intermediate south-east winds blew during the previous week. On 26.5.74 the ridge crest had moved 18 metres landwards and gained 0·2 metre in height. The runnel was much reduced in width because of this landward movement of the ridge. The winds during the previous week were moderate northerlies and westerlies. On 3.6.74 the infilling of the runnel was complete and the lower beach ridge was almost gone. There was only a slight convexity between the base of the upper beach and the low water mark. The lower beach, seawards of the former ridge crest was raised over 0·3 metre. The winds during the previous week had been light and variable with intermittent calms.

Profile A (south). Profile A, at the southern end of the ord was only slightly affected by the presence of the ord further north on 22.4.74. The top of the upper beach was above the high water mark of all but the very highest Spring tides, and the upper beach was almost 100 metres wide. The lower beach seaward of the water-filled runnel was formed into a small asymmetrical ridge with a crest 0·3 metre above the runnel, and 135 metres from the cliff foot. Near the low water mark the lower beach sloped steeply seawards but the top of the ridge was almost flat for 30 metres. On 29.4.74 after a period of moderate to strong northerly winds (10 to 25 knots), the lower beach ridge crest was 8 metres seaward and 0·1 metre higher. On 5.5.74 after moderate northerly winds, the ridge crest was again 0·1 metre higher but also 12 metres landwards. On 13.5.74, after a week of moderate south-easterly winds, the ridge crest was 0·2 metre higher and 8 metres landwards. The runnel was also raised and the crest of the lower beach ridge 0·5 metre above the runnel. On 20.5.74 the ridge crest was

13 metres landwards but 0·1 metre lower. The landward slope of the lower beach was very short. Light south-easterly winds prevailed during the previous week. On 26.5.74 the ridge crest reacned its highest position, 0·2 metre above the previous week, and it was 9 metres seawards after a week of moderate northerly and westerly winds. By 3.6.74 the runnel had been completely filled in and therefore the ridge form destroyed, but the lower beach was at the same height as the week before. This was after a week of light intermittent winds of variable directions.

Table 5.1 lists the main changes on each profile after one week of the wind regimes recorded during the period of study. As already noted, the relatively calm conditions did not produce a large variety of wind speeds and directions during the survey period at Easington in 1974. When the wind blew from the north, with speeds over 15 knots (the most constant speed was 20 knots), the lower beach on profiles D and C were both lowered and flattened and the ridge crests moved seawards. Alternatively, in the southern part of the ord, profiles A and B were both raised and steepened, but the ridge crests again moved seawards. After a week of southerly winds of less than 15 knots, profile D, in the north, showed no change. The lower beaches of profiles A and C were lowered and flattened, their crests moved seawards. Profile B had a slightly raised lower beach with the ridge crest moving landwards. All these movements were comparatively small in size (all less than 0·4 metre vertical change).

TABLE 5.1 THE RELATIONSHIP BETWEEN WIND CONDITIONS AND FORM OF CHANGE ON THE LOWER BEACH SECTION OF THE EASINGTON ORD, 1974.

PROFILE WIND DIRECTION (QUARTER) AND SPEED (KNOTS)	HORIZONTAL MOVEMENT OF THE RIDGE CREST		VERTICAL MOVEMENT OF THE RIDGE CREST			CHANGE OF THE RIDGE SHAPE	
	LANDWARD	SEAWARD	RAISED	LOWERED	NO CHANGE	STEEPENED	FLATTENED
PROFILE D							
>15 knots north		X		X			X
<15 knots south					X		
>15 knots south					X		
10-20 knots west	X		X				
intermittent	X_1	X_2	X_1	X_2		X_1	X_2
PROFILE C							
>15 knots north		X		X			X
<15 knots south	X			X			X
>15 knots south					X		
10-20 knots west	X			X			X
intermittent	X_1	X_2	X_1	X_2		X_1	X_2
PROFILE B							
>15 knots north		X	X			X	
<15 knots south	X		X			X	
>15 knots south		X		X			X
10-20 knots west		X	X			X	
intermittent	X_1	X_2	X_1		X_2	X_1	X_2
PROFILE A							
>15 knots north		X	X			X	
<15 knots south	X			X			X
>15 knots south	X		X			X	
10-20 knots west		X	X			X	
intermittent	X_1 X_2		X_1		X_2	X_1	X_2

N.B. All X's on the same horizontal line relate to one observation only (except where marked X_1, X_2).
The change in the lower beach form was not recorded

Following southerly winds of over 15 knots, profiles D and C showed no change. Profiles A and B were both raised and the ridge crests moved landwards with steepened profiles. Following westerly winds between 10 and 20 knots, profile D was raised and steepened with the ridge crest, the ridge crest moved landwards. The ridge crest also moved landwards on profile C, but was lowered and flattened overall. On profiles A and B the ridge crest was moved seawards while the whole lower beach was raised and steepened. The most common winds during this period were light and variable in strength and of intermittent duration. These caused only slight changes on the profiles and none of great significance or size.

The Holmpton ord also had a well-developed lower beach ridge, especially in the northern section of the ord. The southern part of the ord near Old Hive had only a low and non-ridged lower beach until the middle of 1975 when the northern part of the ord began to influence the beach south of the farm and the southern section of the ord became less important and eventually it filled in by the movement southwards of the upper beach that was positioned originally between the two sections of the ord.

On 16.5.75 the lower beach ridge was well developed on profiles D and E in the north. Both these profiles were south of the centre of the ord. Profile E at the erratic (figure 5.3) had an upper beach 28 metres wide and a narrow runnel from which the lower beach ridge rose seawards. The ridge was asymmetrical, the crest 0·7 metre above the runnel and 48 metres from the cliff foot. Seawards of the ridge crest the top of the ridge was almost flat for 40 metres and then it sloped quite steeply to the low water mark. On 23.5.75 after a week of moderate to light (5 to 12 knots) northerly winds, the lower beach ridge had grown both upwards and landwards, whereas the upper beach had not changed. On 29.5.75 after moderate to strong northerly winds (11 to 25 knots), the ridge had again grown upwards and landwards, the landward-facing slope now very steep.

Profile D on 16.5.75 had an upper beach 45 metres wide and a symmetrical lower beach ridge. On 23.5.75 after light to moderate northerlies, this ridge was still symmetrical but higher. On 29.5.75 the ridge had become asymmetrical and moved landwards from its previous position. It was also 0·2 metre higher, and the runnel was also raised. This occurred during strong northerly winds.

Between 23.7.75 and 30.7.75 there were intermittent light winds of variable direction. On profile E the lower beach ridge changed only slightly. It was much flatter than in May as the runnel had been filled in, but the ridge was also raised 0·3 metre and the crest had moved landwards during June and July. Profile D had not been raised since May although there had been a slight landward movement. Between 23.7.75 and 30.7.75 the lower beach ridge crest on profile D moved landwards 6 metres but was not raised higher. Profile C, which on 23.7.75 had a sloping lower beach to the low water mark, was raised 0·9 metre over all of its length seaward of the runnel and became a very well-formed asymmetrical lower beach ridge with a crest 62 metres from the cliff foot by 30.7.75. Over such a calm week this was a massive gain of material on the lower beach, especially as there was very little change both on the upper beach of this profile and the lower beaches of the other profiles.

In December, between 4.12.75 and 19.12.75, for the first half of the fortnight, light and moderate westerlies blew and were followed by moderate to strong northerly winds. Each profile, C, D and E, was lowered over the whole of the lower beach (profile C by 0·9 metre overall), and this much reduced the lower beach ridges. The runnel of profile D was filled in. Between 19.12.75 and 7.1.76 the winds were moderate to strong westerlies followed by the severe northerly storm on 2nd and 3rd January. Profiles D and E were now north of the ord centre and the upper beaches well formed. On profile C the lower beach ridge had moved landwards by 25 metres and was asymmetrical again, although much lower than on 4.12.75.

Table 5.2 lists the changes on the Holmpton ord lower beach for different wind directions and strengths over the periods of the weekly surveys during 1975. The changes on the lower beach of profiles E and D are very similar. Northerly winds of 5 to 15 knots raised the whole lower beach, steepened the profile and moved the ridge crest seawards. The stronger 15 to 20 knots northerly winds moved the ridge crest landwards but either did not affect the general level of the lower beach or lowered it slightly. With northerly winds stronger than 20 knots the ridge crest was moved landwards, the whole profile raised and steepened. On profiles C, D and

TABLE 5.2 THE RELATIONSHIP BETWEEN WIND CONDITIONS AND FORM OF CHANGE ON THE LOWER BEACH SECTION OF THE HOLMPTON ORD, 1975

PROFILE WIND DIRECTION (QUARTER) AND SPEED (KNOTS)	HORIZONTAL MOVEMENT OF THE RIDGE CREST		VERTICAL MOVEMENT OF THE RIDGE CREST			CHANGE OF THE RIDGE SHAPE	
	LANDWARD	SEAWARD	RAISED	LOWERED	NO CHANGE	STEEPENED	FLATTENED
PROFILE E							
5-15 knots north		X	X			X	
15-20 knots north	X				X	X	
>20 knots north	X		X			X	
intermittent					X		
PROFILE D							
5-15 knots north		X	X			X	
15-20 knots north	X			X			X
>20 knots north	X_1 X_2		X_1 X_2			X_1 X_2	
intermittent	X				X		
PROFILE C							
15-20 knots north		X		X			
>20 knots north	X		X			X	
intermittent	X		X			X	

N.B. All X's on the same horizontal line relate to one observation only (except where marked X_1, X_2).

The change in the lower beach form was not recorded for wind of other directions and strengths.

E all four occasions of these strong northerly winds recorded the same profile changes. As at Easington, the light intermittent winds caused variable minor changes.

The lower beach on the Atwick ord was only rarely in the form of a ridge although along most of the ord the lower beach was above the beach water table and therefore dry. The changes on the lower beach of this ord during 1975 are given in table 5.3, with the corresponding wind conditions of the week leading up to each survey. After light south-easterly winds the lower beach remained unchanged on all profiles. After moderate to light southerly winds the lower beach is slightly higher on profiles D and B and the same on profile C. Following moderate westerlies, each profile is higher , but after strong westerlies each is lower. After moderate and light northerlies there is no change on each profile, whereas after moderate to strong northerlies, each profile is again higher on the lower beach. After strong northerly winds, including a severe storm in the North Sea, profile C, just south of the centre of the ord, showed a landward movement of the slight ridge on the lower beach as well as a gain in height at the ridge crest, but profile B showed no real change. Profile A also was raised.

Most of the changes on the lower beach of the Atwick ord over the weeks of the surveys of 1975 were of a small scale compared with those of the Holmpton and Easington ords discussed above. One other feature that was more prominent on the Atwick ord than on the others was a small low water ridge, only seen at low water Spring tides. This feature also

TABLE 5.3 THE RELATIONSHIP BETWEEN THE WIND CONDITIONS AND FORM OF CHANGE ON THE LOWER BEACH SECTION OF THE ATWICK ORD, 1975.

WIND SPEED AND DIRECTION (QUARTER)	PROFILE D (NORTH)			PROFILE C			PROFILE B			PROFILE A (SOUTH)		
	HIGHER	LOWER	NO CHANGE	HIGHER	LOWER	NO CHANGE	HIGHER	LOWER	NO CHANGE	HIGHER	LOWER	NO CHANGE
< 15 knots southerly	1		1		2		1		1			1
< 15 knots westerly		1		1	1			1				
> 15 knots westerly				1					1			
< 15 knots northerly		1			1				1	1		
> 15 knots northerly	1			3			3			1		
Intermittent	1				1		1					1

N.B. No landward/seaward movement of the ridge crest because a ridge form is rarely seen.

Each number refers to the number of observations for each set of conditions.

The change in the lower beach form was not recorded for winds of other directions and strengths.

occurred between the ords along the Holderness coast and on the other ords in the northern part of the coast. This feature is also part of the larger ridge and runnel system of Bridlington Bay and is associated with the break point of the waves of the mean low water tides (see above, Davies 1972). The steeper slope of the lower beach near the low water mark in the southern ords does not allow this feature to be formed in the same way.

For Easington and Holmpton where the lower beach was formed into a ridge, the changes resulting from the corresponding wind conditions are summarised in table 5.4. Thirty-five of the lower beach changes observed were definite enough to be attributed to one wind type or another. Three strengths of northerly winds were recorded, one westerly, two southerly and also periods of light and intermittent winds from variable directions. Easterly winds played little part in the beach development and they did not blow for long enough periods to be included on the table. On this table profile position has not been included, and the movements of the lower beach are recorded solely on the vertical gains and losses of the whole lower beach, and the horizontal movement of the ridge crests. When no change occurred in either or both directions this, too, has been recorded.

On two occasions when northerly winds blew with strengths less than 15 knots, the lower beach was raised and the ridge crest moved seawards. These were the only records of this wind type. After northerly winds between 15 and 20 knots, a

TABLE 5.4 THE RELATIONSHIP BETWEEN WIND CONDITIONS AND FORM OF CHANGE ON THE LOWER BEACH SECTION OF THE EASINGTON AND HOLMPTON ORDS, 1974/1975.

WIND DIRECTION AND SPEED	LOWER BEACH CHANGE HORIZONTAL AND VERTICAL						NO CHANGE
	LANDWARD LOWERED	LANDWARD RAISED	SEAWARD LOWERED	SEAWARD RAISED	LANDWARD NO CHANGE	SEAWARD NO CHANGE	
NORTHERLY QUARTER							
< 15 knots				2			
> 15 knots	1		3	2	1		
> 20 knots		4					
WESTERLY QUARTER							
10-20 knots	1		2				
SOUTHERLY QUARTER							
< 15 knots	2	1					1
> 15 knots		1	1				2
VARIABLE AND LIGHT INTERMITTENT WINDS		5	2		2	1	1

N.B. 35 observations in all.

variety of changes were found to have occurred. Out of the seven observations at this wind speed, five showed a seaward movement of the ridge crest, three of these with the lowering of the lower beach, two with the raising of the lower beach. Northerly winds were observed to blow with strengths over 20 knots on four occasions with the results from all the same. This was a landward movement of the ridge crest accompanied by the raising of the whole lower beach. When westerly winds of between 10 and 20 knots were recorded on three occasions, the lower beach was lowered with a seaward movement of the ridge crest on two and lowered with a landward movement of the ridge crest on the other. Southerly winds of less than 15 knots blew on four occasions. Two of these showed a lowering of the beach and a landward movement of the ridge crest, one the raising of the beach and also a landward movement of the ridge crest, and the fourth no change. Again four occasions were noted when southerly winds blew at over 15 knots. On two of these there was no change on the lower beach, the others showed a raising of the beach, and the lowering of the beach. There were eleven occasions when light and intermittent winds had been blowing. On five of these the beach was raised and the ridge crest moved landwards. All the movements associated with these winds were slight. From table 5.4 it can be seen that the most conclusive changes were produced by the northerly winds of over 20 knots when the lower beach was raised and the ridge crest moved landwards.

No other definite conclusions can be reached. Sediment movement produced by a reverse undertow in the surf zone is not evident, in fact the opposite occurs. With the offshore westerly winds the whole lower beach is lowered, and with the onshore northerly winds the beach was raised on eight occurrences out of thirteen.

The mechanism by which the lower beach ridge moves landwards can be explained as follows. It is caused by wave activity moving across the ridge as each tide rises. A thin layer of swash flows over the ridge each time a wave breaks. Sand, set into motion by the force of the breaking wave, migrates across the gently sloping surface of the seaward-facing slope of the lower beach with the swash. This avalanches down the steeper landward slope as the tide rises and the swash reaches the crest of the ridge. Therefore with each breaking wave the swash carries grains of sand on to and down the prograding landward-facing slope of the ridge. Davies et al (1972) studied the movement of a similar ridge form below the water surface on the shores of Lake Michigan. This ridge migrated landwards by wave-generated ripples of sand moving over the surface of the ridge. It is possible this mechanism can occur on the lower beach ridge of the ords once they are covered by the tide at high water. This would be a much slower process than the swash movement outlined above, especially as the ripples, if they exist, would be destroyed as the tide ebbs. These ripples generated by the waves are not the same as the ripples sometimes found on the lower beach ridge after the tide has retreated. These are formed by the minor currents generated as the shallow water falls over the almost flat ridge surface on the ebb tide. When the tide ebbs much of the water is carried out to sea southwards along the runnel once the water level falls below the ridge crest. This stream of running water cuts into the base of the lower beach ridge, steepening the landward slope.

Therefore the single ridge and runnel system is part of the ord system and is especially developed in the southern ords where there is more material available on the beach. It is completely separate from the ridges and runnels in Bridlington Bay but it is still a response of the beach slope to the wave slope and the abundant sand on the lower beach. The position of the lower beach ridge is not affected by the Spring/neap tidal cycle as the ridge is well covered by the tide at each high water, although it may not be exposed at each low water, especially in the northern ords, for example at Atwick.

B. THE UPPER BEACH

The short term changes of the other major sand components of the ords, the northern and southern upper beaches are not so marked as the changes on the lower beaches of the ords. During 1974 the surveys of profile D at Easington, the northernmost profile, north of the centre, with a low narrow upper beach (figure 5.2), showed very little change on the upper beach. Between 22.4.74 and 3.6.74 the beach was raised only 0·3 metre at the cliff foot. The upper beach was never more than 26 metres wide and became narrower as the runnel at its base was filled towards June. This narrow upper beach was found for over a kilometre north of the ord and the upper beach did not build up to its widest until opposite Out Newton (see location map). In figure 4.9, profile D is superimposed upon the other profiles on each survey and this shows how the upper beach at the northern end of the Easington ord was not much higher than the beach just south of the centre of the ord. This narrow, low upper beach seen on 8.4.74 and after was much wider and higher than on 27.1.74. On this first survey of the ord the centre was further north and the upper beach north of this widened out with a gentle sweep to profile E, 1060 metres north of the end of the ord on 8.4.74 (figure 4.7). Between 27.1.74 and 22.4.74 the ord centre moved south 600 metres but the northern upper beach did not build up in its place. The influence of the ord was therefore felt as far north as it was on 27.1.74. This condition remained, with no build up of the northern upper beach, until the last survey on 3.6.74.

A similar situation was found in the movements of the northern upper beach of the Holmpton ord. On 27.12.73 the ord centre was just south of the Runnel stream outlet (figure 4.12). North of this the upper beach built up until it reached its maximum width at the skerrie opposite Nevills Farm. This build up was not as rapid northwards as was seen at Easington on 27.1.74. Until 28.12.74 the northern upper beach of the Holmpton ord only altered a little in its size and position. Sometimes it was present at the cliff foot the whole length of the ord, joining the southern upper beach. At other times it ended just south of the Runnel stream outlet. On 8.10.74 it was very low and merged undefined into the lower beach. On

28.12.74 the centre of the ord was north of the Runnel stream outlet. The upper beach north of this was very high and wide and merged southwards with the lower beach of the ord. But by 10.1.75 this feature had disappeared, leaving the centre of the ord still north of the Runnel stream outlet and the upper beach ending north of this in the usual manner. This remained the case with the end of the northern upper beach approximately positioned at the Runnel stream outlet until 3.10.75. Then, for the first time, the upper beach at the Runnel stream outlet was well built up (see Chapter Four), ponding the stream water at the cliff foot. The upper beach then consisted of a series of ridges which swept round from a line parallel with the shoreline in a curve to the cliff foot south of the stream outlet. After this date the northern upper beach continued to move southwards, and extending on to the lower beach ridge opposite the centre of the ord. This considerably raised the lower beach from its normal height. During December 1975 and January 1976 this upper beach/lower beach ridge migrated towards the cliff, at the same time filling in the runnel landwards of the ridge, while the seaward slope of the lower beach became steeper in this northern part of the ord. On 7.1.76 profile E in the north had the profile of a very wide (70 metres) steep upper beach with no lower beach visible at low water. Profile D, which was just north of the new centre of the ord, sloped gently from the cliff foot to the low water mark with no signs of a lower beach ridge.

The northern upper beach of the Atwick ord was of modest width and height during all the period of fieldwork. Its position fluctuated around the Atwick road end. Often a narrow upper beach was continuous along the whole length of the ord, only widening at the southern end. It was discussed in Chapter Two how the ords could be grouped into two categories. The northern ords,including the Atwick ord which have poorly-developed lower beach ridges and upper beaches which only widened at the southern end of the ord, and the southern ords, which include the Holmpton and Easington ords, where both the lower and upper beaches are well-formed features of the ord. Therefore if the plans of the Atwick ord are studied from 23.1.74 to 6.1.76, figures 4.17 to 4.21, it can be seen that it is not until 3.12.75 that a change begins to occur in the position of the northern upper beach. For the first time the upper beach of profile D is over 30 metres wide. Between 3.12.75 and 6.1.76 it continues to widen and move south until its southern end is 450 metres south of the road end. This rapid movement south is the first the northern upper beach has made since the study began, but even through this movement the end of the upper beach has always the same characteristic curve towards the cliff foot. This curving end of the northern upper beach in the Atwick ord is of very limited length, less than 300 metres on 22.12.75.

Therefore it can be shown, especially in the case of the two southern ords, that the northern upper beach does not quickly adjust to the gradual movement of the centre of the ord southwards. At times the lower beach may be found extending from the cliff foot to the low water mark between the end of the northern upper beach and the till platform exposed at the cliff foot. In both the Easington and Holmpton ords the northern upper beach remained low and narrow for many months after the ord centre had moved south. It was not until exceptional conditions occurred towards the end of 1975 that the northern upper beach of the Holmpton ord moved or changed its form in any distinctive way. In the short term the northern upper beach of an ord is not a very dynamic feature.

The southern part of the upper beach of an ord, like the northern upper beach, does not show any major changes in the short term. Figure 5.2 shows the Easington profiles for each week and it can be seen that the changes are very slight. The overall change is a lowering of the upper beach on each of the three profiles south of the centre of the ord. The same lowering is found on the Atwick ord south of the centre with very few exceptions whatever weather conditions prevailed the previous week. Only occasionally, after strong northerly winds, for example, between 20.5.75 and 30.5.75, does a build up in the upper beach take place and this is only slight, especially in the south of the ord. It is not infrequent for the changes on the southern upper beach to be the reverse of those on the northern upper beach. Therefore throughout the year there is a general lowering of the southern upper beach in each ord as the presence of the ord is felt further south.

C. THE TILL BOULDERS

The distribution of till boulders on the beach of an ord changes from week to week and indicates a number of important factors about the state of the ord, the cliffs behind it, and the recent wind and wave conditions. The till boulders are the product of the erosion of the cliffs and are found on the beach when undercutting promotes cliff falls and landslides. When these blocks of till first fall on to the beach near the cliff foot, many may be over one metre in diameter, and they are usually dry and angular. They are formed of small pebbles, erratics in the till, up to 5 centimetres in diameter (the larger ones dropping out separately) which are fixed in a clay matrix. After the tide has washed over these boulders once it can be seen that they are quickly eroded and shrink rapidly in size after a few tidal cycles. They are reduced to small spherical balls and the whole boulder is very soft and easily flattened by a boot. After a few days they are completely disintegrated. While still quite large they can be rolled about by the waves and tend to collect in depressions on the beach, especially near the cliff foot.

These boulders are found on a beach after particularly rough weather when the sea has been able to batter the cliffs excessively at high water. The nature of these unconsolidated till cliffs on the Holderness coast, with sand lenses common within the boulder clay, makes them particularly subject to erosion both by the sea and subaerially. It has already been indicated that within an ord, because of the very low beach at the cliff foot the waves may attack the cliffs for very long periods at each high water. This is likely to be much longer than along the coast between the ords where the high water mark may be below the cliff foot and therefore no erosion of the cliffs by the waves can occur.

In the northern ords of the Holderness coast there is often little or no till platform exposed at the cliff foot, or it may be covered only by a thin veneer of sand. Here, after stormy weather with steep waves, there is a line of closely-packed till boulders, a few metres from the cliff foot. This line of till boulders never moves far from the cliff foot but it is found the whole length of the ord until the upper beach builds up once more in the south. This line of till boulders is a very common feature in the northern ords. Where a narrow strip of till platform is exposed, it is often covered by till boulders, especially along its lower seaward edge. On 24.7.74 a line of till boulders near the cliff foot was seen in the Rolston, Cowden/Aldbrough, Ringbrough and Hilston ords after a period of strong northerly winds. After calm conditions little or no till boulders were found on the beaches of these ords, and where they were present they were very small and often protected from wave attack by being partially buried in the sand when constructive conditions follow a storm.

Figure 5.4 shows a plan of the cliffs and beach at the Hilston ord on 2.10.74 after heavy rain lubricated the cliffs and initiated very large cliff falls and landslides. North of the centre the narrow upper beach had a modest covering of till boulders. South of the northern upper beach was a very large cliff fall and till platform was found at the cliff foot from that point southwards. The cliffs here had suffered smaller falls and the lower parts of the till platform and the top of the raised lower beach were covered by many till boulders, packed very closely together. Where the southern upper beach became established, covering the till platform, the proportion of till boulders on the beach fell and they were very few in number south of the area of till platform. On 8.10.74, after strong northerly winds on the two preceding days, there were still fresh till boulders at the cliff foot and on the till platform at the southern end of this ord, but not as many as on 2.10.74. The landslides that occurred up to 2.10.74 were the first major falls for some months and therefore the instability of the cliffs was greater than on 8.10.74 when, despite the northerly gales, the cliffs were relatively stable and not undercut.

A similar situation occurred during December 1975 at Holmpton. After the storms of November the large area of exposed till platform was densely covered with large till boulders on 4.12.75. By 19.12.75 there were still a few till boulders on the till platform near the cliff foot, but most of them had been destroyed by the waves. On 7.1.76, after the storm on 2nd and 3rd January, the area of till platform was again densely covered with till boulders. The cliffs also showed many signs of recent falls, landslides and mudflows (the latter carrying mud, not boulders, on to the beach).

Therefore the presence of till boulders on the sand and till platform of an ord reflects two conditions. The first is the absence of a well built up beach to protect the cliff foot from wave action at high water. The second condition is steep storm waves reaching the shore, usually from the north, to attack the cliffs.

D. SEDIMENT SIZE DISTRIBUTION

Finally in this chapter further comment must be made on the sediment sampling programme. It has already been discussed in Chapter Four how the sediment distribution on the beach within the ords is very uniform from ord to ord, and indeed also corresponds with the beach between the ords. The upper beach is made up of coarse sand and shingle of all sizes, often formed into minor beach cusps on the lower slopes of the upper beach. The lower beach is quite distinct from the upper beach, and is formed of fine sand, from its junction with the upper beach, which is often a very sharp one in sediment size, to the low water mark where the finest sediment occurs. Only very rarely is shingle of any size found on the surface of the lower beach (see Chapter Six).

The type of sediment is also fairly uniform along the whole of the Holderness beach, as the material is derived from the till cliffs behind the beach.

In figure 5.5 all the samples collected from the Easington, Atwick and Holmpton ords have been grouped into the profile types classified in Chapter Three and in figure 3.3.

For each of the five profile types the samples have been plotted on a graph with the mean size (in phi units) against the standard deviation of each sample (the sorting). The data is given in tables 4.2, 4.3 and 4.4.

The samples from the type I profiles, in the north of the ord, show a scattered pattern on the graph. Most of the samples are in the "well-sorted" range with a few only in the moderately-sorted category. As already noted, the low water mark samples are finer in mean size than the cliff foot samples.

The number of samples from profile type 2, at the centre of the ord, are too small to be evaluated in a group. Type 3 profile samples, south of the centre of the ord, show a similar sorting pattern to profile I samples, most of them are in the well-sorted bracket. On the whole the cliff foot and low water mark samples are better sorted than the samples from the top and mid-lower beach. This could be accounted for by the currents generated on the beach surface as the water in the runnel drains southwards on the ebb tide, while the main tide falls across the main slope of the lower beach. The runnel outflow can affect the top of the lower beach and also the ridge crest where there is a well-formed lower beach ridge. On the graph no tight groupings can be made for each sample position.

On profile type 4, in the same position as type 3 (south of the ord centre) but with a less raised lower beach, the samples as a whole are all finer than on profile 3. They all occur in a tight group in the well-sorted range with a small tail into the moderately-sorted range. But again no groupings of the individual sample types can be made, except the cliff foot samples are better sorted than the rest.

On profile type 5, at the southern end of the ord, the high water mark is often found below the cliff foot on the beach. The samples taken at this point are noticeably coarser than the rest on the profile. The sorting pattern of all the samples is the same as the other profiles. The low water mark samples are quite tightly grouped between 0·4 and 0·6 standard deviation, and 2·0 and 2·5 phi.

These results, plotted in figures 5.1 to 5.5, are very uniform along the whole ord. The sorting pattern is as would be expected in a beach environment. The samples differ little from profile to profile, except that they are a little finer towards the south of the ords, especially on the lower beach.

The account of the short term beach changes given in this chapter provide the framework for the major but less frequent larger scale changes that occur and which will be discussed in the next chapter. It can be seen that the week to week changes within the ord do not greatly affect the position or general shape of the ords, both in north or south Holderness. The area of till platform exposed may be reduced or expanded due to the fluctuations of the upper and lower beaches, but often the cover of material over the till platform is only thin and these changes are of no real importance in the overall movement of the ords.

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CHAPTER SIX

LONG TERM BEACH CHANGES

A. Large scale southward movement of the ords.

B. A review of similar features around the world.

C. The mechanism of ord formation.

D. The effects of ord movement on the rate of cliff erosion.

The overall pattern of the ords along the Holderness coast is not a stationary one, the position of each ord changes over a period of time and is dependent on the external conditions of wind and waves. In Chapter Two the month to month movements of each of the ords during 1974/75 were discussed. In figure 6.1 the position of five of the ords (Atwick, Rolston, Cowden, Hilston and Holmpton) are recorded for nine occasions throughout the two years. At the time of the first observations in January 1974, each of these ords was long and well established. During the following six months each ord became shorter from the southern end, while the position of the northern ends fluctuated. They were never further north than in January 1974. In July 1974 the ords were at their shortest over all the study period. In each case the shortening was from both ends. During the first six months of 1974 very few strong northerly winds blew (figure 4.1, the 1974 wind speeds and directions). During this period the features within the ords became subdued and less distinct than they were in January (see figures 4.12 and 4.17, the Holmpton and Atwick ord plans). From July 1974 onwards the ords grew again in length, mainly from their southern ends, and by November 1974 they were almost as long as in January 1974, and in approximately the same positions, with the northern ends slightly further south at Hilston and Holmpton. The positions of the ords then remained approximately the same until the Autumn of 1975 when the first southern movement of the ords occurred. This movement continued into January 1976, when after calmer weather they once more became stationary. Therefore, during most of the study period 1974/75, very little change occurred in the position and length of the ords, except on the small scale discussed in the previous chapter. No real movement of the ords occurred until October 1975. This movement was not instantaneous and was associated with more than one period of severe northerly storms. The ord at Atwick did not move southward by the same mechanism as the ord at Holmpton. The changes within each ord between July 1975 and January 1976 have been fully discussed in Chapter Four.

A. LARGE SCALE SOUTHWARD MOVEMENT OF THE ORDS

At Holmpton the movement of the ord southwards was achieved by considerable amounts of the northern upper beach building up to the north of the ord. This upper beach material formed a tongue which jutted out on to the lower beach of the ord at a slight angle away from the line of the cliff. This body of material was subsequently moved landwards to re-establish an upper beach at the cliff foot where previously the centre of the ord has been. In July 1975 the upper beach to the north of the ord was very low and narrow opposite the Runnel stream outlet (figure 4.15). At this time profile E, in the north, was characteristic of the beach within an ord (figure 4.30), with a low narrow upper beach and a well-formed lower beach ridge of fine sand, 1·83 phi. By 3.10.75 the northern upper beach had become much higher and wider at the cliff foot and extended 300 metres south of the Runnel stream outlet (figure 4.16). The transverse profile across this upper beach was not the usual smooth convex curve from the cliff foot to the seaward edge of the upper beach but a series of three ridges. These are shown on figure 4.16. On 16.10.75 this upper beach material had moved further south and a tongue of material extended over the lower beach between profiles E and D. The ord south of profile D remained the same as it had been since July 1975. By 4.12.75 the northern upper beach was built up even higher at the cliff foot but the centre of the ord was still positioned at profile E. Much of the upper beach south of the ord centre had been removed and this exposed a very large area of till platform at the cliff foot. The tongue of upper beach in the north extended further south over the lower beach than it did previously. On 19.12.75 much of the tongue of upper beach material had moved landwards, covering the centre of the ord at profile E, and establishing the northern upper beach in a new position where the tongue joined the cliff foot. The centre of the ord was then formed at the new position on profile D. The lower beach seaward of the centre was still part of the remainder of the tongue of upper beach material, and was made up of coarse sand and small shingle. On 7.1.76 the build up of material at the cliff foot north of the centre of the ord was complete as the tongue of material completed its movement landwards to meet the cliff foot. The northern upper beach had become smooth and convex in transverse profile from the cliff foot to the low water mark, and was so wide as to leave no room for a visible lower beach at the low water mark (figure 4.33). South of the centre of the ord the lower beach had also moved landwards, covering much of the till platform which had been exposed on 4.12.75 and 19.12.75. Therefore on 7.1.76 the Holmpton ord was a single ord feature and was also the shortest it had been during the study period, as the removal of the upper beach at the southern end of the ord had not been as rapid as the build up of material in the north.

The Atwick ord also moved south during the latter half of 1975, but this was a more gradual and less obvious movement than at Holmpton. The end position of the northern upper beach gradually moved southwards between July 1975 and January 1976 but this end always remained a gentle curve and never formed into the tongue of upper beach material seen at the Holmpton ord. The northern upper beach moved southwards 150 metres between 28.7.75 and 3.12.75. During December 1975 the movement became more rapid and between 22.12.75 and 6.1.75 it moved over 150 metres further south (figure 4.21).

The exposure of till platform within the Atwick ord remained very small until the survey on 3.12.75, when, like the Holmpton ord, a much larger area of till platform was exposed at the cliff foot than had previously been surveyed. Unlike the ord at Holmpton, where the till platform was gradually reduced in area during December by the landward movement of the lower beach, at Atwick the area of exposed till platform became larger as the upper beach to the south was removed. By 6.1.76 there was till platform exposed at the cliff foot most of the length of the ord.

The main question to be answered at this point is why did the ords move substantially southwards during the latter half of 1975 after remaining almost stationary for the previous 18 months? For the answer to this question it is necessary to study the external conditions acting on the beach. Figures 4.1 and 4.2 give wind directions and speeds for 1974 and 1975. Very few periods of extremely strong winds were recorded (January, October and December 1974, November 1975 and January 1976) and on most occasions these blew from the westerly quarter, from where they had little destructive effect on the beach. From figure 4.2 it can be seen that four short periods of strong northerly winds blew on to the Holderness coast between September 1975 and January 1976. These were on 14th and 15th September, 11th October, 16th-18th November, and 2nd-4th January 1976. The first two periods were of very short duration with maximum speeds of 28 knots. The meteorological conditions which brought about these strong winds were by no means out of the ordinary and were associated with the usual passage of low pressure cells across the British Isles. But despite this, after many months of calmer winds (the storms previous to this occurred in March and April), both these storms had an effect on the configuration of the beach. Both the Atwick and Holmpton ords showed changes between 30.7.75 and 3.10.75. The most obvious change was the build up of the northern upper beach at Holmpton near the Runnel stream outlet. At Holmpton itself no corresponding change occurred but the centre of the ord was moved slightly southwards, as was the end of the northern upper beach. Between 3.10.75 and 16.10.75 the movement of the northern upper beach southwards, begun during the previous period, continued with the results seen in figures 4.16 and 4.20 (the ord plans). Again the most noticeable change was to the northern upper beach at Holmpton. During the whole of this period the southern parts of both ords remained virtually unchanged.

The next northerly storm on 16th and 17th November was much greater in strength than the previous storms and was associated with the movement of a depression across central Scotland (figure 6.2). Wind speeds during this storm reached 50 knots by noon on 17th as the depression centre moved southwards down the North Sea with strong northerly Arctic winds behind it. The passage of this storm also caused a moderate storm surge in the North Sea (see figure 6.3 for predicted and recorded heights of the tides). On 15.11.75 the recorded tide heights were 0·2 metre below the predicted heights. On 16.11.75, between midnight and 0600 hours, the recorded tide was 0·2 metre above the predicted tide. Between 0600 and 2400 hours the maximum recorded tide above the predicted tide was 1 metre, and this occurred at 1100 hours. On 17.11.75 the maximum of 0.7 metre above the predicted tide occurred at 0900 hours on the low water. By 18.11.75 the recorded tide was 0·2 metre below the predicted tide. The Spring tide occurred on 20.11.75, four days after the maximum of the surge on 16.11.75, and was predicted to reach a peak of 5·4 metres, 0·1 metre below the raised surge height of the high water at 1400 hours on 16.11.75. This Spring tide was one with the least range from high water mark to low water mark in 1975. Therefore although the surge maximum was above the predicted Spring high water mark it was still less than predicted Spring tides during the year, for example 6·0 metres on 28.2.75, 8.9.75 and 6.10.75. Therefore tidal conditions of the prolonged and high, high water cannot have had an extraordinary effect on the beach at this time. The northerly wind generated waves from the direction of the maximum length of fetch possible for this coast (see figure 2.6) and these were the main cause of beach change. The changes that took place within the ords can be seen on the beach plans for 3.12.75 and 4.12.75 (figures 4.21 and 4.16). At Atwick the southern end of the northern upper beach had moved 50 metres to the south since October, and it had also become wider. There was a much greater area of till platform exposed from the centre of the ord southwards, but the centre of the ord was slightly further north than on 15.10.75. At Holmpton the northern upper beach, which extended in a tongue-like form, of upper beach material, on to the lower beach between profiles E and D, had become higher at the cliff foot north of profile E and reached further on to the lower beach, south of profile D. The centre of the ord was just north of profile E (and had not changed positions during the whole of 1975). South of the centre there was a very large exposure of till platform which was found at the cliff foot as far south as profile C. South of this the southern upper beach built up again quite rapidly but the till platform continued at the base of this upper beach further south than profile A.

Therefore the effects of the mid-November storm had been two-fold. Firstly a movement and build up of the northern upper beach in both ords, although the build up took different forms in each ord. Secondly, much of the upper beach south of the centre of the ords had been removed and exposed very large areas of till platform in both ords. In both cases the surface of the till platform was covered by many till boulders of all sizes indicating recent cliff erosion (see Chapter Five). In both ords it is noticeable that the centre had moved slightly northwards into a position it had occupied in September and October.

The final storm of the winter of 1975/76 was at the beginning of January 1976. This, like the November storm, was caused by a depression moving across southern Scotland and then across the North Sea to Denmark. Behind the centre of the depression were strong northerly winds of greater speed and duration than in November. The track of the depression is plotted in figure 6.4. By 1800 hours on 2.1.76 the winds on the Holderness coast had reached 25 knots from the west as the warm front passed. By midnight on 2/3.1.76, after the cold front had passed, the winds veered to northwest and blew at 48-52 knots. The winds blew at over 40 knots for a day until they subsided to 10 knots by midnight on 3/4.1.76. The centre of the depression at its lowest reached 968 millibars, much lower than the 980 millibars of the November storm. There was also a storm surge in the North Sea associated with this storm, and, as would be expected from the similar depression track but deeper centre of this storm, the surge was also greater than that in November. On 2.1.76 as the centre of the depression was passing over Scotland the recorded tide height was 0·5 metre below the predicted sea level. On 3.1.76 the recorded tide gradually became greater than the predicted heights. On the first high water of 3.1.74, at 0500 hours, the recorded height was 0·2 metre higher than predicted. At the low water at 1100 hours this was increased to 0.7 metre. The maximum surge occurred on the flood of the following high water at 1700 hours when the sea level was 1·0 metre above the predicted, and the maximum surge of 1·5 metres occurring at 1300 hours. The surge was quickly over and by 1900 hours the tide was only 0·4 metre above the predicted. By 4.1.76 the centre of the depression had moved into Poland and the strong winds behind it had died down in the North Sea, where only light north-westerly winds prevailed during the next few days. During this time the recorded tides were below the predicted heights.

The high water which occurred at the top of the Spring tide at 1700 hours on 3.1.76, with the storm surge reached 6·4 metres, 1·0 metre higher than predicted and 0·4 metre higher than any predicted high tide during 1975. Therefore this tide would have been expected to have had some considerable effect on the cliffs, if not on the actual beach. Added to this was the steeper waves, generated by the strong northerly winds behind the centre of the depression. These large waves would have generated a seaward undertow landwards of the breaker zone and thus account for a general flattening of the beach.

The main changes to the Atwick and Holmpton ords during this storm were associated with the northern upper beach, which appears to be the dominant feature on the beach when an ord moves. At Atwick on 6.1.76 the southern end of the northern upper beach had been moved 150 metres southwards since 22.12.75. It was also higher at the cliff foot. The exposure of the till platform was approximately in the same position. The lower beach was also higher south of the centre of the ord. At Holmpton on 7.1.76 the northern upper beach had become flatter but higher at the cliff foot to the north of profile D, the centre. South of this the lower beach ridge had become lower and flatter but had moved landwards covering much of the till platform exposed on 19.12.75. The southern upper beach was reduced in height, especially at the cliff foot and at the southern end of the ord at profile A. Therefore again as in November the main effect of the storm was to move the northern upper beach southwards, with a simple movement of material at the cliff foot at Atwick and by a more complex mechanism at Holmpton. This latter involves the movement of beach material both during a storm, to form the tongue of upper beach material, and in the calmer periods following a storm, when the tongue of material is moved landwards to form the northern upper beach in a position further south than before. During a storm the upper beach to the north of the ord becomes built up by a movement of material southwards along the cliff foot. The combination of a surplus of beach material and the angle of the dominant northerly waves, aligns the upper beach perpendicular to the wave fronts and thus the tongue of upper beach is moved out on to the lower beach. In no way is this part of the lower beach. The material is, of course, sand and shingle and not the fine sand of the normal lower beach system. After the storm this tongue of material extends from the upper beach at the cliff foot across the lower beach almost to the low water mark. It is very high and wide, although it declines in height southwards and it has a steep, short landward slope, similar but much higher and steeper than the normal lower beach ridge. Landwards of the tongue is a depression at the cliff foot and as at Holmpton in January 1976, the centre of the ord is in this depression. In calmer weather the tongue is moved landwards in a similar way to the landward movement of the lower beach ridge (see Chapter Five). Within a few days the tongue is moved up against the cliff foot, covering the old ord centre at the cliff foot, and forming the northern upper beach of the ord. In this way this upper beach can be built up to a great height, often at or above the mean high water mark, very quickly. The till platform exposed at its southern end becomes the new centre of the ord. The movement of the tongue on the Holmpton beach between 4.12.75 and 19.12.75 (figure 4.16), illustrates the landward movement of the material described above.

It would appear that the build up of the tongue of upper beach does not occur during a single storm but over a period of weeks or even months. The beach material of which it is formed must move along the cliff foot from the north and is often depleted from the southern end of the next ord to the north, although usually in a very gradual manner. The movement of the southern end of the ord is always a gradual process, lowering the upper beach, especially at the cliff foot. At Holmpton the first signs of the northern upper beach build up was on 3.10.75 when a series of ridges were formed on the wide upper beach opposite the Runnel stream outlet. By 16.10.75 this wider and higher upper beach had moved southwards and begun to form a slight tongue, spreading on to the lower beach at profile E. No severe northerly storms had occurred in this period. By 4.12.75, after the mid-November storm, the upper beach to the north had reached its greatest height at the cliff foot north of profile E, and the tongue of material was formed into a high ridge across the lower beach between profiles E and D. At profile D its maximum height was 50 metres from the cliff foot. It was 1·6 metres lower at profile D than profile E. During December, as discussed above, the tongue of material moved landwards, covering the old ord centre. This process was fully completed after the January storm, which, despite its strength, did not produce another tongue. The new upper beach was well formed at the cliff foot with no surplus of material to form a new tongue. Therefore in its new position the ord was once more stationary and the lower beach ridge began to build up again.

Why does this mechanism of movement, tongue formation, occur at the Holmpton ord and not at the Atwick ord? It was mentioned above how the tongue of material, as it lies across the lower beach, aligns itself up to become perpendicular to the direction of the storm waves, which are usually from the north (allowing for refraction as they approach the coast). The wave refraction diagrams, figure 6.8, for the northerly waves show a similar pattern of orthogonals for each wave period from 12 seconds to 6 seconds. In each case the orthogonals become closer together towards the southern end of the Holderness coast (there is equal wave energy between each orthogonal). For the 12-second waves the orthogonals do not become regularly spaced until south of Hornsea, and a similar pattern occurs with the 10-second period waves. North of Atwick in both cases the effect of these waves is very slight. The pattern for 8 and 6-second northerly waves is similar. Therefore during northerly storms the beach at Atwick is receiving considerably less wave energy than the beach at Holmpton. This is mainly due to the sheltering effect of the promontory of Flamborough Head. This greater wave energy at Holmpton, together with the larger quantity of material on the beach in the southern part of Holderness (see Chapter Two) is probably sufficient to allow the building up of the tongue of material. These northerly waves also produce the greatest longshore drift potential. These observations coincide with Phillips (1962) on the Spurn Head ords. There is a surplus of material on the beach and the ords were noted to move by a mechanism involving the formation of a northern upper beach tongue.

Also from the wave refraction diagrams (figure 6.8), it can be seen that the more easterly the direction of the waves the more they become effective in Bridlington Bay, and the more even the distribution of wave energy along the Holderness coast

The January storm was extremely severe on land, the high winds caused much damage to buildings and trees. As the maximum storm surge occurred only hours before a Spring high water it will be interesting to compare the meteorological conditions with those which caused the major storm surge at the end of January 1953. This storm which occurred on 31 January and 1 February caused severe flooding on the east coast of England, especially south of the Tees. Over 200,000 acres were flooded. This surge did not occur on the high tide, nor on a Spring tide, which saved much more damage from being done. Figure 6.6 shows the synoptic charts for this 1953 storm. Although the depression was no deeper than in January 1976 (968 millibars at its deepest), the track of the depression was different, and this was the significant factor in the height of the surge. The depression moved around the north of Scotland and down into the North Sea, not across it as in 1976. This was an important factor in the build up of the sea-level into the surge. In both 1953 and 1976 the deepest intensity of the storm centre occurred when it was in the middle of the North Sea. Figure 6.7 gives the predicted and recorded tides for the River Tees entrance for 31 January to 2 February 1953. At 1700 hours on 31 January at the high water the tide level was almost 2·0 metres higher than predicted and the effects of the surge did not completely die out until 1800 hours on 1 February. The effects of flooding reported from the east coast in January 1976 cannot be compared with the disaster of 1953.

Another question which remains to be answered is how well the results of this study confirm Phillips' conclusion:-

.. "only when winds of over 15 knots blow from the northerly quarter for at least several hours can a major breakdown in the form of a beach occur."

In figure 4.2, the 1975 wind speeds and directions, northerly winds of more than 15 knots, and more than 20 knots are marked. Several periods of winds over 15 and 20 knots occurred during March and April but the surveys of the ords show that very little overall movement occurred, only some slight adjustments within the ords themselves. Very few strong northerly winds occurred until September and all these storms have been dealt with above. Therefore although it can be said that only when winds of over 15 knots blow from the northerly quarter for at least several hours does a major breakdown in the form of the beach occur, the statement cannot be revised. It is not true that major beach changes occur during every period of northerly winds over 15 knots. As far as this study is concerned the speed of 15 knots is very arbitrary and 20 knots could be as easily applied. During all the severe storms the wind speeds exceed 30 knots for much of the time, and these can occur very suddenly (for example on 16 to 18 November 1975 and 12 and 13 December 1975). It is also true that strong winds from all other directions, apart from the northerly quarter, are not associated with a major breakdown of the beach and even facilitate a build up in certain cases (see Chapter Five).

B. A REVIEW OF SIMILAR FEATURES AROUND THE WORLD

It was mentioned in the introduction that ords have not been reported from any other part of the world. This may be because of a lack of communication and differing terminology, and therefore it would be useful to review the literature on similar features reported and studied around the world, and to assess the relevant characteristics of such features compared with the Holderness ords.

There are four types of coastal landforms similar in form to the ords. Table 6.2 lists these, with their general characteristics and the suggested processes operating upon them to maintain the features. Ords are also included in the table for comparison. The first of these features are the crescentic sand waves, common on many sandy beaches and studied by Dolan (1971, 1974) on the outer banks of North Carolina, U.S.A. Sand waves are part of the beach-bar-trough system, rhythmic in the longshore direction and consisting of a gentle crescentic or wave-like shape of the shoreline. Sandwaves are associated with the dynamics of the longshore transport system:

> "They are larger than beach cusps and extend well into the subaqueous zone. The seaward projections and landward embayments are subaerial manifestations of complex but systematic transverse bars and troughs that are more common than uncommon along sandy coasts. This configuration coupled with the uniform sizes and dynamics of the sand waves indicate that the shoreline and inshore configuration respond to a system of inter-related processes and not as randomly distributed irregularities dependent wholly upon local conditions."
>
> (Dolan 1971)

Various authors have suggested a wide range of processes for their formation, including near-shore circulation cells,

TABLE 6.2 A COMPARISON OF ORD-LIKE FEATURES AROUND THE WORLD

FEATURE	LENGTH (METRES)	IMPORTANT OFFSHORE TOPOGRAPHY	RHYTHMIC	PROCESS OF FORMATION AND ALONGSHORE MIGRATION	AUTHOR
Crescentic sand wave	100-3000	Offshore bar system	YES	Many theories, no one singled out - wave action - nearshore circulation cells - back eddies of longshore transport currents	DOLAN 1971 1974
Giant cusps	150-1000	None	YES	Nearshore cell circulation with rip currents and associated longshore currents	KOMAR 1971
Beach erosion	3000	Transverse submarine bars with associated parallel bars	NO	Deficiency of beach sediment for longshore drift owing to build up of offshore bars	DYHR-NIELSEN 1970
Zones of beach accretion	500-1000	Ebb and flood channels and associated bars	NO	Movement of sediment in nearshore zones by ebb and flood tidal streams associated with sediment accumulation on offshore bars	KING 1964 ROBINSON 1966
ORDS	500-1000	Continuation of lower beach ridge offshore in southern ords. No bar and channel system	NO	Migration by longshore movement of beach sediment	PHILLIPS 1962 1964

edge waves and kinematics of a flowing mass of sediment. Their life span ranges from weeks to years. They have been observed to migrate alongshore at rates, greatest during the stormy winter season, of between 100 to 200 metres per month. The focus of destructive storm surges along any given reach of the coast can be a factor of sand wave field position, rather than the chance variation in the submarine bars. Submarine bars associated with the sand waves have deepwater channels immediately offshore from the embayments. These channels can be seen clearly on aerial photographs by comparing the shoaling of the incoming breakers with the sand wave field.

The "giant cusps" reported by Komar (1971) on the East coast of the U.S.A., are very similar in form to the sand waves discussed above. In size they are similar, 150 to 1000 metres in length and projecting 15 to 25 metres seawards. After laboratory experiments in a wave tank, Komar favoured nearshore cell circulation for the formation of these features. Figure 6.10 illustrates how these crescentic beach forms are associated, according to Komar, with rip current systems and the adjacent longshore currents. The cusps develop in the lee of the rips which hollow out the embayments. Rip currents can produce either isolated cusps or can form a rhythmic series where the cusp spacing corresponds to the spacing of the rips. Rips are known to migrate slowly alongshore so that the cusps may likewise migrate.

The next set of features similar in form to the Holderness ords are the erosion features associated with offshore transverse bars studied by Dyhr-Nielsen (1970) on the West coast of Jutland. Beach erosion was found to occur in a down-drift direction of where an inner submarine bar ran transversely out to sea to join an outer submarine bar (see figure 6.10). The formation of the transverse bar causes a deficit of sediment in the nearshore transport downstream of the bar, which in turn affects the stability of the beach profile. Erosion of the beach occurs in the downdrift region in order to reduce the deficit and satisfy the transport capacity of the waves and currents downstream of the transverse bar. Dyhr-Nielsen quotes the case of the beach south of Hvide Sande, a small town on the west coast of Denmark. The building of two groynes to prevent sand build up in the harbour has caused a deficiency of sand to the two parallel offshore bars south of the town. Transverse bars have developed to connect the nearshore bar with the remnants of the outer bar and south of these transverse bars severe beach erosion has been observed. The transverse bars migrate twoards the south with a velocity of about 600 metres per year, and this changes the points of attack on the beach so that the erosion at a certain point decreases. South of the transverse bar the outer bar builds up again, which indicates that this bar was supplied with sand from the nearshore zone. It is also noted that transverse bars are found on other coasts without man-made interference but again in connection with local erosion.

The last example of beach features which show erosion and accretion along a shoreline are the beach changes associated with offshore bars and channels formed by the ebb and flood tidal streams. Although this situation is not very similar to the Holderness ords these studies have been included in the main because of the proximity of the areas involved to Holderness (South Lincolnshire and East Anglia), and also in the case of East Anglia the coastline is of similar age and form to Holderness (mid and late Pleistocene till cliffs).

Beach changes associated with these offshore features have been studied by King (1964) and Robinson (1966) in south Lincolnshire and East Anglia, respectively. The pattern of the tidal channels and intervening sand banks controls the movement of sediment in the nearshore zone. The intervening banks represent areas of sediment accumulation between the opposing flows and determines where it can most easily reach the foreshore. Along the East Anglian coastline, "ness" features represent areas of excess shoreline sedimentation and are associated with the ebb-flood channel system immediately offshore. The flood channel carries material southwards into the northern flank of the ness while an ebb channel carries material northwards on to the southern flank. The growth and movement of the individual nesses can be traced and related to the development of offshore banks which are the result of tidal streams. The low beach areas between the nesses leave the cliffs and dunes behind susceptible to wave erosion, although the beach configuration here in no way resembles the ords of Holderness. Variations in the position of the East Anglian nesses can be connected with the movement of the offshore banks over a period of years. In the case of East Anglia, Robinson (1966) believes that the effect of wave action as an agent of erosion is considerably reduced by the tidal currents where a favourable sediment supply is available.

How far does the Holderness ord system compare with any of the above systems? In form the ords do not directly resemble any of the above features although Dyhr-Nielsen's areas of beach erosion associated with the transverse offshore bars are not described in detail. The ords are much more irregular in internal form and in their relationship to each other than the symmetrical crescentic sand waves and giant cusps. By size the ords would fit into any of the groups in table 6.2.

The offshore zone of the Holderness coast is relatively simple compared with many of the examples above, for example the south Lincolnshire or East Anglian offshore zones. Figure 1.1 shows the offshore contours which run approximately parallel to the coastline from Skipsea in the north to Kilnsea at the northern end of Spurn Head. North of Skipsea in Bridlington Bay the sea bed becomes much shallower and south of Flamborough Head is the sandbank of South Smithic, a typical feature formed in the lee of the promontory by northerl waves. This bank of sand only affects the wave pattern reaching the shore locally in Bridlington Bay; the effect on the rest of the Holderness coast is nil. Around Spurn Head the ebb and flood currents have developed banks and channels on the seaward side of the spit, but these again only affect the local pattern of the waves. The tidal streams off the

Holderness coast, except around Spurn Head and the mouth of the Humber, are very simple in form and weak in their flow. The flood stream flows northwards, parallel to the coastline, and the ebb stream in the opposite direction slightly nearer the shore. They do not form definite banks and channels. Off the Holderness coast this probably indicates a lack of available sediment for this. In the mouth of the Humber the main ebb channel runs out of the estuary very close to the tip of Spurn Head and then turns north-east to flow around the sand bar known as the Chequer Shoal. A secondary minor ebb stream runs north-east very close to the shore of Spurn Head for a short period in each tidal cycle. This is reversed during the flood. The flood channels are shorter and shallowe and form a series of prongs, one of which runs south-west between the Binks and the spit. But northwards of this the flood current is very weak although it may run quite close to the shore. Therefore the influence of the tidal streams can be discounted as an influence on the Holderness beach.

The influence of the offshore topography does not appear likely from the smooth offshore slope indicated in figure 1.1. To investigate the nearshore zone around the ords, echo-sounding experiments were carried out, one at Atwick and the other at Easington (figures 4.10 and 4.34). The results from both of these surveys show the same pattern. On all the transverse profiles taken within and north of the ords, the sea bed slopes smoothly seawards from the lower beach ridge crest. There is no sign of an offshore bar of any size. The longitudinal profiles were taken 100 metres seaward of the mean low water mark and show a smooth profile. The highest point along these is opposite the centre of the ords and they decline slowly in height northwards and southwards of this point. This shows the build up of sediment offshore opposite the ord centre. At Atwick the longitudinal profile is almost flat. Therefore the influence or interaction of beach and offshore bars does not seem to be in operation on the Holderness coast. It would appear from table 6.2 that a smooth offshore topography is unusual off a sand beach but the answer to this problem is the low sediment supply to this coastline. The lack of sediment on the beach is reflected by the lack of abundant sediment in the offshore zone. Although there is much sediment in the flow of the North Sea a few miles further east, the currents in that area do not make this sediment available to the Holderness beach.

Finally, does the presence of rip currents play an important part in the formation of the Holderness ords? There is no evidence for a series of rips associated with the presence of the ords. Although rips do occur on the Holderness coast, their presence is more random, dependent on the wave and tidal conditions on any one day. The giant cusps which Komar (1971) suggested formed by nearshore cell circulation, all show a great symmetry of form and position. These do not resemble any features in the ord system.

With the ords the problems are the lack of symmetry of the features. They all show different characteristics and the grouping used in Chapter Two are only very general. No ord is the same size as another; no ord exactly responds to the processes operating upon it as another does. They occur at irregular intervals along the Holderness coast. Will any of the suggested theories of formation and movement in table 6.2 explain the presence of the ords on the Holderness coast? The answer to this is no. The most likely hypothesis is that of Dyhr-Nielsen with the transverse bars, but to produce erosion on the scale of an ord it seems unlikely that the corresponding transverse bars could have remained undetected so far.

In summary, none of the features in table 6.2 are the same as the ords. They do not even have main characteristics that resemble those of the ords. Therefore the question still remains as to how the ords are formed and how do they move. Movement of the ords is no longer an unknown fact. They move by the build up of beach material to the north of the ord which only moves southwards at certain periods. Is the general rate of movement of material along the coastline the same as the rate of movement of the ord, or is the sediment movement rate faster? Only experiments measuring the rate of longshore drift could answer this. The ords are formed in the zone south of Barmston, north of Atwick, from which they migrate south. No observations have yet been made of the beginnings of an ord.

C. THE MECHANISM OF ORD FORMATION

The formation of the ords must now be considered. Phillips (1962) put forward a theory on the following lines: During a northerly storm when the winds reach speeds of over

15-20 knots for a period of several hours, the northerly waves they generate are refracted around Flamborough Head, and in Bridlington Bay the sea is sheltered from the direct northerly storm waves. Where the storm waves reach the Holderness coast, at a point of impact the high energy waves cause a strong southward movement of the beach material. North of this point the beach is not subjected to the high energy waves and the beach material is not moved alongshore in the same way or at the same rapid rate. This energy differential between the two areas, north and south of the point of impact of the storm waves on the coast, is the key to the ord formation. At the most northerly point where the beach material is moved southwards, its place cannot be filled by material from the north (as the waves are not producing a southward movement of material in Bridlington Bay). Therefore there is a gap created in the beach material at this point. Subsequent southward movement of material along the whole beach will not fill in this gap as any southward movement of the material north of the gap will have a corresponding movement of the material to the south of the gap. Thus an ord is formed and maintained.

During this present study the formation of a new ord in the northern part of Holderness did not occur and therefore the mechanism of formation outlined above cannot be confirmed or rejected by observation. But the above theory may be evaluated in the light of the recent study of the ords made here.

Firstly, why must the ords form in the northern part of Holderness? The ords have been observed to migrate southwards, never substantially northwards. If they did not move their positions the rate of erosion along the Holderness coast would be much more irregular than it is at the present. Therefore it can be said that the ords must form in the northern part of Holderness. The waves refracted around the Head reach the Holderness coast at a point between Barmston (map ref. TA 172594) and Skipsea (map ref. TA 182553), for the longer waves, 12 and 10-second periods, and further south towards Hornsea with the shorter waves (see the wave refraction diagrams, figure 6.8).

The wave refraction diagrams, as already mentioned, confirm the theory of an energy differential between Bridlington Bay and the rest of Holderness. The important "point of impact" changes its position slightly depending upon the length of the waves. The sheltering effect of Flamborough Head was first discussed in Chapter Two when the form of the beach in the northern part of Holderness was outlined. In the northern part of the Bay, sheltered from the steepest northerly storm waves, the beach profile is wide and relatively flat compared with the profile which develops south of Barmston (figure 2.1). Here the beach material has adjusted to the steeper waves and the upper beach has a steep seaward slope. It is in this zone that the ords most probably form.

Considering the present evidence, the above theory for the formation of the ords cannot be rejected. Intensive study and observations in this northern zone of the Holderness coast is needed before it can be substantiated.

D. THE EFFECTS OF ORD MOVEMENT ON THE RATE OF CLIFF EROSION

Finally in this chapter some mention must be made of the effects of the changes of the Holderness beach on the cliffs behind. Except for the concrete sea walls and revetments at Bridlington, Hornsea and Withernsea, and along the Spurn Head seaward beach, the only protection the cliffs of Holderness have against the destructive action of the waves is the beach. The unconsolidated till cliffs, predominantly of clay, with sand and gravel lenses, are rapidly eroded where the waves can attack their base. Although important in the retreat of the cliffs, subaerial processes such as landslides, mudflows and falls are gradually brought to a halt when the products of such processes are no longer removed from the base of the cliffs by the waves. Then the slope of the cliffs becomes less steep and stabilises with a covering of vegetation. As far as the subaerial processes are concerned, the rainfall has an effect on the type of process that is dominant. For example, more mudflows occur in wet weather (and produce fewer till boulders on the beach) and falls and landslides occur in the drier weather, but cliff retreat continues regardless of subaerial factors when the sea can attack the base of the cliffs.

The very rapid retreat of the Holderness coast has created considerable interest from research workers for many years. The loss of the land affects the lives not only of the farming population but also of villagers and townspeople, many of whom, over the centuries, have seen their villages and towns break up and fall over the cliffs (Shepard 1910). Every road approaching the coast suddenly ends at the cliff top, often with an overhang of the tar macadam.

The most extensive study of the rate of erosion of the Holderness coast was carried out by Valentin (1954). Using the earliest six-inch ordnance survey maps of 1852 and his own measurements in 1952, to reference points on the top of the cliff, it was possible to measure the land loss over the 100 years to ±10 feet (3 metres). Altogether 307 measurements were taken at approximately 200 metre intervals. Valentin's results by parish are shown in table 6.1. The annual cliff recession rate shows a lessening of cliff retreat immediately north of Hornsea and Withernsea, and a large increase south of these towns. Figure 6.9 shows these results in diagrammatic form. The reason for the alternative between rapid and slow erosion along the coast is accounted for by Valentin as follows:-

> "The effect of the sea walls in reducing land loss is localised to the stretch of coast actually protected. On the other hand, groynes have an effect in checking the southward movement of beach material which begins several kilometres northwards of the groynes, and also checks the rate of cliff recession. This reduction is compensated for by increased erosion south of the groynes."

This explanation is quite adequate in explaining the difference in the 100 years' results. But Valentin also notes:-

> "..the present S-shaped alignment of the coast between Bridlington Bay and Spurn Head is largely the result of the relief as it existed at the end of glacial times and cannot be explained simply by the present coastal processes which erode the land rapidly in the south-east but more slowly in the north-west."

Therefore Valentin is saying that over thousands of years the erosion rate of the Holderness coast has been fairly uniform. In all this discussion the Holderness beach is only briefly mentioned, and this is also the case in many of the studies of cliff retreat on the Holderness coast. Not only has the presence of the ords been left unmentioned by most workers but their effect on cliff erosion has been completely disregarded in most cases. From many observations made during this present study it has been noted that between the ords the upper beach at the cliff foot is usually so well built up as to be above the mean high water mark, and therefore it affords protection to the cliff foot from wave attack at most times of the year. Where this has been in operation for some time the cliffs have become relatively stable, less steep and sometimes even vegetated, especially where the conditions exist for a year or two. It is the cliffs within an ord system which are unprotected at each high water and are therefore eroded relatively rapidly by the waves. Not only do the storm waves with their high energy remove large blocks of the cliffs at one time, but also the lower energy waves produced in calmer weather, by frequently wetting the surface of the till cliffs, enable significant quantities of clay-sized material to be removed.

At the centre of an ord the mean high water mark can reach three to four metres above the cliff foot, thus washing a large proportion of the lower parts of the cliffs.

As an ord approaches a section of the coast, the upper beach at the cliff foot becomes lower. This gradually allows the waves to attack the cliff foot for longer and longer periods at each high water. This reaches a peak as the centre of the ord becomes established at a particular location. If northerly storm conditions occur, the erosion at this point will be extremely severe and it is not uncommon for landslides of five or six metres in width to slip into the sea at one time. The cliffs become almost vertical. As the ord passes southwards, the upper beach begins to build up again at the cliff foot and eventually effective wave attack at the cliff foot ceases and during the next few months the steep cliffs readjust to a gentler angle by more falls and landslides, and they eventually become relatively stable once more.

Any doubts as to the migration of the ords can be removed when it is considered what would happen to the Holderness coastline if the ords remained stationary. The rapid erosion where an ord is present, and the lack of serious erosion between the ords would lead to a very indented coastline. For the coastline to remain a smooth curve over the long term, if not in the short term, the ords must be moving features.

Therefore most of the erosion of the Holderness coastline, south of Skipsea, is associated with the presence of the ords, a fact which has not been fully recognised in earlier research work.

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C H A P T E R S E V E N

THE CONCLUSION

In the introduction three questions were asked about the ords. Firstly, what are ords and where are they found on the Holderness coast? Secondly, how do they move and under what conditions does this occur? Thirdly, where and how do the ords originate? How successful has the present study been in answering these questions?

In Chapter Two the first question was answered. The overall shape of the whole Holderness beach was discussed and the ords found to be present in the zone south of Skipsea, where the beach is well developed into the upper beach/lower beach transverse profile. The presence of an ord interrupts this beach form and substitutes a lower beach at the cliff foot and a raised lower beach towards the low water mark, often in the form of an asymmetrical ridge.

There is little previous information about the Holderness ords. The two main sources are the work by Phillips(1962) and the sets of aerial photographs of the Holderness coast in the Geography Department at the University of Hull. The latter provided a valuable record of the position and form of the ords present on the beach during the 1960's.

The ords can be classified into two types. North of Withernsea the limited amount of material on the beach does not allow the features within an ord to develop as distinctly as the ords south of Withernsea where there is more beach material available. Chapter Two ends with a general discussion of the changes in the ords between December 1973 and February 1976, with a resume of the wind conditions on the coast during that period. During westerly and southerly winds the features within an ord become subdued. An upper beach may form along the cliff foot and the areas of exposed till platform become less extensive.

After a sustained period of easterly winds, of all strengths, the lower beach is usually flattened. This also completely obscures all the till platform.

Northerly winds of light and moderate strength do not cause much alteration on the beach within an ord but during periods of strong northerly winds the most marked changes take place on the beach. Large areas of till platform are re-exposed and in the southern part of an ord where the upper beach narrows fresh areas of platform are exposed. Between the ords the upper beach is often lowered and much damage occurs to the cliffs all along the coast.

In order to study the ord form in more detail and to answer the second question posed in the introduction as to how the ords move, it was necessary to study some of the ords in greater detail. Three of the ords were selected for closer study. These were at Atwick, Holmpton and Easington. In Chapter Three each of these ords was discussed at length, including their form and position at the beginning of the study period. The Atwick ord is a fine example of the northern group of ords, with a poorly-developed lower beach ridge and no real build up of the upper beach south of the ord centre until the southern end of the ord. The Holmpton and Easington ords belong to the southern group of ords whose features are more emphasised, especially in the development of the lower beach ridge.

The remainder of Chapter Three deals with the techniques used for monitoring the ords during the study period. The beach environment is the scene for the complex interaction of many variables. These can be divided into two groups: the process variables operating on the beach, the wind, waves and tide; and the response variables, the characteristics of the beach which respond to the process variables. Records of the wind speed and strength were obtained from the Kilnsea meteorological station. Waves observations of direction, period and height, were made at times of the surveys. The tidal data was obtained from the Admiralty Tide Tables and recorded heights from the tide recorder at the River Tees Entrance. The response variables were recorded in three main ways. Firstly, by beach plan recording with a supplementary photographic record. Secondly, by levelling profiles across and along the beach, continued seawards on two occasions by echo-sounding. Thirdly, the beach material was sampled, along the grid of the surveyed profiles, and analysed for size distribution, using the four moment measures proposed by Fold and Ward (1957), the mean, standard deviation (sorting), skewness and kurtosis.

The main results of the surveys and the sampling programme over the study period are given in Chapter Four. The wind regime between each survey has been analysed and the resulting changes within the ord have been discussed. The results showed two main points. Firstly, in 1974, when the Easington ord was under detailed study, there were only small changes in the form of the ord. All the wind conditions monitored showed no prolonged strong winds from any direction. There was no movement north or south of the ord as a whole. Secondly, in 1975, when the Atwick and Holmpton ords were under study, only slight internal changes occurred over most of the year. The ords did not move as units until October 1975 and then they moved southwards in stages until January 1976. The southward movement of the ords was associated with severe northerly storms.

The changes within the ords can be divided into short and long term changes. The short term changes, Chapter Five, are not usually very large scale and do not contribute to the overall movement of the ords alongshore. The most noticeable day-to-day change is in the form of the lower beach ridge, which, depending on the prevailing wind conditions moves landwards or seawards, covering and re-exposing the till shore platform, and becoming built up or flattened. During winds of over 20 knots from the northerly quarter, the lower beach was raised and the ridge crest moved landwards. During less strong winds from the northerly quarter, the ridge crest was usually moved seawards. During winds from the westerly quarter of 10 to 20 knots, the lower beach was lowered in height over all its surface but the ridge crest moved either landwards or seawards. Results of lower beach movement during the southerly and easterly quarter winds are much less distinct. During periods of light and intermittent winds of variable direction, the lower beach was most commonly raised and the ridge crest moved landwards. The alignment of the lower beach ridge is found to be perpendicular to the line of approach of the northerly storm waves. The changes outlined above are less noticeable in the northern ords of Holderness where the lower beach is rarely formed into a ridge form than in either the Holmpton or Easington ords which display well-developed lower beach ridges.

The changes to the northern and southern upper beaches of an ord are much smaller in the short term than those of the lower beach. The major changes to the upper beach only occur in the long term as the ord moves southwards along the coast. The presence of till boulders on the beach, especially where they collect on the surface of the exposed till platform, is an indication of the recent cliff erosion. The till boulders do not remain intact longer than a week.

In the long term the ords move southwards along the Holderness coast (Chapter Six). The mechanism of movement differs between the northern ords and the southern ords. In the north at Atwick the ord moves by the southerly movement of the upper beach north of the ord, along the cliff foot. This occurs during severe northerly storms. Till platform previously exposed in the northern part of the ord is covered by this movement but a similar movement of the southern upper beach exposes till platform at the cliff foot further south.

In the southern group of ords the movement differs. The northern upper beach builds up at the cliff foot and eventually protrudes obliquely southwards across the lower beach in the form of a tongue of upper beach material. This feature forms only during severe northerly storms (winds of over 25 knots for a period of several hours). At the same time the material of the southern upper beach moves southwards, near the cliff foot. After the storm, when calmer weather prevails, the smaller waves gradually move the tongue of upper beach material towards the cliff foot. Eventually, after a period lasting between a few days and a few weeks, and depending upon the size of the tongue of material and the wave conditions, the beach material will be moved up against the cliff foot. It will cover the till platform exposed before the storm, and form the new northern upper beach of the ord in a position that is to the south of its previous location. Thus the second question asked in the introduction, how and why do the ords move, is answered.

The third question asked in the introduction, as to where the ords originate, cannot be conclusively answered with the information available at the present time. In the light of the data available, it appears that they form along the coast between Barmston and Skipsea, and certain points appear to favour the mechanism of formation proposed by Phillips (1962). This theory involves the sheltering effect of Flamborough Head on Bridlington Bay and the northern part of the Holderness coast, as far as northerly storm waves are concerned. Where these waves do reach the coast an energy differential is set up. The storm waves move beach material rapidly southwards, but north of this point in the zone sheltered by Flamborough Head, wave energy is not available to move material southwards to replace the material moved by the direct impact of the storm waves. Thus a gap in the beach is formed which cannot be permanently filled.

In this work an attempt has been made to answer the problems first posed in the introduction. The main aim was to investigate the ords of the Holderness coast, which, despite their key role in the erosion of the cliffline, had been neglected in much of the previous research along this coast. A thorough working knowledge of the week to week changes throughout the year has been gained, and also some light shed on to the less frequent, long term major movement of the ords southwards along the Holderness coast.

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GLOSSARY

CONCRETE BLOCKS - Gun emplacements and tank traps, mainly Second World War, many of which, originally sited on the cliff top, have now fallen on to the beach as the cliff has been eroded.

LOWER BEACH - Section of sandy beach on the Holderness Coast seaward of the UPPER BEACH (see below) and near the low water mark.

DRY LOWER BEACH - Common within an ord where the lower beach is built up above the beach water-table and there is no surface water on the lower beach at times of low water.

WET LOWER BEACH - Common between the ord systems where the lower beach is almost flat, lying below the beach water-table and therefore covered by a thin sheet of surface water at times of low water.

ORD CENTRE - Where the beach is lowest at the cliff foot within an ord, often but not always till shore platform is exposed at this point.

ROCK BOULDERS - Erratics washed out of the eroding till cliffs, too large to be moved far by the waves. These are found in abundance on the lower parts of the exposed till platform.

SKERRIES - Till surfaces covered by many partly-embedded rock boulders. They are usually seen at the mean low water mark or just seaward of this, exposed only at the lowest Spring tides.

TILL BOULDERS - Blocks of the till cliffs, made up of pebbles in a clay matrix, that fall on to the beach as the cliff is eroded. They are quickly rounded by the waves, broken up and dispersed within days. Their presence on the beach shows recent cliff erosion.

TILL SHORE PLATFORM - This underlies all the Holderness beach and where exposed, in the ords and near the low water mark, it shows many of the structural features within the till upon its surface.

UPPER BEACH - The beach nearest the cliff foot which is built up into a convex bank of sand and shingle usually protecting the cliff foot from most high waters.

NORTHERN UPPER BEACH - The upper beach north of an ord which becomes lower at the cliff foot and narrower as the ord is approached and disappears completely at the centre of an ord.

SOUTHERN UPPER BEACH - The upper beach south of the centre of an ord. This builds up in height and width southwards until, at the southern end of the ord, it reaches its full size again.