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Some Aspects of the Coastal Geomorphology of Spurn Head, Yorkshire

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by

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C O N T E N T S

PREFACE

The aim of this thesis is to present an analysis of the variations of beach and shoal forms, erosion, accretion and the movement of material, as observed during the past three years at Spurn Head, Yorkshire, in relation to conditions of winds, waves, and tidal streams. This investigation of the processes in operation today, is of interest in itself, and should throw light on the likely course of future events at Spurn. Furthermore, since similar processes have probably been in operation during the whole period of the existance of a spit at the mouth of the Humber, it is hoped that it will provide a useful contribution to the study of its history and evolution.

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C H A P T E R 1

The Structure of Spurn

As Smeaton, the 18th century engineer and lighthouse builder said, "Spurn hangs like a rudder" from the coast of Holderness. It forms a sand and shingle spit, three and a half miles long, which projects south-eastwards from the south-east corner of the undulating boulder clay plain of Holderness in the East Riding of Yorkshire, into the mouth of the Humber estuary. (See Plate 1A and the location map Figure 1.1.).

The structure of the spit will be described in detail, with reference to photographs taken as part of the air survey carried out on 3rd September, 1959, and Figure 1.2. The village of Kilnsea (air photographs 9341 and 9339) was originally sited on a mound of boulder clay, flanked to the north and west by low alluvial land. Erosion of the cliffs on the east caused the loss of the medieval core of the village about 1830, and all that remains are a number of scattered farms. An army battery site on the vantage point of the boulder clay mound is endangered now by the breaching in 1954 of the revetment, and the subsequent rapid retreat of the boulder clay cliffs. South of Kilnsea, the Humber bank and the boulder clay cliffs, which lose height rapidly, approach closer to each other. Cultivated fields give way to dunes about a quarter of a mile south of the village, and here the spit itself begins.

It may be divided into three sections: Kilnsea Warren, which lies adjacent to Holderness; High Bents, the long, narrow, central section; and South Spurn, which may be subdivided into four parts, from north to south, the Chalk Bank Area, Spurn Warren, the Lighthouse Zone, and the Battery Area.

Kilnsea Warren (air photographs 9378, 9444, 9446) consists of a strip of low dunes about 800 feet wide opposite groyne XXV11 and gradually narrowing to about 50 feet opposite groyne X1X. The low boulder clay cliffs, at their maximum about 10 feet high, persist as far south as groyne XX1V and are aligned as is the coast of Holderness, in a north-west to south-east direction. The boulder clay beach platform has been seen exposed as far south as groyne XX11, but once the boulder clay cliffs give way to dunes, the spit begins to swing southwards.

High Bents (air photographs 9409, 9410, 9411, 9412, 9413) which forms the narrowest part of the spit, is nearly a mile in length, and contains one of the two highest parts. Between groynes XV11 and X1X the dunes rise to over 30 feet O.D. with the highest point 31 feet O.D. The width increases from 50 feet in the north near groyne X1X, to 1000 feet between groynes X1 and X11, and the spit swings round until in the extreme south of the section it is aligned as is South Spurn from north-east to south-west.

The spit broadens south of groyne XI and South Spurn varies in width between 1,500 feet and 2,000 feet. (see air photographs 9413,9415,9416,9418,9419). The most northerly sub-section takes its name from the Chalk Bank, a clearly visible feature, built in 1870 to strengthen the spit here, after the 1849 breach which widened to 1,500 feet before being sealed in 1855. The low, marshy ground on either side of the bank is drained by a well-developed channel, and flanked on the east by sand dunes. At the northern end of Spurn Warren, the next sub-section southwards, the dunes rise to 28 feet O.D. south of groyne X, but become lower towards groyne VIII. The whole of Spurn Warren is composed of dunes, and those on the east side of the spit form a ridge. Within the Lighthouse Zone the dunes rise to what was called the light-house hill, through which the road was cut in World War II. Within the Battery Area the spit becomes bulbous and terminates in the Tip. The straightness of the seaward side of South Spurn, aligned north-east to south-west, contrasts with the river side where the Battery Area and the Chalk Bank Area bulge westwards, with many smaller indentations and promontories lying between.

Offshore Conditions

The Admiralty Survey by H.M.S. "Scott" between 12th September and 11th November, 1959, and 4th May and 1st November, 1960 gives an up-to-date picture of off-shore conditions around Spurn Head. (See Figure 3.1)

Two prominent banks lie off Spurn Head, the Binks, and Old Den. The Binks is a crescent-shaped series of shingle banks curving eastwards then north-eastwards away from the south-east corner of South Spurn. The Inner Binks are linked to the spit by a narrow neck which is uncovered at maximum spring tides. The highest and broadest part lies only about 1,000 feet from the edge of the dunes on the east side of the Battery Area, and reaches heights between 1 foot and 5 feet abo ve Chart Datum (- 9.53 to -5.53 feet O.D.). Thus with a tidal range varying between 3.4 and -3.1 feet O.D. at neap tides, and 11.4 and -12.1 feet O.D. at spring tides, this part of the Inner Binks is exposed at most low waters except at maximum neap tides. The height of the bank gradually decreases north-eastwards, as it becomes narrower. The Middle Binks which continue along the same line as the Inner Binks, rise at their highest to 2 feet C.D. (-8.53 feet O.D.). The Outer Binks is the name given to a series of small banks lying east of the extremity of the Middle Binks.

Old Den is a shingle bank lying approximately 1,000 feet west of the Chalk Bank, and tapering away southwards. At its broad northern end it curves eastwards towards the spit.

Off Kilnsea Warren and High Bents the isobaths on both the seaward and river sides run generally parallel to the spit. East of South Spurn the isobaths curve eastwards round the Binks, and west of South Spurn, North Channel penetrates northwards from the south-west of the Battery Area. The isobaths are closely spaced south of the Tip. Within 2,000 feet of the edge of the dunes, depths of between 11 and 15 fathoms below Chart Datum (- 20.6 and -24.6 feet O.D.) are reached in the centre of the main shipping channel of the estuary. A marked hole lies immediately south of the broadest part of the Inner Binks. South of the main channel lies Bull Sand, with a branch of the channel penetrating south of it.

Vegetation

Only a few very specialized plants can grow in the loose sand at the top of the beach, but once they are established, they change the sand quickly. The surface becomes stabilized and organic matter accumulates by the decay of both plants and material left by the tide. On most sand dune systems when the sand is no longer flooded by high tides, rain water quickly washes out the sodium chloride and the P.H. value drops. As the sand gradually changes, so does the vegetation. Usually this change can be traced clearly from the foredunes, inland, but at Spurn the situation is complicated. Only at the southern end of the Battery Area does the dune system grow out normally, as fresh sand is stabilized by pioneer species. Along the seaward side of the spit, the dune edge is periodically eroded, and the river shore is colonized by a different, more specialized succession of plants. The most mature vegetation, therefore, is found in the centre of the spit.

The Main Plant Communities of Spurn Head

The main pioneer grasses of the foredunes are Couch grass, (Agropyron juncieforme), Marram grass (Ammophila arenaria) and Lyme grass (Elymus arenarius). All have extensive rhizome systems, and leaves with very hard, pointed apices, which roll inwards when the atmosphere is dry, but flatten out in humid weather. These features enable them to survive in the loose dry sand at the top of the beach.

Couch grass can tolerate a certain amount of flooding by sea-water. Its limp leaves reduce wind speed and cause sand which is being moved to come to rest around the plant, and eventually a low dune will be built up. The plant has little power to grow through the new sand and the dunes it helps to form are rarely more than 4 feet high. Marram grass is the main dune builder on Spurn as on most British sand dunes because its stiff tall leaves trap sand efficiently and the plant grows upwards with the dunes by means of a vertical rhizome system which can cause a rise of 1 foot per year as well as a horizontal spread of about 36 square feet. Dunes built by Marram and Lyme grass, which is similar, may coalesce after 2 or 3 years growth to form a ridge.

When the sand ceases to move within the shelter of the leaves and the supply of fresh sand ceases, other plants become established, e.g. Creeping Fescue (Festuca rubra), Groundsel (Senecio vulgaris), Sea Bindweed (Calystegia soldanella) and Creeping Thistle (Circium arvense).

The fact that a certain amount of sand is always being blown across the spit, and there is a good deal of disturbance by man may explain why Marram grass survives, and although less vigorous than on the foreshore, remains the most common plant on the whole spit. In well trodden places and around rabbit warrens a short turf, containing fixed dune species, can be found. During winter and spring there is a plentiful supply of water even in the surface layers of the sand, and one group of plants germinate in September and grow until the following summer. These include Mouse ear Chickweed (Cerastium semidecandrum), Dove's foot Cransbill (Geranium molle), Storksbill (Erodium circutarium) and Scarlet pimpernel (Anagallis arvensis). The perennial and biennial species which must survive the summer generally have deep penetrating roots. Sea holly (Eryngium maritimum) grows in an exposed and dry position at the narrowest part of High Bents, in a pebbly substate, and has roots about 130 cms. long. Rest Harrow (Ononis repens) is very common and has tap roots over 150 cms. long.

In many parts of the spit there is a dense growth of Sea buckthorn (Hippophäe rhamnoides), a characteristic shrub of dunes along the east coast of England.

Around a creak which brings muddy water at high spring tides on to the land west of the Chalk Bank an interesting plant community is found. The mud becomes intermingled with blown sand, but evaporation of water at low tide leaving salt deposits, results in conditions which cannot be tolerated by any of the plants mentioned above, but which is highly suitable for the small shrub Sea Purslane (Halimione portulacoides).

On the river shore there is a new and rapidly growing colony of Cord-grass (Spartina townsendii). A dense growth is now found west of Kilnsea Warren, with new hummocks west of High Bents. Cord-grass taps mud and silt in an analagous manner to the sand trapping action of Marram grass. Its broad stiff leaves slow down water currents and allow the deposition of mud both on and around the leaves. The trapped material is stabilized by a dense rooting system just under the surface. Long tap roots hold the plants firmly in position. Each tussock spreads many feet each year by the growth of horizontal rhizomes just beneath the surface of the mud, and new tussocks grow from seedlings and broken rhizome pieces. Also along the river shore is a narrow zone of Lyme and Couch grass on the loose sand, but there are also a few typical salt marsh plants amongst them.

<u>The Beaches</u>

Before considering the condition of the beaches in September 1959, as seen on the air photographs of 3rd September, certain general factors must be considered.

Along the whole length of the seaward side of Spurn Head groynes have been built. The first ones were constructed in the 1860's after the breaches in 1849, 1852 and 1856. It was hoped that the groynes would help to protect the spit from attack from the sea, and since then many more have been built. These are shown in figure 1.2. In addition concrete revetments were built along the east side of High Bents, near the lighthouse, and at Kilnsea. Except for a new section at the narrowest part of High Bents, built in 1958, most of the revetments were in poor condition in 1959.

In order to protect the river side of the spit chalk rubble was dumped on the beaches from the northern end of High Bents to the southern end of Spurn Warren. At the weakest points of the dune bank along High Bents, Cave oolite was used to buil~~t~~d artificial sections. Along the west side of the Battery Area a solid concrete protecting wall was built to protect the army battery itself.

A brief look at the beaches of Spurn Head shows that those on the seaward side of the spit can usually be divided into two parts, which will be termed the upper beach, and the lower beach. The upper beach is that part, adjacent to the dunes or cliffs, which is usually built up into a convex form in section. It is composed of sand and shingle with pebbles up to approximately 8 inches in long diameter, which appear at the surface in proportions varying in time and space. At low water no surface water is present. The lower beach extends from the bottom of the upper beach to low water mark. This part is characterized by a more gentle, even, slope, and much is covered by surface water at low water. Sand ridges and low rises of varying sizes and shapes lie slightly above the general level and are not covered by surface water at low water. The whole is composed of sand alone with the exception of a few pebbles of up to 2 inches in long diameter, which may be present occasionally. The division between upper and lower beach may be a sharp line or there may be a zone where one grades into the other.

The air photographs of September 3rd, 1959, were taken after a long calm spell during which the beaches became well built up. They will be considered in detail now as they set the scene for the period of intensive work which followed. Those on the seaward side will be described first, working south from Kilnsea to the Tip, followed by those on the river side working north from the Tip.

A well developed upper beach was a marked feature of the area north of Fort Godwin at Kilnsea. (See air photographs 9339, 9341, 9342, 9344). A large and almost continuous sand rise was present on the lower beach. The upper beach was narrow, only opposite Fort Godwin, and broadened immediately southwards to remain constant in width to groyne XXVlll. The crest of the beach (the crest of the convex form) was clearly discernible on all the broad sections of the upper beach. On the lower beach a series of generally parallel ridges, aligned south-west to north-east, were a feature. The way in which the revetment at Fort Godwin has protected the cliffs against retreat, and as a result, has caused that section to project seawards of the general line of the cliffs to the north and south is noteworthy. Where the northern section of the revetment has been breached, rapid retreat of the cliffs has taken place.

Between groynes XX and XXVlll (air photographs 9344, 9346) a well developed upper beach was present giving way to a lower beach on which but few sand rises were seen, lying oblique to the line of the dune edge, from north-west to south-east, which was at right angles to those at Fort Godwin.

Between groynes XX and XlV (air photographs 9357, 9358) almost no upper beach existed, but broad sand rises were visible on the lower beach. The southerly movement of material on the upper beach was suggested by the fact that the only remnants of the upper beach lay immediately north of the groynes in the angle they form with the revetment. Large shingle was seen near groynes XV11, XV111, and X1X showing that all the sand had been stripped off to reveal the basement of the beach.

The upper beach between groynes X1V and V111 (air photographs 9360, 9362, 9364) was a broad clearly defined feature, with the crest visible along the whole length. Between groynes X1V and X11, and again opposite the Chalk Bank large sand rises occured on the lower beach. Between them and to the South of the Chalk Bank lay concave sand ridges of varying size aligned north-west to south-east at about 45° to the angle of approach of the waves. Large shingle lay near groynes X11 and X111, and opposite the southern end of the Chalk Bank at the juncture of upper and lower beaches. The extensive development of foredune especially in the northern part of this section is noteworthy.

Between groynes V111 and 1 (air photographs 9364, 9418) the seaward projection of the section protected by groynes 1V to V111 and the revetment between them, caused the upper beach to become narrower than further north, whilst the division between upper and lower beaches remained in alignment with the section northwards. The beach crest was clearly visible. The lower beach, especially south of groyne V1 was characterized by the presence of marked elongated ridges aligned south-west to north-east oblique to the dune face.

South of groyne 1, (air photograph 9419) the beach broadened to the south-east corner of the Tip where it reached its maximum width as the neck of The Binks joined the beach. The beach narrowed to the south-west corner of the Tip whence it widened to the lifeboat house. Almost all the beach was upper beach with only a narrow tapering lower beach south of groyne 1 and another narrow one south from the south-west corner to the lifeboat house. A small sand bank extended from the end of the jetty to the lifeboat slipway.

The Inner, Middle, and Outer Binks (air photographs 9419, 9398, 9404, 9405, 9406) were clearly visible on this very low equinoxial spring tide. The smoothness of the outer, southern edge of the Inner Binks contrasted with irregularities of the other two edges which joined to give an approximately triangular outline to the bank. Well defined ridges covered the bank and in general were aligned south-east to north-west except on the southern side near the neck where the alignment was north to south. All the ridges had steep slopes facing east or north-east and gentle slopes facing west, or south-west. The Middle Binks were shown to be a less well-defined bank, and being lower, projected above the surface of the water only at two places. No pronounced features were visible on the surface. The only evidence of the Outer Binks was in a few patches of breaking waves east of the Middle Binks.

From the lifeboat house to the long boom (air photographs 9418, 9416) only a very narrow upper beach existed reaching its broadest development between the lifeboat cottages and the boom. The broad expanse of lower beach bore a distinctive series of elongated sand ridges, concave southwards and generally symmetrical in section. The boom interrupted this development slightly, but four well-marked ridges lay north of it.

From north of the long boom to the northern end of South Spurn on the river side of the spit (air photographs 9416,9415,9413) a narrow upper beach, was present with a number of ridges on it near the edge of the dunes. In the centre of this section the beach broadened and a series of long sand ridges extended from the shore into the area covered by estuarine mud which first appeared north of the boom. Opposite the northern end of the Chalk Bank where the channel draining the low marshy area west of the Chalk Bank winds out into the river, the beach broadened and splayed out into a series of ridges. This is the most northerly point on the river side to which sand and fine shingle was carried in large quantities. The bank of Old Den (air photographs 9387, 9386, 9384) formed a broad expanse of shingle exposed at low water. The highest part lay on the west in an almost unbroken ridge. East of this lay a series of drainage channels parallel to the shore, with a major one culminating northwards in a delta formation. One channel led away from the shore towards the southern end of the bank, and another flowed westwards across the northern end.

Finally the river sides of High Bents and Kilnsea Warren are considered, (air photographs 9412, 9411, 9410, 9409, 9378). Throughout the whole section the beach, again an upper beach, was narrow. The artificially dumped chalk rubble can be seen as far north as opposite groyne XV11. North of this, the beach widened slightly to fill in an angle in the dune face, then continued as a narrow strip flanking the dunes. Ridges of mud extended at right angles from the beach in the south of the section, but a smooth expanse of mud adjoined the beach elsewhere and was dissected only by a series of fine parallel channels. In the mud, close to the beach in the northern part the Cord-grass (Spartina townsendii) can be seen.

Beach material

Mention has been made of the appearance of varying sizes of pebbles on the upper beach on the seaward side of the spit, and on the narrow beach on the river side. Sand, however, is present on all parts of all the beaches. In order to ascertain in general terms the variation in coarseness, samples were taken and analyzed. As all but five samples were taken on 21st December, 1961, they are strictly comparable with each other, although it must be realized that the distribution of particle size varies with meteorological conditions, and there may be a marked change from season to season. (It was not possible to collect samples from the lower beach at Point E on the seaward side on 21st December, 1961, as none was present, owing to the boulder clay beach platform being exposed throughout. A complete set of five samples were taken on 5th April, 1962, when sand was again present, on all parts of the beach).

The lines along which samples were taken were those along which profiles were surveyed in the year's programme of observations from April 1960 to April 1961, with the addition of: i. A line 5oo feet east of the jetty, east of the lifeboat house. ii. A line from Point B Riverside, opposite Point B Seaside. iii. A line from Point E Riverside, opposite Point E Seaside. iv. A line through the breached revetment at Kilnsea. The sand was taken from the top six inches of the beach.

An anlysis of the results obtained from sieving the samples is shown graphically in figure 1.3., and Table 1.1. shows median grain sizes. The samples were each dry sieved on an electric sieving machine for 15 minutes through British Sandard Sieves sizes 8, 10, 30, 60, 90, 120, and 200.

Certain generalizations about grain size may be made. In the upper beach zone the coarsest material is found at the crest, that near the dunes being a little finer, but not as fine as at the

Table 1.1.

Median Grain Sizes of Sand Samples

21st December 1961		5th April, 1962	
Point	Median Size in Mms.	Point	Median Size in Mms.
Point A		Point E Seaside	
A1	0.175	ES1	0.175
A2	0.190	ES2	0.215
A3	0.160	ES3	0.240
		ES4	0.145
		ES5	0.135
Point B Seaside			
BS1	0.180		
BS2	0.165		
BS3	0.170		
BS4	0.135		
BS5	0.125		
Point C			
C1	0.160		
C2	0.235		
C3	0.160		
C4	0.145		
C5	0.155		
Point E Seaside			
ES1	0.195		
ES2	0.235		
ES3	0.155		
Kilnsea			
K1	0.310		
K2	0.265		
K4	0.200		
K5	0.270		
East of Lifeboat			
L1	0.170		
L2	0.230		
L3	0.170		
Point B Riverside			
BR2	0.205		
BR4	0.175		
BR5	0.155		
Point I			
I1	0.215		
I2	0.210		
Point E Riverside			
ER2	0.310		

Key to Numbers Appended to Points

1. Top of Upper Beach
2. Crest of Upper Beach
3. Bottom of Upper Beach

} or "Beach" where upper & lower divisions absent

4. Middle of Lower Beach
5. Low Water Mark

Condition of Beach at East Point

A. Smooth convex beach
BS. Upper grading imperceptibly into lower beach.
C. Upper grading imperceptibly into Lower beach.
ES. (21.12.61) Markedly convex upper beach. (5.4.62) Upper grading imperceptibly into lower beach.
K. Upper grading imperceptibly into lower beach. Upper rebuilding after complete removal.
L. Smooth, slightly convex beach.
BR. Narrow upper and broad lower beach.
I. Narrow smooth beach
ES. Narrow evenly-sloping beach.

bottom of the upper beach. The material of the lower beach is finer than that of the upper beach, and there is no great variation between the middle and lower parts of it. There is no marked grading in sediment size along the seaward side of the spit, nor is there a marked variation between the seaward side and the river side, if the beach at the northern end of the latter is equated with the upper beach of the former. It is noteworthy that the median grain size at the top of the upper beach at Kilnsea was the same as that in the middle of the beach at Point E on the riverside, on the day of the sampling, and also that the highest percentage of material of less than 0.076 mms diameter was found at low water mark at the point east of the lifeboat house, followed by that at low water mark at Point B on the seaward side.

The ranges in median grain size within the different zones across the beach were as follows:

1. The top of the upper beach	0.160 - 0.310 mms
2. The crest of the upper beach	0.165 - 0.310 mms
3. The bottom of the upper beach	0.155 - 0.240 mms
4. The middle of the lower beach	0.135 - 0.200 mms
5. The bottom of the lower beach	0.125 - 0.270 mms

CHAPTER 2

A Year's Observations of Beach Change. April 1960 - April 1961

No detailed observations had been made on the beaches of Spurn Head before this project was begun, and the only records available were two sets of air photographs, one from the R.A.F. survey in 1946, and the other from the survey carried out for the University of Hull, Department of Geography in September, 1959, which give a picture of the beaches on two specific days.

Even the most cursory glances at the beaches, over a short period of time, show that they are changing, often markedly within the space of only a few tides, or even one. The key to the understanding of the development of the spit obviously lies in part in these day to day changes, and the cycles of which they may form a part.

The first problem was how to record these changes in the most comprehensive and useful way, and three months of experimentation preceeded the detailed programme which was begun in April 1960 and ran for one year. The profile of the beach was surveyed from datum posts on the edge of the dunes on both seaward and river sides of the spit. Whilst this gave accurate measurements of vertical changes, it was felt that a broader picture was required. Mapping of the beach morphology, together with the recording of variations in beach material was carried out on either side of the profile lines each time they were surveyed. Thus a three dimensional record was obtained.

This method of recording observations was tried at nine points round the spit. These were spaced at half mile intervals along the seaward side, and three were placed on the riverside in positions which avoided the sections which were strengthened by chalk rubble on the beach. Two periods of low water were required for each complete survey. After three months it was apparent that fewer points, if carefully selected from the nine, would give almost as good a record of the changes, which varied rather between different sections of the spit, than between individual points, at any one time. Point A was selected as representative of the Tip, Point C of the straight seaward side of South Spurn and the southern part of High Bents, Point E of the north-east facing seaward side of Kilnsea Warren and the northern part of High Bents, and Point I of the only section of the riverside of the spit where changes are clearly visible from week to week, and are not masked by the presence of chalk rubble. In July, 1960, it was decided to add Point B where the straight seaward side of the South Spurn nears the Tip and where the presence of the Middle and Outer Binks offshire might have effect. The position of these five Points is shown in Figure 1.2. The heights of the datum levels used at each were as follows, in relation to Ordnance Datum at Newlyn:-

Point A	17.45 feet
Point B	15.28 feet
Point C	14.33 feet
Point E	22.53 feet
Point I	16.10 feet

The main advantage of having five as opposed to nine observation points was that all could be surveyed during one low water period and therefore the records at each Point were strictly comparable with each other Point at a given date.

Whilst change takes place day by day it is obviously impractical to survey so frequently except under special circumstances when rapid change is occuring. Fortnightly surveys, which were tried at first, proved to be too far apart as frequently several different phases of build up and erosion occured between surveys and the effects became superimposed on each other, making the sequence of events difficult to decipher. About a week was found to be a more reasonable interval of time. During the main programme of observations therefore, surveys were carried out at as near seven day intervals as possible. During the winter months with short hours of daylight alternate intervals of ten and five days were necessary to obtain a coincidence between a period of low water and daylight. Further irregularities were caused by bad weather conditions when surveying was impossible. Every six weeks the morphology of all the Spurn beaches was mapped. This was done either the day before or the day after the main weekly observations had been taken.

A simultaneous record of the elements causing or affecting beach change was of vital importance to the analysis of the data obtained by surveying the beaches.

The Coastguard Station at Spurn Head collects weather data for the Meteorological Office and it was possible to obtain three-hourly records of wind speed and direction throughout the period of observations.

No wave recorder is sited near Spurn and it was not possible to insert one, therefore observations were made from the beach at the time of each survey. Wave height at breaker point was obtained by noting the difference in height between wave crest and trough at a groyne. Wave period was calculated from the number of waves passing a given point in three minutes. Wave direction was obtained by taking a compass bearing along the wave crests and calculating direction of approach from this. Whether the waves were of a spilling or plunging type was noted also.

The nearest tide gauge to Spurn is at Immingham, and access to the records for the year was obtained. These were corrected for both time and height for Spurn Head, according to the conversion table in the Admiralty Tide Tables. Details of the predicted tides were obtained from the Admiralty Tide Tables, for purposes of comparison.

Tidal streams are of importance only around the Tip of Spurn and they will be considered separately in Chapter 5.

In an attempt to show both beach change and the elements causing and affecting this, a series of composite diagrams was devised (see Figure 2.1). The continuous wind and tide records are shown at the bottom, and above these the beach and wave observations made on dates indicated beneath the wind records. The amount of loss and gain of material was obtained by superimposing the set of beach profiles on the previous week's, and to avoid difficulties of calculating amounts when the vertical exaggeration had to be taken into account, they were plotted in this form. The beach morphology maps Figure 2.2 are shown in weekly sets together with a wind rose for the preceeding period, which shows any marked trends which appeared in wind speed and direction. Figure 2.3 consists of the sets of six-weekly beach feature plans of the whole of the spit.

The remainder of this chapter is devoted to a description and preliminary analysis of all the data collected from April, 1960, to April 1961. Each set of observations will be considered separately, and in the correct time sequence. A description of the wind conditions since the last observations, details of the wave data obtained on the day of observations, and a note of the position of the tides in the tidal cycle will be given first, followed by a description of the beach conditions. Within this latter section a general assessment of the type of change which has occured since the previous observations will be made first, then the beach morphology and finally the movement of material will be discussed. Every six to eight weeks when a complete morphological survey of the beach was made, a paragraph describing the conditions then observed will be inserted.

It should be noted that deep water wave energy[1.] was calculated according to the formula:

$$E = 41 \, H_o{}^2 T^2$$

where E is wave energy in foot-~~panels~~ pounds per foot of wave crest per wave length

H_o is deep water wave height

T is wave period

Wave steepness is H_o/Lo, where Lo is deep water wave length. The observational data used for these calculations were taken at Point E, unless otherwise indicated, when figures were not obtained there. Waves from all the directions for which it was possible to draw wave orthogonals (Figures 3.1, 3.2, 3.3, 3.4) are shown to be least refracted when reaching Point E, in comparison with any other Point, and are farthest from the Binks, which considerably modify waves passing over them. The use of data from Point E is likely to produce the most accurate results, therefore.

13th April, 1960. (See Figures 2.1 and 2.2)

WINDS. Winds were predominantly from S., S.W., and W., with nearly half,[+] over 15 knots, from 7th to 12th April.

WAVES. Point A: T, 5 secs.; Hb, 2 feet; plunging

Point D: T, 6 secs.; Hb, 2 feet; spilling; from 160°

Deep water wave energy: 2,690 ft.-lbs. per ft. of wave crest per wave (length)

Wave steepness: .0073

(Wave energy and steepness calculated from figures for Point D)

TIDES. The tidal range was increasing in height from maximum neaps on 6th April, towards maximum springs on 13th April. The p.m. high water and low water on 12th April were depressed by 1 foot when strong W. and S.W. winds blew.

BEACH CONDITIONS. During the preceeding week the building up of the beach was predominant.

A swash bar had formed around the south-east corner of the Tip and also south from Point C. Swash bars were also a feature of the beach about Point E but they were not continuous, only appearing south of each groyne and dying out before reaching the next groyne. Where swash bars were absent there was a marked crest to the upper beach, where a swash bar had probably been smoothly incorporated. At Point I, there was an even sloping beach.

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[+] The proportion of winds over 15 knots refers only to those from the predominant direction, not to the total number recorded from all directions.

The top part[+] of the beach showed little change in profile at all. Points since the end of March, 1960 except at Point C,[*] where there was a loss. At Points A, C, and I there had been a loss of material from the bottom part of the beach except where the swash bars had developed at Points A, and C, but at Point E there had been a gain.

18th April, 1960

WINDS. Winds were predominantly from W., all of which were over 15 knots, and from N., about a quarter of which exceeded 15 knots.

WAVES. Point D: T, 7.5 secs.; Hb, 1 foot; Plunging; from 90°.

Deep water wave energy: 467ft.-lbs. per ft. of wave crest per wave length.

Wave steepness: .0016

(Wave energy and steepness calculated from figures for Point D)

TIDES. The tidal range was decreasing in height from maximum springs on 13th April towards maximum neaps on 20th April.

BEACH CONDITIONS. The beaches continued to be built up slowly.

+ For considering the movement of material, the profile is divided transversely into two approximately equal sections, which will be termed "top part", and "bottom part". These should not be confused with the two morphological units, the "upper beach", and the "lower beach".

* At Point C from April to October, 1960 100 feet of dunes is included in the top part of the profile. When movement of beach material is considered this 100 feet will be disregarded. From October 1960 to April 1961 the dunes were eroded and reduced to 40 feet from the datum. This is taken into account then.

The swash bars around the south-east corner of the Tip, and in discontinuous form about Point E had not been disturbed since the previous observations as the level of subsequent high waters had been falling. About Point C, the swash bar which previously had existed southwards, had extended north. An evenly sloping beach remained about Point I.

There was a slight lowering of the top part of the beach, by deflation probably, at Point A, but a gain at all other Points, at the top. The bottom part of the beach at all Points showed a gain of material.

25th April, 1960.

WINDS. Winds were predominantly from N., and N.E. with about a fifth over 15 knots. Lighter winds were recorded from all directions.

WAVES. Point A: T, 5 secs.; Hb, 0.5 ft.; Spilling

Point D: T,7.5 secs.; Hb, 2.5 ft.; Spilling; from 100°

Deep water wave energy: 8,760ft.-lbs. per ft. of wave crest per wave length.

Wave steepness: .0068

(Wave energy and steepness calculated from figures for Point D).

TIDES. The tidal range was increasing from maximum neaps on 20th April, towards maximum springs on 25th April.

BEACH CONDITIONS. The beaches were built up slightly more in the preceeding period.

The upper beach had a marked crest about Points A, C, and E. The previously developed swash bars had been completely obliterated on the high spring tides. The beach continued to have an even slope about Point I.

The top parts of the beach at Points A, C, and E showed a slight gain of material whilst there was no change at Point I. There was a loss from the bottom part of the beach at allPoints.

4th May, 1960.

WINDS. The winds were predominantly from N. and N.E., with about a tenth over 15 knots.

WAVES. Point A: T, 3 secs.; Hb, 0.5 foot; Plunging

Point C: T, 8.5 secs.; Hb, 1 foot; Plunging

Point D: T, 8.5 secs.; Hb, 1 foot; Plunging

Point E: T, 8.5 secs.; Hb, 2 feet; Plunging

Point I: T, 2.5 secs.; Hb, 0.5 foot; Spilling

Deep water wave energy: 3,585 ft.-lbs. per ft. of wave crest per wave length.

Wave steepness: .0030

TIDES. The tidal range was decreasing from maximum springs on 25th April to maximum neaps on 5th May.

BEACH CONDITIONS. The building up of the beaches continued during this period.

Around the Tip and about Point C the beach had a double crest. The upper one was built on the preceeding spring tides and since then had been left undisturbed by the tides which were decreasing in range; the lower crest was formed subsequently. At Point E a single crest was found in a lower position than that observed on 25th April and therefore built subsequently. At Point I a smooth slope remained.

On the upper parts of the beach at Points A, C, and I the level of the profile was raised, but at Point E it was lowered. The lower parts of the beach at Points A and I showed a gain of material, whilst Points C and E showed a loss.

12th May, 1960.

(Observations between 11th and 13th May, owing to rain and strong winds)

WINDS. The winds were predominantly E. and S.E., with a third over 15 knots.

WAVES. Point C (11th May): T, 5 secs.; Hb, 1.5 feet; Spilling; from 115°

Point E (13th May): T, 6.6 secs.; Hb, 3 feet; Spilling; from 90°

Deep water wave energy: 8,650 ft.-lbs. per ft. of wave crest per wave length.

Wave steepness: .0099

TIDES. The tidal range was increasing from maximum neaps on 5th May to maximum springs on 13th May. Between 12th and 13th May the heights of high and low waters were depressed up to 1.5 feet as strong S. and S.W. winds blew.

BEACH CONDITIONS. There was a slight lowering of the beach about most Points.

Discontinuous crests had formed on the upper beach near Points A, C, and E; where they were missing the upper beach consisted of an even slope from the edge of the dunes, except east of Point A where the beach had been eroded. The edge of the erosion was marked by a two feet high cliff in the beach, facing seawards. About Point I again the beach was of an even slope. Near the junction of the upper and lower beaches, at Point C, large pebbles (over 6 inches long diameter) which form the base of the beach were exposed, and below these on the lower beach were elongated sand rises. South of Point C these gave way to ridges of sand aligned north-west to south-east and having steeper slopes to the south-west suggesting a movement of material towards the Tip. The obliquity of the ridges to the water's edge is probably due to the obliquity of approach of the waves with only partial refraction.

There was a loss of material from the top part of the beach at Points C, E, and I; and gain on the bottom part at Point C, and a loss at Points E and I. (Strong winds made it impossible to survey the profile at Point A).

COMPLETE BEACH SURVEY. 12th May, 1960 (See Figure~~s~~ 2.3)

The beach on the seaward side of the spit may be divided into three sections according to variation in form. First, from the Tip to groyne XI the upper beach had a crested convex form, with the exception of the section round the south-east of the Tip where the waves had eroded the beach and left a 2 feet high cliff. The lower beach where it was exposed from groyne 1 northwards was almost completely covered with sand ridges and hummocks, with hollows and channels between them containing water. These features were aligned obliquely to the beach, north-west to south-east. Only a few larger sand rises existed.

Secondly, from groynes X1 to XV, the upper beach was narrower than in the first section, being especially so immediately south of each groyne. With one minor exception from groyne X11 north towards groyne X111, the upper beach had an even slope, and the lower beach consisted of ~~the~~ a number of large sand rises, with few small ones.

Thirdly, from groynes XV to XXV111, the upper beach was broader and maintained an even width between groynes. It had an even slope except between groynes XX111 and XXV1. The lower beach had well defined sand rises on it; these decreased in size and number northwards.

On the riverside of the spit the beaches may similarly be divided into three sections which, in contrast to the seaward side, do not change during the year of observations. The most southerly section extends from the lifeboat house to the northern end of the Lighthouse Zone opposite groyne V111. Here a narrow upper beach was being built up in part by two swash bars. The lower beach was a broad expanse of sand, ripple marked and built into a series of long ridges concave southwards towards low water mark. The middle section extends from opposite groyne V111 to opposite groyne X1. The division into upper and lower beach is lost here as only a narrow beach is flanked on its lower side by estuarine mud. The beach is featureless except in its extreme northern part where the channel draining the low area round the Chalk Bank flows out parallel to the beach on the south. About it a number of low ridges have been built. A series of long tongues of sand project out into the estuarine mud from the beach in the centre of the section. The third and most northerly section the beach, flanked by mud, is only about 40 feet wide and shows small swash bars only opposite groynes Xvlll and XX; elsewhere it consists of an even slope from the edge of the dunes.

18th May, 1960 (see Figures 2.1 and 2.2)

WINDS. Winds were predominantly from the N., E., S.E., and S. From the first three directions about half were over 15 knots, from the south all were lighter.

WAVES. Point A: - Hb, 1 foot; Plunging

Point C: T, 5 secs.; Hb, 2.5 feet; spilling; from 130°

Point D: T, 5 secs.; Hb, 4 feet; Spilling and Plunging; from 95°

Point E: T, 5 secs.; Hb, 4 feet; Spilling; from 85°

Point I: T, 3 secs.; Hb, 1 foot; Spilling

Deep water wave energy: 14,050 ft.-lbs. per ft. of wave crest per wave length

Wave steepness: .0289

TIDES. The tidal range was decreasing from maximum springs on 13th May towards maximum neaps on 19th May.

BEACH CONDITIONS. Building up processes were predominant on the beaches.

Around the Tip and east of it, and south of Point C a swash bar had developed. The cliff facing seawards, cut in the beach before 12th May, remained up-beach of the swash bar, east of the Tip. A discontinuous swash bar existed about Point E. Where it was missing a double crest to the upper beach gave it a markedly convex profile. The lower beach about Point C was characterized by elongated sand rises, seawards of an exposure of large pebbles. About Point E, on the lower beach, large pebbles forming the base of the beach were visible in patches; elsewhere was a smooth slope of sand with surface water. About Point I, two swash bars had developed.

There was a loss of material from the top part of the beach at Point I, and markedly so at Point C, but a gain at Point E. On the bottom part of the beach there was a gain of material at Points C and I, but a slight loss near low water mark at Point C. (The profile surveyed at Point E was too short to include the lower part of the beach).

A complete morphological survey of the beaches on the seaward side of the spit was made on 18th May. Building up was a predominant process throughout, on the upper beach. Discontinuous swash bars were much in evidence alternating with crested sections of markedly convex profile. Sand ridges and rises of assorted sizes were present on the lower beach south of groyne Xll. Between groynes Xll and XV only one large sand rise existed. North of groyne XV to groyne XXVlll there were few, generally small sand rises and several patches of large pebbles.

25th May, 1960.

WINDS. Winds were predominantly from N. and N.E. with half over 15 knots, in the period from 18th to 21st May, but were predominantly from the S. and S.W. between 22nd and 24th May with a fifth over 15 knots.

WAVES. Point A: T, 4 secs.; Hb, 1 foot; Plunging

Point C: T, 10 secs; Hb, 2.5 feet; Spilling; from 105°

Point D: T, 10 secs.; Hb, 3 feet; Spilling; from 100°

Point E: T, 7.5 secs.; Hb, 3 feet; Spilling; from 80°

Deep water wave energy: 8,760 ft.-lbs. per ft. of wave crest per wave length.

Wave steepness: .0068

TIDES. The tidal range was increasing from maximum neaps on 19th May, to maximum springs on 26th May. A tidal surge occured on 24th May in connection with strong N. and N.E. winds, and raised the levels of the p.m. low water and high water by 1 foot and 1.5 feet respectively.

BEACH CONDITIONS. There was an overall build up of the beaches.

A double crest to the beach west of Point A died out at the Tip itself. A remnant of the cliff in the beach and the subsequently built swash bar east of the Tip had not been disturbed by the high spring tides. Swash bars had been built also about Point C on the upper beach except immediately south of groyne Xll1 where there was an even slope. Dis-continuous swash bars were found about Point E, south of each groyne, and the beach was markedly crested. The lower beach at Point C was again characterized by a large sand rise north of groyne Xll and elongated, divided, sand rises south. About Point E on the lower beach the boulder clay beach platform with large pebbles embedded in it had begun to emerge.

There was an overall gain of material on the top parts of the beach at all Points, and a loss from the bottom parts, except at Points A and C, where there was a gain towards low water mark.

30th May, 1960.

WINDS. The winds were variable but predominantly N. with about half over 15 knots.

WAVES. Point A: T, 3 secs.; Hb, 1 foot; Plunging

Point C: T, 6 secs.; Hb, 1.5 feet; Spilling; from 120°

Point D: T, 6 secs.; Hb, 2 feet; Plunging; from 90°

Point E: T, 6 secs.; Hb, 1.5 feet; Spilling; from 80°

Point I: - Hb, 0.25 foot; Spilling

Deep water wave energy: 2,690 ft.-lbs. per ft. of wave crest per wave length.

Wave steepness: .0073.

TIDES. The range was decreasing from maximum springs on 26th May to mqximum neaps on 3rd June.

BEACH CONDITIONS. There was no great change on the beaches during the preceeding period, but a slight build-up occurred.

West of Point A, the beach retained its double crested form and east the cliff with swash bar before it was still visible in part. About Point C a swash bar had been built up south of groyne X1 and immediately north of groyne X11, elsewhere the crest to the upper beach was etched with beach cusps, except immediately south of groyne X111 where the upper beach sloped smoothly from the cliffed dune edge. The lower beach north of groyne X11 was mainly composed of one large sand rise, but south of the groyne smaller rises were divided by water channels. A markedly convex beach was formed about Point E where a double crest was present in parts. Between groynes XX111 and XX1V the lower beach was bare of sand, and the boulder clay beach platform with large pebbles in it was exposed.

There was an overall gain of material on the top part of the beach at Points A, E, and I,but a loss at Point C. There was gain on the bottom part of the beach at Points A, C, and I, but a loss at Point E.

June 10th, 1960

WINDS. The winds were variable but predominantly from E, S.E., S., S.W., and W. They were primarily from E. and S.E. until 5th June and lighter than 15 knots. Between 5th June and 10th June they were predominantly from S, S.W., and W, with a third over 15 knots.

WAVES.	Point A:		Hb, 0.5 foot;	Plunging
	Point C:	T, 4.5 secs.;	Hb, 1 foot:	Plunging
	Point D:	T, 5 secs.;	Hb, 1 foot;	Plunging
	Point E:	T, 5 secs.;	Hb, 1 foot;	Spilling

Deep Water wave energy: 369 ft.-lbs. per ft. of wave crest per wave length

Wave steepness: .0047

TIDES. The tides were increasing in range from maximum neaps on 3rd June towards maximum springs on 12th June.

BEACH CONDITIONS. The building up of the beaches continued.

The double crested beach west of Point A retained its form, and the cliff facing seawards, east of Point A, formed prior to the last observations, remained. A swash bar which had been previously built a little lower down the beach had been extended northwards. Well developed swash bars were a feature of the upper beach at all the other observation Points. About Point C, their crests were etched by beach cusps. The lower beach at Point C retained the same form as at the time of the previous observations. Boulder clay containing large pebbles was still exposed on the lower beach at Point E, although an elongated sand ridge had formed near low water mark, south of the Point itself.

There had been a gain of material on the top part of the beach at Points C, E, and I, but a slight loss at A. There was an overall gain of material on the bottom part of the beach at Points A and C, with a slight loss near low water mark at C; at Point E a slight loss was counter balanced by a slight gain; and there was a very slight loss at Point I.

June 15th 1960.

WINDS. The winds were predominantly from W. with 1/3 over 15 knots.

WAVES. Point A: T, 4 secs.; Hb, 0.5 foot; Plunging

Point C: - Hb, 1 foot; Spilling

Point D: T, 6.6 secs.; Hb, 1 foot; Plunging

Point E: T, 6 secs.; Hb, 1 foot; Spilling

Point I: T, 2.5 secs.; Hb, 0.1 foot; Spilling

Deep water wave energy: 447 ft.-lbs. per foot of wave crest per wave length.

Wave steepness: .0030

TIDES. The tidal range was decreasing from maximum springs on 12th June to maximum neaps on 19th June.

BEACH CONDITIONS. The building up of the beaches continued.

West of Point A the beach showed only a single crest. Eastwards, the cliff facing seawards remained with the swash bar below it. Discontinuous swash bars were present about Points C and E. Where they were absent a markedly convex profile existed, except immediately south of groyne X11l again. The features on the lower beach were similar to those at the previous time of observations, although the sand rises were more extensive south of groyne X1l. A little boulder clay with large pebbles was exposed about Point E on the lower beach. Elsewhere sand with surface water was featureless. Two well defined swash bars had developed about Point I.

Material was added to the top part of the beach at Points A, C, and I and there was little change at Point E. There was an overall gain of material on the bottom part of the beach at all Points.

23rd June, 1960

WINDS. Variable winds, lighter than 15 knots except at three observation times were recorded. Winds from S.E., and W. were most frequent.

WAVES. Point A: T, 5 secs.; Hb, 1.5 feet; Plunging

Point C: T, 5 secs.; Hb, 2 feet; Spilling

Point D: T, 5 secs.; Hb, 2.5 feet; Plunging; from 115°

Point E: T, 5 secs.; Hb, 2.5 feet; Spilling

Deep water wave energy: 6,400 ft.-lbs per ft. of wave crest per wave length

Wave steepness: .0195

TIDES. The tides were increasing in range from the maximum neaps on 19th June towards maximum springs on 25th June.

BEACH CONDITIONS. Building up continued during this period.

West of Point A the beach had regained its double-crested form, but this soon gave way to a single crest westwards. Eastwards the small cliff with swash bar before it remained. Discontinuous swash bars remained south of Point C and about Point E on the upper beach. Beach cusps etched the crests in parts. The lower beach at both Points C and E had changed but little from their condition on 15th June. The steep southward facing slopes to certain of the sand rises about Point C suggest a movement of material south along the spit. The two well defined swash bars previously developed about Point I remained.

There was little change in the profile of the top part of the beach at Points A and C, but there was a gain at Point E, and a loss at Point I. Material was lost from the bottom part of the beach at Point A, E, and I, but there was an overall gain at Point C.

29th June, 1960

WINDS. Winds were predominantly N. with half over 15 knots.

WAVES. Point A: Hb, 3 feet; Plunging

Point C: T, 10 secs.; Hb, 4 feet; Spilling; from 110°

Point D: T, 10 secs.; Hb, 4 feet, Spilling; from 110°

Point E: T, 10 secs.; Hb, 4 feet; Spilling; from 50°

Deep water wave energy: 21,700 ft.-lbs. per ft. of wave crest per wave length.

Wave steepness: .0045.

TIDES. Tides were decreasing in range from maximum springs on 25th June to maximum neaps on 3rd July. A storm surge, association with strong N.W., and N. winds on 28th and 29th June raised the heights of low water and high water about 1.5 feet above the predicted levels.

BEACH CONDITIONS. The powerful waves, coupled with a storm surge wrought considerable changes on the beaches.

All the features previously formed at Points A, C, and E were obliterated as the whole beach from the edge of dunes down to low water mark was swept over by the waves. The convex profile of the beach about Point A and north of Point E was retained, but elsewhere about Point E and at Point C the upper beach graded into the lower beach in one even slope. On the lower beach at Point C there were hints of the sand rises, and the large pebbles near the junction of upper and lower beaches remained. The boulder clay beach platform at E was buried, but some large pebbles continued to be exposed between groynes XX11 and XX111. Only the beach about Point I showed little variation from 23rd June owing to its sheltered position in the estuary.

There was a general loss of material from the beach at Points A, C, and E, the maximum loss being near the middle of the beach, and decreasing in amount both up and down the beach from there. At Point E there were gains of material near the edge of the dune and near low water mark. At Point I there were small gains of material at both top and bottom parts of the beach.

7th July, 1960 (Observations began at this date at Point B)

WINDS. Winds predominated from N. and N.W. until 1st July, and about half were over 15 knots. They were light and variable until 5th July when they became predominantly W, with over three-quarters over 15 knots.

WAVES. Point A: T, 2.5 secs.; Hb, 1.5 feet; Plunging

Point B: T, 7.5 secs.; Hb, 1 foot; Plunging

Point C: T, 7.5 secs.; Hb, 1.5 feet; Plunging

Point D: T, 7.5 secs.; Hb, 2.5 feet; Spilling; from 110°

Point E: T, 7.5 secs.; Hb, 2.5 feet; Plunging

Point I: T, 3 secs.; Hb, 0.5 feet; Spilling

Deep water wave energy: 8,760 ft.-lbs. per ft. of wave crest per wave length.

Wave steepness: .0068

TIDES. Tides were increasing in range from maximum neaps on 3rd July towards maximum springs on 11th July.

BEACH CONDITIONS. After the period of intensive combing down of the beaches, build up recommenced.

Swash bars were built up round Points A, B, C, and E, and where they were missing the upper beach had a crest, aligned with the crest of the swash bars, and suggesting that at those places they had been incorporated in the general curve of the profile. At Point B the lower beach was in the form of hummocks of sand separated by deep, water-filled hollows. The sand rises which had characterized the lower beach at Point C prior to 29th June had reformed, the only difference being that there were less divisions south of groyne X11. At Point E the lower beach consisted of a gently sloping expanse of sand with surface water. At Point I only the upper of the two previous swash bars remained.

The removal of material from the beaches continued after 29th June, before wind and wave conditions changed and build up recommenced. The removal was particularly marked from the top parts of the beach at Points C and E, and was only slight at Point A. Subsequently material began to be pushed up the beach again, and a gain ~~is~~ was seen on the lower parts of the beach at Points A and E, and very slightly at Point C. At Point I there was a loss of material from top and bottom parts of the beach.

COMPLETE BEACH SURVEY 8th July 1960 (see Figure 2.3)

The building up of the beaches was seen along the whole length of the seaward side of the spit. Discontinuous swash bars were very much in evidence and where they were missing the upper beach was crested. South of groyne X111, on the lower beach, large sand rises existed, but north of this very few were present. On the river side discontinuous swash bars were found between the southern end of the Lighthouse Zone and opposite groyne X1. Long narrow tongues of sand continued to project outwards into the estuarine mud from the beach opposite the southern end of the Chalk Bank. North of opposite groyne X1 the narrow beach was featureless except opposite groyne XV11 to XX where a swash bar was built.

14th July, 1960 (see Figures 2.1 and 2.2)

WINDS. Winds were variable, but predominantly from S, W, and N.W., of which 1/3~~rd~~ were over 15 knots.

WAVES.	Point A:	-	Hb, 0.25 foot;	plunging	
	Point B:	T, 6 secs.;	Hb, 0.5 foot;	Spilling	
	Point C:	T, 5 secs.;	Hb 1 foot;	Spilling;	from 110°

Point D: T, 5 secs.; Hb, 1 foot; Spilling; from 110°

Point E: T, 5 secs.; Hb, 1 foot; Spilling

Point I: T, 3 secs.; Hb, 0.5 foot; Spilling

Deep water wave energy: 369 foot-lbs. per ft. of wave crest per wave length.

Wave steepness: .0047

TIDES. Tides were decreasing in range from maximum springs on 11th July towards maximum neaps on 18th July.

BEACH CONDITIONS. The building up again of the beach, begun before 7th July, continued up to 14th July.

West of Point A the beach had a markedly convex profile. From slightly west of that Point to north of Point B a continuous swash bar had been built; the same beach form was found on the upper beach about Point E. About Point C, except immediately south of groyne X111, the upper beach had a marked crest, and the lower beach displayed large, but more broken sand rises than on 7th July. The lower beach at Point E showed an even slope of sand with surface water. At Point I the swash bar close to the dune edge remained.

The top and bottom parts of the beach at all points showed an overall gain of material, except at Point I where there was no change.

20th July, 1960.

WINDS. Winds were predominantly from S., S.W., and W., with 1/6 over

15 knots until 19th July. Then winds veered to the north and became over 15 knots.

WAVES. Point A: T, 2.5 sec.; Hb, 0.5 foot; Plunging

Point B: T, 6 secs.; Hb, 1 foot; Plunging

Point C: T, 6 secs.; Hb, 1 foot; Spilling and Plunging

Point D: T, 6 secs.; Hb, 1.5 feet; Spilling; from 105°

Point E: T, 6 secs.; Hb, 1.5 feet; Spilling

Deep water wave energy: 2,690 ft.-lbs. per ft. of wave crest per wave length.

Wave steepness: .0073

TIDES. The range was increasing from maximum neaps on 18th July towards maximum springs on 26th July.

BEACH CONDITIONS. The building up of the beach by the pushing of material upwards continued.

At least one swash bar existed about all Points. There were a pair from near Point A to north of Point B, with three in one section, and two opposite Points E and I. The upper swash bars, where a series existed, represented the building action of the waves when the high water mark was higher than with these neap tides. Off the south-west of the Tip material was removed, as evidenced by a low cliff facing seawards. The lower beach at Point C again had large discontinuous sand rises on it, and the large pebbles at the junction of upper and lower beach were being partially buried by sand. The lower beach at Point E remained featureless.

There was a general building up of the beach in the top and middle sections except at Point C, and a slight lowering of the bottom section as material was taken from there and pushed up the beach. Only at Point I was there a gain on the bottom part. The profile at Point C suggests that material was removed after 14th July, but before 20th it was being replaced as a swash bar was being built up.

31st July, 1960.

WINDS. Winds were variable, but predominating from S, S.W., and W. with about 1/6 over 15 knots.

WAVES, Point~~s~~ A: T, 4 secs.; Hb, 0.5 foot; Plunging

Point B: T, 3 secs.; Hb, 0.5 foot; Plunging

Point C: T, 3 secs.; Hb, 1.0 foot; Spilling

Point E: T, 3.5 secs.; Hb, 1.5 feet; Spilling

Deep water wave energy: 1,536 ft.-lbs per ft. of wave crest per wave length.

Wave steepness: .0279

TIDES. Tides were decreasing in range from maximum springs on 26th July towards maximum neaps on 2nd August.

BEACH CONDITIONS. The building up of the beach continued, and the upper beach as a result became more convex in profile.

A marked swash bar had been built on the spring tides all around the Tip, and from east of it to north of Point B three swash bars were preserved. The fact that the highest one up the beach, was nearer the dunes than the highest observed on 20th July indicated that this later series were formed on the spring tides from 26th July onwards. About Point C, south of groyne X11 swash bars formed a feature of the upper beach as was the case at Point E, and Point I, where two were well defined. South of groyne X111 the upper beach had reverted to its even slope. The lower beach at Point C showed a similar form to the previous observations. Burial of the large pebbles by sand continued.

There was a gain of material on the top part of the beach at all Points. A loss of material immediately below the maximum gain in the swash bar, occurred at Points A and B, with a gain towards low water mark. There was a gain on the bottom part of the beach at Point C, loss at Point I, and no change at Point E.

5th August, 1960

WINDS. Winds were very variable and almost all under 15 knots.

WAVES. Point A: T, 7.5 secs.; Hb, 0.5 foot; Plunging

Point B: T, 7.5 secs.; Hb, 1 foot; Spilling; from 110°

Point C: T, 7.5 secs.; Hb, 2 feet; Spilling; from 115°

Point D: T, 8 secs.; Hb, 2.5 feet; Spilling; from 105°

Point E: T, 7.5 secs.; Hb, 2.5 feet; Spilling; from 85°

Deep water wave energy: 8,760 ft.-lbs. per ft. of wave crest per wave length.

Wave steepness: .0068

TIDES. The range was increasing from maximum neaps on 2nd August to maximum springs on 9th August.

BEACH CONDITIONS. The building up processes continued generally.

The three swash bars which previously extended from east of Point A to north of Point B had coalesced into one which was continuous with the one extending west of A. This coalescence probably was caused by the rising high water levels, pushing the lower swash bars up the beach, into the higher ones. Conditions showed little change about Points C and E on the upper beach, except that the beach south of groyne X111 had taken on a convex form again and the swash bars at Point E were slightly higher up the beach than on 31st ~~August~~ July. The lower beach at Point C consisted of a larger, continuous sand rise towards low water mark, with divided ones up-beach of it. A little of the boulder clay beach platform was exposed on the lower beach north of Point E, otherwise the lower beach consisted of an even slope of sand and small pebbles. At Point I the two swash bars remained.

There was a gain of material on the top part of the beach at Points A, B, and E, but a loss at Points C and I. The lower beach at Points A and B showed a gain, but there was a loss at Points C, E and I.

10th August 1960.

WINDS. Winds were variable and under 15 knots, but predominantly from N.E.

WAVES. Point A: T, 3 secs.; Hb, 0.5 foot; Plunging

Point B: T, 6 secs.; Hb, 0.5 foot; Spilling

Point C: - Hb, 0.5 foot; Spilling

Point D: T, 6 secs.; Hb, 0.5 foot; Spilling; from 120°

Point E: - Hb, 0.5 foot; Spilling

Deep water wave energy; 447 ft.-lbs. per ft. of wave crest per wave length

Wave steepness: .0030

TIDES. The range was decreasing from maximum springs on 9th August.

BEACH CONDITIONS. The beaches continued to be built up. The upper beach showed little variation in form from the previous observations. A continuous swash bar was built around the Tip to north of Point B, and about Points C and E on the upper beach. A pair of swash bars remained at Point I. At Point B the lower beach was composed of crescent-shaped sand hummocks. The lower beach at Point C consisted of a larger continuous sand rise than on 5th August and this was divided by channels containing water only south of groyne X1 to any great extent. The boulder clay platform seen at Point E on the lower beach previously was buried again. Large pebbles however were exposed immediately north of groyne XX111, and usually these are held in the boulder clay.

The top part of the beach at A, E and I showed an overall gain of material, but there was a slight loss at Points B and C. There was a general loss from the lower parts at Points A and B, but a gain at Points C, E and I.

18th August, 1960.

WINDS. Winds were predominantly from N. until 12th August with over $\frac{3}{4}$ over 15 knots. Between 12th and 17th August winds were predominantly from W., and N.W. with $\frac{1}{8}$ over 15 knots.

WAVES. Point A: - Hb, 0.5 foot; Plunging

Point B: T, 7.5 secs.; Hb, 1 foot; Plunging

Point C: T, 6 secs.; Hb, 1 foot; Plunging; from 130°

Point D: T, 6 secs.; Hb, 1.5 feet; Spilling & Plunging

Point E: T, 6 secs.; Hb, 1.5 feet; Spilling

Deep water wave energy: 2,690 ft.-lbs. per ft. of wave crest per wave length.

Wave steepness: .0073

TIDES. The range was increasing from maximum neaps on 16th August towards maximum springs on 24th August.

BEACH CONDITIONS. Material continued to be pushed up the beach.

A swash bar was left around the Tip and patchily about B by the previous spring tides, but elsewhere they had gently rounded the upper beach, into a convex profile. With the neap tides the lower beach was exposed at low water only at Point C. There was only a relatively small sand rise visible in comparison with 10th August. The swash bar in the middle of the beach remained at Point I. The top was completely covered by vegetation then.

At the top of the beach at all Points material was added, and this appeared to have been removed from the bottom part of the beach where there was loss from all Points, except Point I, where no change took place.

27th August, 1960.

WINDS. Winds were predominantly from the S., and S.W. and mainly under 15 knots.

WAVES. Point A: - Hb, 0.5 foot; Plunging

Point B: T, 6 secs.; Hb, 0.5 foot; Spilling; from 140°

Point C: T, 7.5 secs.; Hb, 0.5 foot; Spilling

Point E: - Hb, 0.5 foot; Spilling

Deep water wave energy: 467 ft.-lbs. per ft. of wave crest per wave length

Deep water wave steepness: .0016

(Wave energy and steepness calculated from figures from Point C)

TIDES. The range was decreasing from maximum springs on 24th August towards maximum neaps on 31st August.

BEACH CONDITIONS. **The building up of the beach continued.**

The high spring tides had built a swash bar from slightly west of Point A to north of Point B, and a second one lower down the beach around the Tip. Discontinuous swash bars were found about Point E, and the continuous one in the middle of the beach about Point I remained. At Point C the upper beach had a marked crest showing where the swash bar, of which there is a hint on the profile itself, had been absorbed into

the smooth slope. The lower beach showed again a large sand rise divided by a number of channels. The area where large pebbles were visible was much diminished. At Point E the lower beach had sand rises only round the ends of the groynes.

There was a gain of material on the top part of the beach at all Points. On the lower parts at Points A and E there was gain, but loss at Points B and C, except for a slight gain near the low water mark at the latter; there was no change at Point I.

COMPLETE BEACH SURVEY. 28th August, 1960 (see Figure 2.3)
The built up form of the beaches was shown along the whole of the seaward side of the spit. From the Tip to groyne 1X and between groynes X1V and XXV111 almost continuous swash bars were built and in the intervening section the upper beach was crested, giving a convex profile. Large sand rises were seen on the lower beach everywhere south of groyne XX1, with fewer, smaller ones north of this point.

On the riverside, swash bars were built on the western side of the Lighthouse Zone, and opposite the middle of Spurn Warren to opposite groyne X1. The broad expanse of ripple-marked sand with long curved sand ridges continued to form the lower beach opposite the Lighthouse Zone, and the tongues of sand projecting from the beach opposite the southern end of the Chalk Bank remained. The only feature interrupting the even slope to the beach west of High Bents and Kilnsea Warren was again a swash bar built south from opposite groyne XX, and terminating opposite groyne XlX.

3rd September 1960. (see Figures 2.1 and 2.2)

WINDS. Winds were variable, but predominantly from S., and S.W., with almost all recordings under 15 knots.

WAVES. Point A: - Hb, 0.5 foot; Plunging

Point B: T, 7.5 secs.; Hb, 1 foot; Spilling; from 120°

Point C: T, 8.5 secs.; Hb, 1 foot; Spilling & Plunging; from 120°

Point D: T, 10 secs.; Hb, 1.5 feet; Spilling

Point E: T, 10 secs.; Hb, 1.5 feet; Plunging; from 90°

Deep water wave energy: 3,700 ft.-lbs per ft. of wave crest per wave length.

Wave steepness: .0019

TIDES. The range was increasing from maximum neaps on 31st August towards maximum springs on 7th September.

BEACH CONDITIONS. Continued build up in parts was counter-balanced by slight erosion of the upper beach at others.

The previously built swash bars remained around the Tip, but on the eastern side there was slight erosion, the edge of which was marked by a low cliff feature. Discontinuous swash bars remained south of Point B and about Point E, and where they were missing, including the area about Point C, the upper beach had a marked crest. About groyne Xll the beach and the edge of the dunes were slightly cliffed. About Point I the beach retained an unbroken swash bar. The lower beach about Point C once again consisted of large sand rises. Large pebbles were seen only immediately south of groyne X11, About Point E the lower beach was featureless, except that some large pebbles became visible north of groyne XX111.

The top part of the beach at Points A and C showed a loss of material, but there was a gain at all the others. There was a gain of material on the lower beach at all Points except Point B where there was a slight loss.

7th September, 1960.

WINDS. Winds were predominantly from W., N.W., and N., with $\frac{1}{8}$ over 15 knots.

WAVES. Point A: - Hb, 0.25 foot; Plunging

Point B: T, 6 secs.; Hb, 0.5 foot; Spilling; from 130°

Point C; T, 6 secs.; Hb, 0.5 foot; Spilling; from 115°

Point D: T, 6 secs.; Hb, 1 foot; Spilling

Point E: T, 6 secs.; Hb, 1 foot; Spilling

Deep water wave energy: 447 ft.-lbs. per foot of wave crest per wave length

Wave steepness: .0030

TIDES. Maximum spring tides occurred on 7th September.

BEACH CONDITIONS. There was no great change from 3rd September.

The occurrence of maximum spring tides, permitted access to the Binks at low water as the neck was exposed. In the region of the neck three sets of ridges and troughs were exposed. On the south side the ridges were aligned north-east to south-west with a steeper slope to the south-east, on the north side the alignment was north to south, with the steeper slope eastwards, and on the beach north of the neck was a set of ridges aligned north-west to south-east with the steeper slope facing north-east. There was a well-developed swash bar around the Tip. Elsewhere apart from about Point I, swash bars were discontinuous but the crest of the upper beach was clearly visible. The lower beach at Point C again showed large sand rises, and large pebbles were exposed again around the end of groyne Xl. At Point E large pebbles were exposed on the lower beach near groyne XX111, and a series of crescent shaped sand rises had formed between that groyne and groyne XX11, elsewhere an even slope of sand with surface water existed.

There was generally a slight build up of the top part of the beach near high water mark, but a general loss of material below this down to near low water mark.

21st September, 1960.

WINDS. The winds were predominantly from S. with 1/5 over 15 knots until 19th September. On 19th the wind swung to N, and continued to blow strongly from this direction until 21st September, half the recordings being over 15 knots.

WAVES.	Point A:	-	Hb, 1 foot;	Plunging	
	Point B:	T, 10 secs.;	Hb, 5 feet;	Spilling;	from 110°
	Point C:	T, 10 secs.;	Hb, 4 feet;	Spilling;	from 110°
	Point D:	T, 10 secs.;	Hb, 5 feet;	Spilling;	from 100°
	Point E:	T, 12 secs.;	Hb, 5 feet;	Spilling;	from 80°

Deep water wave energy: 46,300 ft. lbs. per ft. of wave crest per wave length

Wave steepness: .0038

TIDES. The range was increasing from maximum neaps on 14th September towards maximum springs on 22nd September. Strong S. winds on 14th September caused a lowering of the p.m. high water and p.m. low water by 1.5 feet and 1 foot respectively below the predicted levels. The strong northerly winds caused a slight tidal surge on 20th September when p.m. low water was 1foot above the predicted level.

BEACH CONDITIONS. The powerful waves associated with strong northerly winds wrought considerable changes on the beaches, especially as they occurred on spring tides.

Only discontinuous swash bars existed around Point A and to the east of it and south of Point B. A crest to the upper beach existed continuously only about Point B, elsewhere it was patchy, and even slopes from the dune edge to the junction of the upper and lower beaches existed in parts near Points E and C. At Point E the upper beach was markedly narrowed as the lower beach had thrust a tongue into it, the lower beach had only a few sand rises to break its even slope, and no large pebbles were exposed. Large sand rises existed on the lower beach about Point C, but their form had been changed considerably by the powerful waves. At Point I the beach had an even slope from the dunes to the edge of the mud of the estuary.

There was a general gain of material at the top part of the beach at all Points, except Point E, where there was a considerable loss. There was a gain on the bottom part of the beach at all Points except Point C, where a slight gain was counter balanced by a slight loss.

27th September, 1960

WINDS. Winds were variable and under 15 knots after 21st September, when they were N.W. with over half over 15 knots. From 25th to 27th winds were from N., N.E. and E.

WAVES. Point A: T, 4 secs.; Hb, 1 foot; Plunging

Point B: T, 8.5 secs.; Hb, 1.5 feet; Spilling; from 100°

Point C; T, 10 secs.; Hb, 2 feet; Spilling; from 110°

Point D: T, 8.5 secs.; Hb, 3 feet; Spilling; from 105°

Point E: T, 8.5 secs.; Hb, 3 feet; Spilling; from 80°

Deep water wave energy: 9,580 ft. - lbs. per ft. of wave crest per wave length

Wave steepness: .0049

TIDES. Tides were decreasing in range from maximum springs on 22nd September towards maximum neaps on 29th September.

BEACH CONDITIONS. The beach which had been so well built up before 7th September continued to be combed down slightly during this period.

Very little building of swash bars took place, the only noteworthy one being near Point I. A crest to the beach existed in a continuous form only round the Tip, elsewhere on the upper beach it was discontinuous. Immediately north of Point C the dune face was cliffed to 4 feet. The features on the lower beach showed but little change since 21st September. At Point E on the lower beach the only features were two small sand rises at the end of groyne XX111.

There was a loss of material from the top part of the beach at all Points except A, where an overall gain occurred; there was also loss from the lower part at Points B, C and I, but a gain at Points A and E.

7th October, 1960.

WINDS. Winds were predominantly from E. and S.E. with over 2/3 over 15 knots.

WAVES. Point A: T, 4 secs.; Hb, 1 foot; Plunging

Point B: T, 8.5 secs.; Hb, 2 feet; Plunging

Point C: T, 8.5 secs.; Hb, 1 foot; Spilling; from 110°

Point D: T, 8.5 secs.; Hb, 1 foot; Spilling; from 110°

Point E: T, 8.5 secs.; Hb, 1 foot; Spilling; from 80°

Deep water wave energy: 473 ft.-lbs. per ft. of wave crest per wave length.

Wave steepness: .0011

TIDES. Tides were decreasing in range from maximum springs on 5th October towards maximum neaps on 14th October.

BEACH CONDITIONS. The break up of the stable beach forms continued at an increased rate.

Building up of the beach in the form of a swash bar took place only round the Tip and east of it, and about Point I. A crest to the upper beach existed only about Point E. There was considerable disruption to the beach forms about both Points C and E. Especially north of Point C itself the division between upper and lower beach changed considerably, and what had been separate sand rises on the lower beach, were attached to the upper beach to form a part of it and all the large pebbles were buried. Almost continuously along this section the edge of the dunes was cliffed to between 1 foot and 3 feet. At Point E the division between upper and lower beach was hard to determine. North of groyne XXlV the division was clearest, although the upper part of the lower beach consisted of sand and small and medium pebbles, and the bottom part was covered in sand with surface water. South of groyne XXlV the division between upper and lower beach could have been in either of two divisions, where the solid line or the dashed and dotted line is shown. Pebbles had been combed down the beach to the low water mark opposite

Point E itself. A few sand rises occurred south of groyne XX111 on the lower beach.

There was a slight gain of material on the top part of the beach at all Points except C, where there was a marked loss, but a gain immediately below it. There was a loss from the lower beach at Points A and C, a gain at Points B and E, and no change at Point I.

12th October, 1960.

WINDS. Winds were predominantly east until 9th October, with 1/5 over 15 knots. From 9th to 12th October the winds predominated from the N.W. to N. with 5/6 over 15 knots.

WAVES. Point A. - Hb, 1 foot; Plunging

Point B: T, 10 secs.; Hb, 7 feet; Spilling; from 100°

Point C: T, 10 secs.; Hb, 7 feet; Spilling; from 100°

Point D: T, 10 secs.; Hb, 7 feet; Spilling; from 120°

Point E: T, 10 secs.; Hb, 7 feet; Spilling; from 60°

Deep water wave energy; 100,500 ft.-lbs. per ft. of wave crest per wave length.

Wave steepness: .0097

TIDES. Tides were decreasing in range from maximum springs on 5th October to maximum neaps on 14th October. The strong north and N.W. winds caused a prolonged tidal surge fromloth to 13th October with high waters up to 1 foot, and lower waters up to 2.5 feet, above the predicted levels.

BEACH CONDITIONS. Despite the fact that this tidal surge occurred at neap tides, the large waves with a powerful swash covered most of the beaches at high water and combed material downwards.

Only immediately round Point A and south of Point I were small swash bars built, where there was protection from the long and high waves from the north and north-west. Elsewhere the beach was smoothed over from dune edge to low water mark, and a crest was left only about Point E on the upper beach. There was increased cliffing of the dune face about Point C. No features were formed on the small part of the lower beach which was visible about Point C and at Point E. At the latter Point, as on the 7th October, the lower beach was composed of sand and shingle with surface water, rather than sand alone as had been the case previously.

There was a slight overall loss from the top part of the beach at all Points, except Point I where there was no change; but a greater loss occurred from the bottom part, where the waves had a more powerful effect, except at Point A where there was a gain.

21st October, 1960.

WINDS. From the 12th to 14th October winds were predominantly from N.W. with $\frac{3}{4}$ over 15 knots. For the remainder of the period winds from N.E., E, and S.E., and S. predominated with nearly half over 15 knots.

WAVES. Point A: - Hb, 0.5 foot; Plunging

Point B: T, 7.5 secs.; Hb, 1 foot; Spilling; from 105°

Point C: T, 7.5 secs.; Hb, 3 feet; Spilling; from 110°

Point D: T, 7.5 secs.; Hb, 3 feet; Spilling; from 120°

Point E: T, 7.5 secs.; Hb, 3 feet; Spilling; from 90°

Deep water wave energy: 46,300 ft.-lbs. per ft. of wave crest per wave length

Wave steepness: .0038

TIDES. Tides were decreasing from maximum neaps on 14th October towards maximum springs on 22nd October.

BEACH CONDITIONS. The beaches underwent considerable changes in the period following 12th October.

Around the Tip to south of Point B, near groyne III a swash bar was built up, as also happened about Point I. About Point C an especially noteworthy change had occurred. From midway between groynes XIII and XII to Point C itself the upper and lower beaches ceased to exist as separate entities, and a smooth slope from the then more cliffed dune face to low water mark took their place, and showed little variation in beach material. About Point E two examples of a beach form, which is seen usually only after stormy conditions, had developed. The feature is a tongue of material which usually composes the upper beach, namely sand with a high proportion of pebbles of assorted sizes, which juts out into the lower beach southwards at a low angle. After several tides the feature is pushed dunewards and becomes absorbed into the upper beach. It seems most probable that this is one form in which a mass of material is moved laterally along the spit.

There was a marked loss of material from the top part of the beach especially at Point C, but also at Points B and E; and a gain at Points A and I. On the lower part of the beach at Point A, after a loss in the middle section, there was a gain, as also occurred at Points E and I. (The storm surge on the day of the previous observations permitted only short profiles to be surveyed, so that it was not possible to compare the lower parts of the profiles surveyed at Points B, C and E on 21st October, with those on 12th October).

COMPLETE BEACH SURVEY. 22nd October, 1960. (see Figure 2.3)

After the destructive action of the powerful waves drives by strong N.W. and N. winds from 9th to 14th October, build up was resumed. Along the seaward side of the spit, there had been only slight and discontinuous development of swash bars except from Point A to groyne III. At most other places a crest had been formed high up the upper beach. It is noteworthy, that whereas, previously the upper beach between groynes X11 and XV had been narrower than the beaches to the north and south, on 22nd October the width between groynes X11 and XV equalled that to the north, and south of groyne X11 the true upper beach had been removed and only a flat featureless expanse of sand remained from the dune edge to low water mark. In other words the low section of beach had moved southwards. The long tongues of sand and pebbles jutting out from the upper beach at a low angle immediately north of groynes XX11 and XXV have been commented upon in the preceeding section on Beach Conditions. A similar feature was seen north of groyne X11 and it was this which built the narrow upper beach outwards. On the lower beach south of groyne X1 many small irregular sand rises were seen. Between groynes X111 and XX1 large sand rises existed on the lower beach, but north of this the lower beach was featureless with only one exception.

On the riverside swash bars were again built up west of the Lighthouse Zone, discontinuously west of the Chalk Bank Area, and opposite groynes XV111 to X1X. Elsewhere the beach possessed an even slope. A surface layer of mud had been deposited on the lower beach west of the Lighthouse Zone, but sand ridges protruded through it towards low water mark. The long projections of sand remained west of the south end of the Chalk Bank.

26th October, 1960 (see Figures 2.1 and 2.2)

WINDS. Winds were predominantly from E., S.E., and S. with about 1/7 over 15 knots.

WAVES. Point A: T, 6 secs.; Hb, 0.5 foot; Plunging

Point C: - Hb, 2 feet; Spilling

Point D: T, 8.5 secs.; Hb, 3 feet; Spilling; from 120°

Point E: T, 7.5 secs.; Hb, 3 feet; Spilling; from 85°

Deep water wave energy: 8,760 ft.-lbs. per ft. of wave crest per wave length.

Wave steepness: .0068

TIDES. The tidal range was decreasing from maximum springs on 22nd October towards maximum neaps on 28th October.

BEACH CONDITIONS. Under the less stormy conditions the beach forms became more stabilized.

The swash bar previously built around the Tip remained near Point A, although it was obliterated north-eastwards from the Tip, where the beach showed a convex form with a marked crest. The swash bar about Point I remained and new discontinuous ones had formed about Point E, where upper and lower beach were once again well defined. About Point C the broad expanse of sand with only a few pebbles, sloping evenly from the dunes to low water mark remained. Sand with surface water appeared only on the lowest part. There was increased erosion of the dune face immediately south of groyne Xll.

There was a loss of material from the top part of the beach at Points A, C, and I but a gain at Point E, followed by a loss in the middle part. There was a gain on the bottom part of the beach at Points C, E and I, but a loss from Point A. (Torrential rain and bad light stopped observations being made at Point B)

4th November, 1960.

WINDS. Winds were variable, but predominantly E. with under half over 15 knots, between 26th and 29th October. From 30th October to 4th November winds were predominantly from the S. and S.W. with over half over 15 knots.

WAVES. Point A: - Hb, 1 foot; Plunging

Point B: T, 6.6 secs.; Hb, 1 foot; Spilling

Point C: T, 6 secs.; Hb, 1.5 feet; Spilling

Point D: T, 6.6 secs.; Hb, 2 feet; Spilling

Point E: T, 6.6 secs.; Hb, 2 feet; Spilling

Deep water wave energy: 2,790 ft.-lbs per ft. of wave crest per wave length

Wave steepness: .0056

TIDES. The range was increasing from maximum neaps on 28th October, to maximum springs on 4th November. On 2nd November low water was 2.5 feet below the predicted level, and the a.m. high water was 1.5 feet, and the p.m. high water was 2 feet below. This coincided with strong south and south-west winds, which reached 30 knots at their strongest.

BEACH CONDITIONS. The beach continued to develop a more stabilized, built up form.

The swash bar development around the Tip was disrupted by the strong onshore winds which caused some erosion there. About Point B however the beach had a well-rounded form with a crest to the upper beach.

Discontinuous swash bars were seen at Points E and I. At the former, the lower beach was featureless except for a low sand rise at the end of groyne XX111. The smooth evenly sloping expanse of sand about Point C remained, although it was possible to distinguish again the upper and lower beaches north of groyne X11 and south of groyne X1.. The high spring tides gave the waves ample~~s~~ opportunity to cut the cliff in the face of dunes, even further back.

There was a loss of material from the top part of the beach at Points A and I, and again at Points C and E. From the bottom part of the beach there was a loss at all Points except Point C, which showed a slight gain.

9th November, 1960.

WINDS. Winds were predominantly from N.W., and N. with a quarter over 15 knots.

WAVES. Point A: - Hb, 0.5 foot; Plunging

Point B: T, 10 secs.; Hb, 0.5 foot; Plunging

Point C: T, 10 secs.; Hb, 0.5 foot; Spilling; from 125°

Point D: T, 7.5 secs.; Hb, 1 foot; Spilling and Plunging; from 115°

Point E: T, 8.5 secs.; Hb, 1 foot; Spilling

Deep water wave energy: 473 ft.-lbs per ft. of wave crest per wave length

Wave steepness: .0011

TIDES. The range was decreasing from maximum springs on 4th November to maximum neaps on 12th November. A tidal surge on 5th and 6th November raised the high waters between 1 foot and 1.5 feet above the predicted levels.

BEACH CONDITIONS. There was again slight building up of the beaches.

At all Points except C there was a clear crest to the beach although swash bars were to be found only west of Point A and south of Point I. The conditions at Point C were similar to those on 4th November, although it was again impossible to distinguish upper and lower beaches north of groyne X11. The lower beach at Point E was again featureless.

There was a gain of material on the top part of the beach at all Points except Point C where there was a loss, and there was an overall gain on the bottom part of the beach at all Points except Point E, where there was a loss.

18th November, 1960.

WINDS. Winds were almost entirely from S., and S.W. with about half over 15 knots.

WAVES.	Point A:	-	Hb, 0.5 foot;	Plunging	
	Point B:	T, 6.6 secs.;	Hb, 1.5 feet;	Plunging;	from 125°
	Point C:	T, 6.6 secs.;	Hb, 0.5 foot;	Spilling	
	Point D:	T, 6.6 secs.;	Hb, 3 feet;	Spilling;	from 110°
	Point E:	T, 6.6 secs.;	Hb, 1 foot;	Plunging	

Point I: T, 3.5 secs.; Hb, 0.25 foot; Plunging

Deep water wave energy: 447 ft.-lbs per foot of wave crest per wave length

Wave steepness: .0022

TIDES. The tides were increasing in range from maximum neaps on 12th November towards maximum springs on20th November.

BEACH CONDITIONS. The preceeding period was again one of building up of the beaches.

Almost continuous swash bars were built at all Points except Point C where conditions were almost identical to those existing previously, on 9th November. The lower beach about Point E had only two small sand rises around the ends of groynes XX111 and XX1V.

The top part of the beach gained material at all Points except Point A, where a slight gain was counter-balanced by a slight loss. There was a loss from the bottom part of the beach at Points, A, C, and E, a slight gain at Point B, and no change at Point I.

23rd November, 1960

WINDS. Winds were variable and almost all under 15 knots, but with a predominance from S, and W.

WAVES. Point B: T, 7.5 secs.; Hb, 2 feet; Spilling; from 120°

Point C: T, 7.5 secs.; Hb, 2 feet; Spilling

Point D: T, 7.5 secs.; Hb, 2 feet; Spilling; from 100°

Point E: T, 7.5 secs.; Hb, 2 feet; Plunging

Deep water wave energy: 3,325 ft.-lbs. per ft. of wave crest per wave length.

Wave steepness: .0042.

TIDES. The tidal range was decreasing from maximum springs on 20th November towards maximum neaps 27th November.

BEACH CONDITIONS. (It was impossible to survey profiles due to heavy rain). The building up of the beach continued, with swash bars around all Points except Point C where the evenly sloping beach from dunes to lower water mark continued to exist. There was a broader strip of sand with surface water towards low water mark than on 18th November, and the upper and lower beaches were distinguishable north of groyne X11. The lower beach about Point C showed little change.

30th November, 1960.

WINDS. Winds were predominantly from W., S.W., and S. with under a third over 15 knots.

WAVES.	Point A:	-	Hb, 1 foot;	Plunging	
	Point B:	T, 10 secs.;	Hb, 1 foot;	Spilling	
	Point C:	T, 8.5 secs.;	Hb, 1 foot;	Spilling;	from 120°
	Point D:	T, 10 secs.;	Hb, 1 foot;	Spilling;	from 110°
	Point E:	T, 10 secs.;	Hb, 1 foot;	Spilling	

Depp water wave energy: 656 ft.-lbs per ft. of wave crest per wave length

Wave steepness: .0008

TIDES. The tides were increasing in range from maximum neaps on 27th November towards maximum springs on 3rd December.

BEACH CONDITIONS. The beaches were further built up in this period.

Swash bars were built around the Tip, at Point I, and on the upper beach at Point E, there being no change on the lower beach there. About Point B, an even slope from dunes to low water mark existed as at Point C, but there was a marked variation in angle of slope as can be seen on the profiles.

Since 18th November there had been a gain in material at the top of the beach at all Points, and also on the bottom part of the beach at Points A, B and C, but there was loss from Points E and I.

7th December, 1960

WINDS. Winds were predominantly from W., S., and S.W. with 3/5 over 15 knots.

WAVES. Point A: - Hb, 1 foot; Plunging

Point B: T, 8.5 secs.; Hb, 2.5 feet; Spilling; from 115°

Point C: T, 10 secs.; Hb, 3 feet; Spilling; from 110°

Point D: T, 8.5 secs.; Hb, 3.5 feet; Spilling; from 110°

Point E: T, 6.6 secs.; Hb, 3.5 feet; Spilling; from 80°

Deep water wave energy: 18,300 ft.-lbs. per ft. of wave crest per wave length.

Wave steepness: .0144

TIDES. The range was decreasing from maximum springs on 3rd December towards maximum neaps on 12th December.

BEACH CONDITIONS. A slow building up process continued.

The form of the beaches was similar to that on 30th November, but the swash bar around the Tip had been obliterated by the spring tides, although a crest was marked. At Point I also, the swash bar no longer existed as a continuous feature and there a smooth, even slope had taken its place, except about the profile line, where a small swash bar remained.

There was a loss of material from the top part of the beach at Points A and B, but a gain at Points C,E, and I. Loss from the lower part of the beach occurred at Points B, C, and E, there was a gain at Point I, and loss and gain cancelled each other out at Point A.

17th December, 1960.

WINDS. Winds were variable, but predominantly from E. and N.E., with a third over 15 knots.

WAVES.	Point A:	-	Hb, 0.5 foot;	Plunging
	Point B:	-	Hb, 0.5 foot;	Spilling
	Point C:	-	Hb, 0.5 foot;	Plunging
	Point D;	T,4.3 secs.;	Hb, 0.5 foot;	Plunging
	Point E:	-	Hb, 0.5 foot;	Plunging

Deep water wave energy: 321 ft.-lbs. per ft. of wave crest per wave length

Wave steepness: .0086

(Wave energy and steepness calculated from figures from Point D)

TIDES. The range was increasing from maximum neaps on 12th December towards maximum springs on 20th December.

BEACH CONDITIONS. Again building-up processes predominated.

There had been a period of erosion early in the period and probably associated with the strong winds from between E. and N. which blew from 9th to 11th December. The cliffing of the beach south of Point C and north of Point E gives evidence for this. After 11th December when winds became more variable building-up of the beach recommenced. A continuous swash bar was built from Point A to north of Point B, and discontinuous ones were built about Points E and I. The form of the beach about Point C showed little variation from 7th December apart from the fact that the top part had been eroded. A small feature similar to those described about Point E on 21st October had formed south of groyne X111. In this case the tongue of sand and pebbles lay in juxtaposition with the upper beach which would rapidly absorb it. The lower beach at Point E was completely featureless.

There was a slight increase in material on the top part of the profile, at all Points except Points B and I where there was slight loss. The gain would be associated with mainly quiet weather conditions and spring tides, from 7th to 9th December. There was a loss from the middle part of the beach at all Points except C and I, where there was a smallgain and no change respectively. The loss represents the effect of the strong E. to N.E. winds between 9th and 11th December with neap tides. A powerful swash to the waves would affect a larger proportion of the beach than would normally be the case with neap tides. As the tidal range began to increase after 12th December and light variable winds blew, build up began again as is shown in the gain of material on the bottom part of the beach at Points A, C, and E. There was a slight loss at Points B, and I.

22nd December, 1960

WINDS. After 17th December, winds were predominantly from N., N.W., and N.E., with over half over 15 knots.

WAVES. Point A: - Hb, 0.5 foot; Plunging

Point B: T, 8.5 secs.; Hb, 1 foot; Spilling; from 110°

Point C: T, 8.5 secs.; Hb, 3 feet; Spilling; from 120°

Point D: T, 8.5 secs.; Hb, 3 feet; Spilling; from 110°

Point E: T, 8.5 secs.; Hb, 4 feet; Spilling and Plunging; from 80°

Deep water wave energy: 21,550 ft.-lbs per ft. of wave crest per wave length

Wave steepness: .0073

TIDES. Tides were decreasing in range from maximum springs on 20th

December towards maximum neaps on 27th December. There was a slight tidal surge on 20th December when a.m. and p.m. low waters were raised 1 foot above the predicted levels, and a.m. high water 0.5 foot above.

BEACH CONDITIONS. Destructive action was of paramount importance on the beaches.

The powerful waves combed material down the beach to give a smooth and almost even slope from the dune edge to low water mark about all Points. All the beach features built during the preceeding weeks were completely obliterated. About Point C the edge of the dunes was further cut back to give a sheer 12 feet high cliff from the top of the dune crest to the beach. North of Point E a tongue of sand and pebbles jutted out from the upper beach at a low angle, as was seen there on 21st October. The lower beach at Point E remained featureless except for a small sand rise at the end of groyne XX111.

There was a marked loss of material from the top part of the beach at all Points, and also a loss from the bottom part of the beach at Points A, B, and T, there was however a considerable gain at Point C, and a small gain at Point E.

COMPLETE BEACH SURVEY 21st December, 1960 (see Figure 2.3)

The powerful waves driven by strong N.W., N., and N.E. winds had combed material down the beaches throughout the whole length of the seaward side of the spit. The upper beach was slightly crested near the edge of the dunes in a few places, but generally an even slope existed. The narrow width of the upper beach between groynes XV11 and XX is worthy of note. Many small irregular or crescent-shaped sand rises were seen on the lower beach about groyne X and between groynes XV and XV111. An uncommon formation, consisting of a large sand rise with hollows containing water scattered irregularly in it, existed between groynes XV111 and XX. Elsewhere, however, the lower beach was generally featureless, and consisted of an even slope of sand with surface water.

On the riverside the upper beach west of the Lighthouse Zone and the beach north of that were generally featureless. Only a very small swash bar existed opposite groynes XV111 and X1X. The long ridges of sand on the lower beach west of the Lighthouse Zone and those projecting from opposite the southern end of the Chalk Bank into the estuarine mud, remained.

1st January, 1961 (see Figures 2.1 and 2.2)

WINDS. Winds were predominantly from S., and S.W. under half of which were over 15 knots.

WAVES.	Point A:	-	Hb, 1 foot;	Plunging
	Point B:	-	Hb, 0.5 foot;	Spilling
	Point C:	-	Hb, 0.5 foot;	Spilling
	Point D:	T, 5 secs.;	Hb, 1 foot;	Plunging
	Point E:	T, 5 secs.;	Hb, 1 foot;	Spilling

Deep water wave energy: 369 ft.-lbs. per ft. of wave crest per wave length.

Wave steepness: .0047

TIDES. The tides were increasing in range from maximum neaps on 27th December towards maximum springs on 4th January. On 30th December both the a.m. high water and the a.m. low water were 2 feet below the predicted level. This coincided with strong southerly winds.

BEACH CONDITIONS. Building up processes recommenced in this period.

Swash bars developed only around the Tip and in a discontinuous form about Point E. Elsewhere, apart from about Point I and south of Point C where an even slope remained, the upper beach had developed a marked crest again. The general form of the beach about Point C remained the same with upper and lower sections being inseparable, except north of groyne Xll and soŭth of groyne Xl. The lower beach was exposed about Point B and low sand rises were a feature of it. The lower beach about Point E showed a slight change from 22nd December, where the tongue of sand and pebbles were then, now was only a patch of sand and pebbles with surface water, the bulk of the material having been absorbed into the upper beach.

There was a gain of material on the top part of the beach at all Points, and a loss from the bottom part at Points A, B, and C, but a gain at Points E and I.

14th January, 1961.

WINDS. Winds were predominantly from S., S.W., W., N.W., and N., with over a third over 15 knots.

WAVES. Point A: - Hb, 0.75 foot; Plunging

Point B: T, 7.5 secs.; Hb, 1.5 feet; Spilling; from 115°

Point C: T, 7.5 secs.; Hb, 1 foot; Spilling

Point D: - Hb, 1.5 feet; Spilling

Point E: T, 6 secs.; Hb, 1.5 feet; Spilling

Deep water wave energy: 2,690 ft.-lbs. per ft. of wave crest per wave length

Wave steepness: .0073

TIDES. The tidal range was increasing from maximum neaps on 11th January towards maximum springs on 19th January. The a.m. high water and the a.m. low water on 12th January were 1.5 feet and 2 feet below the predicted level, respectively. This coincided with S. to S.W. winds over 10 knots.

BEACH CONDITIONS. There was no great change in the form of the beaches during this fortnight.

There was little evidence of build up in the form of swash bars, but a crest to the beach existed in patches. Smooth and relatively even slopes existed from the dunes to low water mark about Points B, C and I, and immediately about Point E. North of groyne XII it was again impossible to distinguish the upper from the lower beach.

On the lower beach about Point E, a series of elongated sand rises had been formed.

There was a small gain of material on the top part of the beach at Points A and C, but a loss at Points E and I and no change at Point B. There was an overall gain of material on the bottom part at Points A, B, and I, but loss from Points C, and E.

19th January, 1961.

WINDS. Winds were predominantly from E. and S. with 2/5 over 15 knots.

WAVES.	Points A:	-	Hb, 1 foot;	Plunging	
	Point B:	T, 5.5 secs.;	Hb, 2 feet;	Spilling;	from 120°
	Point C:	-	Hb, 2 feet;	Spilling	
	Point D:	T, 6.6 secs.;	Hb, 3 feet;	Spilling;	from 100°
	Point E:	T, 6.6 secs.;	Hb, 3 feet;	Spilling;	from 90°

Deep water wave energy: 8,650 ft.-lbs. per ft. of wave crest per wave length

Wave steepness: .0099

TIDES. Maximum spring tides occurred on 19th January. Between 17th and 19th January both high and low waters were up to 2 feet below the predicted heights. This coincided with S. winds over 10 knots.

BEACH CONDITIONS. Slight building up of the beaches took place.

Swash bars were built east of Point A, and about Points E and I. Around Point B, from groyne I to groyne V the beach was cut into however, and also immediately north of groyne XII, north of Point C.

A smooth evenly sloping beach remained about Point C mainly with little change from the previous observations. The lower beach at Point E had again become featureless except for a small rise round the end of groyne XX111.

There was a gain of material on the top part of the beach at all Points except Point B where there was a loss, and also a gain on the bottom parts at Points B, C, and E but loss from Points A and I.

29th January, 1961

WINDS. Winds were predominantly from E. and S. with half over 15 knots.

WAVES. Point A: T, 3.5 secs.; Hb, 3 feet; Plunging

Point B: - Hb, 1 foot; Spilling

Point D: - Hb, 2.5 feet; Spilling

Point E: T, 5 secs.; Hb, 2.5 feet; Spilling

Deep water wave energy: 6,400 ft.-lbs. per ft. of wave crest per wave length

Wave steepness: .0195

TIDES. The tidal range was increasing from maximum neaps on 25th January towards maximum springs on 4th February. High and low waters on 27th January and after noon on 26th January were up to 3 feet below predicted heights. This was again coincident with strong southerly winds.

BEACH CONDITIONS. Building up of the beaches was predominant during this period.

Series of swash bars were built up around Point A, especially eastwards, and about Point E. The upper ones represented build-up on the preceding springs, and the lower ones build-up on the neap tides. A continuous swash bar had formed about Point I. West of Point A, a 3 foot cliff ~~gives~~ gave evidence of erosion near low water mark. Evidence of the previous down-cutting of the beach south of Point B, remained in the form of a concave slope to the top part of the upper beach. About Point C the beach continued to retain the same form as previously. It is noteworthy that about Point E the upper beach had been extended out to low water mark south of groyne XX1V as the build up proceeded.

There was a gain of material on the top part of the beach at all Points except Point A where there was a loss. Loss from the bottom part of the beach occurred at Points A, C, and I, and from the middle section at Point E. There was a gain on the bottom part at Points B and E.

4th February, 1961

WINDS. Winds were predominantly from S.W., W., and N.W. with half over 15 knots.

WAVES. Point A: - Hb, 2 feet; Plunging

Point B: T, 10 secs.; Hb, 2 feet; Spilling; from 110°

Point C: T, 8.5 secs.; Hb, 2 feet; Plunging; from 130°

Point D: T, 8.5 secs.; Hb, 2.5 feet; Plunging

Point E: T, 8.5 secs.; Hb, 2 feet; Plunging; from 80°

Deep water wave energy: 3,585 ft.-lbs. per ft. of wave crest per wave length

Wave steepness: .0030

TIDES. Maximum springs occurred on 4th February.

BEACH CONDITIONS. A slow build up of the beach continued during this period.

The high spring tides had obliterated most of the swash bars seen on 29th January, except for those highest up the beach about Point E, and for a short section south-east of Point A. Elsewhere, except at Points C and I the beach was generally convex in profile, with a crest clearly defined. At Point I a smooth even slope was seen, as existed again about Point C, although a low bar interrupted the evenness near low water mark south of groyne Xll. South of groyne Xlll where upper and lower beach were separate features, two sand rises had formed on the lower beach, as was seen on the lower beach about Point E.

A slight loss of material from the top part of the beach occurred at Points A, B, and I, but there was a gain at Points C and E. There was a loss from the bottom part of the beach at Points B, C, and E, but gain at Points A and I.

COMPLETE BEACH SURVEY. 3rd February, 1961 (Figure 2.3)

Most of the beach along the seaward side of the spit showed a gently rounded upper part with short discontinuous swash bars in places, but more commonly with only a crest line. Both swash bars and crests were high up the beach near the edge of the dunes as they were formed on the spring tides. The upper beach remained narrower between groynes XV11 and XX, than to the north and south. A bar was being joined to the lower part of the upper beach from south of groyne X to groyne X11. The lower beach was not exposed south of groyne X11, but north of that it contained generally large sand rises.

Almost all the beach on the riverside was of an even slope from the edge of the dunes seawards, except where a small swash bar had been built opposite groynes XV111 to XX. The sand ridges on the lower beach west of the Lighthouse Zone, and those projecting west further north remained.

13th February, 1961 (see Figures 2.1 and 2.2)

WINDS. Winds were predominantly from S.W. and W. all under 15 knots.

WAVES.

Point A:	-	Hb, 1.5 feet;	Plunging	
Point B:	T, 8.5 secs.;	Hb, 0.5 foot;	Spilling;	from 120^{o}
Point C:	T, 8.5 secs.;	Hb, 1 foot;	Spilling	
Point D:	-	Hb, 1.5 feet;	Spilling and Plunging	
Point E:	T, 5.5 secs.;	Hb, 2 feet;	Plunging	

Deep water wave energy: 2,610 ft.-lbs. per ft. of wave crest per wave length.

Wave steepness: .0090

TIDES. The tidal range was increasing from minimum neaps on 10th February towards maximum springs on 17th February. The a.m. high water on 7th, and the p.m. high and low waters on 9th February were all 2 feet above the predicted levels, and coincided with strong westerly and south-westerly winds.

BEACH CONDITIONS. The building up of the beaches continued.

About all Points, including Point C, discontinuous swash bars were built up, and where they were missing a crest to the beach existed. Only west of Point A was there evidence of erosion in the form of a 2 to 3 feet high cliff in the beach facing seawards. The lower beach was not definable as a separate unit from the upper beach south of groyne X11, but north of that where the two were separable an exposure of large pebbles marked the junction. On the lower beach there was a large sand rise. A series of elongated sand rises existed on the lower beach about Point E, and north of groyne XX111. About Point E also large pebbleswere exposed near the junction of the upper and lower beaches, indicating that in this part the boulder clay beach platform lay close to the surface.

There was a gain of material at the top part of the beach at all Points except Point I where there was a slight loss, and an overall loss from the bottom part at all Points.

20th February, 1961

WINDS. Winds were predominantly from S. and S.W. and under 15 knots.

WAVES. Point A: - Hb, 0.5 foot; Plunging

Point B: - Hb, 0.5 foot; Spilling

Point C: - Hb, 0.5 foot; Spilling

Point D: T, 6.6 secs.; Hb, 1 foot; Spilling

Point E: T, 4 secs.; Hb, 1 foot; Plunging

Deep water wave energy; 321 ft.-lbs per ft. of wave crest per wave length

Wave steepness: .0086

TIDES. The range was decreasing from maximum springs on 17th February, towards maximum neaps on 24th February.

BEACH CONDITIONS. There ware no marked changes on the beaches during this spell.

Irregularities in the profiles which had existed on 13th February were smoothed over to give even slopes in most places. Discontinuous swash bars were seen, however about Points A, E and I. Near the neck to the Binks which was exposed a series of large hummocks and hollows had formed. The lower beach existed as a separate entity near Point C, south from near groyne X1, where crescent-shaped sand rises had formed, and north of groyne X11 where a large sand rise was seen again. Large pebbles were exposed extensively at the junction of upper and lower beaches, from groynes X11 to X111. Elongated sand rises existed as on 13th February, on the lower beach about Point E, north of groyne XX111.

There was a slight gain on the top part of the beaches at all

Points except Point A, where no overall change occurred and loss from the bottom part at Points B, C, and I, but gains at Points A and E.

27th February, 1961.

WINDS. Winds were predominantly from E., S.E., and S. with about a quarter over 15 knots.

WAVES. Point A: - Hb, 1 foot; Plunging

Point B: T, 4 secs.; Hb, 0.5 foot: Plunging

Point C: - Hb, 1 foot; Spilling

Point D: - Hb, 1.5 feet; Spilling

Point E: T, 6 secs.; Hb, 1.5 feet; Spilling

Point I: T, 2.5 secs.; Hb, 0.5 foot; Spilling

Deep water wave energy; 2,690 ft.-lbs. per ft. of wave crest per wave length

Wave steepness: .0073

TIDES. The range was increasing from maximum neaps on 24th February towards maximum springs on 4th March.

BEACH CONDITIONS. There was little change again in this period.

On the whole the beaches showed a convex form to the top part of the profile. Except about Point B and south of Point C itself where there was an even slope to the beach, discontinuous swash bars or a crest had been formed. On these neap tides little of the lower beach at Points C and E was exposed. There was little change from what could be seen at Point C, but about Point E the large sand rises seen on 20th February had disappeared and two small ones and a mound of pebbles were all that broke up the even slope of sand with surface water.

There was a small gain of material on the top part of the beach at Points A, and B, a loss at Point C and E, and no change at Point I. At Points A and B on the bottom part of the beach there was a slight gain, but loss in the middle part; this was reversed at Point E. There was a loss from the bottom part at Points C and I.

8th March, 1961.

WINDS. Winds were predominantly from S., S.W., W., N.W., with about a sixth over 15 knots.

WAVES. Point A: - Hb, 0.25 feet; Plunging

Point B: T, 6 secs.; Hb, 1 foot; Spilling, from 120°

Point C: T, 6.6 secs.; Hb, 1 foot; Plunging; from 120°

Point D: T, 10 secs.; Hb, 1 foot; Spilling

Point E: T, 10 secs.; Hb, 1 foot; Plunging

Deep water wave energy: 656 ft.-lbs. per ft. of wave crest per wave length

Wave steepness: .0008

TIDES. Tides were decreasing in range from maximum springs on 4th March towards maximum neaps on 12th March.

BEACH CONDITIONS. This was a period of slow building up of the beaches. Discontinuous swash bars existed south-east of Point A and about Points C, E, and I. At most places where they were absent there was a marked crest to the beach. At Point C, the top part of the beach had re-developed a convex form, despite the fact that it was still difficult to distinguish the upper and lower sections. A number of large sand rises appeared on the lower beach about Point E.

There was an overall gain of material on the top part of the beach at all Points except Point I, where a small loss occurred. There was an overall gain on the bottom part of the beach at all Points except Point I, also; there no change occurred.

16th March, 1961

WINDS. Winds were predominantly from W., S.W., and S., with a quarter over 15 knots.

WAVES. Point A: T, 2.5 secs.; Hb, 0.5 foot; Plunging

Point B: T, 12 secs.; Hb, 0.5 foot; Spilling

Point C: T, 8.5 secs.; Hb, 1 foot; Plunging

Point D: T, 10 secs.; Hb, 1 foot; Spilling

Point E: T, 10 secs.; Hb, 2 feet; Plunging

Deep water wave energy: 3,700 ft.-lbs. per ft. of wave crest per wave length

Wave steepness: .0019

TIDES. Tides were increasing in range from maximum neaps on 12th March towards maximum springs on 18th March.

BEACH CONDITIONS. The slow building up of the beaches continued during this period.

The spring tides had smoothed over the beaches generally, but remnants of swash bars remained about Points E and I. Elsewhere about these Points there was a well defined crest to the beach. About Point C there was no marked change from conditions on 8th March. The central section of the beach south of Point C itself was concave in profile, below the top section which was being built up gradually. North of Point C there was an even slope to the beach, as was found also about Points B and I. Where the lower beach was definable as a unit about Point C, large sand rises had formed on it. The lower beach about Point E bore similar features.

There was a general gain of material on the top part of the beach at Points A, B, and E, a slight loss from Point C, and no change at Point I. There was a slight gain on the bottom parts of the beach at Points A and B, a small loss from Points C and E, and no change again at Point I.

COMPLETE BEACH SURVEY. 17th March, 1961. (see Figure 2.3)

The beach had a well-rounded built up form throughout the whole length of the seaward side of the spit.

Swash bars were built in a few places, but almost everywhere the upper beach was crested. It still remained narrow between groynes XV111 and XX. The low section of beach remained about Point C, and immediately southwards. On the lower beach sand rises varying enormously in size were found from one end of spit to the other.

On the riverside the upper beach west of the Lighthouse Zone and the beach northwards consisted of an even slope, except once again opposite groynes XV111 to XX a swash bar had been built. The long ridges of sand concave southwards, on the lower beach west of the Lighthouse Zone remained, as did the sand ridges projecting west from the beach near the southern end of the Chalk Bank.

23rd March, 1961 (see Figures 2.1 and 2.2)

WINDS. Winds were predominantly from W., N.W., and N. of which $\frac{3}{4}$ were over 15 knots.

WAVES. <u>18th March</u>

Point D: T, 7.5 secs.; Hb, 5 feet; Plunging

Deep water wave energy: 34,400 ft.-lbs. per ft. of wave crest per wave length

Wave steepness: .0134

(Wave energy and steepness calculated from figures from Point D)

<u>19th March</u>

Point A:	-	Hb, 2 feet;	Plunging	
Point B:	T, 10 secs.;	Hb, 2 feet;	Spilling;	from 95°
Point C:	T, 10 secs.;	Hb, 3 feet;	Spilling;	from 110°
Point D:	T, 8.5 secs.;	Hb, 6 feet;	Plunging;	from 100°
Point E:	T,10 secs.;	Hb, 5 feet;	Spilling;	from 70°

Deep water wave energy: 41,900 ft.-lbs. per ft. of wave crest per wave length

Wave steepness: .0063

<u>22nd March</u>

Point A:	-	Hb, 0.5 foot;	Plunging	
Point B:	T, 10 secs.;	Hb, 2 feet;	Spilling:	from 110°
Point C:	T, 8.5 secs.;	Hb, 3 feet;	Plunging;	from 120°
Point D:	T, 10 secs.;	Hb, 4 feet;	Spilling;	from 90°
Point E:	T, 10 secs.;	Hb, 4 feet;	Plunging;	from 85°
Point I:	T, 2 secs.;	Hb, 0.5 foot;	Spilling	

Deep water wave energy: 21,700 ft.-lbs. per ft. of wave crest per wave length

Wave steepness: .0045

<u>23rd March</u>

Point A:	-	Hb, 1 foot;	Plunging and Spilling	
Point B:	T, 10 secs.;	Hb, 3 feet;	Plunging;	from 120°
Point C:	T, 10 secs.;	Hb, 2 feet;	Plunging;	from 120°
Point D:	T, 10 secs.;	Hb, 3 feet;	Plunging;	from 110°
Point E:	T, 10 secs.;	Hb, 3 feet;	Plunging;	from 90°

Deep water wave energy: 10,500 ft.-lbs. per ft. of wave crest per wave length

Wave steepness: .0031

TIDES. Tides were decreasing in range from maximum springs on 18th March towards maximum neaps on 26th March. Two storm surges occurred coinciding with strong north to north-west winds. The first, a relatively minor one, occurred on 18th March, when the p.m. low and high waters were 2 feet and 1foot respectively above the predicted levels. The second, and major surge occurred on the p.m. high water on 20th March, which was 3.5 feet above the prediction, and the a.m. low water on the following day which was 3 feet above the prediction.

BEACH CONDITIONS. The powerful waves coupled with a storm surge at the time of spring tides on 19th March affected the whole beach from the dunes downwards and generally smoothed over the irregularities in the profiles to give even slopes everywhere. Sand rises on the lower beach about Points B, C and E were the only features on the beach, to break this evenness.

The profiles surveyed on 19th March showed that there had been an overall loss of material from the top part of the beach at Points A, B and I; this was coupled with a gain on the bottom parts at Points A and I, but loss at Point B. The profiles at Points C and E showed that material was added near the dunes, removed below that, and more was added on the bottom part of the beach.

The beaches had been further smoothed over and eroded by the powerful waves associated with the major storm surge on 20th and 21st March but by the time observations were made on 22nd March there were signs of material being returned up the beach. The beach was crested again east of Point A, and about Point C, and a swash bar was being built north of Point E, between groynes XXlV and XXV. Elsewhere however there was little change from 18th March.

The profiles surveyed on the 22nd March, showed that there had been a general loss of material from the top part of the beach at all Points except I, where there was no change. There was loss from the bottom part of the beach also at all Points but a slight gain in the middle at Points A, B, and C.

On 23rd March, the profiles surveyed showed that building up processes were under way again. Material was added to the top part of the beach at all Points and was added to the bottom part also except at Point E where there was a slight loss.

29th March, 1961

WINDS. Winds were predominantly from W., and N.W., with about a third over 15 knots.

WAVES	Point A:	-	Hb, 2 feet;	Plunging	
	Point B:	T, 12 secs.;	Hb, 3 feet;	Spilling;	from 110°
	Point C:	T, 12 secs.;	Hb, 3 feet;	Plunging:	from 110°
	Point D:	T, 12 secs.;	Hb, 3 feet;	Plunging;	from 110°
	Point E:	T, 12 secs.;	Hb,4feet;	Plunging;	from 85°

Deep water wave energy: 26,000 ft.-lbs. per ft. of wave crest per wave length

Wave steepness: .0029

TIDES. Tides were increasing in range from maximum heaps on 26th March towards maximum springs on 2nd April. Another storm surge, associated with strong north-westerly winds, occurred on the 26th and 27th March when high waters were up to 2 feet, and low waters up to 3 feet above the predicted levels.

BEACH CONDITIONS. The powerful waves which were still breaking on the beaches continued to have a generally smoothening effect although there were patchy signs of build up, as were seen on 23rd March.

Two small swash bars had been built near the Tip, and the beach north of Point C, between groynes X11, and X111 was crested. Elsewhere the profiles generally showed a smooth, even slope.

A small amount of material was added to the top part of the beach at all Points, except Point I where there was a slight loss. At Points A and B there was loss from the middle part, but a gain on the bottom part. There was a slight loss from the bottom part at Point C, but no overall change at Points E and I.

5th April, 1961

WINDS. Winds were variable, but predominantly W., with a third over 15 knots.

WAVES.	Point A:	-	Hb, 1 foot;	Plunging	
	Point B:	T, 6 secs.;	Hb, 1 foot;	Spilling;	from 125°
	Point C:	T, 7.5 secs.;	Hb, 1 foot;	Plunging	

Point D: T, 7.5 secs.; Hb, 2 feet; Spilling and Plunging

Point E: T, 7.5 secs.; Hb, 2 feet; Plunging

Deep water wave energy: 3,325 ft.-lbs per ft. of wave crest per wave length

Wave steepness: .0042

TIDES. The range was decreasing from maximum springs on 2nd April towards maximum neaps on 10th April.

BEACH CONDITIONS. Under the conditions of lighter variable winds, producing less powerful waves, build up of the beaches was marked.

Swash bars had developed only around Point A, and south of Point I, but about other Points the beach was clearly crested. The beach about C, whilst having a convex upper profile, still showed an even slope below that, where upper and lower beach formed an inseparable unit. A large sand rise persisted on the lower beach north of groyne XII, and a small one south of groyne XIII. Medium and large pebbles were exposed from groynes XII to XIII at the junction of upper and lower beaches. The lower beach about Point E, was featureless except for a small sand rise at the end of groyne XXIII.

There was a marked gain on the top part of the beach at all Points, and a loss from the bottom part at Points A, B, and E, but a gain at Points C and I.

BIBLIOGRAPHY

CHAPTER 2

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C H A P T E R 3

Short Term Beach Changes

The changes observed on the beaches between April 1960 and April 1961, and described in Chapter 2, will be divided into short term and long term for further consideration and analysis. The short term changes are those which are apparent week by week, and this chapter will be concerned with them. It will be divided into two sections; in the first, the causal factors of winds, waves and tides will be considered; and in the second the changing beach morphology will be related to conclusions drawn from the first section. In Appendix 1, the relative value of the different methods of analysis used, is discussed.

Section 1. Causal Factors

a) Winds

King [1.] found a close correlation between wind direction and sand movement at Marsden Bay; with an offshore wind accretion took place on the top part of the beach and erosion on the bottom part. The reverse applied with an onshore wind. As the beach was composed almost purely of sand with a median particle size of 0.37 mms. at the north end of the bay, and 0.35 mms. at the south end, whereas on the upper beach at Spurn there is a mixture of sand and shingle, and sand alone only on the lower beach, certain differences might be expected.

Table 3.1. was drawn up to correlate the loss and gain of material on both the top and bottom parts of the beach with the predom-

TABLE 3.1

Loss and Gain of Material on the Top and Bottom Parts of the Beach in Relation to Wind Direction

	N		NE		E		SE		S		SW		W		NW	
Point A																
Top part +	2	2	2				3			3	4	1	4	2	1	1
Top part -	2			1			3			1			1		1	1
Bottom part +	2	2	1			1	1			3	4	1	5		2	2
Bottom part -	2	1					5			3	1	1	1	2	1	1
Point B																
Top part +	1			1		1	2			3	5	2	2	2	1	2
Top part -	1		2	1			2				1		2		1	
Bottom part +	1			1			3				2	1	2	1		
Bottom part -			1							2		1	1	2	1	2
Point C																
To p part +	2	2					2			4	5	1	4	1	1	
Top part -	3		1	2		2	3			1	1				2	2
Bottom part +	2		1	2		1	3			3	4		2		2	1
Bottom part -	2	2	1			1	2			2	1		2	2		1
Point E																
Top part +	1	1	1	1		1	4			7	5	1	4	1	4	1
Top part -	4	1	1			1	2						1			2
Bottom part +	3		2	1		1	3			3	1		2		2	
Bottom part -	1	2					2			2	3	1	4	2	1	2

	N		NE		E		SE		S		SW		W		NW	
<u>Point I</u>																
Top part +	3	1	1				1			3	2		3		1	1
Top part -				1		1	2			1			2	1	1	2
Bottom part +	3	1	1	1		1	2			1	2		4	1	1	1
Bottom part -	1	1	1	1		1	4			3	2	1	2		1	1

Figures refer to number of periods between consecutive observations from April 1960 to April 1961.

ie. the number of approximately weekly intervals between the dates when observations were made, when winds blew predominantly from the directions indicated at the top of the columns.

inant wind direction immediately prior to the measurements being taken. All this shows clearly is that there is a marked gain of material on the top part of the beach all round the spit when the winds are from between south and north-west. Table 3.II. which shows the loss and gain of material on the whole beach in relation to wind direction emphasizes the total gain when winds are from between south and north-west, but no other general conclusions can be drawn from it.

In the compilation of Table 3.III. winds were divided into two groups, onshore and offshore. The directions included in each group varied from the seaward side of the spit to the Tip and to the riverside, and are given on the right hand side of the table. When the figures for all the Points are considered together it can be seen that the gain of material at the top of the beach is predominant with offshore winds. Loss and gain are relatively evenly balanced at the top part with onshore winds and at the bottom part with both onshore and offshore winds. When only the Points on the seaward side are considered there is a hint of a similar picture emerging to that which King found at Marsden Bay. With offshore winds there is a gain of material at the top part of the beach, but loss from the bottom part, with the reverse occuring when onshore winds have predominated for a few days. Again, the clearest fact to emerge is that the gain of material on the top part is very marked with offshore winds.

In Table 3.IV when loss and gain of material from the whole beach is related to onshore and offshore winds, and all Points are considered

TABLE 3.II

Loss and Gain of Material on the Whole of the Beach in Relation to Wind Direction

	N		NE		E		SE		S		SW		W		NW	
Point A																
Total Gain	3	1	1			1	1			3	5	3	5	1	2	2
Total Loss	2					1	3			2	3		1		1	
Point B																
Total Gain				1		1	2		1	1	5	1	2	1	1	1
Total Loss	1		2			1	1			3	1		1		2	1
Point C																
Total Gain	1			1			2		1	6	4	2	2	1	3	
Total Loss	2	1	1		1	2				2	3		2		4	2
Point E																
Total Gain			1			2	2			4	6	2	3	2	2	
Total Loss	4	2	1	1		2	2			3	2		1	1	3	2
Point I																
Total Gain	3	1	1			2	1			3	4		3		3	1
Total Loss	1	1	1	1		4				3	3	2		1	4	1

Figures refer to number of periods between consecutive observations from April 1960 to April 1961.

TABLE 3.III

Loss and Gain of Material on the Top and Bottom Parts of the Beach in Relation to Onshore and Offshore Winds

	Onshore Winds				Offshore Winds				
	Top		Bottom		Top		Bottom		
	+	-	+	-	+	-	+	-	
Point A	17	5	15	13	8	5	10	5	(Onshore S.E. to W.-N.W.)
Point B	5	6	5	1	17	4	6	9	(Onshore N. to S.E.)
Point C	6	11	9	8	16	6	12	8	(Onshore N. to S.E.)
Point E	9	9	10	5	23	3	8	15	(Onshore N. to S.E.)
Point I	6	4	8	6	10	7	11	13	(Onshore S.W. to N.W.)
All Points	43	35	47	33	74	25	47	50	
Points B,C,E.	20	26	24	14	56	13	26	32	

Figures refer to number of periods between consecutive observations from April 1960 to April 1961.

TABLE 3.IV

Net Loss and Gain of Material on the whole of the Beach in Relation to Onshore and Offshore Winds

	Onshore Winds		Offshore Winds	
	+	-	+	-
Point A	18	9	10	4
Point B	4	5	13	8
Point C	4	7	19	13
Point E	5	12	19	12
Point I	10	10	12	12
All Points	41	43	73	49
Points B,C, E.	13	24	51	33

Figures refer to number of periods between consecutive observations from April 1960 to April 1961 together, the marked gain of material when offshore winds blow is again immediately apparent. Gain and loss are almost equal with onshore winds. When only Points B, C, and E are considered it may be seen that loss is associated with onshore winds and gain with offshore.

Eight beach surveys each made after the wind had blown predominantly from either north, east, south or west will be examined next. Of the two surveys relating to each wind direction, one followed light winds, and one strong winds.

North Winds

4th May, 1960. After 25th April winds had been predominantly north and north-east, under 15 knots. The form of the beach became more built up. Material was added to the top of the beach generally, and removed from the bottom part, on the seaward side, but added at the Tip and on the riverside.

29th June, 1960. After 23rd June winds were predominantly north with over half over 15 knots. A storm surge on 28th - 29th June was accompanied by powerful waves. The previously built-up form of the beach was broken down and material was removed from all parts of the profile on the seaward side and at the Tip with a maximum loss near the middle of the profile; only on the riverside was there a gain.

East Winds

11th - 13th May, 1960. After 4th May winds were predominantly light, from east and south-east, until the 11th May when they became stronger.

There was a partial break down of the built up form, with marked erosion east of the Tip. Material was lost from the seaward and riversides with gain occuring only on the bottom part of the beach at Point C.

29th January, 1961: From 21st to 26th January winds were east and on 27th to 28th January were south. Only about half from each direction were over 15 knots. Building up of the beaches predominated and the fact that swash bars existed high up the beach and lower down indicated that build up occurred on the spring tides, early in the period with east winds, but continued on the neap tides later with south winds. Generally, material was added to the top part of the beach, but removed from the bottom, only at the Tip was there removal from the top and bottom.

<u>South Winds</u>

18th November, 1960. After 9th November the winds were almost solely from south and south-west, and mainly south. About half were over 15 knots. The beaches were built up with material being added at the top and removed from the bottom, generally.

20th February, 1961. After 13th February the winds were predominantly south and south-west, and under 15 knots. Little change in the form of the beaches took place, but generally a slight gain at the top part was counterbalanced by a loss from the bottom part.

<u>West Winds</u>

15th June, 1960. After 10th June winds were west with only a third over 15 knots. Building up of the beaches was predominant and there was a gain on the top and bottom parts almost everywhere.

29th March, 1961. After 23rd March winds were mainly from west and north-west with a third over 15 knots. On 26th and 27th March however strong north-west winds produced a storm surge coupled with powerful waves. Slight build up occurred but the powerful waves gave many parts of the beach an even slope. There was a small gain of material at the top part of the beach at all places except on the riverside, and a general loss on the bottom part everywhere. The small gain on the top part of the beaches resulted from the westerly winds which blew before the maximum neap tides occurred on 26th March, and the main effect of the north-westerly winds appears to have been the lowering of the middle and bottom parts.

To summarize the information gleaned from considering conditions after the wind had been mainly from a specific direction: the beaches were built up in form and material was added to the top part of the beach, and removed from the bottom, except when strong winds blew from between north-west, north-east, and south-east. The greatest break down in form occurred with strong winds from a northerly quarter.

Because the break down of beach form occurs rapidly, whereas the build up is a slow, gradual process, Tables 3.I., 3.II., 3.III., and 3.IV., which took into account the number of occasions when loss and gain occurred, did not yield the information about loss as well as about gain of material. They also took only wind direction into accout and not wind speed. The analysis which followed a consideration of the tables gave more information about the break down, than the build up of the beach.

By combining the two analyses a clear picture of the relationship between beach change and wind conditions begins to emerge.

b) Waves *

Figure 1.1. shows that the longest fetch, over 1500 miles, lies between bearings of 350° and 010° from Spurn Head. When a strong wind has been blowing over this fetch for some hours it is possible that the largest possible waves which can affect Spurn Head will be generated. Derbyshire[2] considers that a fetch of 100 nautical miles is all that is needed to generate a full sea for a wide range of wind speeds, while Newmann[3] and Bretschneider[4] require increasing fetches and durations for increasing wind speed. Newmann and Bretschneider's forecasts agree with observations in severe storm conditions whereas Darbyshire's results are usually too low for high winds of long duration. Observations show that on Lake Superior where the fetch varies between 100 and 250 nautical miles waves of a height over 20 feet are not produced whereas in the open Atlantic over long fetches waves of 60 feet high are developed, which would support Newmann and Bretschneider's theories.

Table 3.V relating the energy content and steepness of waves to wind direction and speed shows that the most powerful waves, all those over 20,000 foot-pounds per foot of wave crest per wave length were

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Footnote * The wave conditions which are discussed, are those which directly affect the seaward side of the spit. If the riverside is affected by them it is only indirectly.

TABLE 3.V

Energy Content and Steepness of Waves in Relation to Wind Direction and Speed

Date	Wave Energy	Wave Steepness	# Wind Direction and Speed in Knots	Date	Wave Energy	Wave Steepness	Wind Direction and Speed in Knots
4.5.60	3,585	.0030	S.W.10	7.9.60	447	.0030	S;N.W.10
13.5.60	8,650	.0090	E.20	21.9.60	46,300	.0038	N.W,N.25
18.5.60	14,050	.0289	N.,N.E.20	27.9.60	9,580	.0049	E.10
25.5.60	8.760	.0068	N.W.15	7.10.60	473	.0011	E,N.E.10
30.5.60	2,690	.0073	N,N.E.10	12.10.60	100,500	.0097	N,N.W,25
10.6.60	369	.0047	W.15	21.10.60	8,760	.0068	E,S.E.20
15.6.60	447	.0030	light,var. & calm	26.10.60	8,760	.0068	S.E.15
23.6.60	6,400	.0195	S.E,E.15	4.11.60	2,790	.0056	S.20
29.6.60	21,700	.0045	N.W,N.25	9.11.60	473	.0011	S.5
7.7.60	8,760	.0068	W.20	18.11.60	447	.0022	S;W.10
14.7.60	369	.0047	S.15	23.11.60	3,325	.0042	W;S.10
20.7.60	2,690	.0073	N,N.E.15	30.11.60	656	.0008	S,S.W.15
3.7.60	1,536	.0279	S,S.W.10	7.12.60	18,300	.0144	E.10
5.8.60	8,760	.0068	W,S.W.10	17.12.60	-	-	S.W.10
10.8.60	-	-	light var. & calm.	22.12.60	21,550	.0073	N.W.15
18.8.60	2,690	.0073	var.10	1.1.61	369	.0047	S.W.10
27.8.60	-	-	S.E.10	14.1.61	2,690	.0073	N.10
3.9.60	3,700	.0019	S.W,W.10	19.1.61	8,650	.0099	S.20

Table 3.V continued

Date	Wave Energy	Wave Steepness	Wind Direction and Speed in Knots	Date	Wave Energy	Wave Steepness	Wind Direction and Speed in Knots
29.1.61	6,400	.0195	S.W.20	18.3.61	-	-	W.20
4.2.61	3,585	.0030	S.W,W.20	19.3.61	41,900	.0063	N.W,N.20
13.2.61	2,610	.0090	S.W.15	22.3.61	21,700	.0045	N.W,N.15
20.2.61	321	.0086	S.W.10	23.3.61	10,500	.0031	W.10
27.2.61	2,690	.0073	S.W.15	29.3.61	26,000	.0029	N.W,W.20
8.3.61	656	.0008	light var. & calm	5.4.61	3,325	.0042	light var. & calm
16.3.61	3,700	.0019	light var. & calm				

For details of calculation of wave energy and wave steepness see Chapter 2 page 24.

Wind direction and speed given for approximately 24 hours before wave observations made.

associated with winds of not less than 15 knots blowing from between north-west and north, over the longest fetch.

Appendix 2 listing all the wave information collected shows that the waves associated with north to north-west winds over 15 knots in addition to having the highest energy content of any reaching Spurn were also the longest. All were between 8.5 and 12 seconds in period, although 10 seconds was the most common. King[1] found both experimentally and in direct beach observations at Marsden Bay that as wave period, which is related to length, increases, the beach gradient becomes flatter. With increasing wave length, provided that the percolation volume is constant, the proportion of backwash to swash increases, and hence the flattening effect.

Rector[5] and Meyers[6] have shown experimentally that for any given sand size the beach gradient decreases as wave steepness, (deep water wave-height/deep water wave length) increases. On natural sand and shingle beaches this relationship has been observed. King[1 and 7] refers to this at Marsden Bay and Chesil Beach. As with an increase in wave length, the change is due to the increased proportion of backwash to swash, provided the percolation volume is constant. At Spurn Head, see Table 3.V. wave steepness is greatest with onshore winds, that is winds from between north and south-east, than with offshore winds, as is shown below:

Onshore Winds		Offshore Winds	
Maximum steepness	.0289	Maximum steepness	.0279
Minimum steepness	.0011	Minimum steepness	.0008
Average steepness	.0089	Average steepness	.0063

Waves associated with winds from north and north-west are not the steepest; they vary between .0029 and .0097.

Wave orthogonal diagrams (Figs. 3.1, 3.2, 3.3, 3.4) have been constructed according to the "crestless" method, details of which are given in the U.S. Hydrographic Office Publication No. 605.[8] The method which requires the insertion of wave crests before orthogonals can be constructed has been found by Pierson[9] to lead to serious cumulative errors which develop as the waves are traced progressively inshore. He recommends that the "crestless" or "orthogonal" method be used exclusively in all future wave refraction studies. In this latter method it is possible to construct the orthogonals without previously inserting wave crest positions. The wave orthogonal diagrams were constructed for 10, 8, and 6 second period waves from north and north-north-east, 8 and 6 second period waves from east-north-east and 6 second period waves from north-east, east, and east-south-east. 10, 8 and 6 second periods were selected for waves between north and north-east as the observational records showed that most periods were between 10 and 6 seconds. The position and form of the Dogger Bank causes 10 and 8 second period waves from north-east to be so refracted that orthogonals constructed from the north-east of the North Sea miss Spurn Head completely. It is unlikely that waves of a period longer than 8 seconds could develop from east-north-east, and greater than 6 seconds from east-south-east. It is impossible to construct orthogonal diagrams for higher periods owing to the fact that the southern part of the

North Sea is so shallow that such waves would be refracted even whilst developing. Pierson[6] acknowledges the fact that when refraction is such that wave crests cross, inaccuracies emerge when the refraction diagrams are constructed according to the crestless method. The diagram for Spurn Head for waves from east-south-east is likely to be unreliable as the orthogonals and therefore the wave crests cross.

These diagrams show that the more nearly waves come from north and the longer is their period, the more they are refracted. Waves from a northerly direction which break on the shore of the south part of the spit suffer considerably more refraction and therefore lose more energy than those which break on the northern part. Waves from the east suffer only slight refraction.

Table 3.VI. shows the relationship between wind direction and strength and the angle of wave approach, which is the angle between the shore and the wave crest immediately before the wave breaks. In the case of waves produced by winds from between north-west and north-east the angle of approach may be up to 40° southwards; the average is 15.6°. With waves associated with winds from all other directions the angle of approach is rarely greater than 20° southwards, and the average is only 4.28°. In the case of waves with an energy content of over 20,000 foot-pounds per foot of wave crest per wave length which were all associated with winds of at least 15 knots blowing from between north-west and north, the average angle of approach at all Points was 18.3° southwards. The angle of wave approach

TABLE 3.VI

The Relationship Between Wind Direction and Speed and Angle of Wave Approach

Date	Wind Direction and Speed in Knots	+ Angle of Wave Approach°				Date	Wind Direction and Speed in Knots	+ Angle of wave Approach°			
		Pt.B	Pt.C	Pt.D	Pt.E			Pt.B	Pt.C	Pt.D	Pt.E
13.4.60	S.W.20	-	-	40 N	-	18.8.60	var.10	0	0	0	0
18.4.60	N,N.E.10	-	-	30	-	27.8.60	S.E.10	10 N	0	0	0
25.4.60	N,N.W.10	-	-	20	-	3.9.60	S.W,W.10	10	10	0	0
4.5.60	S.W.10	-	0	0	0	7.9.60	S,N.W.10	0	15	0	0
11.5.60	E.20	-	15	0	0	21.9.60	N.W,N.25	20	20	20	10
18.5.60	N,N.E.20	-	0	25	5	27.9.60	E.10	30	20	15	10
25.5.60	N.W.15	-	25	20	10	7.10.60	E,N.E.10	0	20	10	10
30.5.60	N,N.E.10	-	10.	30	10	12.10.60	N,N.W.25	30	30	0	30
10.6.60	W.15	-	0	0	0	21.10.60	E,S.E.20	25	20	0	0
15.6.60	light,var. & calm	-	0	0	0	26.10.60	S.E.15	0	0	0	5
23.6.60	S.E,E.15	-	0	5	0	4.11.60	S.20	0	0	0	0
29.6.60	N,W,N.25	-	20	10	40	9.11.60	S.5	0	5	5	0
7.7.60	W.20	0	0	10	0	18.11.60	S,W.10	5	0	10	0
14.7.60	S.15	0	20	10	0	23.11.60	W,S.10	10	0	20	0
20.7.60	N,N.E.15	0.	0	15	0	30.11.60	S,S.W.15	0	10	10	0
31.7.60	S,S.W.10	0	0	0	0	7.12.60	E.10	15	20	10	10
5.8.60	W,S.W.10	20	15	15	5	17.12.60	S.W.10	0	0	0	0
10.8.60	light,var. & calm	0	0	0	0	22.12.60	N.W.15	20	10	10	10

Table 3.VI continued

Date	Wind Direction and Speed in Knots	* Angle of Wave Approach°				Date	Wind Direction and Speed in Knots	* Angle of Wave Approach°			
		Pt.B	Pt.C	Pt.D	Pt.E			Pt.B	Pt.C	Pt.D	Pt.E
1.1.61	S.W.10	0	0	0	0	8.3.61	light.var. & calm.	10	10	0	0
14.1.61	N.10	15	0	0	0	16.3.61	light.var. & calm.	0	0	0	0
19.1.61	S.20	10	0	20	0	18.3.61	W.20	0	0	0	0
29.1.61	S.W.20	0	0	0	0	19.3.61	N.W,N.20	35	20	20	20
4.2.61	S.W,W.20	20	0	0	10	22.3.61	N.W,N.15	20	10	30	5
13.2.61	S.W.15	10	0	0	0	23.3.61	W.10	10	10	10	0
20.2.61	S.W.10	0	0	0	0	29.3.61	N.W,W.20	20	20	10	5
27.2.61	S.W.15	0	0	0	0	5.4.61	light.var. & calm.	5	0	0	0

Var. = variable

Wind direction and speed given for approximately 24 hours before wave observations made.

* All the angles open to the south unless otherwise marked.

is significant to the rate of littoral drift which will be considered in more detail in Chapter 4.

The type of breaker which was recorded in each set of wave observations was not found to be significent in the gain or loss of material from the beaches. It is generally accepted that the relationship which Lewis[10] suggested between spilling breakers and constructive action, and plunging breakers and destructive action is over simplified, and that wave steepness, and wave length which affects steepness, are of greater s ignificence.

c) Tides

Table 3.VII relates all the occasions when the tides were either above or below the predicted heights, according to the Admiralty Tide Tables, for a period of not less than one tidal cycle, (i.e. from one low water to the following low water, or from one high water until the following high water) to wind direction and speed. It is obvious that winds from between north-west and north-east over 15 knots generally are associated with a rise in tidal level and that winds from between south and west of a similar speed are associated with a depression of level.

Much research has been carried out on storm surges, which result in a rise in sea level due to meteorological conditions, in the North Sea. Rossiter [11 & 12] has analysed the most recent severe one, which occurred on 31st January and 1st February 1953. It is known that meteorological conditions affect sea level in two ways. First, when atmospheric pressure falls, sea level rises, and vice versa; approximately a one inch change of

TABLE 3.VII

TIDAL DISTURBANCES

Date	Wind Direction and Speed in Knots		Tidal Rise above predicted level, in feet	Date	Wind Direction and Speed in Knots		Tidal depression below predicted level, in feet
24.5.60	N.W.	15-20	1-1.5	12.4.60	S.W.,W.	15-25	1
28-29.6.60	N.W.,N.	20-28	1.5	14.9.60	S.	15-24	1-1.5
20.9.60	N.,N.W.	20-30	1	2.11.60	S.,S.W.	20-30	1.5-2.5
10-13.10.60	N.	20-28	1-2.5	30.12.60	W.	15-22	2
5-6.11.60	W.,N.W.	10-20	1-1.5	12.1.61	S.W.	10-17	1.5-2
20.12.60	N.W.,N.,N.E	20-30	0.5-1	17-19.1.61	S.	10-24	1-2
18-19.3.61	N.W.,N.	18-24	1-2	26-27.1.61	S.	15-30	1.5-3
20-21.3.61	N.W.,N.	20-29	3-3.5				
26-27.3.61	W.,N.W.,N	15-21	2-3				

Wind direction and speed given for approximately 24 hours before wave observations made.

All tidal disturbances noted lasted for not less than 1 tidal cycle (about 13 hours) pressure produces a one foot change of sea level. Second, wind blowing over water exerts a tractive force which causes the water to be pulled along in the direction of the wind. This effect is most noticeable in an almost closed sea. For example, in the Baltic Sea when strong westerly winds blow the level of the sea rises in the eastern part of the basin, but falls in the west; and vice versa. In the North Sea, whilst there is wide access between the North Atlantic and the northern part there are only the narrow Straits of Dover to the south, and this basic configuration is important in the consideration of storm surges. The geostropic force, caused by the rotation of the earth results in the wind-driven water in the North Sea being deflected to the right. Whilst the effect of a change in atmospheric pressure is felt almost immediately in the sea, a wind produced change takes time to become effective and is not a steady but an oscillating change. The time lag and amount of oscillation depends on the dimensions of the sea and because of their importance the name "storm surge" has been given to a disturbance of sea level due to these combined causes.

Within the North Sea there are two types of storm surge, an internal one directly due to the variations of level within the North Sea, and an external one which has its origin outside the North Sea and appears to be generated when a deep depression crosses the Wyville Thomson Ridge.[13]

The meteorological conditions accompanying storm surges usually follow a distinct pattern. A deep depression develops west of Scotland and subsequently moves quickly eastwards across the northern part of the North Sea and thence into the Baltic region. When such a depression lies over southern Scandinavia strong north to north-west winds blow over the North Sea. A surge, of either type associated with such a depression moves southwards along the east coast of England and northwards along the continental coast. The Straits of Dover are so narrow and shallow as to act only as a small safety valve which slightly reduces the height of the surge before it swings northwards.

Table 3.VIII gives details of the meteorological conditions associated with the storm surges and depressions of predicted tidal levels, during the year of detailed observations. Whenever a storm surge occurred, a depression was centred over southern Scandinavia, with only one exception, on 26th to 27th March, 1961, when a deep depression lay further north. Most of the depressions had moved from near Iceland, although on two occasions they had developed in situ, along the line of a front, and on another two occasions the depressions had approached from west of the British Isles. The depression of tidal levels was not associated with so definite a meteorological pattern, indeed any distribution of fronts and troughs associated with depressions to the north of England, which caused a steep pressure gradient northwards or north-eastwards produced this effect.

TABLE 3.VIII

STORM SURGES, AND METEOROLOGICAL CONDITIONS

DATE OF SURGE.	METEOROLOGICAL CONDITIONS
24.5.60	Depression which had passed between N.Scotland and Iceland was centred between N.Scotland and W.Norway. 992 mbs.
28-29.6.60	Depression developed over Denmark and S. Sweden. 992 mbs.
20.9.60	Depression ~~nearing~~ moving from Iceland to N.Germany. 1004 mbs.
10-13.10.60	Depression which had approached from S.W. of British Isles moved from S.North Sea to Denmark and S.Sweden. 992 mbs.
5-6.11.60	Depression which had passed between N.Scotland and Iceland moved N.E. from Denmark over Sweden. 984 mbs.
20.12.60	Two depressions developed over S.North Sea and Denmark. 992 mbs.
18-19.3.61	Depression from W. of British Isles moved from W.Norway to central Sweden. 976 mbs.
20-21.3.61	Depression from E. of Iceland moved from W.Norway across Denmark to N.Germany. 980 mbs.
26-27.3.61	Depression moved from Iceland to N.W.Norway. 972 mbs.

Table 3.VIII continued.

TIDAL DEPRESSIONS AND METEOROLOGICAL CONDITIONS

Date of Depression	METEOROLOGICAL CONDITIONS
12.4.60	Occluded front over W.Scotland and N.Ireland associated with depression S.W. of Iceland
14.9.60	Trough of low pressure over Ireland associated with depression S.W. of Iceland.
2.11.60	Depression of 960 mbs. moving from N.Ireland to N.Scotland
30.12.60	Occluded front from S.Wales to N.E.Scotland associated with depression S.W. of Iceland.
12.1.61	Two warm fronts lying over England associated with a depression N. of Iceland.
17-19.1.61	Troughs and fronts crossing British Isles associated with depression moving from central N.Atlantic to Iceland.
26-27.1.61	Depression of 968 mbs. moving from W. of Ireland to W. of Scotland.

SECTION II

Beach Morphology

Before considering the form of the changes which were described week by week in Chapter 2, the reasons for the basic subdivisions of the beach will be discussed.

Throughout the length of the seaward side of the spit, the whole beach was divided into upper and lower beaches as defined on page 10. Why do these exist? Russell[14] suggests the answer. Beach material moves in three ways on the sea bed, pebbles roll, coarse sand saltates, and fine sand moves in suspension. Movement of material in these three different ways means that they are not necessarily moved in the same direction. In shallow water, when the depth is less than half the deep water wave length, the particles move in elliptical orbits, the vertical axes of which equal the wave height at the surface, but become progressively smaller towards the bed where they oscillate to and fro along a straight horizontal line about a mean position which stays substantially still. The velocities of the forward and backward movements are not usually equal and the asymmetry of motion causes beach material on a horizontal plane to move in the direction of wave motion and causes stable beach profiles to slope up towards the shore. Before the waves break there is usually a slow drift of water shorewards near the sea bed. When the wave breaks the flow of water carried shorewards is usually compensated by a drift of water seawards near the bed. As King[1] found evidence of at

Marsden Bay, onshore and offshore winds affect this simple condition, because an onshore wind drags the surface layers of water shorewards, and results in an offshore drift near the bed, and vice versa.

Drift appears to influence particles in suspension most, and carries them at the rate of the drift. It can move also saltating particles when they have been lifted off the bed, but is generally too weak to move rolling material.

When waves are long in relation to the depth of water there is a short sharp forward movement of the water but a slow and protracted return flow. This movement has a great effect on rolling particles and causes them to move in the direction of wave motion. A certain size of pebble can be moved by the high forward velocity only and therefore moves shorewards rapidly. As the water becomes shallower, larger and larger particles can be moved shorewards and therefore a greater proportion of coarse particles are then found shorewards. This asymmetrical motion has no net influence on particles in suspension, and its effect on saltating particles is not known.

Because rolling, saltating and suspended particles are influenced by different aspects of wave motion they are sorted into zones parallel to the shore. Usually the forces which propel rolling particles shorewards are greater than those which move sand shorewards. This explains why the upper beach on the eastern side of the spit is composed of sand and shingle and the lower beach is almost purely sand. In addition the analysis of sand samples to discover median particle size (see Table 1.I page 17) revealed that sand was coarser on the upper beach than on the lower. The conditions on the beaches at the southern end of the riverside may be similarly explained. At the northern end of the riverside where only a narrow sand and fine shingle beach exists, flanked by estuarine mud, the distribution of material may again be explained by the movement of the coarser material shorewards, the coarser being the sand and fine shingle and the finer, the mud. The presence of smaller pebbles on the riverside beaches reflects the lower energy content of the waves generated within the estuary.

Morphological Features of Beach Build Up

The form of the beach with its upper and lower divisions is constantly changing, as has been described in Chapter 2. Building up of the beach was observed most frequently throughout the year. This was effected by the removal of material from the bottom part of the profile and the addition at the top. The most common way in which material was added to the upper beach was in the form of a swash bar, a low ridge built on the beach at the limit of effectiveness of the swash, with a steep slope shorewards and a gentle slope seawards. (See plate 3.A). Usually only a single swash bar was present, but on occasions when tides were decreasing in range from springs to neaps, several parallel ones were observed ranging in age from the oldest highest up the beach to the newest lowest down. An example of the latter was found between Points A and B on 31st July, 1960. The presence of a swash bar shows that the waves are steepening the profile in order to attain a state of equilibrium. When a swash bar was absent and yet building up processes predomina~~a~~ted, the upper beach was markedly convex in profile and a crest was clearly defined. In some of these cases a swash bar may have been fully incorporated into the beach, in others the material was probably added so slowly that nearly complete equilibrium was maintained during the whole process. On a few occasions beach cusps etched the edge of the crest, for example near Point C on 10th June 1960. The reasons for the development of these features is still not fully understood.

Table 3.IX relates the development of sand rises on the lower beach to varying wind conditions. It appears that these features are best developed with offshore winds after a period of several weeks during which building up has predominated, as for example on 12th May and 28th August,1960. and 3rd February and 17th March, 1961. The only exception was on 12th May, 1960 when winds in the preceeding period had been predominantly east and south-east, yet building up had been proceeding from the time of the first observations on 13th April, 1960.

The scale of the building up of the beaches under all wind, wave and tide conditions varied little between the Points from the northern end of the seaward side of the spit to the Tip, on any particular occasion. The most rapid build up at all these Points occurred immediately after a period of breakdown. The scale of the building up on the riverside is considerably less than elsewhere and will be considered more fully in Chapter 6.

TABLE 3.IX

Sand Rises on the Lower Beach in Relation to Varying Wind Conditions

Date	Winds in preceeding wk	Lower Beach Features
12.5.60	E,SE,1/3 15K	Groynes I-VI. Sand hummocks and hollows. Groynes VI to XI. Oblique sand ridges and hummocks NW-SE, few large rises Groynes XI-XV. Large sand rises, few small ones. Groynes XV-XXVIII. Sand rises decreasing in size and no. N.
8.7.60	NW,var.W ($\frac{3}{4}$ 15K)	Groynes I-XIII. Large sand rises Groynes XIII-XXVIII. Few sand rises
28.8.60	S,SW 15K	Groynes VIII-XI. Large sand rises, oblique NW-SE Groynes XI-XXI. Large sand rises. Groynes XXI-XXVIII. Smaller sand rises than further S.
22.10.60	NE,E,SE,S $\frac{1}{2}$ 15K	Groynes IX-XI. Small irreg. sand rises. Groynes XI-XIII. No clear division between upper and lower beach. Groynes XIII-XXI. Large sand rises Groynes XXI-XXVIII. Featureless lower beach (1 exceptior

Table 3.IX continued.

Date	Winds in preceeding week	Lower Beach Features
21.12.60	N,NW,NE $\frac{1}{2}$ 15K	About groyne X and XV-XVIII, small irreg. and crescent-shaped sand rises. Groynes XVIII-XX, large sand rise, with water filled hollows in it. Elsewhere sand with surface water.
3.2.61	SW,W,NW $\frac{1}{2}$ 15K	S. of groyne XII, lower beach not exposed N of groyne XII-XXVIII large sand rises
17.3.61	W,SW,S $\frac{1}{4}$ 15K	Sand rises varying enormously in size, from groynes II to XXVIII.

The conditions under which these forms develop will now be summarized briefly. The morphological features of build up may be expected primarily after an offshore wind has been blowing for several days although they can develop with light onshore winds also. The gain is most marked on the top part of the beach, and on the bottom part of the beach on the seaward side of the spit there is often a loss. A net gain may be expected over the whole beach however. These offshore winds lessen the steepness of the waves to an average of .0063; and produce an offshore movement of water in the surface layers ofthe sea which is compensated by a shoreward movement near the bed. The relatively low steepness value of the waves and the shoreward drift of the lower layers of the water help to build up the beach. The energy content of the observed waves was less than 20,000 foot-pounds per foot of wave crest per wave length and the period less than 8.5 seconds, on the seaward side. The maximum recorded angle of approach of these waves was 20^{o} southwards, with an average of 4.28^{o}. When building up processes predominate, the only disturbance of the predicted tides is likely to be a depression of level when strong winds blow from between south and west. This means that less of the beach than normal is subjected to wave action.

Morphological Features associated with Storm Conditions

As a detailed examination of the effect of one stormy period on the beaches is to be made and it will be necessary to refer to the wind, wave, and tide conditions in this, storm conditions in general will be summarized first, then a brief resumé of conditions during the particular period will be given.

Onshore winds tend to lower the beach on the seaward side of the spit, especially at the top part. The presence of a cliff in the beach facing seawards, as was seen east of Point A on 12th May, 1960 gives evidence of this. The main break down of the built up form, however, occurs only with strong north to north-west winds associated with a depression centred over southern Scandinavia. Winds from these directions blow over the longest fetch available from Spurn Head, and the largest possible waves may be produced. When winds of not less than 15 knots had been blowing for several hours waves with an energy content greater than 20,000 foot-pounds per foot of wave crest per wave length, which appears to be a critical value between waves which build up and break down the beach form were recorded. The wave period was greater than 8.5 seconds and the waves became more refracted than those from an easterly direction. Despite the refraction they reached the shore at an angle of up to 40° southwards; the average was 18.3°. Whilst onshore winds produced steeper waves than offshore ones, the storm waves from the north were not the steepest recorded. When these strong north to north-west winds blew, a storm surge occurred. If the peak of the surge coincided with near high water more of the beach than was normally affected by wave action was subjected to these very powerful waves (see Plates 3.B, 3.C, 3.D, 3.E, 3.F)

The effects of the stormy conditions towards the end of March, 1961 will be considered in detail with especial reference to the two sets of air photographs taken on 16th and 23rd March respectively. Two storm surges occurred between these two dates, on 18th and 20th to 21st March. Wave energy on 18th March was 34,000, on 19th was 41,900, on 22nd was 21,700, and on 23rd March was 10,500 foot-pounds per foot of wave crest per wave length. The profiles surveyed and the beach feature plans drawn during this period showed that the beaches were smoothed over and material was removed from the top of the beach but added to the bottom part between 19th and 22nd March, but by 23rd March there was evidence of building up processes re-commencing. Plates 3.G, 3.H, 3.I, 3.J, 3.K, and 3.L. show the effect of the first storm surge at Points B, D, and E.

With reference to the air photographs the beaches will be considered on the seaward side, southwards from Kilnsea to the Tip and then northwards along the riverside from the Tip to Kilnsea Warren. The beaches will be divided into sections within which the morphology was similar. In each section conditions on 16th March will be described first, then those on 23rd March will be compared with them.

<u>Kilnsea</u> (Air photographs 158,235,237)

A well built up upper beach existed north of Fort Godwin on 16th March. Large isolated sand rises had formed on the lower beach. About Fort Godwin only a narrow upper beach was present, with a long tongue of sand on the lower beach extending from the north groyne to the sixth south of it. South of Fort Godwin to groyne XXVIII there was a well built up upper beach and a lower beach with large isolated sand rises.

By 23rd March the upper beach north of Fort Godwin had been combed down by the powerful waves which occurred in conjunction with the two storm surges. A less well defined line separated the upper and lower beaches. On the lower beach a long tongue of sand was extending southward. The narrow upper beach remained about Fort Godwin, but the tongue of sand on the lower beach had been broken into three parts and did not commence until two groynes south of the northernmost one, but it extended a little further south than on 16th March. South of Fort Godwin to groyne XXVIII the upper beach had been combed down, and the lower beach had been swept bare of sand rises.

<u>Kilnsea Warren to Groyne XVII</u> (Air photographs 161, 237, 239)

On 16th March between groynes XXIII and XXVIII the upper beach was well built up, and the highest parts formed a clear subdivision which will be termed the "high upper beach". This had not been affected by waves for a considerable time during the preceeding non-stormy spell. Large, almost continuous sand rises were found on the lower beach. Between groynes XX and XXIII an upper beach narrowing in width southwards was present, with a lower beach devoid of features. Between groynes XVII and XX there was a suggestion of movement of material southwards. The upper beach, whilst it was narrow immediately south of each groyne broadened to the north of the next groyne south. The lower beach contained small sand rises aligned obliquely to the beach, north-west to south-east.

By 23rd March the upper beach between groynes XX and XXVIII had been combed down and the sharp line demarkating the lower edge had been obliterated. The lower beach had been swept almost completely clear of sand rises, only between groynes XXI and XXII were there any signs of such features. The high upper beach between groynes XX and XXIII was completely obliterated as a separate feature. Between groynes XVII and XX there was still a suggestion of the southerly movement of material on the upper beach but that had been combed down and narrowed markedly between groynes XVII and XVIII. Sand rises on the lower beach were limited to near the ends of the groynes.

Groyne XVII to Groyne XII (Air photographs 185,258,239)

A clearly defined upper beach existed on 16th March, with a marked high upper beach. An almost continuous sand rise was seen on the lower beach throughout the section. The oblique alignment of channels through this suggests a southerly movement of material.

On 23rd March the upper beach remained a well developed feature although the high upper beach had been obliterated. There was a slight build up of the upper beach between groynes XIII and XVI, and a narrowing between groynes XII and XIII. The lower beach was devoid of features except between groynes XII and XIII where a complicated set of features had been removed. As the tides were neaps on 23rd March some of the features may still have existed below low water mark.

<u>Groyne XII to Groyne I</u> (Air photographs 183,173,256,258,254)

About Point C on 16th the wide expanse of sand from the dunes to opposite the ends of the groynes was clearly seen. Seawards of this, and separated from it by sand with surface water, was an almost continuous strip of sand rises. A broad well developed upper beach had developed between groynes I and XI. A broad, high upper beach formed a continuous feature except on the eastern side of the Lighthouse Zone where the revetment juts east of the general line of the dune edge. Elongated lozenge-shaped sand rises were marked features of the lower beach north of groyne VIII. The channels between them were aligned obliquely to the beach, and appear to be related to the angle and approach of the waves.

With the neap tides on 23rd March, only the upper beach was visible at low water, except about Point C. There the broad expanse of sand sloping gently from the dunes was well marked. The upper beach remained well built up south of Point C. Cliffing of the dune face immediately south of groyne XI had occurred and the high upper beach had been obliterated along the whole section. The lower half of the upper beach is typified by longitudinal strips of shingle alternating with sand. These are slightly oblique to the line of the dunes.

<u>Groyne I to the Lifeboat House</u> (Air photographs 173, 254)

A well built up upper beach was seen on 16th March extending all round the Tip, with a high upper beach forming a marked feature. The broadness off the beach to the east of the Tip where the Binks join it contrasted with the narrowness immediately west of the Tip before it broadened towards the Lifeboat House.

The entire beach had been subjected to wave action at the times of the tidal surges so that the high upper beach had been completely obliterated by 23rd March. The edge of the dunes had been slightly cliffed. There were signs of a slight build up in the middle section of the beach round the south-east corner of the Tip, by 23rd March.

The Lifeboat House to the Concrete Blocks west of Spurn Warren (Air photographs 173,254,256)

On 16th March a narrow upper beach existed northwards from the lifeboat cottages, but was missing southwards. A broad expanse of sand and mud below the upper beach contained a series of sand ridges aligned obliquely to the shore and suggesting a northward movement of material. Sand was held up markedly by the jetty and life-boat house and also by the former sewage pipe and the long boom.

The surges caused no substantial changes in this section. The ridges on the lower beach were less clearly delineated and there was a broader spread of sand. A slight upper beach had developed around the walls of the battery. Elsewhere the upper beach showed no change.

The Concrete Blocks west of Spurn Warren to the Northern End of South Spurn (Air photographs, 183,256,258)

On 16th March a narrow upper beach existed with ridges developed on it close to the dunes. In the middle of this section a series of finger-like projections of sand extended from the upper beach slightly oblique to the main line of the dune edge. The bank of Old Den lay beyond these projections. A broad area of sand accumulation lay at the mouth of the channel which drains the area near the Chalk Bank. The sand banks splayed northwards, and their northern edge was the northerly extremity of sand accumulation below the upper beach on the riverside of the spit.

By 23rd March the features on the upper beach had been smoothed over. The bank of Old Den showed no change. The greatest difference between conditions on the two dates was seen between the two. Whilst the long finger-like projections of sand remained substantially the same they had been extended slightly westwards and had increased in width by 23rd March. Many more shorter ones, not attached to the beach had developed north of those seen on 16th March. The area of sand accumulation extended to opposite the northern end of the Chalk Bank as before, but more sand was present in the marginal area.

<u>The Riverside Beach of High Bents and Kilnsea Warren</u> (Air photographs 185,161 158,258,239,237,235)

For about a third of a mile north of the south end of High Bents any changes which occur on the beach are masked by the presence of chalk rubble. From the lower edge of the beach on 16th March ridges of mud extended westwards. The beach broadened slightly and contained a series of swash bars opposite groyne XIX. At this point there was a marked angle to the dune edge, and the broader section of beach gave a smooth curve to the lower edge of the beach on the western side of the spit. The expanse of mud below the beach in this central section contained a pattern of fine channels lying parallel to each other and which have swung widely round the northern end of Old Den and splay out towards the spit.

Little change occurred between 16th and 23rd March. The ridges on the broader section of the beach had been smoothed over by 23rd March. The dune edge had been slightly cliffed along most of the section as a result of the surges. The pattern of fine drainage channels in the estuarine mud was not disturbed.

Other periods when the break down of the built up form of the beach was marked all occurred when strong north to north-west winds blew, and the break down was more complete the longer the winds blew. Five such occasions occurred during the year of detailed observations, about 29th June, 21st September, 12th October, and 21st December, 1960, in addition to that which has already been discussed.

It is possible to draw a number of conclusions about the effect of storm conditions after considering them all.

1. Material is combed down the beach from the highest part at which wave action is effective. All the features which may have been built previously on the upper beach, and a high upper beach if that had developed, are obliterated, as are features on the lower beach (see Table 3.IX). This gives an almost even slope to the beach from the edge of the dunes down to low water mark. The boundary between the upper and lower beaches, which is usually a clear line when the beach is built up, becomes ill-defined.

2. The material which is removed from the top part of the beach may be deposited on the bottom part, or material may be removed from there also, and the whole may be taken out below low water mark.

3. One particular beach form, the tongue of sand and shingle which splays out from the upper beach at a low angle to it southwards, suggests a rapid movement of material laterally. The large angle at which these very powerful waves approach the shore means that material must move laterally faster under such conditions, than at any other time. (This will be considered more fully in Chapter 4)

4. Once the storm conditions die down material returns to the beach rapidly. For example, on 23rd March, 1961 there were already signs of the re-building of the beach, although another slight surge on 26th and 27th March slowed down this process. By 5th April, 1961, after a period of light and variable winds interspersed with calm spells there was a rapid return of material.

5. Whilst the form of break down of the built up beach is the same at all Points along the seaward side of the spit, that at Point E has been observed to be the most complete. This Point is representative of the section of the spit facing north-east, and as Figures 3.1 and 3.2 show, the orthogonals for waves from the north and north-north-east converge on this section.

6. The riverside under storm conditions could be considered most fully on the two sets of air photographs taken in March, 1961. In contrast to the seaward side, which receives the full force of the storm waves,

the riverside is more sheltered. Here, there were signs of the accumulation of material on the lower beach north to the northern limit of the Lighthouse Zone, and about the projections of sand opposite the southern end of the Chalk Bank. Many of the ridges, especially the northern ones, became more clearly delineated, and increased in number northwards. Over the whole of this area from the Tip to the northern end of the Chalk Bank, there was a broader spread of sand. The riverside beach of High Bents and Kilnsea Warren was little affected, but the dune edge was cliffed in parts, due to the storm surge raising the height of high water to an unusually high level.

7. The low section of beach which was seen about Point C after the middle of October 1960 was moved to that position by the most powerful waves which were recorded during the year of observations. Once in position less powerful storm conditions could rapidly erode the dunes. This however, will be considered in detail in the next chapter.

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CHAPTER 4

LONGER TERM BEACH CHANGES

This chapter will be devoted to a consideration of larger and longer term beach changes which are of greater significence to the evolution of the spit. These changes appear to affect only the seaward side, directly.

Along much of the Holderness coast features which in dialect are known as "ords"* form part of the pattern of change in the beaches. No published references to these have been located, nor descriptions of similar features elsewhere. A local fisherman has described them in the following terms. "Ords are low sections of beach, which are commonly between 50 and 60 yards long. The sea sweeps away the sand and shingle which form the beach at other times, and lays bare the boulder clay platform beneath, with large boulders embedded in it. Large storms do not fill in these ords but cause them to move southwards. The rate of movement varies greatly, but the average is probably about one mile per year. Ords are not found immediately south of Flamborough Head, but appear north of Hornsea and are common from there south to Spurn Head. When an ord passes an unprotected section of coast the removal of sand and shingle enables every tide to reach the base of the cliff and hence the rate of erosion is rapidly increased. Where groynes and revetments have been built, they frequently fail to withstand wave attack especially during stormy conditions, as the waves can penetrate

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Footnote * "Ord" is spelt according to the Holderness dialect pronunciation, as the word has not been traced in written form.

below the defences and in the case of revetments attack them from the rear".

In the description of the beach cnditions at the time of the 1959 air survey it was noted that the upper beach was practically non-existent between groynes XV and XX (see air photographs 9409, 9410, 9411), and that large pebbles, which appear to form a base to the beach south of the southern most extension of the boulder clay, were visible near groynes XVII, XVIII and XIX. Broad sand rises were seen on the lower beach. Attention may be drawn to the collapsed revetment top north of groyne XVII, and the completely broken down revetment between groynes XX and XXI, behind a then well built up upper beach. The low section of beach was closely observed during the autumn of 1959 and the winter of 1959 to 1960.

On 18th and 19th November, 1959 the upper beach began to narrow south of groyne XXI. The previously broken revetment between groynes XXI and XX was partly buried by sand and shingle. The upper beach continued to narrow southwards past groynes XX and XIX at both of which the beach was two feet lower on the south side than on the north. The upper beach lowered about groyne XVIII and the bottom cross-planks were exposed. There was no upper beach about groyne XVII and the duneward part of the lower beach between groynes XVII and XVIII consisted of ridges of sand and water filled hollows, with a larger sand rise seawards. The beach was hollowed out beneath the bottom plank of groyne XVII and large boulders which appear to form the base of the beach, lay on either side of it. There was a very narrow upper beach between groynes XVII and XVI but it broadened towards groyne XV.

On 10th December, 1959, between groynes XVII and XVIII there was a gently sloping sandy lower beach with runnels flowing across it. Masses of large boulders were piled up half-way along groyne XVIII on the south side. Between groynes XVII and XVI there was again a gently sloping lower beach, with the upper beach appearing only towards groyne XVI. The upper beach was 3 feet lower to the south of groyne XVI than to the north. There was a mass of large pebbles piled up half way along groyne XVII to the south of it. Below the junction of groyne XVII and the revetment there was a gap of 3'9".

On 17th December, 1959 conditions on the beaches were almost the same as on 10th December. Many holes were visible in the wooden revetment wall north of groyne XVII. The maximum depth of the gap beneath groyne XVII was 4'5".

On 31st December, 1959 between groynes XVIII and XVII there was still only a gently sloping lower beach of sand extending from the revetment. On the bottom part towards low water mark sand ridges and runnels had formed, either straight and at right angles to the beach, or in an crescentic form concave southwards. Between groynes XVII and XVI the upper beach appeared only immediately north of groyne XVI, and the lower beach was similar in form to north of groyne XVII. The maximum space below groyne XVII was 3'6".

By 20th January 1960 the part of groyne XVII nearest the revetment had been torn up and laid at an angle southwards. The concrete facing on top of the revetment had been broken from further north than seen on air photograph 4910 to the south of groyne XVII, by waves forcing their way beneath the revetment facing wall and through the holes in it. A large semi-circular bite had been taken out of the eastern edge of the dune opposite groyne XVII. On December 31st 1959 there had been 40 feet 6 inches of dune between the eastern edge of the road and the dune edge, on 20th January 1960 there was only 23ft. 6 inches.

The evening high tides of 26th January, 1960 smashed more of the revetment immediately north of groyne XVII and broke off most of the previously torn up section of the groyne itself. The evening high tide of 28th January tore away 30 ft. 6 ins. of the revetment wall 47ft.6ins. north of groyne XVII. By 29th January the bite taken out of the then unprotected dune face behind groyne XVII had been increased and there were only 13 feet from the eastern edge of the road to the top of the dune edge (see plates 4 A,B,C.D.) A tongue of shingle and pebbles of varying sizes which on 29th January extended three quarters of the distance between groynes XVIII and XVII had by 2nd February extended a little south of groyne XVII. Whilst extending south, this tongue was also pushing up the beach from about half way along groyne XVIII to the beach in groyne XVII. A channel up-beach of it on 29th January was almost filled in by 2nd February and pebbles instead of the almost pure sand of the lower beach filled the area beneath the rubble of the collapsed part of the revetment.

This tongue began the rebuilding of the upper beach between groynes XVIII and XVI, and was of a similar type to those seen along various parts of the seaward side of the spit after stormy conditions, which suggest the rapid movement of coaser material southwards.

The profiles surveyed from 3rd February to 19th March at three points, D North half way between groynes XVII and XVIII, D Breach through the breach in the revetment, and D South half way between groynes XVII and XVI, have been superimposed (see figure 4.1). The ridge and remnants of the channel up-beach of it can be seen at D North and D Breach on 3rd and 4th February respectively. By 17th February the beach had built up most markedly at D South, beyond which the ridge had extended by this time. At one point along the profile the beach was 4 feet higher than on 4th February. At D Breach the maximum build up was 3 feet and at D North the figure was the same although this represented sand swept up against the revetment wall, whereas the top of the ridge had been cut away. By 2nd March a swash bar had been built up and this shows clearly on all the profiles. The profiles for a fortnight later show that the top of the swash bar had been cut away.

The building of swash bars and their partial removal depending on weather conditions is clearly part of the small term changes which occur on the beaches week by week. By 19th March the upper beach had been well established again after the movement south of the low section of beach, during the presence of which the upper beach had been completely absent.

It is noteworthy that while there was no upper beach the ~~lower~~ bottom part of the beach maintained a relatively high level, and the profile had a gentle slope. As the upper beach became built up again the lower beach became lower and the profile became steeper.

Measurements from the eastern edge of the road to the top of the dune slope where the revetment breach occurred showed a gradual retreat of about 3 feet up to March 1960. The base of the dune slope showed little overall movement. Only high spring tides reached the base, cut into it, and made the slope above unstable, causing a partial collapse, and the general slope to be thus steepened. However, the wind moved so much dry sand, that the loss so incurred was readily replaced, especially when the wind was from the west and blew sand across the spit and deposited it down the slope. A small amount of erosion of the slope was observed with easterly winds.

Before considering the further movement of this low section of beach the weather conditions affecting its movement southwards ffom the position centred on groyne XVII will be examined.

It was shown in Chapter 3 that only when north to north-west winds of over 15 knots blew for a period of several hours to several days ~~in~~ there a major break down in the form of the beach. Under all other wind conditions the beach tends to become built up in form. Between September 1959 and March 1960 conditions which would be likely to cause the greatest beach changes occurred as follows:-

28th-29th October, 1959	N.,N.W.Winds, 20-26 Knots;	neap tides
4th - 5th December,1959	N.,N.W.Winds, 14-20 Knots;	neap to spring tides
14th-16th January,1960	N.W.,-N.E.Winds 15-35Knots;	spring tides
27th-29th January,1960	E-N.W.Winds,15-33 Knots;	spring tides
3rd-4th March, 1960	N.W.,N.Winds,15-30 Knots;	neap tides

Of these five occasions it is obvious that the two most crucial are those in January, 1960 when strong northerly winds blew for two separate spells of three days, and both coincided with spring tides. The p.m. high water of 29th January was predicted to be one of the highest of the year. It has been shown that considerable damage was caused between 31st December and 20th January, and as 14th to 16th January was the only stormy period, it may be assumed safely, that this was when it occurred. The severest damage and the movement of this low section of beach southwards as a ridge extended from the north occurred only during the last week in January when wind and tide conditions combined to effect the maximum change.

The fact that the revetment was breached at the particular point near groyne XVII was the result of the presence of the low section of beach at the time when a severe storm occurred, coupled with the fact that this part of the revetment jutted slightly eastwards of the general line of the edge of the dunes in this section of the spit, and therefore was most directly exposed to the storm waves.

By 23rd March, 1960 the low section of beach lay between groynes XIv and XVI. The concrete top of the revetment caved in along the whole of this section as the waves pounded beneath the wall and poured through holes torn in the wooden planking, but there was no storm severe enough to cause another breach in the revetment. The subsequent movement of this low beach may be traced in Figure 2.3. By 12th May only a small movement had occurred to centre it between groyne XIII and XV. The stormy period at the end of June 1960 caused a further movement, so that on 8th July it was found to lay between groynes XII and XIV, where it remained until the following October. There was a slight build up of the beach between groynes XIV and XIII. during July and August, but there was no movement of the southern end. When the low section lay between groynes XII and XIV where the dune edge is not protected by a revetment, the upper beach was not completely removed, but it became very narrow immediately south of each groyne and as a result, the previously well developed fore-dune was eroded and the main dune behind was cut back to give an approximately 12 foot high sand cliff. The upper beach broadened towards the next groyne southwards, and therefore north of each groyne the foredune and main dune suffered little erosion. The lower beach was generally devoid of sand rises, except where a large one had formed between groynes XII and XIII and persisted from May, 1960. It is noteworthy that large sand rises persisted south of groyne XII to beyond groyne XI during this period.

At Point C, between groynes XI and XII, the winds from an easterly quarter, which blew between 25th September and 9th October, 1960, began to lower the upper beach, and the division between the upper and lower beaches became less well defined. The north to north-west winds between 15 and 28 knots which blew from 10th to 13th October, caused a prolonged storm surge and produced the most powerful waves recorded during the year of detailed observations. These conditions caused the low section of beach to move southwards again and become centred on Point C. The true upper beach was swept away to leave a very gently sloping expanse of sand from the edge of the foredune which was cut into a cliffed form. Water appeared on the surface of the sand only near low water mark. The conditions week by week until 5th April, 1961 have already been described in Chapter 2, but certain general observations may be made here.

The presence of this low section allowed all the high spring tides to wash the foot of the sand cliff, steepening it and causing the slumping of material from higher up. The foredune had been completely removed by 4th November, 1960 and then the waves began to attack the seaward face of the main dune ridge. This retreated slowly and was finally completely removed by the storm conditions about 22nd December. The cliff is shown in January 1961 on Plates 4E and 4F.

Soon after the low section had become established about Point C the top part of the beach adjacent to the cliffed dune began to develop a slightly convex profile and shingle was added to the almost pure sand. This protected the cliffed edge from wave attack and there was little retreat after the end of December, 1960.

The storm conditions in the latter half of March 1961 caused the low section of beach to penetrate southwards, although there was little sign then of the infilling of the northern part to move the entire feature southwards. Plates 4G and 4H show the low section of beach on 19th March, 1961.

The beach feature plans and the profiles surveyed at Point C between April and August 1961 (see Figures 4.2, and 4.3) when there were no major stormy spells associated with strong north to north-west winds, showshow the upper beach was slowly rebuilt. From 14th April onwards it was possible to differentiate between the upper and lower beach. The upper beach steepened and became more convex in profile. Either a swash bar or well defined crest was present after 4th May. Early in April large pebbles became visible near the end of groyne XII showing that at least part of the lower beach lay near to the base of the beach again. When the upper beach had been absent the bottom part of the beach had been raised in level. The pebbles were seen intermittently during these months, and by the beginning of June large pebbles became visible at the junction of the upper and lower beaches from groynes XI to XII indicating a more marked build up throughout this section. On the lower beach after the beginning of May well defined sand rises began to appear again. The single large one remained north of groyne XII, but many smaller ones formed intermittently between groynes XII and XI.

Between October 1960 and August 1961 the passage of this low section of beach past Point C was observed. Its presence at Point C wrought considerable changes to the outline of the spit there, with the complete destruction of the foredune and the seaward slope of the main dune ridge. At the time of writing (July 1962) it lies about groyne VIII. During its passage from Point C southwards it has caused similar changes along this section of the spit. The foredune which was best developed between groynes VIII and XI is now seen only in isolated patches, and in many places the main dune ridge has been cut back.

The development of large rises on the lower beach south of groyne XII during the summer of 1960 when the low section lay north of it has already been noted (see page 147) In February 1962, when it lay between groynes VIII and X there was an extensive development of sand and shingle rises on the lower beach extending from groynes VIII to IV. (See Plate 41)

The passage of a low section of beach past a dune section of the coast protected by groynes and a revetment and past a section protected only by groynes has been described. In order to make a further comparison observations were carried out for a year from April 1961 to April 1962 at Kilnsea where a boulder clay section of coast was protected by groynes and a revetment. The latter however was partly breached in 1954, enabling the sea to attack the boulder clay behind. Once a fortnight a profile was surveyed along a line through the centre of the breached section of the revetment, and plans of the beach features on either side of this line were drawn. Measurements were taken of the rate of cliff recession by recording distances from the broken revetment to the cliff foot and from the cliff top to a nearby fence. The height, period, type and angle of approach of the waves were noted also. Wind data at 3 hourly intervals continued to be collected during the year.

The changes which occurred on the beach as seen in figure 4.4 of the profiles and figure 4.5 of the plans of beach features will be described first. They will then be related to wind and wave conditions. Finally changes in the cliff behind the broken section of the revetment will be discussed.

Between the end of April and the end of September 1961 the profiles and beach feature plans show that a well built up beach existed about Fort Godwin. The boundary between the upper and lower beaches was clearly defined. The upper beach was either crested or had swash bars developed on it. Large pebbles embedded in the boulder clay beach platform were visible from time to time at the junction of the upper and lower beaches near the north groyne showing that the beach reached its lowest at this part of the profile. A variety of sand rises were seen on the lower beach. All the profile changes fell into the category of small scale changes as defined and described in Chapter 3.

Between 25th September and 8th October 1961 a significant change occurred. The superimposed profiles showed that there was a slight drop in the level of the top part of the beach and the bottom part was slightly raised. The beach feature plan for 8th October revealed a marked morphological change. The boundary between upper and lower beaches had been obliterated. Sand and a little shingle remained near the cliff foot but sand and small pebbles covered the area towards the low water mark. North and south of this low section of beach centred on the breached revetment, upper and lower beaches were still well defined entities, with the upper beach crested. It should be noted that a low section of beach had previously been stationary immediately north of Kilnsea. By the 20th October along the whole section, the upper beach had been partially removed to give the profile an even slope from top to bottom. Lowering of the top part of the surveyed profile line continued, and the boulder clay platform was exposed in parts. On 6th November, the top part of the beach had the same form as a fortnight earlier except at the southern end of the section there was a crest again. Along the middle of the beach as far south as the southern short groyne lay a channel of water draining south. Seawards of it was a large and continuous sand rise with small pebbles, which in form was similar to the tongue of sand and shingle which filled in the low section of beach about groyne XVII after the beginning of February 1960. The profile surveyed on 6th November showed the channel position the large sand rise, and also revealed that the level of the top part of the beach was still falling. Towards the southern end of the beach feature plan, upper and lower beaches had become distinguishable again. By 19th November the profile had fallen to its lowest level. Between the broken revetment line and the cliff foot, the boulder clay platform was exposed or lay only a few inches beneath the sand and shingle. The rubble from the revetment lay on the boulder clay. (It may be noted at this stage that the hump in the profile line about the datum post represents part of the remnants of the concrete foundations to the revetment). The large sand rise noted previously had pushed up the beach north of the north groyne, but was still clearly recognisable in form. Between this groyne and the third long groyne south it appeared to have been smoothly incorporated into the beach to cause the middle part of the profile to be raised slightly.

Between 19th November 1961 and 30th January, 1962 the beach at Kilnsea was raised in level. On 5th December the long projecting tongue was still clearly visible immediately north of the north groyne. At the extreme northern end of the area of the plan of beach features it had become completely incorporated into the beach after pushing up-beach to the foot of the cliff. It was discernible opposite the breached revetment at this date after apparently extending southwards. Towards the southern end of the section the upper and lower beaches remained separate entities. The profile showed how this tongue had raised the level of the bottom part of the beach. By 21st December there was no sign of it. North of the north groyne the beach was slightly crested but elsewhere sloped fairly evenly from top to bottom. The superimposition of the profile on that of 5th December showed that the beach had been markedly raised in level along almost the whole width. By 11th January a remarkable build up had taken place. A considerable quantity of material had been pushed up the beach and sand

and shingle together composed the lower beach in the northern part of the section as sometimes occurs when there is a mass return of material to the upper beach. Only about the end of the third long groyne south was there no clear division between upper and lower beaches. The upper beach was crested in the north and along the profile line a swash bar had been built on the markedly convex profile. At the datum post the level of the beach had been raised 4.5 feet since 21st December. The upper beach had a smoother slope south of the second groyne from the north. As was seen when the low section of beach about groyne XVII was being filled in during February and March 1960, the lower beach fell in height as the upper beach was raised. Between 21st December 1961 and the 11th January 1962 the profile at low water mark at Kilnsea fell 2.5 feet. As the presence of sand and shingle on the lower beach on 11th January suggested, the build up was not complete. In the northern part of the beach feature plan a slightly more convex upper beach was seen and this was shown clearly by the profile. (Regrettably this could not be tied in to the datum post which had been completely buried and could not be found). South of the third groyne from the north another projecting ridge of beach material extended southwards towards the only partially developed low section of beach, which lay immediately south of the area covered by the plans, after never becoming fully established in the southern part where the line of the revetment curves westwards suddenly.

During February and March 1962 the beach fell from this very high level. A smooth slope along the whole section was seen on 18th February. Along the profile line the maximum drop was 2.5 feet from 11th January, but there had been a slight rise in the level at the foot of the cliff. On 3rd April the upper beach was crested north of the north groyne and south of the third long groyne south of it. Only in the central section where the revetment juts east of the general line of the cliffs, did the beach slope smoothly as was shown on the profile, and this represented the part of the beach which sloped from the crest, north and south of it. In the extreme south of the plan the northern extremity of a southerly projecting tongue was ~~can be~~ seen.

The wind conditions during these observations at Kilnsea will be considered, as shown in figure 4.6 and the wave data as given in Table 4.1 From figure 4.6, Table 4.II was compiled to show when strong north to north-west winds blew, and when therefore the greatest changes would be most likely to occur. The severest stormy period the year occurred between 17th and 20th October, 1961 and at this time the low section of beach became fully established at Kilnsea. The wave data for 20th October showed that the wave energy in deep water was over 20,000 foot-pounds per foot of wave crest per wave length, and as shown in Chapter 3 pages 127 to 137 this amount of wave energy is likely to produce the greatest of the short term changes. In order to move this low section southwards there must have been a considerable movement of material from the north to raise the level of the beach where the low section had previously been established. The fact that after stormy conditions material is often moved in the form of a long tongue of

TABLE 4.1

Wave Data Related to Wind Conditions at Kilnsea

Date	Wave Ht. in ft.	Wave Period in Secs.	Type of Wave	Direction of wave approach°	Angle of Wave Approach°	Wave Energy in ft. lbs/ft. of wave crest/ wave length	Wave Steepness Ho/Lo	Wind Direction and speed in Knots
29.4.61	2	8.5	P	85	15N	3,585	.0030	NW,N 5
12.5.61	3	7.5	P	60	10S	8,760	.0068	N,NW 15
26.5.61	3	10	S	50	20S	10,500	.0031	N, 15
9.6.61	0.5	-	P	-	0	-	-	W 10-15
21.6.61	1	8.5	S	65	5S	473	.0011	W, 10
27.8.61	0.5	-	S/P	-	0	-	-	SW, 15
8.9.61	2	7.5	S	70	0	3,325	.0042	W,NW, 10
25.9.61	1	-	P	-	0	-	-	W,N, 5-10
8.10.61	2.5	8.5	S/P	-	0	9,580	.0049	S 15
20.10.61	4	8.5	S	60	10S	21,550	.0073	NW, N, 30
6.11.61	1	-	S	-	0	-	-	S 15
19.11.61	2.5	12	S	65	5S	11,530	.0019	Calm,E,o-5
5.11.61	3	12	S	65	5S	11,530	.0019	S,W. 20
21.12.61	3	-	S	-	0	-	-	W,N.W, 5-10
11.1.62	1	-	P	-	0	-	-	SW 25
30.1.62	2	5	P	-	0	2,305	.0117	Calm,S. 0-10
18.2.62	4	10	S	70	0	21,700	.0045	W,NW, 25
3.4.62	3	12	S	65	5S	11,530	.0019	W,SW 20

TABLE 4.II

The Occurrence of Strong North to North-West Winds. April 1961 to April 1962

Date	Wind Direction	Wind strength in Knots.
9-10.5.61	N,NW	15-20
20.5.61	N,NW	15-20
25-26.5.61	N,NW	15-20
31.5-2.6.61	N,NW	15-25
13.6.61	N,NW	15-23
4.7.61	W,N	20-27
17-20.10.61	NW,N	15-35
3-4.11.61	W,NW	20-24
8.2.62	NW,N	15-28
13-14.2.62	NW	20-35
17.2.62	NW	15-30
12-14.3.62	N,NW	15-23

sand and shingle has been noted already (See Chapter 2, beach conditions on 21st October, 1960, pages 62/63). By 6th November 1961 the bottom part of the beach consisted of what appeared to be the southern end of such a tongue. Had such a feature been established north of Kilnsea after the storms which established the low beach at Kilnsea, it would be moved south during the next stormy period if it had not been absorbed into the upper beach by then. On 3rd and 4th November another storm occurred of considerably less severity than the former, which whilst not being able to move the low section could extend the tongue of beach material southwards. Under calmer conditions this would probably move slowly south and gradually be incorporated in the beach. It is suggested that this is the explanation for the sequence of changes which occurred at Kilnsea during November and December. Once the upper beach was re-established the absence of strong north to north-west winds during January 1962 would enable the building up of the beach to proceed at the rapid rate which was observed. When the second most severe storm of the year occurred on 13th and 14th February 1962 followed three days later by another storm with waves of over 20,000 foot-pounds per foot of wave crest per wave length, the upper beach was so well built up that only a combing down of the upper beach occurred, a short term change in fact. By 3rd April another slight lowering had occurred but the well-built up upper beach remained, and this change falls into the same category, as do those which occurred between April and September 1961.

What relationship, if any, exists between the form of the beaches and the rate of recession of the cliffs? Between the end of April and the beginning of October 1961, there was no measureable change in the position or form of the cliff (see plate 4J) when the beach form was well built up and stable. On 20th October however when the low section of beach had become established and the base of the cliff foot was revealed the two eastward projections of cliff had their points clipped off. No further change was recorded until 19th November when slightly more of the projections had been clipped off and the whole had a battered appearance. With the presence of the low section of beach almost every high water washed the bottom of the cliff, slightly undermining the higher parts) By 21st December whilst the foot and top of the cliff were in the same position, slips occurred on the cliff face, primarily in the Hessle clay which forms the top part of the cliff at Kilnsea. This began to slump down over the lower clay, in places forming a mud flow. This was probably in part due to the slight undermining of the cliff. On 11th January 1962 half of what remained of the north projection of cliff was found to have been broken off and lay in a heap on the beach (see photographs 4K and 4L). Despite the well built up beach form, which had protected the rest of the cliff from being eroded, the spring tides at this time had been able to so undermine this feature that it collapsed. By the 30th January movement occurred on the steepest part of the cliff at the southern end of the section and the top was slightly eroded back. By 18th February a slip had occurred between the two eastward projections of cliff, and there had been slight erosion from the top and bottom of the cliff towards the north end of the section. A slight extension eastwards of the foot of the cliff here in one place was due to a slip from near the middle of the cliff. No other changes were recorded in the cliff before 3rd April, 1962. Figure 4.7 shows the complete change between the 29th April, 1961 and 3rd April 1962. This was indeed slight. Had the low section of beach remained in the position centred on the breached revetment for longer, and had stormy conditions with north to north-west winds occurred, greater changes due to more ~~to~~ undermining of ~~the~~ cliff might have been expected.

The characteristics of low sections of beach as observed at Spurn and Kilnsea may be summarized as follows:-

1. During a severe storm with strong north to north-west winds a low section of beach will be moved into a new position southwards. The upper beach is swept away and no division of the beach into upper and lower divisions is possible therefore. The bottom part, however, is raised, but not with any more than some of the sand and small pebble components of the former upper beach. Where the remainder of the material goes is not clear, although it appears probable that it is swept southwards to form a well developed system of sand and shingle rises on the lower beach, in front of a well built-up upper beach.

2. The presence of a low section of beach 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 a storm with strong north to north-west winds occurs when a low section is established, and the storm is not strong enough to move it, it may cause rapid retreat of the cliff of sand or boulder clay, and smash groynes and revetments. It should be noted that because of the nature of the material a sand cliff retreats immediately it is attacked, whereas a boulder clay cliff must be considerably undermined before parts collapse.

3. The movement of a low section south during a severe storm is inseperably linked with the movement of material from the north. The building up of the beach as a low moves south may be by the pushing up-beach of a tongue of sand and shingle as it moves south. Once the upper beach becomes re-established short term changes will recommence upon it. Build up is likely to be rapid, and as the upper beach is raised so the lower beach is reduced in level.

The low sections of beach are the main causes of erosion along the coast of south Holderness and the seaward side of Spurn Head. Only when one is present at any particular place does marked erosion occur. The cause of these features is not known, and must be sought far north of Spurn and Kilnsea. The fact that they are unknown in Bridlington Bay yet are common towards Hornsea, suggests that they may be connected with the sheltering effect of Flamborough Head. Storms associated with strong north to north-west winds produce powerful waves which approach the whole of the Holderness coast at the largest angle possible and therefore must cause the most rapid rate of littoral drift. Maybe the low sections of beach are instigated where these powerful waves first meet the coast with full force, after Flamborough Head has ceased to afford protection. At this point a more rapid rate of longshore movement of material than was occurring northwards of it would be started, and a gap in the built up beach would develop. As the position where this gap would develop would vary with the angle of approach of the waves, one which formed well to the south would be moved (southwards) from its position as storm waves attacked further north and moved the high beach north of it towards the south. Once the low sections developed ~~(low sections)~~ their infilling would be almost impossible as the rate of the longshore movement of material at any one time along this only slightly curving coast must be approximately the same, therefore the low and higher sections of beach would move as a unit.

The Longshore Movement of Material

Longshore movement takes place in two zones of the beach. Littoral drift occurs along the limit of wave action and is caused by waves breaking obliquely to the shore and sending swash obliquely up the beach, whereas the backwash returns at right angles to the contours of the beach. This causes material to travel along the shore in a zig-zag path. Longshore movement occurs also in the surf and breaker zone where the material in suspension is carried by the weak longshore currents.

Model studies of sand transport along straight-beaches with differing angles of wave attack have been carried out by Saville[1] and Shay and Johnson[2]. The former showed that steep waves moved most sand in the breaker zone, and flat waves moved most in the swash zone. The optimum wave steepness for longshore movement was between 0.02 and 0.025. Shay and Johnson, in extending Saville's work showed that most sand was moved when waves approached the shore at 30°. These studies cannot be applied directly to natural beaches because experimental conditions do not allow for irregularities in the coast, changing wind and wave characteristics and tides. Yet, it is very difficult to measure the amount of sand being transported alongshore in nature.

Caldwell[3] carried out a study near Anaheim Bay, California in an attempt to determine the degree to which mass alongshore sand movement on the beach and off-shore bottom could be correlated with the characteristics of ocean waves impinging on the beach. This followed an earlier study in 1952 at South Lake Worth Inlet, Florida[4]. From the findings of both studies the equation

$$Qi = 210\ Ei^{0.8}$$

where, Qi= intensity of net alongshore sand movement in cu. yards per day

Ei= intensity of net alongshore wave energy in millions of ft.lbs. per ft. of beach per day

was developed and may have more than local application to similar kinds of coasts.

The development of new tracer techniques especially in the last decade is helping to advance our knowledge of longshore movement of beach material.

Radio-active tracers were used off Scolt Head Island[5,6] to trace the movement of shingle over the sea bed. The tracer material, barium 140-lanthanum 140, was inserted in holes drilled in the pebbles to be used. This costly technique was improved upon in experiments carried out by the Nature Conservancy Physiographic Unit at Orfordness in 1957 [7]. It was found that the tracer could be made to adhere to the surface of the flint shingle of Orfordness, and that it could be fixed by baking. Allen and Grindley[8] applied the technique to silt in the Thames Estuary, and Reid[9] used radio-active sand to experiment on the east Anglian coast. The use of radio-active tracers, to detect the general direction and rate of movement of material, whilst proving a very valuable tool suffers from the disadvantages of being costly to prepare and needing expensive equipment to detect the tracers, and from the fact that great care is needed in handling the material which may be used only on isolated parts of the coast, where public access is restricted.

Because of these disadvantages much attention has been turned to the development of fluorescent tracers. In England this work has been done primarily by the Hydraulics Research Station of the D.S.I.R.[10]. Fluorescent sand tracers have been made by mixing beach sand with a fluorescent dye and a plastic glue. When the plastic hardened the whole was crushed producing individual sand grains coated with hard plastic impregnated with fluorescent dye. Tracer pebbles were made from heavy concrete stones in which were embedded small fragments of fluorescent plastic. The aggregate in the concrete was selected so that the end product was of the same density as the beach particles. Eight different fluorescent dyes, some fluorescing under short wave ultra-violet rays, and some under long wave ultra-violet rays may be used. It has been found possible to relate the total movement of shingle to the movement of tracers and to calculate the total net yearly littoral drift along a beach. Experiments carried out at Rye where the actual drift could be measured by the accretion against the western break water at the entrance to the River Rother, to compare with rate of drift calculated from the fluorescent tracer method, gave figures which were tolerably close together. Fluorescent sand has been used in wave basin experiments with success, but when the Hydraulics Research Station used it for an experiment on the Holderness coast at Tunstall, too low a percentage of tracer was found to make any deductions valid. This appeared to be due to the injection of too small a quantity of tracer sand, and the fact that the beach in the upper part is composed of sand and shingle probably complicates the issue. Sand fluorescent tracers have been used successfully in field experiments carried out by the Russians in the Black Sea,[11] and by the Germans in the western Baltic Sea and the German Wadden Sea. (The results of the latter have not been published, yet.)

In addition to the development of radio-active and fluorescent tracers, the cheapest and easiest to produce are painted pebbles, which are very effective as tracers. In addition they need no expensive equipment to locate them. The Nature Conservancy Physiographic Unit who have developed this technique farthest, in England coat shingle, from the area in which the experiment is to be made, with ship's paint, cover it with resin and bake it at 180° C to make it hard and able to resist attrition.

It was decided to carry out a series of short experiments on the lateral movement of material at Spurn Head and because of the ease and cheapness of preparation, and the simplicity in tracking, it was decided to use painted pebbles as tracers.

Experiment on the Longshore Movement of Material near Groyne III

The first experiment was carried out near groyne III to investigate the rate and direction of movement of pebbles on the seaward side of the spit.

Preparation

Pebbles were collected from the beach at Spurn Head near the proposed injection line for the experiment. They were coated with a hard gloss enamel paint of a bright turquoise colour and when dry were baked for half an hour at 150° C to harden the paint. (As it was not expected to be possible to track the material for more than a week or two at the longest, it was hoped that the paint alone would be sufficiently durable. It was not possible to use an oven capable of attaining temperatures higher than 150°C). They were graded according to size; small less than 2 inches long diameter; medium between 2 and 4 inches; and large, greater than 4 inches. A random sample of 10 from each group were weighed, and the average weights were: small, 57.3 grammes; medium, 207 grammes; and large 959.4 grammes.

Method

3rd September, 1961.

1,000 painted pebbles, approximately 1/3~~rd~~ of each size, were placed in a line down the beach from high to low water marks on the upper beach, 60 feet south of groyne III. The sizes were mixed in the same proportions throughout the total length of the line.

4th to 7th September, 1961

The beach was completely surveyed over the area where the tracer stones were visible at low water using a 5 foot sampling square. Wave conditions were recorded and wind data obtained.

8th to 10th September, 1961.

The beach was examined but so few tracer pebbles were visible that sampling was not considered worthwhile. Wave conditions continued to be recorded, and wind data collected. On 10th September the injection line was surveyed and the profile including both upper and lower beaches is shown in fig. 4.8. Plate 4M shows the area of the experiment, on the same day.

Beach, Wind, Wave and Tide Conditions

When the tracer was injected the whole of the inter-tidal zone had shingle at the surface. After one period of high water the shingle near high water mark was partially buried by a layer of sand, which remained during the whole period of observations. This explains why so few tracer pebbles were found in this part of the inter-tidal zone. A large quantity of sand was brought in by the p.m. rising tide on 7th September and more was brought in on the following one. This completely buried the shingle and hence only an odd tracer pebble was found on 8th September. On 9th September less sand was present and the shingle beneath was exposed in diagonal strips. Even so, less than ten tracer pebbles were found. By the following day more shingle had been laid down on top of the sand, so it was not surprising that less than ten tracers were visible.

Wind and wave conditions are given in Table 4.III. Winds were very variable and generally light. As a result only small waves were formed. The angle of wave approach was generally only 5° southwards although on 4th and 8th September it rose to 15° and 20° respectively. Maximum neap tides occurred on 4th September and maximum springs on 12th September.

<u>Results</u>

Figure 4.9 shows that all the tracer pebbles moved south from the injection line up to 7th September. There was a great concentration near the injection line on 4th September when only one tide had acted upon them. A much wider distribution was found on 5th, 6th, and 7th September, however, when a similar distribution pattern occurred each day. Table 4.IV shows that the average distances moved by all sizes of material spread over the whole of the inter-tidal zone, were as follows, commencing on 4th September: 19.35, 83.7o, 89.80, 96.20 feet.

Figures 4.10 and 4.11 show the actual distribution on the whole of the inter-tidal zone of different sized tracer pebbles, and the distribution

TABLE 4.III

Wind and Wave Data for the Longshore Drift Experiment near Groyne III

Date	Wave Height in feet	Wave Period in secs	Wave Type	Direction wave of Approach	Angle of Wave Approach	Wind Direction and wind speed in Knots	
3.9.61	1	6.0	P*	135°	5°S	Calm,SE,S	>10
4.9.61	1	5.5	P	125°	15°S	NE-SE	5-10
5.9.61	1	8.5	P	135°	5°S	Calm,W	>16
6.9.61	1	-	P	-	-	W	8-16
7.9.61	1	6.6	P	135°	5°S	W,NW	13-19
8.9.61	1	7.5	P	120°	20°S	NW,E,SE	3-14
9.9.61	1	-	P	-	-	[illegible]W-SE,Calm	>8
10.9.61	1	6.0	P	135°	5°S	S	8-14

*P = Plunging

of all the tracer pebbles found within the different parts of the inter-tidal zone. In Table 4.IV the distribution is tabulated and the movement averaged.

Considering the whole period most tracer pebbles were found in the middle part of the inter-tidal zone, followed by the lower, with least in the upper parts. Within each zone most were of medium size, less of large size and least were small.

The greatest average distances were travelled in the middle, followed by the upper and then the lower parts of the inter-tidal zone. Medium and small tracer pebbles travelled the greatest distances in the middle and lower parts, but small, medium and large alternated on different days to travel the farthest in the upper part.

The fact that the deposition of sand on top of the shingle on 7th September effectively stopped the tracking of tracer material hints at a complex movement of material. More so, does the fact that so few tracer pebbles were found when the shingle was partially laid bare again on 9th September, before more shingle was deposited on top of the sand and shingle. The reasons for the change in surface beach material are not apparent as waves conditions varied so slightly and tides were only rising slowly from neaps towards springs. Whatever the cause, the rates of movement of material recorded between 3rd and 7th September must be treated with great caution.

Table 4.IV

Movement of Tracer Pebbles near Groyne III

4.9.61

A. Distribution

Pebbles	Whole I.T.* Zone	Upper I.T. Zone	Middle I.T. Zone	Lower I.T. Zone
Small	86	21	26	39
Medium	138	26	52	60
Large	161	29	64	68
Total	385	76	142	167

B. Average Distances Moved in Feet

Pebbles	Whole I.T. Zone		Upper I.T. Zone		Middle I.T. Zone		Lower I.T. Zone	
	N	S	N	S	N	S	N	S
Small	-	23.57	-	34.00	-	28.25	-	20.20
Medium	5	18.98	-	12.14	5	34.30	-	23.45
Large	-	16.34	-	15.00	-	20.25	-	18.45
Total	5	19.35	-	19.02	5	22.00	-	20.80

Table 4.IV continued.

5.9.61

A.Distribution

Pebbles	Whole I.T. Zone	Upper I.T. Zone	Middle I.T. Zone	Lower I.T. Zone
Small	57	8	32	17
Medium	83	17	45	21
Large	70	14	43	13
Total	210	39	120	51

B.Average Distances Moved in Feet

Pebbles	Whole I.T. Zone		Upper I.T. Zone		Middle I.T. Zone		Lower I.T. Zone	
	N	S	N	S	N	S	N	S
Small	-	99.82	-	36.25	-	118.20	-	93.90
Medium	-	84.94	-	42.50	-	89. 00	-	73.30
Large	-	67.22	-	51.42	-	77.50	-	79.20
Total	-	83.70	-	43.00	-	92.70	-	81.90

Table 4.IV continued.

6.9.61

A. Distribution

Pebbles	Whole I.T. Zone	Upper I.T. Zone	Middle I.T. Zone	Lower I.T. Zone
Small	63	4	41	18
Medium	79	5	40	34
Large	76	8	42	26
Total	218	17	123	78

B. Average Distances Moved in Feet

Pebbles	Whole I.T. Zone		Upper I.T. Zone		Middle I.T. Zone		Lower I.T. Zone	
	N	S	N	S	N	S	N	S
Small	-	127.20	-	20.00	-	140.30	-	102.50
Medium	-	84.87	-	9.00	-	91. 25	-	84.60
Large	-	62.27	-	18.00	-	72.40	-	60.60
Total	-	89.80	-	15.35	-	102.20	-	82.10

Table 4.IV continued.

7.9.61

A. Distribution

Pebbles	Whole I.T. Zone	Upper I.T. Zone	Middle I.T. Zone	Lower I.T. Zone
Small	69	11	32	26
Medium	78	3	46	29
Large	54	3	34	17
Total	201	17	112	72

B. Average Distances Moved in Feet

Pebbles	Whole I.T. Zone		Upper I.T. Zone		Middle I.T. Zone		Lower I.T. Zone	
	N	S	N	S	N	S	N	S
Small	-	105.80	-	155.90	-	78.00	-	90.30
Medium	-	104.10	-	163.30	-	101.40	-	91.70
Large	-	77.38	-	70.00	-	87.30	-	58.50
Total	-	96.20	-	119.70	-	100.75	-	77.20

*I.T.Zone = Inter-Tidal Zone

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CHAPTER 5

THE TIP OF SPURN HEAD AND THE BINKS

Chapter 3 was concerned with all parts of the spit, Chapter 4 with the seaward side and now attention will be turned to the Tip and the Binks.

The form of the Tip has already been described in general terms in Chapters 1 and 3 (see pages 132-3 and 13). It will now be considered in detail with reference to air photograph 9419, taken in September 1959, which shows more of the beach exposed than do the photographs of the two 1961 air surveys.

The beach widens to its broadest part where the neck of the Binks joins the beach. On the seaward side of the spit, the beach narrows only slightly northwards. Westwards around the extremity of the Tip, where Point A was established, there is a marked narrowing to a section about 100 yards west of Point A, whence it broadens again towards the jetty. Almost the whole of the beach is "upper beach" in form, with only a narrow strip of "lower beach" north of the neck of the Binks and west of the extremity of the Tip. There are certain unique features of the beach here, to which attention needs to be drawn. First, a high upper beach which is clearly visible in the air photograph is an almost permanent feature which suffers only slight modification when a storm surge occurs, (See plate 5.A) and is soon re-established. Around material left after a surge, new dunes develop and these are soon colonized by vegetation. When they are stabilized the vegetation spreads outwards rapidly and the new dunes become the outer edge of the main dune development. Thus the spit grows in length, and also in height as the vegetation traps sand blowing off the beach. As the dunes penetrate outwards so does the high upper beach. Second, whilst the generally convex form associated with an upper beach, is present, there is a very marked convexity at the narrowest section of the beach and west of that a considerable flattening of the form occurs. Shingle only is found on the bottom part of the narrowest section, whereas almost pure sand forms the beach further west. (see Plates 5.B, and 5.C). The third noteworthy feature is a broad, gently sloping, triangular expanse of fine sand, sometimes pitted with deep hollows, and with its apex joining the neck of the Binks. (See Plates 5.D, 5.E, and 5F) With very low tides a band of shingle extending below low water mark is seen to bound the south side. All these above mentioned features have formed permanent characteristics of the beach at the Tip since the summer of 1959.

The form of the Tip appears to be inseparably linked with that of the Binks, the characteristics of which will now be described before considering the main forces which affect both.

The Inner Binks are accessible from the beach only at low water of maximum spring tides, owing to the relative lowness of the neck. The Middle and Outer Binks are not accessible from the beach. On the occasions when it was possible to examine conditions on the Inner Binks much useful information was obtained. The shape of the bank showed a number of changes between September 1959 and February 1962. The straightness of the southern side and the irregularities of the northern and western sides were shown on the

1959 air photographs (9419, 9398, 9404,9405,9406); by February 1962 a broad shallow emboyment had developed on the southern side and the neck which lay at its western end had been pushed north of its earlier position. There appeared to be little change on the other sides, however. Well developed ebb ripples characterize the surface. (See Plates 5.G, 5.H, 5.I, 5.J, 5.K, and 5.L). These usually fall into two sets. Those on the southern side are aligned north to south, and have a steep slope facing east and a gentle slope facing west. North of this set, and over by far the greatest part of the bank the alignment is north-west to south-east, with the steep slope facing north-east and the more gentle one sloping south-west. Sometimes the ripples at the neck are aligned with the southern set, sometimes with the more northerly. The material which makes up the Inner Binks and the neck is almost purely pebbles, under 4 inches long diameter. The coarsest is found near the neck and on the southern side of the bank, with material gradually becoming finer northwards. Occasionally some sand is found either mixed with the pebbles or in isolated hummocks on top of the pebbles (see Plate 5M). On several occasions sand has been seen on the southern side and then no ebb ripples had developed, and the sand, mixed with pebbles formed a firm southward facing slope. Generally material over the whole bank is loosely packed, but the firmest area is always towards the south side.

On one occasion 19th January, 1961 when an exceptionally low tide occurred the embayment between the Binks and the beach north of the neck was completely drained. Whilst soft sand with a few pebbles made up the area round the lowest part, the centre was found to consist of firm finely rippled sand (see Plate 5N).

Probably the most important factor influencing the form of the extremity of Spurn Head is tidal streams. In estuaries[1], with a rising tide the flood stream runs in one direction for just over six hours before turning and running in the opposite direction as an ebb stream for a similar length of time. If an adequate thickness of unconsolidated bottom sediment which may be transported by the tidal streams, is present, elongated channels and banks will be developed parallel to the main direction of stream flow. There is usually a residual flow in one direction during each tidal cycle in each channel, therefore the terms ebb and flood have been applied to the distinctive channels. The two types of channel tend to be mutually evasive because the momentum of flow of each tidal stream causes it to continue to flow for 20 to 30 minutes after the turn of the tide. The opposite tidal stream therefore cuts a separate channel parallel to the first and separated from it by a bar. At the meeting of the two water masses about the turn of the tide the saline flood water tends to form an undercutting wedge, beneath the lighter fresh water above it. The boundary layer, both in section and in plan is often sharply defined.

In the Humber estuary the ebb channel is the dominant element in the bottom configuration and forms the main navigation channel at the entrance between the Tip of Spurn Head and Bull Sand. The flood stream creates a number of barbs running from the edge of the ebb channel where it changes direction, into the bordering mud and sand flats where they fade out rapidly.

The only really well-developed flood channel in the estuary lies south of Bull Sand. The number of flood barbs from the main ebb channel result in the formation of closed cell circulation units. On the flood tide material is carried upstream along the flood channel, some of it crosses the bar into the main ebb channel to be carried downstream on the following ebb tide. Some of this material will be transferred back to the flood stream. This movement results in the lateral transfer of material being slow, whether it be outside the entrance to the estuary or upstream.

"The North Sea Pilot"[2] gives information about the rates and directions of tidal streams at the entrance to the Humber estuary. During and after periods of heavy rain both the duration and rate of the out-going tidal stream are increased and the in-going stream is correspondingly reduced. Even at such times the quantity of fresh water running into the sea in the entrance to the estuary appears to be very small in relation to the tidal water. Under all conditions the out-going stream is considerably stronger and of longer duration than the in-going stream. As observations have been made only at the surface, however, this may be a rather false picture, as it is probable that the fresh water runs out at the surface, whereas the saline water from the North Sea flows in at some depth where the strength and duration of in-going and out-going streams may be in inverse proportions to what is indicated at the surface.

Ten miles east of the entrance to the Humber the tidal streams are entirely unaffected by the streams of the estuary. The south-going stream begins 4 hours 55 minutes before high water at Immingham and the north going stream 1 hour 30 minutes after high water. The spring tide rate in both directions is about 2 knots and the neap tide rate slightly less. As the entrance to the estuary is approached the direction of the south-going stream becomes gradually more westerly, and that of the north-going stream more easterly. In the entrance itself the streams run in the direction of the channels and sweep strongly across Chequer Shoal, and round Spurn Head. The streams are weaker on the south side of the estuary than on the north.

In order to obtain a detailed picture of tidal streams close to the shore of the Tip of Spurn Head, investigations were made. After preliminary work during the summer months of 1960, more detailed observations were carried out in June, 1961, and these will now be considered.

Observations on the Tidal Streams off the Tip of Spurn Head

Aim:

The aim was to test the strength and direction of the tidal streams at spring and neap tides, as far as this was possible from the beach.

Method

Bottles 9" high, with a base diameter of 2", and weighing approximately 11 ozs were painted with either red or yellow enamel, and used as markers which were visible clearly in the water when some distance from the beach.

Two base points were selected. "A West" was 200 feet west of Point A, at 15 feet O.D. and lay at the edge of the dunes where the beach reached its narrowest and steepest part. "A East" was 335 feet east of Point A, again at 15 feet O.D. and lay at the edge of the dunes north of where the neck of the Binks joins the beach.

On 12th June, 1961 when spring tides occurred, and on 20th June, 1961 when neap tides occurred, one bottle was thrown at half hourly intervals from the water's edge opposite A West, and one from opposite A East, about 35 feet into the tidal stream. This procedure was continued for 12½ hours through one complete tidal cycle. So that the exact position of the point from which each bottle was thrown might be recorded, piles of pebbles were used to mark the water's edge opposite A West and A East each half hour as the tide fell. At low water a profile was surveyed from each base point, and the position of each pile of stones was carefully marked on the profile. On the rising tide the position of the water's edge each half hour was measured in relation to the nearest pile of pebbles. When the tide was rising as the experiment began, piles of pebbles were place at arbitrary distances apart along lines down the beach from A West and A East. The lines were surveyed to include the positions of the piles, and the water's edge was related to them each half hour. The general direction which each bottle travelled was noted, and the speed of movement was calculated from the distance travelled in the first few minutes. It must be noted that the speed is completely accurate only when the bottle travelled parallel to the shore. As the direction was judged from the shore by eye this gave only a general indication and it was not possible to make an allowance for the direction when this was not parallel to the shore in calculating the speed.

Wave information was recorded each half hour, together with a description of the type of beach material found at the water's edge.

On 13th June, the day after the first day of observations, the contours were surveyed round the Tip from 15 feet O.D. to -2 feet O.D. by plane tabling and levelling. Both profile lines, from which bottles were thrown into the tidal stream, were included so that the information obtained from the observations could be plotted on this as a base map. As only slight changes had occurred by 20th June it was possible to use the same base map, on which to plot the later information.

Figures 5.1, 5.2, 5.3, 5.4, show the tidal streams as revealed by the two sets of observations, and the information on them is condensed in Tables 5.1 and 5.II. With reference to the figures and the tables, conditions will be considered in general terms first then attention will be directed to special points which emerge. As winds were generally under 15 knots and there was no especially heavy rainfall before either experiment it may be safely assumed that the tidal streams were behaving relatively normally.

On 12th June, when spring tides occurred, from low water to high water there was an easterly drift close to the shore from A West. There was a shoreward movement in conjunction with this to begin with, then a

TABLE 5.I

Tidal Streams around the Tip of Spurn Head on 12th June, 1961 with Spring Tides

Place	Time	Direction and Strength of Tidal Streams
A West	L.W.	E.S of Binks 150'/Minute
	L.W.+$\frac{1}{2}$ to + 2 hrs.	E. and shorewards 65'-100'/minute
	L.W.+2$\frac{1}{2}$ to +3hrs([illegible])	E. to Point A at 22-142'/min. outwards, then W
	L.W.+3$\frac{1}{2}$ to +6$\frac{1}{2}$hrs. (H.W.)	E.towards choppy water over Binks neck 20' - 130'/minute (2 lost in choppy water S of Point A at +4$\frac{1}{2}$ to +5 hrs.)
	HW + $\frac{1}{2}$ hr.	E.parallel to shore 60-95'/minute
	HW + 1 hr	E.round Tip, past A East 165'/minute
	HW + 1$\frac{1}{2}$to L.W.	E.south of Binks 150 - 375'/minute (2 lost in choppy water S of Point A, HW+2 to + 2$\frac{1}{2}$ hrs at 75-190'/minute)
A East	LW to LW+5$\frac{1}{2}$ hrs	S.towards choppy water over Binks neck - moved along western edge and lost generally 10-225'/minute
	L.W.+6 to+6$\frac{1}{2}$ hrs (HW)	N. 3'-30'/minute
	HW +$\frac{1}{2}$ to+2$\frac{1}{2}$hrs	S. then N. at 3-75'/minute
	HW+3 to+5$\frac{1}{2}$hrs	N. 20-96'/minute (some outwards then N)

Winds were from between W. and N.E. and from 6 to 16 knots

Wave data is given in Tables 5.III and 5.IV

Table 5.II

Tidal Streams around the Tip of Spurn Head on 20th June 1961, with neap Tides

Place	Time	Direction and Strength of Tidal Streams
A West	LW to LW + $4\frac{1}{2}$ hrs	E and shorewards 25-150'/minute (slightly west at LW + $2\frac{1}{2}$hrs, and one round choppy water S of Point A at LW + $4\frac{1}{2}$ hrs)
	LW+5 to 6 (HW)	E towards choppy water over Binks neck. 42-95'/minute
	H W+$\frac{1}{2}$to+1 hr	E round Tip past A East. 125-175'/minute
	HW +$1\frac{1}{2}$ to + $5\frac{1}{2}$ hrs	E.S of Binks (3 lost in choppy water S of Point A at HW+$2\frac{1}{2}$,+3, and $5\frac{1}{2}$) 175-275'/minute
	LW	E and shorewards east of Point A 150'/minute
A East	LW	N 15'/minute
	LW+$\frac{1}{2}$ to +$4\frac{1}{2}$hrs	S towards choppy water over Binks neck - around west edge, lost (2 came ashore) 24-100'/minute
	LW+5 to + $5\frac{1}{2}$ hrs	N and outwards then S 20-32'/minute
	LW +6hrs to HW+1hr (HW)	N 40-75'/minute (1 ashore)
	HW +$1\frac{1}{2}$ hrs	S and shorewards 60'/minute
	HW + 2 to + 6 hrs (LW)	N erratically at times (9-50'/minute

Winds were from between W. and N.W. up to 14 knots

Wave data is given in Tables 5.V and 5.VI.

movement away from the shore towards the flood current flowing west. After about the mean tide level the movement was steadily east towards choppy water over the neck of the Binks, although a choppiness developed south of Point A for a short time where the eastward stream was intercepted. The maximum rate of movement in an easterly direction was 150 ft. per minute.

Meanwhile from A East, from low water until an hour before high water the tidal stream was flowing southwards towards the choppy water over the neck of the Binks at a rate of 10 to 225 feet per minute reaching a maximum slightly before the mean tide level was reached. By half an hour before high water a north-going stream was beginning to establish itself gradually.

From high water to low water, from A West, there was a strong easterly movement of water. Shortly after high water the tidal stream flowed round the Tip past A East and over much of the Inner Binks. As the water level began to fall however the Binks began to exert an influence on the direction of flow and the main tidal stream ran south of the Inner Binks. The rate of flow varied between 150 and 375 feet per minute, reaching a maximum about mean tide level. A patch of choppy water south of Point A slowed down part of the stream at this time.

During the same part of the tidal cycle at A East the predominant flow of the tidal stream was northwards, although especially shortly after high water there was a southward movement away from the shore, until the main north flowing stream was encountered, flowing between 3 and 96 feet per minute.

On 20th June, when neap tides occurred, only a few slight differences in the tidal stream pattern were observed. From low water to high water, from A West, again an easterly flow was seen. Until an hour before high water the movement was towards the shore at a rate of 25 to 150 feet per minute. At the time of one measurement there was a very slight westerly movement, and on one other occasion a patch of choppy water south of Point A diverted the stream east and then west towards the shore. Within an hour of high water the stream was flowing at between 125 and 175 feet per minute towards the choppy water over the neck of the Binks.

In the meantime, the tidal stream passing A East was flowing towards the choppy water over the neck of the Binks at between 24 and 100 feet per minute. Within an hour of high water there was a slight movement northwards away from the shore before the south flowing stream was encountered.

From A West, between high water and low water, the tidal stream again flowed strongly eastwards. At first it flowed round the Tip and past A East but as the level of the tide began to fall the influence of the Inner Binks was felt and the main ebb stream flowed south of the bank at a rate of between 175 and 275 feet per minute. Choppy water south of Point A again slowed the flow in small parts about mid-tide and towards low water. By the time of low water the stream was being pushed shorewards east of A West in contrast to the state of affairs on the spring tide.

From A East, between high and low water, there was a predominantly northerly flow of between 9 and 75 feet per minute. At one period of observation a southwards and shorewards movement was recorded and the movements north were very irregular in speed, and occasionally a movement south occurred for a few minutes. The main north flowing stream appeared to lie east of the farthest distance the markers could be thrown and their movement was probably so irregular because they were caught by counter currents.

The overall picture emerging from the above description will now be considered. The most powerful tidal stream affecting the Tip is the ebb, the main channel of which lies close to the shore. This becomes established by the time of high water and flows until after low water with spring tides, but until low water with neaps. At A West the stream washes the shore itself (see Plates 5.O, and 5.P) but from that point pulls away from the shore. Except shortly after high water the stream is divided into two parts, the main one flowing south of the Inner Binks, but with a weaker branch flowing over the neck and northwards, approximately parallel to the shore. Between the shore and the ebb streams, counter currents develop in the relatively slack water. The choppy patches seen off Point A from time to time are probably caused by eddies in the main ebb stream.

The only part of the Tip affected by a flood stream is that lying to the north of the neck of the Binks. This stream cannot be traced south of the neck over which it encounters water pushing eastwards dlose to the shore. Where the two streams meet there is a wedge of choppy water. The water to the north and east of the western margin of this wedge is brown in colour, in contrast to the water west of this line, which is much clearer. The markers which floated south were carried generally through or round the choppy water to the west side of the wedge and were then carried away from the shore along it. At least from low water to mid-tide a flood stream can be seen from the shore beyond the east flowing stream, and on two occasions markers were caught in it and transported westwards. The east flowing stream exerts more and more pressure on the flood stream as high water is approached and the shoreward movement within the east flowing stream, ceases. The choppy patches of water seen off Point A on the rising tide are caused by tongues of brown water penetrating into the clear water.

This distribution of tidal streams means that north of the neck of the Binks the beach is affected by alternately north and south flowing streams, and counter currents developed from them. The neck itself is affected by counter-currents and choppy water alternately; and west of it the beach is affected only by east flowing streams, alternately the powerful ebb stream washing the shore around A West, pulling away from it eastwards but washing the south and west sides of the Binks when it divides, and a weaker shoreward moving stream during the rising tide.

At this stage attention may be directed to the wave data collected simultaneously with the current observations, and given in Tables 5.III, 5.Iv, 5.V, and 5.VI. Winds were between west and north-east, varying from 6 to 16 knots on 12th June, and were west to north- west, calm to 14 knots on 20th June. At A west on both dates there was little variation

TABLE 5.III

12.6.61		Wave Data			A West
Time	Wave Ht	Type *	Direction	Frequency	Beach Mat. at H_2O edge
8.00a.m	1'	P	-	20/min	SPsm
8.30	1'	P	-	15/min	SPsm
9.00	1'	P		22/min*	SPsm
9.30	6"	P	-	24/min*	SPsm
10.00	6"	P	-	27/Min	Psm
10.30	6"	P	-	22/min	Psm
11.00	6"	P	-	19/min	Psm
11.30 L.W.	3"-6"	P	-	30/min	Psm
12.00 noon	3"	P	-	18/min	Psm
12.30 p.m.	6"	P	-	30/min	Psm
1.00	6"	P	-	22/min	Psm
1.30	3"-6"	P	-	20/min	Psm
2.00	3"	P	-	20/min	Psm
2.30	3"	P	-	20/min	SPsm
3.00	6"	P	-	20/min	SPsm
3.30	6"	P	-	18/min	SPsm
4.00	6"-1'	P	-	10/min	SPsm
4.30	6" - 1'	P	-	10/min	SPsm
5.00	6" - 1'	P	-	9/min	SPsm
5.30	6"	P	-	8/min	S[illegible]

Table 5.III continued.

Time	Wave Ht	Type	Direction	Frequency	Beach Mat. at H_2O edge
6.00 H.W.	6"-1'	P	-	12/min	SPsm
6.30	6"-1'	P	-	11/min	SPsm
7.00	6"-1'	P	-	10/min	S
7.30	1'	P	-	12/min	S
8.00	6"	P	-	15/min	SPsm
8.30	6"	P	-	20/min	SPsm

* P = Plunging

* Watch stopped - frequency approximate

TABLE 5.IV

12.6.61			Wave Data		A.East
Time	Wave Ht	Type*	Direction	Frequency	Beach Mat. at H_2O edge
8.00 a.m	2'	P	-	15/min	SPsml
8.30	6"-1'	P	-	-	SPsml
9.00	6"-9"	P	-	12/min	S
9.30	6"-9"	P	-	10/min	S
10.00	6"	P	-	12/min	S
10.30	6"	P	-	14/min	S
11.00	3"	P	-	-	SPs
11.30 L.W.	3"	S	-	-	SPs
12.00 noon	1"-2"	S	-	-	SPs
12.30 p.m.	3"	S	-	-	S
1.00	1"	P	-	-	S
1.30	9"-1'	P	-	-	S
2.00	1'-1½'	P	-	9/min	S
2.30	2'	P	-	11/min	S
3.00	2-2½'	P	-	9/min	SPs
3.30	2'-3'	P	-	8/min	SPsm
4.00	3'-4'	P	-	10/min	SPsm
4.30	2'-3'	P	-	9/min	SPsm
5.00	3'	P	-	9/min	SPsml
5.30	3'-4'	P	oblique S	8/min	SPsml

Table 5.IV continued.

Time	Wave Ht.	Type	Direction	Frequency	Beach Mat. at H_2O edge
6.00 H.W.	3'	P	S oblique	8/min	SPsml
6.30	3'	P	"	8/min	SPsml
7.00	3'	P	"	7/min	SPsml
7.30	3'	P	"	8/min	SPsm
8.00	3'	P	"	7/min	SPsm
8.30	1'-2'	P	"	7/min	SPsml

* P = Plunging
S = Spilling

TABLE 5.V

20.6.61			WAVE DATA		A West
Time	Wave Ht.	Type	Frequency	Direction	Beach mat. at H_2O's edge
8.00 a.m.	6"	P	22/min	-	Psm
8.30	6"	P	23/min	-	Psm
9.00	6"	P	22/min	-	Psm
9.30	6"	P	17/min	slightly oblique N	Psm
10.00	3"-6"	P	18/min	-	Psm
10.30 H.W.	6"	P	25/min	-	Psm
11.00	6"	P	21/min	-	Psm
11.30	3"-6"	P	20/min	-	SPsm
12.00 noon	3"-6"	P	21/min	-	SPsm
12.30 p.m.	6"-1'	P	14/min	-	SPsm
1.00	6"-1'	P	18/min	-	SPsm
1.30	6"-1'	P	21/min	slightly oblique N	SPsm
2.00	6"-1'	P	25/min	-	Psm
2.30	3"	P	17/min	-	SPsm
3.00	3"	P	20/min	-	SPsml
3.30	3"	P	25/min	-	SPsm few Pl
4.00	6"	P	29/min	-	Psm
4.30 L.W.	6"	P	30/min	-	Psm
5.00	6"	P	28/min	-	Psm
5.30	3"-6"	P	29/min	-	Psm

Table 5.V continued.

Time	Wave Ht.	Type	Frequency	Direction	Beach mat. at H_2O's edge
6.00	6"	P	27/min	-	Psm
6.30	6"	P	28/min	-	Psm
7.00	6"	P	32/min	-	Psm
7.30	6"-1'	P	30/min	slightly oblique N	Psm
8.00	3"-6"	P	22/min	" "	SPsm
8.30	3"-6"	P	23/min	" "	SPsm

* Plunging

TABLE 5.VI

20.6.61 WAVE DATA A East

Time	Wave Ht	Type*	Frequency	Direction	Beach mat. at water's edge
8.00 a.m	1'6"	P/S	6/min	-	SPsml
8.30	1'-2'	P	6/min	-	SPsml
9.00	1'6"	P	6/min	becoming oblique S	SPsml
9.30	1'6"-2'	P	6/min	oblique S	SPsml
10.00	1'-1'6"	P	6/min	" "	SPsm
10.30 H.W.	2'-4'	P	6/min	" "	SPsml
11.00	2'-4'	P	5/min	" "	SPsm
11.30	2'-4'	P	6/min	" "	SPsm
12.00 noon	2'-3'	P	6/min	" "	SPs
12.30 p.m.	1'-2½'	P	9/min	" "	SPs
1.00	1'	P	8/min	" "	S few Psm
1.30	1'	P	6/min	slightly oblique S	S few Psm (lower beach emerging)
2.00	1'	P	6/min	S "	S few Ps
2.30	6"-9"	P	6/min	-	S
3.00	9"	P	7/min	-	S
3.30	6"	P	10/min	-	S
4.00	6"	P	-	-	S

Table 5.VI continued.

Time	Wave Ht	Type	Frequency	Direction	Beach mat at water's edge
4.30 L.W.	6"	P	-	-	SP
5.00	6"-9"	P	17/min	-	SPs
5.30	3"-6"	P	-	oblique N	SPs
6.00	6"	P	12/min	" "	S
6.30	9"-1'	P	12/min	" "	S
7.00	1'-1½'	P	12/min	oblique S S of AEast	S
7.30	1'	P	10/min	"	S
8.00	1½' -2'	P	8/min	"	S
8.30	2'	P	8/min	"	SPsm

* P = Plunging
S = Spilling

in wave height throughout the tidal cycle, but at A East there was a marked increase in height towards high water when the waves were breaking on the steepest part of the upper beach. Almost no variation in wave type was recorded at either point. The observations on the direction of wave approach yielded the most interesting information. On 12th June at A West the waves broke directly onshore, but at A East across high water, they approached obliquely to the shore southwards, i.e. the angle of approach opened southwards. On 20th June at A West they broke directly onshore with a few slight exceptions, but at A East the approach of the waves obliquely south across the high water period was more noticable than on the previous date. In addition it was noticed that the obliquity of the waves increased towards the neck of the Binks and continued to slightly west of Point A. The irregularity of the frequency of the waves at A West and A East on both dates may be explained partly by the refraction and diffraction of waves over the Binks and by the effect of the tidal streams especially the powerful ebb. The beach material as is usual at A West consisted of almost purely pebbles near low water on both occasions. At A East the change from sand mixed with pebbles, to pure sand or sand with only a few small pebbles showed when the gently sloping triangular area of sand near the neck of the Binks began to emerge, and vice versa when the tide completely covered it. It should be noted that waves broke obliquely south only when this sandy triangle was completely submerged, and when this occurred the wave height increased as the waves broke on the steeper slope of the upper beach proper. As the angle of approach of the waves is important in its affect on the longshore movement of material, and must therefore be a considerable influence in moulding the Tip of Spurn, further wave observations, this time opposite the neck of the Binks, were carried out.

Table 5.VII gives details of the observations made on 7th September, 1961, when the tides were mid-way between neaps and springs, and when the wind swung from west, between 8 and 16 knots, to northwest between 13 and 19 knots. The waves showed a marked rise in height towards high water and a decrease afterwards, as the~~y~~ tide rose and fell over the steepest part of the beach. The wave type was mainly plunging, but west of the neck of the Binks it was spilling as the tide rose. The frequency again showed considerable variation. The observations of wave direction yielded very useful information. As the tide covered the triangle of sand a pattern of crossed waves developed, as waves from east of the spit met waves from west of the neck. Once the tide began to rise up the upper beach the waves from the east began to predominate and completely mask those from the west. The waves from the east approached the beach at this point obliquely and the angle of approach increased markedly west of the neck. This state of affairs continued until the tide had fallen again to the upper edge of the sand triangle when a pattern of crossed waves developed as the waves from west of the neck were able to re-assert themselves. When the waves break obliquely, littoral drift may be observed around this part of the Tip and to the west of Point A, as shingle is pushed up

TABLE 5.VII

Obliquity of Waves opposite the Neck of the Binks 7.9.61

Time	Angle of Approach°	Wave Ht in Ft.	Wave Type	Wave frequency per min.	
2.15 p.m	-	2	(P at Neck) (S West)	8	Sand triangle just covered crossed waves well developed
2.45 p.m.	10W	2	"	10	Only waves from E. of spit oblique
3.15 p.m.	20W	2	"	9	"
3.45 p.m.	20W	2	"	9	"
4.15 p.m.	10W	2-3	"	8	"
4.45 p.m. High water	0	2-3	P	8	"
5.15p.m.	10W	2-3	P	8	Direction of approach less definite.
5.45 p.m.	0	3	P	8	Marked angle of approach again
6.15 p.m.	5W	3	P	7	"
6.45 p.m.	40W	1-2	P	8	"
7.15 p.m.	5W	1	P	'	"
7.45 p.m.	-	1	P	8	Crossed waves re-appearing as waves from E. of spit meeting waves from W. of neck

the beach at a very oblique angle to the west and is rolled down by the backwash at right angles to the slope of the beach, to be picked up again by the swash of the next wave and carried obliquely west again. The zig-zag movement of the marker at 12 noon on 20th June (See figure 5.4) further illustrates this.

From this movement it might reasonably be expected that the spit would grow outwards rapidly about A West, but it has already been noted that the beach reaches its narrowest and steepest at this point. It was observed that the powerful ebb current washes the shore there, and this in addition to the fact that west of this pure shingle gives way in a short space to almost pure sand, suggests that the ebb current must transport material from the beach and carry it eastwards. Evidence of the down-combing of material at this point has been observed frequently. Plate 5.Q shows an intricate development of channels cutting back into the sand and shingle as the tide was falling from the middle of the beach. Plates 5.R and 5S show a cliff cut into the same part of the beach as a rapid removal of material has taken place. Such a cliff is cut by the waves as the tide rises, and Plate 5.T shows one being cut on the steeper lower part of the beach.

As Twenhofel[3] shows, considerable turbulence exists close to the lower part of a steep slope when a powerful current passes near it. The turbulence causes a forward thrust of water which may set particles in motion, either in suspension or by traction. Suchier's findings, quoted by Twenhofel, shows that a current of the maximum strength observed at A

West can begin to move material up to about two inches in diameter. Turbulence will be likely to increase the possible size, and once in motion a lower velocity will be needed to continue the movement. The material transported by traction will be deposited in a direct ratio to a decrease in current velocity. Even slight turbulence will keep fine material in suspension, however.

It is therefore possible for material to be moved by the powerful ebb stream and to be transported by it slightly away from the Tip past Point A. As the stream swings north-eastwards, as already noted, a less powerful branch breaks away from it and flows parallel to the east coast of South Spurn, whilst the main stream flows south of the Binks. The decrease in velocity of the branch stream as it leaves the main one will cause considerable deposition; and it is in this area that the highest and broadest part of the Inner Binks is found. Most of the traction load of the main stream will be moved along the northern side of the ebb channel. The proximity of water moving at a velocity lower than that of the main stream on its northern margin will cause a gradual deposition there also. In this position lie the major part of the Binks. As would be expected the coarsest material is found on the Binks close to the neck.

The two sets of ebb ripples usually seen on the Inner Binks appear to be related to the movement of water in the two streams. The southerly set, aligned north to south, and composed of relatively well compacted material seem to be formed by the main ebb stream, whereas the northerly set, more loosely compacted, appear to be related to the branch stream, which will broaden as it extends northwards from the south-east corner of the Tip.

The neck of the Binks appears to be a continuation of part of the beach westwards, which is exposed only at very low spring tides. Below the sand forming the western extremity of the sand triangle, a belt of shingle, rarely over 2 inches long diameter, and extending below low water-~~water~~ mark is partially uncovered. This usually is built into low ebb ripples, and appears to be the very edge of the traction load of the ebb stream. The main division of the stream seems to occur east of the neck where the Binks attain their greatest width as a mass of material is deposited. South of the neck lies the main ebb channel and north of it, at right angles to it lies a flood channel. The constriction of the flood stream between the Inner Binks and the shore increases its scouring power as it approaches the neck, and maintains the channel in this position. The meeting at the neck between the flood stream and stream flowing eastwards round the Tip lessens the power of the flood stream to scour it. A delicate balance between deposition at the edge of the ebb channel, and the scouring action of the flood stream must exist.

The triangle of sand sloping gently towards the level of the neck of the Binks is affected by the convergence of the flood stream and the eastward flowing stream on the flood tide, and is covered by choppy water which will be able to move only sand in suspension normally. On the ebb tide it is affected by the outer edges of the brach of the ebb stream and the counter-currents shoreward of it. Before they reach this area any pebbles which they were moving will have been deposited, and the only load they will be carrying will be sand in suspension. Some of this sand will probably be deposited here, depending on the velocity of the currents. The hollows which are sometimes seen in this sand (See Plates 5.E and 5.F) are probably caused by the counter currents and the crossed waves which develop as the tide nears the upper edge of the triangle and continue through low water until the tide has risen again to the same position.

In order to test the theories on the movement of material round the Tip it was decided to carry out two experiments on the longshore movement of material, one at the extremity of the Tip and the other on the Binks. The preparation of tracer pebbles was the same for these experiments as for the first one carried out near groyne III (See page 167).

Experiment on the Longshore Movement of Material at the Tip

Method

22nd September, 1961

1,000 painted pebbles were placed along the injection line, down the beach from Point A, between high and low water marks. Equal numbers of small, medium and large pebbles were placed in the same proportions throughout the line. The profile was surveyed along the injection line and the wave characteristics were noted.

23rd to 26th, and 28th September, 1961

Each day the whole of the area of the beach over which tracer pebbles were visible at low water was surveyed with a 5 foot sampling square, a profile along the injection line was surveyed, and wave conditions were recorded. Wind data was obtained for the whole period of the experiment.

2nd October, 1961

The beach was examined, but as under ten tracer pebbles were found below high water mark, sampling the beach was not considered worthwhile.

Beach, Wind, Wave and Tide Conditions

Figure 5.5 shows the profiles surveyed along the injections line during the experiment. It can be seen that little change occurred. There was little variation in the surface distribution of beach material also. The high upper beach was as usual composed of sand and large pebbles. The middle part of the beach consisted of sand and small, medium, and large pebbles. Below this, from Point A eastwards, lay a belt of sand and below it, disappearing below low water mark was a belt of sand and small pebbles continuous with the neck of the Binks. West of Point A the bottom part of the beach was composed as usual of medium and large pebbles. This distribution remained from 22nd to 28th September but by 2nd October when less of the beach was exposed, more sand was present in the middle part.

Wind and wave data are given in Table 5.VIII. The light and variable wind conditions between 22nd and 26th September produced only low plunging waves, approaching the shore either directly or slightly

TABLE 5.VIII

Wind and Wave Data for the Longshore Drift Experiment at the Tip

Date	Wave Ht. in Ft.	Wave Type	Direction of Wave Approach	Wind Direction and Speed in Knots	
22.9.61	0.5	P	slightly oblique W.	S	6-14
23.9.61	0.5-1.0	P	slightly oblique W	S.E.toS.	>10
24.9.61	0.5	P	directly onshore	SW to N	>10
25.9.61	0.1-0.5	P	slightly oblique W.	NW,SE toS	>10
26.9.61	0.5	P	directly onshore	S to SW	>15
28.9.61	2.0	P	slightly oblique E	S to SW	12-26

obliquely to the west. Stronger south to south-west winds blowing across the estuary to the Tip of Spurn on 28th September produc~~ting~~ed higher plunging waves, which approached the shore slightly obliquely eastwards. The maximum equinoxial spring tides occurred on 26th September, and the maximum neaps on 2nd October.

Results

Figures 5.6 shows that the majority of tracer pebbles moved west although some moved east. The general distribution pattern each day was similar between 23rd and 26th September, but it had smoothed down with less of a concentration just to the west of the injection line, on 28th September. Table 5.IX shows that the average distances travelled by all sizes of material within the complete inter-tidal zone were:-

Westwards, 35.2, 39, 51.0, 55.6, 79.5 feet

Eastwards, 57.0, 50, 123.8, 112.5, 137.8 feet

Figures 5.7 and 5.8 show the actual distribution on the whole of the inter-tidal zone of different sized tracer pebbles, and the distribution of all the tracer pebbles within the different parts of the inter-tidal zone. In Table 5.IX the distribution is tabulated and the movement averaged.

Most tracer pebbles were found in the upper part of the inter-tidal zone, with less in the middle, and least in the lower part. The fact that so few were found in the lower part seemed to be due to the burial of many in the belt of sand. In the upper and middle parts most were large, followed by small then medium pebbles in the upper part but medium then

TABLE 5.IX

Movement of Tracer Pebbles at the Tip

23.9.61

A Distribution

Pebbles	Whole I.T.+ Zone	Upper I.T. Zone	Middle I.T. Zone	Lower I.T. Zone
Small	119	80	29	10
Medium	97	58	39	0
Large	158	93	63	2
Total	374	231	131	12

B Average Distances Moved in Feet

Pebbles	Whole I.T. Zone		Upper I.T. Zone		Middle I.T. Zone		Lower I.T. Zone	
	E	W	E	W	E	W	E	W
Small	57	52.0	-	60.6	70	40.8	50	-
Medium	-	37.6	-	34.6	-	22.7	-	-
Large	-	21.9	-	22.5	-	23.0	-	-
Total	5,7	35.2	-	41.5	70	23.3	50	-

Table 5.IX continued

24.9.61

A Distribution

Pebbles	Whole I.T. Zone	Upper I.T. Zone	Middle I.T. Zone	Lower I.T. Zone
Small	87	53	30	4
Medium	89	50	38	1
Large	136	80	56	0
Total	312	183	124	5

B Average Distances Moved in Feet

Pebbles	Whole I.T. Zone		Upper I.T. Zone		Middle I.T. Zone		Lower I.T. Zone	
	E	W	E	W	E	W	E	W
Small	50	60.2	-	62.7	-	55.7	50	-
Medium	-	40.4	-	46.4	-	33.0	-	5
Large	-	24.8	-	27.5	-	21.1	-	-
Total	50	39.0	-	42.8	-	33.3	50	5

Table 5.IX continued.

25.9.61

A Distribution

Pebbles	Whole I.T. Zone	Upper I.T. Zone	Middle I.T. Zone	Lower I.T. zone
Small	79	46	29	4
Medium	67	34	33	-
Large	124	58	66	-
Total	270	138	128	4

B. Average Distances Moved in Feet

Pebbles	Whole I.T. Zone		Upper I.T. Zone		Middle I.T. Zone		Lower I.T. Zone	
	E	W	E	W	E	W	E	W
Small	123.8	75.1	-	96.0	-	66.0	123.8	-
Medium	-	54.2	-	61.4	-	46.4	-	-
Large	-	33.0	-	37.5	-	29.0	-	-
Total	123.8	51.0	-	58.6	-	42.0	123.8	-

Table 5.IX continued

26.9.61

A Distribution

Pebbles	Whole I.T. Zone	Upper I.T. Zone	Middle I.T. Zone	Lower I.T. Zone
Small	65	44	18	3
Medium	62	34	27	1
Large	124	63	61	0
Total	251	141	106	4

B Average Distances Moved in Feet

Pebbles	Whole I.T. Zone		Upper I.T. Zone		Middle I.T. Zone		Lower I.T. Zone	
	E	W	E	W	E	W	E	W
Small	145.0	82.2	-	87.8	-	68.5	145.0	-
Medium	15.0	59.5	-	69.4	-	45.7	15.0	-
Large	-	40.3	-	49.2	-	30.0	-	-
Total	112.5	55.6	-	66.6	-	41.9	112.5	-

Table 5.IX continued.

28.9.61

A <u>Distribution</u>

Pebbles.	Whole I.T. Zone	Upper I.T. Zone	Middle I.T. Zone	Lower I.T. Zone
Small	50	29	6	15
Medium	60	34	12	14
Large	88	35	27	26
Total	198	98	45	55

B <u>Average Distances Moved in Feet</u>

Pebbles.	Whole I.T. Zone		UpperI.T. Zone		Middle I.T. Zone		Lower I.T. Zone	
	E	W	E	W	E	W	E	W
Small	157.5	85.9	-	85.9	-	112.5	157.5	61.6
Medium	-	84.9	-	75.2	-	152.5	-	50.7
Large	20.0	74.8	-	81.9	-	83.3	20.0	58.0
Total	137.8	79.5	-	80.8	-	107.0	137.8	55.3

* I.T.Zone = Inter-tidal Zone

small in the middle part. In the lower part, almost all were small with very few medium and large ones. The most noteworthy fact was their relative distribution east and west of the injection line. Only in the lower part of the inter-tidal zone, in the belt of sand and fine shingle did material move eastwards, and it was almost solely small pebbles. Only in the upper and middle parts did material of all sizes move west, with one exception, on 28th September, when some in the lower part went west. (Then only the top of the lower part of the inter-tidal zone was exposed as low water was higher than on 23rd September.)

The average distances travelled by the small tracer pebbles were greater than those by the medium, and they in turn were greater than those travelled by the large ones. The small pebbles moving east, travelled faster than those moving west.

Experiment on the Movement of Material on the Binks

Method

5th February, 1962

1,000 painted pebbles, 500 medium and 500 small to correspond with the size of the material making up the bank, were placed along a 100 foot long injection line on the Inner Binks. The two sizes were mixed in equal proportions. The injection line lay approximately parallel to the east shore of South Spurn along a bearing of 30° and was at an angle of about 45° to the ebb ripples. Bearings from the north and south ends of the injection line were as follows:

1. to the lighthouse, 25°
2. to the high lookout tower, 355°
3. to Bull Fort 260°

6th and 7th February, 1962

The area over which the tracer pebbles were distributed was sampled in alternate strips, 5 feet wide, with the 5 foot sampling square. Because of the limited time when the Binks were accessible from the beach it was decided that a complete survey would be impossible with the scatter of pebbles which existed.

8th February, 1962

As only 16 tracer pebbles were located, the position of each of them was fixed in relation to the injection line.

Surface Morphology and Wind and Tide Conditions

Between 5th and 7th February only the northerly set of ebb ripples were well developed, with their steep slopes facing south-west. The difference in height between crest and trough was approximately 1 foot. The southern edge of the Binks consisted of a firm slope of shingle with some sand, whereas almost solely shingle lay further north. On 8th February, the ebb ripples showed the same alignment, but were less well marked, and their steep faces sloped more gently (see Plate 5.K). The best developed ripples were seen on the northern side of the eastern half on the Inner Binks. (See Plate 5.L) Over much of the remainder more irregular, elongated hummocks were found. More sand was present than had been observed on all previous occasions when the bank had been accessible from the shore.

Wind conditions during the experiment were as follows:

5th February 1962	W	7-26 knots
6th February	S-S.W.	10-14 knots
7th February	S-S.W.	8-22 knots
8th February	N	10-28 knots

The veering of the wind from south-west to north, which occurred late on 7th February, and the strengthening which took place early on 8th February produced long powerful waves, which, as they met the ebb stream over the Binks probably produced the changes in surface morphology. Maximum spring tides occurred on 7th February, and access to the Inner Binks from the beach was possible only between 5th and 8th February.

Results

Figure 5.9 shows that all the tracer pebbles moved eastwards from the injection line, with some splaying out eastwards beyond the two ends of the line. More material moved out from the south end and was carried along the southern edge of the Binks. The maximum distance at which this was found south of a line at right angles to the southern end of the injection line was 35 feet. The distribution curve of tracer pebbles flattened out more rapidly than in the two experiments on the beach. As Table 5.X shows, the rate of recovery of material was very low, between 8.8% and 1.6%, in comparison with that at the Tip, between 37.4% and 19.8%, and that near groyne III, from 38.5% to 20.1%. More small than medium pebbles were found. The average distances moved by small and medium pebbles together were 21.6, 33.6, and 52.2 feet, with the small generally moving faster than the medium ones.

The fact that so few were found, and yet the rate of movement was slower than the rates recorded on the beach for similar sized material suggests that there must have been a considerable mixing of material, causing the tracer to be buried. This would be expected with the development of large ebb ripples.

As no tracer pebbles were found west of the injection line, it appears that the flood current is unable to move even small pebbles, although it is likely to move sand.

These two experiments on the movement of material, one at the Tip, and one on the Binks, confirm the pattern of movement suggested by the tidal streams and the waves. Over most of the beach at the Tip material was moved westwards as would be expected when waves approached the shore obliquely southwards, and south-westwards. In the belt of small pebbles exposed near low water with the very lowest spring tides, generally at the equinoxes, material moves eastwards. As this belt lies on the fringe of the powerful ebb stream, it may be assumed safely that larger material is carried on that part of the slope where greater stream velocities are attained. Material will be picked up, or movement by saltation will begin, near A/ West where the stream washes the shore. It is doubtful whether much

TABLE 5.X

Movement of Tracer Pebbles on the Binks

A Number Found

Date	Small Pebbles	Medium Pebbles	Total
6.2.62	27	17	44
7.2.62	22	18	40
8.2.62	9	7	16

N.B. As area where tracer pebbles found on 6.2.62 and 7.2.62 only half sampled, numbers should be doubled to compare with 8.2.62

B Average Distances Moved in Feet

Date	Small Pebbles	Medium Pebbles	Total
6.2.62	20.7	22.9	21.6
7.2.62	37.5	28.9	33.6
8.2.62	55.0	48.6	52.2

of the largest material seen at A West can be moved by the stream. Powerful waves probably roll it down the steep submarine slope on which it comes to rest and forms a basis for the extension of the spit above low water mark. The fact that the spit is extending in length is evidence that only some of the material transported to the Tip is then carried away eastwards. Between December 1959 and August 1962 the dune edge about Point A has extended 20 feet towards the south-west, and vegetation has extended patchily to 50 feet from the earlier dune edge.

Whilst none of the tracer material used in the experiment at the Tip actually reached the Binks, several of the small tracer pebbles moving eastwards were close to and directly approaching the neck, on the last occasion when it was exposed at the equinoxial spring tides. On 19th June 1962, one large tracer pebble, about 6 inches in long diameter, was found on the south side of the Inner Binks. As no pebbles of this size were used in the experiment on the Binks, it can have come only from one of the experiments on the beach, and that at the Tip appears most probable. Whilst neither of these facts provide indisputable evidence, it appears almost certain that the Binks are built from material taken from the spit a little west of the extremity of the Tip. The experiment on the Inner Binks shows that the pebbles which form it generally, move eastwards and because of this can be moved only by the ebb stream.

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CHAPTER 6

The Riverside and Old Den

In Chapter 3 the short term changes as they affect almost all parts of the spit were described and the factors which cause them were discussed. On the riverside of the spit at its southern end swash bars were seen to be the typical features in which build up occurred, and this took place most notably with offshore winds when the top part of the beach was raised and the bottom part showed a slight loss. Build up however did occur when winds blew from any other direction, if they were light in strength. Despite the form being the same as on the seaward side of the spit the scale was completely different, and this is where the most fundamental difference is found between seaward and river sides.

A riverside swash bar rarely exceeded 6 inches in height from the trough in front of it to the crest, and the variation in height of the beach was rarely much more. When a storm surge occurred accompanied by powerful waves on the seaward side, resulting from strong north to north-west winds, the changes wrought on the riverside were usually a direct result of the raised height of the tide. The whole beach could be washed over by the waves and if the surge was high enough, the waves near high water might break against the edge of the dunes and remove sand from the edge leaving a small cliffed feature, with the rhyzomes of the marram grass visible (See plate 6.A). Where only low dunes existed the water might overtop them and spread sand and shingle over the vegetation (see Plate 6.B).

The difference in scale of the changes is directly the result of small waves which are all that are able to form in the limited fetch of the estuary, which at a maximum is only 8 miles wide, between Kilnsea and Tetney Haven. Except with strong winds, primarily from south-west to west-north-west that is, on-shore winds, waves are rarely over 1 foot in height. The maximum observed during gale force winds were only 2 feet high. The period was always short, the longest observed being only 3.5 seconds.

In the northern half of the riverside of Spurn Head as the air photographs and the six-weekly beach feature plans (Figure 2.3) show, the only place where changes occur over a short period is where there is a marked angle to the edge of the dunes opposite groyne XX. There the lowest part of the beach lies close to the dunes, so that on spring tides water collects in the trough. As this drains, when the tide falls, the water scours the sand, thus the trough does not fill in. Swash bars develop west of the trough, but only very rarely is the tide high enough to push them even partly into the trough. Elsewhere the narrow beach slopes evenly from the edge of the dunes to the junction of sand and estuarine mud.

Why does a difference exist between the north and south beaches on the riverside? Even the most casual tidal observations show that the beaches in the north are affected by wave action for only a fraction of time during which the southern ones are, within one tidal cycle. Two sets of observations were made, one at spring and one at neap tides to find out at what stages in the cycle the tide reached and left the junction of sand

and estuarine mud from the southern border of High Bents to the north-western limit of Kilnsea Warren. The results of these observations are shown in figures 6.1, and 6.2. The predicted heights of high water at Spurn Head were on 19th July, 1960, 14.9 feet Chart Datum (5.3 feet O.D.), and on 3rd September, 1960, 18.0 feet Chart Datum (8.4 feet O.D.). Meteorological conditions did not disturb predicted heights. 19th July was one day after maximum neap tides had occurred, and 3rd September was three days before maximum equinoxial spring tides.

On 19th July the edge of the water first reached the junction of sand and estuarine mud at 1.30 p.m. opposite groyne XIII and spread rapidly northwards to nearly opposite groyne XVII by 2 p.m. Thereafter it rose gradually more slowly until high water about 3.30 p.m. when it reached its farthest extremity northwards, opposite mid-way between groynes XIX and X. As the tide fell again it gradually retreated from the lower edge of the sand beach further and further south, until it left it altogether opposite groyne XIII, at 5.50 p.m. Throughout this period between 1.30 p.m. and 5.50 p.m. the sand and fine shingle beaches of south Spurn had been undergoing wave action. The beaches north and west of the position where the tide reached at high water were completely dry during the whole period. The nearest point to which the tide approached the sand beach opposite the north boundary of Kilnsea Warren, was 100 feet.

On 3rd September, the tide reached the lower edge of the sand beach at 2.30 p.m. opposite groyne XIII and rose more rapidly than on the previous occasion on account of its being a spring tide, and at 2.30 p.m. it had reached only the mean tide level. By 3.15 p.m. it had reached the sand and mud junction at two places, opposite groynes XX and XXIV, but lay a little distance out on the mud in between. This mud was covered within the next quarter of an hour. By 3.45 p.m. the tide had reached two points further west, opposite groynes XXVI and XXVIII, leaving the area between above the water, but the highest point between the two was covered by 4 p.m. and remained so until 6.05 p.m. when the tide had been falling for about an hour. By 7.30 p.m. the tide had retreated south to opposite groyne XIII and left the lower part of the sand beach.

The lack of change on the narrow sand beach of the riverside of Kilnsea Warren is clearly the result of being affected by wave action for only probably a maximum of three hours each tidal cycle, at the time of near maximum spring tides. The spread of Spartina causing the accumulation of mud at an increasingly rapid rate close to the shore, means that the sand beach will receive less and less wave attack.

Whereas it was possible to gain some idea of the direction of alongshore movement of material on the seaward side and at the Tip of Spurn, by using painted pebbles, the lack of pebbles except along relatively limited sections of the riverside made this technique of no great value here. As already stated in Chapter 4 (pages 165) the use of fluorescent sand tracers in the field is in only the early stages of development in

England and therefore the idea of attempting to gain data by this method had to be abandoned.

An examination of the beach forms has been made however, and sheds some light on the longshore movement. These features are shown on the 1959 and 1961 air photographs.

The long, curving ridges of sand will be considered first. These fall into two sets, those lying west of the southern half of South Spurn, and those west of the south end of the Chalk Bank. The southern set are shown in a highly developed form on the 1959 air photographs, 9418 and 9416, taken after a long period of building up of the beach. Between the life-boat house and the disused sewage pipe about 400 yards north of it, a spread of relatively smooth sand lay on the higher part of the beach. Fanning out from it towards low water mark were long curved ridges of sand increasing in size and prominence northwards. The best developed ridges lay between the sewage pipe and the southern end of Old Den, where a much thinner layer of sand lay on the part of the beach adjoining the upper section. The long boom disrupted the pattern of ridges. Two facts need noting, first that the ridges splayed out northwards and sub-divided in this direction near the long boom; and second, that although the ridges were mainly symmetrical, where there was asymmetry, the steeper slope lay towards the north. Between the southern and northern sets a well-defined small stream cut through what is usually an area of pure estuarine mud, but which sometimes is coated with a thin layer of sand. The upper beach broadened as the northern ridges were approached from the south, and a blunt formation of sand jutted into the mud at a low angle. North of this, well developed sand ridges were seen. These splayed out northwards, but became smaller and less well-defined as they did so.

On 16th March, 1961, after a shorter period of build up (See air photographs 173, and 183) a broad, relatively smooth, expanse of sand filled the area between the lifeboat house and the sewage pipe, and only north of it were the ridges developed to as far as the southern end of Old Den. There appeared to be little sand cover on the middle part of the beach. Again the ridges splayed out and sub-divided northwards, and towards the north they were asymmetrical with steeper slopes facing northwards. The area around the stream was largely devoid of sand. North of it the beach broadened and jutted out at an angle into the mud and north of that the other set of ridges were seen in a better defined form than on 3rd September, 1959. As they splayed out slightly northwards they rapidly died out. There were signs of a slight asymmetry with the steeper slope facing north.

A comparison between the air photographs of 16th and 23rd March, 1961 between which a very stormy period occurred, has already been made in general terms in Chapter 3 (see pages 129 to 135) but attention will be drawn again to certain facts relating to the sand ridges. On 23rd March the beach between the lifeboat house and the southern end of Old Den consisted in the main of a broad expanse of smooth sand with the sand ridges formed only near low water mark, north of the sewage pipe, and along the southern side of the long boom. The division between the two areas where ridges form was narrower, and many more ridges had developed north, and the already existing ones had been markedly widened.

Certain general conclusions may be drawn from the above descriptions. The sand ridges which have formed a permanent feature during the past three years at least attain a most fully developed form under prolonged calm weather conditions. Where there is a plentiful supply of sand it lies in a smooth sheet, sometimes with the surface ripple-marked. This is found only near the extreme southern end of the riverside of the spit. Northwards until the southern end of Old Den, sand and estuarine mud are often both found. The sand forms the long ridges, whilst the mud is generally deposited up-beach of them, and forms ripple-marked layers which alternate with thin sand layers. The stream flowing from near the shore towards the south of Old Den merely divides what is really one set of ridges into two parts. The northern ridges are smaller than the southern ones and decrease in size northwards. Each of these ridges is usually separated by estuarine mud which only occasionally is covered with a thin layer of sand.

The fact that the sand diminishes in quantity northwards, on what is really the lower beach suggests that the material is moving northwards. The only sand north of the northern end of the Chalk Bank is that which composes the very narrow beach which flanks the estuarine mud and as was shown in Chapter 1 (See Table 1.I, page 17)) this sand is considerably coarser than that found on the lower beach west of the light-house, so for this reason alone it could not be the source. The median grain size on the lower beach west of the lighthouse was between 0.175 and 0.155 mms. which corresponds to that around the Tip of Spurn near low water mark. It appears likely that much of this fine sand is thrown into suspension round the Tip and whilst the major part is carried eastwards by the powerful ebb stream, a little is born westwards where it accumulates mainly south of the lifeboat house but with a little creeping north of it to form a continuous spread for a few hundred yards, but only long ridges north of this to near the northern limit of South Spurn.

The development of the sand ridges may result from the mode of transport of the sand. As Twenhofel[1] shows, sand moving by traction may travel collectively, which involves mass travel through the individuals of the mass travelling a little at a time. With a moderate load and velocity the sand will move as a sheet, with increasing density from the surface downwards, so that no sharp plane of demarcation exists between the sands which are moving and those which are stationary. A decrease in load, and/or velocity results in travel in the form of small dune-like bodies with steeper slopes down-current than up-current. These bodies migrate down-current by sand grains moving from the up-current side, which is being eroded, to the down-current side, which is being extended. If the form of the "dunes" does not alter, it appears that equilibrium has been reached and little or no erosion or deposition is taking place.

It seems very probable that the sand ridges at Spurn Head are a particular form of Tw nhofel's "dune-like features." They occur where the supply of sand is small and the velocity of the water is low. As their form varies only slightly, no permanent increase in size or number occurs, and they do not appear to be spreading over a wider area, they must be in a state close to equilibrium. The fact that they have formed or are forming very slowly from the south is suggested by their fanning out and dividing northwards, and the fact that some show a slight asymmetry with a steeper slope north than south. Only after storm conditions, when the ridges have been attacked by more powerful waves and more material has probably been carried round the Tip is there any sheet movement of the sand, which usually forms the ridges. As the waves become less powerful afterwards, the ridges are slowly rebuilt.

As this point it may be noted that an examination of the spit which forms the southern part of the West German Fresian Island of Sylt, showed that it is almost a complete replica of Spurn Head, allowing for the differences produced by its being built almost solely of sand. A set of sand ridges, similar to those west of Spurn Head is found to the east of the Hörnum spit. Whereas they join the sand beach north of the harbour, on the east shore near the tip, they gradually pull away from it when the shore sweeps westwards in an embayment, which in its middle area is composed of mud with a little sand. The sand ridges become smaller northwards and gradually die out. They form only where a relatively small amount of sand is present, as a powerful ebb stream washes the tip of the spit, and carries most of the sand westwards into the North Sea.

One other particular section of the beach on the riverside requires consideration before attention is turned to Old Den. This is opposite the northern end of the Chalk Bank where the channel draining the low area around it, which is flooded at high water spring tides, leads onto the beach (see air photographs 9413, 183 and 258). Figure 6.3 is a contour map of this section of beach. The channel lies along the edge of the dunes at first after leaving the interior of the spit because of the presence of a beach ridge between it and the river. This ridge appears to be extending northwards very slowly and vegetation is beginning to colonize the top of it. The channel cuts westwards round the northern end of the ridge, but then swings north again and runs out into the estuary approximately parallel to the beach. The ridges into which the beach proper divides towards its northern extremity, are curved gently towards the shore. The ridges have so far been unable to link up with the shore further north, because of the relatively frequent scouring of the channel. As this gradually silts up throughout its length, fewer and fewer high tides will be able to penetrate it and the beach ridges will be able to compete more successfully with it, until they seal its mouth. In contrast to the Binks, the bank of Old Den is one which has shown no change in morphology during the past three years. (see air photographs 9384, 9386, 9387, 183, 256, 258). Plates 6C and 6D show the surface of the bank which is composed of shingle, generally under

2 inches long diameter but up to 4 inches on the western side. The bank broadens northwards and curves shorewards. In cross-section it is markedly asymmetrical with its crest close to the western side, and a long gentle slope eastwards. A curving nose of shingle forms a prominent feature on each set of air photographs, ~~but~~ by catching the light and showing up white as a result. Probably the most outstanding formation on the bank is the delta which results from the bifurcation of a well marked channel lying parallel to the middle of the bank on the east side. As the tide rises around the western end of Old Den, as seen in air photograph 256, the water penetrates between the main part of the bank and the western edge of the northern set of long sand ridges. It digs deeply into the mud where the channel is seen, but as it approaches the main shingle mass of the bank where it curves shorewards it divides into the distributaries of the delta. A small part of the delta is shown in Plate 6.E where it can be seen that the estuary mud, which is well compacted, has been dissected into irregular hummocks. The mud on the eastern side of the bank has suffered a similar kind of surface dissection near the southern end. Only one channel may be seen aligned east to west across the bank, and that lies at its northerly extremity, and appears to be an ebb channel as it broadens and bifurcates westwards. Another east-west channel, not on Old Den itself, but leading towards the southern end, has already been mentioned as it lies in the centre of the area which divides the two sets of long sand ridges. It appears to be primarily an ebb channel also.

Despite the fact that the main formations on Old Den have shown no change during the past three years, is there even a slow movement of material on the bank? An examination of the surface material showed that over the whole area barnacles have established themselves on the pebbles, and small mussel beds have formed. An investigation of the biology of the barnacle, Balanus balanoides has shown that Old Den provides a favourable site.[2] The upper limit of distribution is the level of high water neap tides in sheltered places, but up to the level of high water spring tides where there is more exposure. The most abundant barnacles are found in a localitity exposed to wave action. The bank of Old Den is completely covered at all tides and is affected by wave action, even though the waves are only small in size. Even in such a tidally favourable position, complete stability of the material on which the barnacles may attach themselves is crucial, as the shells would be broken by the pebbles rolling over even once. The examination of sample pebbles with barnacles attached in June 1962 revealed that the barnacles varied in age from a few months to over two years. This suggests that there has been no movement of the pebbles during this time despite many stormy periods. Moreover Knight-Jones[3] has shown in laboratory experiments that the cyprids of barnacles settle readily only on surfaces bearing settled barnacles of their own species, or cemented bases left when they had been removed. Field experiments showed that similar behaviour occurred under natural field conditions. It appears therefore that there has been no movement of material on Old

Den for a period probably considerably longer than two to three years.

The most likely explanation for the presence of the bank explains also why it is not mobile at present. Probably the earliest map on which a bank appears in a position corresponding to Old Den at present is that of Greenvile Collins, 1684. Earlier however, Boyle[4] quotes Abbot Burton, the chronicler of the abbey of Meaux who described the narrow sandy road which linked the town of Ravenser to the mainland, before that town was "altogether consumed", and went on to say, "which road yet remains visible both to pedestrian and equestrian travellers; but in its farthest part, for a space of half a mile, has been washed into the Humber since those days by the tides of the sea". This suggests that a bank similar to Old Den had been formed when the breach occurred which cut off and caused the destruction of Ravenser. Further evidence of this process is found later. Whilst the bank is shown on charts from Greenvile Collins' until the middle of the 19th century it appears that the bank was considerably enlarged at the time of the breach which occurred in 1849. This developed where the Chalk Bank was later built, reached a width of 1,500 feet, and by September 1851 had a high-water depth of 16 feet. It was closed in 1855. Miles and Richardson[5] record that "seven vessels passed through (the breach) in one tide from the sea to the Humber". In the meantime another narrower breach, 400 feet wide, had developed near to the subsequent position of groyne XIII, but that was closed in 1852. In 1856 a breach 240 feet wide and with a depth of 13 feet at high water occurred near the present groyne XXI, and was closed in the same year. After 1864 groynes and revetments began to be constructed to strengthen the seaward side of the spit and rocks were piled on the riverside dune slope at its weakest points and placed on the beach from the present position of the long boom to opposite groyne XVIII. As a result no more breaches of the spit itself have occurred since 1856, and probably there has been little change in Old Den since 1855. As only a flood stream runs parallel to the east shore of South Spurn as shown in Chapter 5 (see pages 182 to 190) it would be expected that material which had formed Spurn itself, would be carried westwards when a breach occurred, and be deposited to form a bank in the estuary.

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CHAPTER 6

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CHAPTER 7

GENERAL CONCLUSIONS

This chapter will be devoted to linking together the conclusions reached in the preceeding chapters, to present a picture of the geomorphological development of Spurn Head as it has been observed during the last three years, A backward look will then be taken at the spit as it is seen on the R.A.F. air photographs of September, 1946.

The first changes to become apparent and those which have been witnessed over and over agaih were discussed in Chapter 3 as short term changes. An analysis of the beach profiles and the plans of beach features which were surveyed during the year of detailed observations from April 1960 to April 1961 showed that these changes could be divided into two main types, those associated with the building up of the beach, and those associated with its break down.

The building up resulted from the removal of material from the bottom part of the beach and its addition to the top part. This transfered material was usually built into the form of a swash bar on the upper beach, but was sometimes added to give a smooth convex slope with a marked crest. After several weeks of building up, sand rises varying considerably in size and shape developed on the lower beach. Such features may be expected primarily when offshore winds have occurred for a few days, after which the whole beach will show a net gain of material, despite a loss from the bottom part. These winds lessen the steepness of the waves to an average of .0063 on the seaward side and produce a shoreward movement of water near the sea bed to compensate for an offshore movement in the surface layers. Both the low steepness and the shoreward movement of water in the lower layers assist the building up of the beach. Building up may occur also after a period of light onshore winds. It appears that the energy content of the waves should be less than 20,000 foot-pounds per foot of wave crest per wave length, and the wave period less than 8.5 seconds on the seaward side. These waves which affect the build up approach the shore at a low angle opening south; the average of the observed angles was 4.28°. The only tidal disturbance which may be expected is a depression of the level due to strong winds from between west and south, which has no effect on the beaches.

When a break down of the built up form of the beach occurred material was combed down from the upper limit of wave action. Some of the material was deposited on the bottom part of the beach, but the rest was carried beyond low water mark. All the features of build up on both upper and lower beaches were obliterated and the division between the two became indistinct. The result was an almost evenly sloping profile from near the edge of the dunes to low water mark. The development of the particular beach form on the seaward side of the spit, consisting of a tongue of sand and shingle extending from the upper beach at a low angle southwards, suggests that there is a rapid lateral movement of beach material when break down occurs. Whilst strong onshore winds can lower the beach on the seaward side of the spit sufficiently rapidly to produce a cliff in the upper beach several feet high, facing seawards, the main breakdown occurs only with winds over 15 knots from north to north-west. These are produced when a deep depression is centred over southern Scandinavia. They blow over the longest fetch from Spurn Head and have been shown to produce the largest waves which break on the beaches there. All such waves observed at Spurn Head have had an energy content greater than what seems to be the critical value between those producing build up and break down, 20,000 foot-pounds per foot of wave crest per wave length. The wave period, always over 8.5 seconds, reflects the long fetch over which the waves were formed. Waves from between north and north-west are refracted before reaching the shore and this results in a concentration of wave energy on that part of the spit which faces north-east. Despite the refraction, the waves break at a relatively high angle to the shore, up to 40° southwards was observed, with an average angle of 18.3° southwards. Whilst these waves are not as steep as those breaking more nearly parallel to the shore, they are nevertheless relatively steep. In addition to producing destructive waves the strong north to north-west winds cause a storm surge, which may result in more of the beach than usual being subjected to wave action.

At any one time when build up is taking place, the scale of the changes along the whole length of the seaward side of the spit and round the Tip are very similar. On the riverside however, the changes which are usually seen only on the beach of South Spurn are on a considerably smaller scale, owing to the fact that they are produced by the small waves which are all that can develop in the fetch of the estuary. The riverside beaches of

High Bents and Kilnsea Warren, which are affected by a shorter period of wave action each tide than those of South Spurn, show little change of any kind with any combination of wind, wave and tide conditions. When break down of the built up form of the beach occurs it is most complete on the north-east facing section of the spit upon which a maximum amount of wave energy is concentrated. Along the remainder of the seaward side of the spit, that part facing south-east, and round the Tip, there is a less complete break down, with little variation in degree between different parts of these beaches. There is, however, considerably less on the riverside beaches of South Spurn, which are sheltered from the direct effect of the very powerful waves in the North Sea. The only effect which conditions producing break down elsewhere, have on the riverside beaches of High Bents and Kilnsea Warren is to cliff the edge of the dunes, if the peak of the storm surge coincides with high water spring tides.

Before the year's programme of detailed observations was begun, it had become apparent that there were certain longer term changes occuring than those which were seen week by week, and these were considered in Chapter 4. During the year's observations it was possible to study these in detail, and after April 1961, further observations were begun in an attempt to gain more information about them. The longer term changes result from low sections of beach passing along the spit. Such features are well known to the inhabitants of the Holderness coast south of a few miles north of Hornsea, and in dialect are called "ords". From observations of these low sections at Kilnsea and along the seaward side of Spurn Head, (they do not appear to be a feature of the riverside) certain generalizations were made.

When a low section of beach is established the upper beach is swept away and a gently, evenly sloping expanse of sand and fine shingle extends from the top of the beach to low water mark, with surface water in parts. Some of the material from the upper beach is deposited on the lower beach which is considerably raised in level, but the bulk of the material is removed completely from the section and seems to go to form large sand and shingle rises on the lower beach immediately south of the low section. The removal of the upper beach allows almost all high waters to reach the edge ofthe dunes, cliffs, or revetments, which flank the top part of the beach. Sand can be removed easily by even small waves, but much larger waves are needed to undermine the boulder clay cliffs and cause parts to collapse. If such powerful waves can penetrate beneath a revetment wall, they may ~~removed~~ remove much of the infilling material behind and be able to attack the wall from the rear, as well as from the front. Under severe storm conditions, the revetment may be breached. Only during severe storm conditions associated with north to north-west winds over 15 knots when powerful waves approach the coast at a marked angle, will a low section of beach be moved, and the direction of movement is always southwards. The rebuilding of the upper beach in the previous position of the low section is usually begun by the extension of a tongue of sand and shingle from the lower edge of the upper beach further north. In the beginning this tongue lies at a low angle to the upper beach, but as it extends south beyond the end of the upper beach it is pushed up the beach until it reaches the edge of the dunes, the foot of the cliff, or the revetment wall. This tongue of material there forms the core of the new upper beach, upon which building up usually occurs rapidly, as material is removed from the lower beach. Once the upper and lower beach divisions are fully established, short term changes will recommence on them.

The presence of a low section of beach is the main cause of erosion on the seaward side of Spurn Head. As the low section passes, foredune may be removed and the main dunes behind cut back; considerable damage may be done to groynes unless they have very deep foundations; and revetments may partially collapse or be breached completely, leaving the dunes behind unprotected.

The southward movement of the low sections led to a consideration of the longshore movement of material. The very presence of the spit of Spurn Head at the southern end of the Holderness coast suggests a southerly longshore movement. The observation of the low sections of beach has confirmed this movement, and has shown that when severe storms occur, associated with strong north to north-west winds, the volume of material moving laterally must be considerable, or the low sections could not be moved. In order to gain a measure of the rate and direction of movement of pebbles along part of the seaward side of the spit, an experiment was carried out near groyne III in September, 1961, with painted pebbles. Full details were given in Chapter

4, but the experiment will be summarized briefly now. Winds were light and variable, and produced only small waves, breaking generally at a low angle to the shore, opening southwards. During most of the experiment the tides were neaps. All the tracer pebbles moved southwards and the average distances moved by all the located pebbles from the injection line were as follows: 19.35 feet one day after the injection, 83.7 feet after two days, 89.8 feet after three days, and 96.2 feet after four days. The burial of the majority of the tracer pebbles after the fourth day, by a layer of sand, and the fact that very few could be found a day later when the shingle was partly laid bare again suggests that there is a very complex movement of material, probably resulting from the mixing of sand and pebbles on the upper beach. The figures obtained for average rates of movement immediately after the injection must therefore be treated with caution, although it may be assumed safely that the direction of movement indicated was accurate.

What happens to the material which moves southwards along the seaward side of the spit, when it reaches the Tip? This problem was considered in Chapter 6. Another experiment similar to the one near groyne III was carried out later in September 1961 at the extremity of the Tip. Light and variable winds produced only small waves except on one day. The experiment was timed to coincide with maximum equinoxial spring tides. The relative distribution of tracer pebbles east and west of the injection line was the most interesting fact to emerge. Only in the lower part of the intertidal zone, where a narrow band of sand and small pebbles, continuous with the neck of the Binks, was visible at low water did tracer pebbles move eastwards, and these were solely small ones. Only in the upper and middle parts, however, did material of all sizes move westwards. The average distance which the tracer pebbles had moved eastwards six days after the injection was 137.8 feet, and the average distance of movement westwards of all sizes of tracer pebbles was 79.5 feet. (The small pebbles travelling westwards reached an average distance of 85.9 feet; this is strictly comparable with the movement eastwards, as this was solely by small pebbles).

West of the extremity of the Tip the beach narrows at the place where observations on the tidal streams showed that the powerful ebb, flowing at a rate of up to 375 feet per minute, washes the shore. As the beach at this point is composed largely of pebbles only, in its bottom part, yet westwards there is a rapid transition in beach material to almost solely sand, it seems almost certain that much of the material which has moved southwards and round the Tip is then moved eastwards by the ebb stream either in suspension or by traction, mainly below low water. The fact that waves break at a high angle to the shore westwards around the south-east corner of the Tip, and extending to slightly west of the extremity of the Tip, for several hours about high water results in the transport of a large quantity of material westwards round the Tip to the narrow part. A current of the velocity of the ebb stream will be able to pick up most of the beach material except probably the largest pebbles, which will be rolled down the steep offshore slope to provide a foundation for the constant south-westerly extension of the spit. This extension shows that not all the material which accumulates at the Tip is transported away eastwards.

The position of the shingle bank of the Binks along the northern margin of the ebb channel as it swings east of Spurn Head, and the fact that at the broadest part of the Binks, close to the eastern side of the spit near the Tip, a branch breaks from the main ebb stream to flow over the neck and along the western edge of the Binks, suggests that they are formed of the material transported from the narrow section of the beach. Deposition would be expected where the ebb stream lies in juxtaposition to water north of it moving considerably more slowly, and it would also be expected where the weaker branch of the ebb divided from it. The deposition of larger pebbles would take place first and then gradually smaller and smaller ones. Such a gradation of material is found on the Inner Binks, with the coarsest lying close to the neck and the finer further eastwards. The triangle of sand on the beach at the Tip, with its apex towards the neck is probably the result of deposition on the extreme inner edge of the ebb stream or where counter currents develop between the stream and the shore. The Binks are separated from the shore, except at the narrow neck which is exposed only at low water spring tides, by the only flood stream to flow near the shore at the Tip. This flows parallel to the seaward side of the spit near the Tip, and because it is constricted by the presence of the Binks it has considerable scouring power. As it meets the stream flowing eastwards round the Tip, over the neck of the Binks its scouring power there must be considerably reduced. As the neck has shown little change in height or form during the past three years, a delicate balance between the rates of deposition by the ebb stream and scouring by the flood stream must exist.

In order to investigate the movement of material on the Binks a third experiment using painted pebbles was carried out and was described fully in Chapter 5. A period early in February 1962 was selected as particularly low spring tides occurred then and gave access to the Inner Binks from the beach on several successive days. Winds during the first three days including the injection day were from between south and west, between 7 and 26 knots, but on the fourth day they veered to north, up to 28 knots. The tracer pebbles, which had been injected along a line at an angle of 45° to the northerly of the two sets of ebb ripples which normally form a feature of the surface of the Inner Binks, all travelled eastwards, although some splayed out eastwards from the ends of the line, especially to the south of it. The average distances moved were 21.6 feet one day after the injection, 33.6 feet after two days, and 52.2 feet after three days. As the rate of movement was slower than that recorded on the beaches of the spit itself, and yet the recovery rate of the tracer pebbles was very much lower, it appeared that there must have been a considerable mixing of material, as would be expected with the extensive devlopment of ebb ripples. Thefact that no tracer pebbles were found west of the injection line indicates that the flood stream is unable to move even small pebbles, and therefore the Binks must be formed almost entirely by the ebb stream.

Whilst the bulk of the beach material which is transported along the seaward side of the spit in a southerly direction, and then round the Tip to slightly west of Point A is picked up or rolled along by the ebb stream in an easterly direction, some of the sand in suspension moves westwards and this was considered in Chapter 6. Most is deposited south of the life-boat house although some penetrates north of that. A continuous spread of sand extending from the Battery wall to low water mark, is usually seen between the life-boat house and the dis-used sewage pipe. The surface is frequently ripple-marked. North of this to the southern end of Old Den the middle section of the beach sometimes is covered with a surface layer of estuarine mud, and at others with sand. Below this section, and extending to low water mark, a series of arcuate sand ridges have developed fanning out and sub-dividing slightly, northwards. North of these a narrow area extending west from the upper beach is drained by a small stream, and the surface of the whole area is usually composed of estuarine mud, but occasionally a thin layer of sand covers it. Northwards again and opposite the southern end of the Chalk Bank another series of sand ridges have formed. These are less extensive than those farther south and are usually divided from each other by a slight hollow filled with estuarine mud. During the past three years these features have remained almost in the same form, only suffering temporary disruption during stormy spells associated with strong north to north-west winds, when they are spread out to give a more even and extensive sand cover to the whole of the beach. The fact that some of the ridges subdivide northwards, and some have an asymmetrical profile with the steeper slope facing north suggests that the sand is moving northwards, but probably at a very slow rate, as they do not appear to be extending over a larger area or increasing in size individually. As the ridges occur where there is a small supply of sand and where the water is moving at a low velocity it appears that they are probably a particular form of what Twenhofel describes as "small dune-like bodies" in which the sand is moving collectively.

The bank of Old Den, west of Spurn Warren and the Chalk Bank Area, broadening northwards as it curves towards the shore was shown in Chapter 6 to have given no evidence of movement or development during the past three years. A marked flood channel has developed on the eastern side, with a well formed delta at its northern end where it approaches the northern part of the bank. The channel and its distributaries have cut several feet into the layers of estuarine mud. Two much smaller ebb channels have developed at right angles to the flood channel, one cutting across the northern end of the bank and the other, mentioned previously as dividing the two sets of sand ridges, leading westwards to the southern end of the bank. The form of these channels and the paths which they follow have shown no variation even in small detail since 1959, nor has a distinctive nose of shingle which projects from the main crest of the bank. The fact that the pebbles, up to 4 inches long diameter of which the bank is composed, are partially covered by the barnacle, Bala~~us~~nus balanoides, indicates that not even a slight movement of the material is occurring. The shells of the barnacles would be crushed even if the pebbles rolled over once. As most of the barnacles were between a few months and a little over two years in age and the cyprids of this species will only settle near others of the species or cemented bases of these which had been left, the pebbles of the bank have probably not moved from some time considerably before 1959. Historical evidence from both chronicles and charts suggests that Old Den and previous banks in a similar position to it have been formed at the time of a breach in the spit. From the geomorphological investigation of the past three years it appears that a breach would be most likely to occur when a low section of beach lay at a narrow part of the spit and a severe stormy spell associated with strong north to north-west winds occurred. It is known that the 1849 breach occurred with these wind conditions,[1] but no information about the state of the beach seems to have been preserved. The flood channel lying close to the seaward side of South Spurn would provide the means of transporting the material from the spit to the position of the bank slightly to the west of it.

A backward look will now be taken to the air photographs of 21st September 1946 to discover what changes if any have taken place in the general formation of the spit during the past fifteen and a half years, and how the detailed state of the beaches sheds light on the development which has been studied during the past three years.

The photographs were taken at maximum neap tides, probably near the time of low water about 8.30 a.m. as may be gathered by the long shadows cast to the west, and the position of the water's edge. Wind conditions during the preceeding 24 hours were as follows:

20th September 1946	0600 hours	S.S.W.	4(Beaufort Scale)	11-16 knots
	1200 hours	S.S.W.	5	17-21 knots
	1800 hours	N.N.E	8	34-40 knots
21st September	0000 hours	E.N.E.	6	22-27 knots
	0600 hours	W.N.W.	5	17-21 knots
	1200 hours	W.N.W.	5	17-21 knots

The strong winds between east-north-east and west-north-west had produced the long powerful waves which show very clearly on the air photographs. As these winds had been blowing for only about 8 hours as marked a break down of the built-up beaches as occurred between 16th and 23rd March 1961 would not be expected. Also, as tides on 21st September 1946 were at maximum neaps, only part of the beach would be affected by the powerful waves in any case.

As the wave pattern is so clear, it will be considered in a little more detail before attention is turned to the beaches. North of groyne XXI the waves were breaking almost directly onshore, whereas south of this point as the spit swings towards the southwest they began to break at a higher and higher angle to the beach opening southwards, until the straight seaward side of South Spurn was reached where the angle remained constant. This illustrates what was shown in the wave orthogonal diagrams (Figures 3.1 and 3.2) namely that with waves from between north and north-east energy is concentrated on the north-eastward facing section of the spit where ~~little~~ least wave refraction occurs. The disruption caused by the Binks to the wave train is clearly seen, as complicated refraction and diffraction patterns were produced. Even on this neap tide, the waves formed in the North Sea were unable to penetrate west of the neck of the Binks, although as shown in Chapter 5 (pages 190 to 202) they would be likely to affect the beach as far as a little west of Point A when they met the most steeply sloping part round the Tip towards high water. Despite the powerful waves east of the spit in the sheltered estuary only very small waves had formed.

Unfortunately not the whole of the Kilnsea beaches were ~~not~~ photographed at the time of this survey, and the only photograph available of part of them was taken five days after the ones of Spurn Head. However, as the wind was from between south and west under 17 knots during this period no great change would have been likely to occur, and the photograph will be treated as approximately comparable with those of Spurn Head.

Where the boulder clay cliffs at Kilnsea (see air photograph 5001) were protected by a revetment and projected eastwards of the low cliffs to the south, no upper beach was present, but a large sand rise had formed on the lower beach. Air photographs 5001 and 2002 show that only a narrow upper beach lay south of the Kilnsea revetment to groyne XXIv, with irregular sand rises scattered over the lower beach. The division between upper and lower beaches was very indistinct. South of groyne XXIV the upper beach became a broader and more well defined feature, but it narrowed again between groynes XXIII and XXII. The sand rises became progressively larger southwards.

The state of the beaches between groynes XXI and XVII ~~is~~ was similar to what it was in September 1959 between groynes XX and XIV (as seen on air photogaphs 9360, 9358, and 9357) owing to the presence of a low section of beach. The low section in September 1946 was not such a well-developed one as the later one, but it showed all the same characteristics. The upper beach was very narrow and almost non-existant in places. The lower beach, on the other hand, was composed of a number of large sand rises, which, because of the broad band of breakers probably extended some distance beyond the position of low water on this neap tide. The width of the beach at this low section at low water was broader than further north and south, suggesting that the height of the lower beach had been raised, which was shown to be a characteristic of these features (see pages160 to 161)

On air phtographs 2003 and 3005 it can be seen that south of the low section of beach as far as groyne XII a well built up beach existed, although the division between upper and lower beaches was indistinct probably as a result of the powerful waves on the previous high water. On the upper beach swash bars were seen, probably above the level of the previous high water. They formed a distinct feature along the whole of seaward side of the spit, wherever the upper beach was well developed. The lower beach between groynes XVII and XII was a very narrow feature.

South of groyne XII the upper beach narrowed again to another smaller low section of beach south of groyne XI. The fact that the waves were breaking beyond the water's edge suggested that where the upper beach was absent the lower beach was raised in level, and was considerably broader at most low waters than the beach on either side. A broad upper beach lay to the south (see air photograph 3007) with a sand rise continuous with it on the lower beach. This terminated southwards in a long projection lying at a low angle to the upper beach, a feature often seen after storm conditions. The relatively jagged edge to the dunes in this section is noteworthy. In contrast, the air photographs in 1959 (9413, 9415,9416) show a much smoother outline with a marked development of foredunes. The accretion of which these were evidence has been halted by the passage of the low section of beach since October 1960, and the foredunes have been almost completely removed.

Opposite the revetment between groynes VIII and IV the upper beach narrowed as the revetment juts east of the general line of the dunes. It broadened again southwards however towards the Tip as the lower beach narrowed to non-existance near the neck of the Binks. The widest part of the beach round the Tip was at the south-east corner whence it narrowed to a little west of the extremity of the Tip before broadening again towards the life-boat house. A broad high upper beach was present around the Tip. The dune edge was not clearly defined as has been the case during the past three years but a number of isolated dune ridges had formed on the top part of the high upper beach with low foredunes in front of them. Between 1946 and 1959 these had become consolidated into the main dunes and the dune edge had extended approximately 300 feet towards the south-west.

This is slower than the 30 feet per annum extimated by Dossor[2] as the rate of growth between 1930 and 1951. Low foredunes which have developed since have had difficulty in establishing themselves, as they have suffered erosion with each storm surge.

The general line of the Binks can be seen on air photographs 3005, 3007, 1003 and 1004. Only a very small part of the Inner Binks was visible above low water as was the case on 23rd March 1961 (see air photograph 254) As the Binks is a mobile bank the changes seen are only what would be expected. The broad crescentic outline remained similar but the more detailed morphology changed. The highest part remained closest to the shore of the spit itself, but changed in shape.

The riverside of South Spurn (see air photograph 3007) was characterized by the same features as have been seen during the past three years. Between the lifeboat house and the disused sewage pipe was a continuous spread of sand, but north of this the long ridges of sand were seen in a very well-developed form. The absence of the long boom in 1946 meant that there was no interuption to their development northwards. Despite this they did not extend beyond their position during the last few years although a number of more irregular ones developed south of the stream draining towards the southern end of Old Den. This stream which at present follows an almost straight course, meandered considerably in 1946. The most marked meander then now remains as a small ox-bow feature. North of the stream a ridge left the beach at a low angle as at present, and north of this many ~~sound~~ sand ridges were seen, decreasing in size northwards. They showed a greater development in number and area they covered in 1946 than in 1959 and 1961. The beach proper terminated opposite the northern end of the Chalk Bank in two curving ridges, with the inner edge of the upper one bounded by the stream draining the area round the Chalk Bank. A ridge of sand, upon which vegetation was establishing itself was closing a small embayment in the dune edge where the stream crossed the breach. In September 1959 the feature was still clearly visible, but by March 1961 the embayment had been almost completely filled in. The bank of Old Den showed no changes from 1946 and 1961, all the features retained their form even in as minute detail as could be traced on the air photographs.

The depth of shadow cast on the narrow beach of High Bents and Kilnsea Warren (see air photographs 2002, 2003, 3005) obliterated from view any features which may have been present. In width the beach was as narrow as at present. There are, however, two facts worthy of note about this section. First, opposite the southern part of the section a number of what appear to be sand ridges are seen extending outwards from the ~~wind~~ mud ridges near the beach, which still remain. During the past three years no sand ridges have been seen north of South Spurn. Second, there is a complete lack of Spartina opposite the northern part of the beach.

This backward look to Spurn Head as it was in September, 1946, has confirmed that the particular forms of the beach which have been studied in detail during the past three years were not unique or of very recent development. Indeed, they have probably all characterized the spit whenever it has reached a comparable stage of development in the past, and those associated with what have been defined as short term and long term changes are probably present whatever the state of the spit.

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CHAPTER 8

The History and Evolution of Spurn Head

The study of some aspects of the coastal geomorphology of Spurn Head, which has been presented in the preceeding chapters, is intended to form a contribution to a wider investigation of its history and evolution.*

Spurn Head has a history of regular growth, destruction and re-growth, which may be the result of the coastline to which it is attached suffering a sustained rate of erosion and retreat, which, according to Valentin[1] is not easily matched elsewhere in the world. A reasonably continuous recorded history of Spurn exists from about 1235 to the present day, and within this time the spit appears to have completed three cycles of development each of between 200 and 250 years in length. None of the facts support Reid's[2] theory of a 400 year cycle terminating as the Tip breaks off to form an island which migrates across the Humber and joins the Lincolnshire coast at Donna Nook. There is evidence of the spit's destruction about 1360, 1620 and had man not intervened it would probably have been destroyed again about 1850. In each cycle of development different names are associated with the spit, Ravenserodd with the first, Ravenser Spurn with the second, and Spurn Head, Spurn Point, or The Spurn with the latest. Before 1235 there are only isolated references to Spurn,

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*Footnote I am indebted to G.de Boer, M.A. for permission to quote from his unpublished work on the history of Spurn Head.

but not sufficient to gain information on possible earlier cycles. The earliest known reference is by Alcuin in the life of Saint Willbrord, who was born either in A.D. 567 or 568. He tells that the Saint's father during the last part of his life "betook himself to the promontaries encircled by the ocean, sea and Humber River". The Scandinavian survivors of the Battle of Stamford Bridge in 1066 sailed from Ravenser, according to Ancient Icelandic literature.

As most information is available about the latest cycle of development it will be considered first, and in the light of this, the two earlier cycles will then be examined.

In 1622[3] Callis in his Lectures on Sewers at Grays Inn says that, "Of late years parcel of the Spurnhead in Yorkshire, which before did adhere to the continent, was torn therefrom by the sea, and is now in the nature of an island". The subsequent history of lighthouses on Spurn Head indicates the development of a new cycle which can be traced in some detail on charts and in manuscripts. By 1660 some Hull shipmasters felt that a light was vital at the northern side of the entrance to the Humber, and asked Justinian Angell, a London merchant who owned the land at the Point of Spurn, to erect a lighthouse. In order to mark the channel effectively two lights in line were necessary, and in 1674 these were erected. In 1675[5] Justinian Angell obtained a patent from King Charles II empowering him "to continue, renew, and maintain certain lights that he had erected upon a very broad, long sand at Spurn Point, which lights had been erected at the requests of masters of ships using the northern trade". A second patent was granted in 1678, and these two enabled Angell to levy compulsory dues. In the case of both lights, open coal fires burned in braziers hoisted by levers or swapes. The coal used was brought by Newcastle lighters which discharged their cargo along the shore near the lights, whence it was carted over sand and shingle.

In 1684, Greenvile Collins, hydrographer to King Charles II made a survey and chart of the Humber from the sea to Hull. Figure 8.1 shows Spurn then as a stumpy, "hammer-toed" spit "tucked under" the south-east corner of Holderness, and aligned north-east to south-west. Angell's erections are shown close to the tip, with the tower of the high light on the west, and the low light (or maybe a day beacon to which reference is made in some manuscripts) on the east side. After 1684 Spurn Head grew rapidly in length, so much so by 1766 that the navigation channel was so distant from the lights that many accidents and shipwrecks were caused.

In that year therefore application was made to Parliament by the Trinity Houses of Hull and Deptford-Strond for power to remove Angell's lights, and in 1766 and 1772 acts were passed for this purpose and to empower the erection of other lighthouses. On 22nd June 1766, Smeaton met a committee appointed by Trinity House to select sites for the new lighthouses. He advised the erection of two lighthouses[2] "to be in a north-west to south-east direction, and to be 300 yards assunder. The great Lighthouse to be placed on Spurn Point at a distance from high-water mark (at common spring tides) of 90 yards, in a north-east and south-west line; and 150 yards in a north-west line, within the Spurn. The small lighthouse to be 116 yards distant from high-water mark in a south-east line without the Spurn". The breadth of the land in a north-west to south-east direction was 566 yards. Because the erection of the lighthouses would take several years two temporary lights were erected and lit in 1767. In case of further sand shifting,[4] the larger temporary swape was set on rollers so that it could be moved as the navigation channel moved.

In 1771,[3] Smeaton reported that Spurn Point had extended 280 yards since 1766, and had increased on the Humber side, but diminished on the seaward side. The position[2] fixed "for the Low Light at 116 yards within high-water mark, according to the line of direction, was now on the very high water mark itself". The position had to be altered to 80 yards further inland, to the north-west. In 1772 the High Light was begun 60 yards further to the north-west than had been planned in 1766, and the distance between the two lighthouses was therefore reduced to 280 yards.

The Low Light appears to have been in danger from the time building was begun. Until the building actually began, Smeaton had never been to Spurn except by water and was not aware that there was a marked westward movement of the spit. In 1766 a great storm washed away the circular wall round the Low Light and laid bare the piles on which the building was erected. Smeaton, realizing that no permanent defense for the building was possible advised its repair at a moderate cost and recommended that a temporary light should be placed 30 yards further inland, ready for use if the lighthouse should be destroyed. The site of Angell's last low light (there had been a sequence of these as the seaward side of the spit was eroded) was destroyed in the same storm in 1766.

In 1776[4] Smeaton's High and Low Lights were lit. (The novel design of the grates and the controlled ventilation in the lanterns, together with the excellant means of raising coals and removing cinders, made them the first scientific coal-burning lighthouses).

In 1786[3] Smeaton's survey of Spurn showed that the High Light was 1,840 yards south of the position of Angell's high light, and was 480 yards from high-water mark at the end of the Point, and that the Point had also moved westward throughout its length. Smeaton concluded that Spurn Point was a necessary appendage to the cliffs of Holderness and was moving westwards, as was the coast of Holderness, as the sea eroded the cliffs, but at the same time was lengthening southwards. The outline of Spurn in 1786 is shown in figure 8.1.

Hewett's Chart[3] of 1828, showed that the spit had lengthened further and the accumulation of shingle east of the tip had increased. Meanwhile the westward retreat of the spit continued. After the destruction of Smeaton's Low Light, which had been built in 1771, no less than five more were erected in quick succession, closer and closer to the High Light. By 1863 the edge of the dunes had retreated to the walls of the latter, and the low light had been placed to the west of the spit in 1851. There had therefore been a westward retreat of 280 yards in 92 years, or an average retreat of approximately 3 yards per annum. Hewett noted on his chart that "a portion of Spurn Neck, north of the Lighthouses, is overflowed at high spring tides". The large breach which developed in 1849 and the smaller ones of 1852 and 1856 have already been described in Chapter 6 (see pages 233 to 234) Figure 8.1 shows Spurn in 1852.

These breaches really marked the end of this latest cycle of development of Spurn of about 230 ~~yards~~ years which will be summarized briefly. After a breach in the previous spit about 1620, the tip was turned into an island which was probably washed away. "A very broad long sand" in the 1670's had developed into a stumpy spit by 1684, and this grew rapidly in length so that by 1766 it was about a mile longer than in 1684. The spit continued to grow in length and at the same time was being eroded on the seaward side, but was extending westwards on the riverside near the tip. Shingle was accumulating east of the tip. In 1828, the neck of the spit which had been narrowing considerably was awash in one part at high spring tides, and in 1849 a major breach developed. Reid[2] summarizes the southerly extension of the spit in this cycle:

1676-1766	1,800 yards	20 yards per annum
1766-1771	280 yards	56 yards per annum
1771-1786	150 yards	10 yards per annum
1786-1851	300 yards	4.6 yards per annum

Had the major breach not been closed and groynes built along the seaward side of the spit shortly afterwards, 1849 and the years immediately following would probably have witnessed the destruction of Spurn Head. The artificial preservation of the spit since the 1850's will now be considered in some detail.

In 1850 itself[3], Captain Vetch held an Admiralty enquiry at the site of the major breach. He reported "in favour of strengthen~~ed~~ing the Point on its seaward face by means of groynes placed at right angles to its length, for the purpose of intercepting shingle in its passage southward, and on the Humber side by the further reclamation of the accretions east of Sunk Island".

In 1863[6], Sir John Coode was placed in charge of the maintenance of Spurn Head, and the following year six groynes were built to collect shingle and increase the beach on the seaward side. They were placed at varying intervals along the whole length of the spit. They were so successful that more groynes were erected, and this was still while the gravel trade was in operation. It had been common practice for shingle to be removed from the Holderness and Spurn beaches for road repairs for a long time, and this grew in the early 19th century, so that frequently a total of 50 to 80 tons might be removed between Spurn and Withernsea by each of 20 to 30 boats, in a single tide. The opening of the Hull and Holderness railway in 1854 gave this trade a great filip. In 1868, the Board of Trade, under the Harbour Transfer Act of 1862, ~~probited~~ prohibited the removal of shingle from any portion of the shore at Spurn, 2½ miles north from the tip.

The following year the Board of Trade prohibited its removal from the whole of the coast from Spurn to the northern boundary of the Hornsea parish. Coode stated in court at the trial of persons who had been caught violating the prohibitions in 1869, "that, if the shingle continued to be removed the port of Hull would be endangered". Oldham on the same occasion, stated that "the removal of shingle would result in the weakening of Spurn Point".

Whilst Coode said that the purpose of the groynes was simply to conserve the beach, Pickwell discovered that by 1878 much more had been achieved. At the extremity of the tip the edge of the dunes had extended 60 yards, and a little east of it an advance of 80 yards had taken place, since immediately before the groynes were built. Along the rest of the seaward side of the spit, "this line of bents (Marram grass) had travelled to seaward from 20 to 40 yards covering a sand-bank of drift from 6 to 10 feet high; which may be called a gain of land equal to 2 to 4 yards per annum. This accumulation of drift sand has been greatly accelerated by constructing small embankments of sand 6 to 8 feet high and planting them on the top and sea face with bent grass, which builds the sand and prevents drift. Pickwell records that during the previous 4 to 5 years, Sea Buckthorn established itself and grew rapidly. It was estimated that the accumulation of the sand colonized by marram grass along 2 miles of the neck of the spit was 60 yards in width and 6 feet deep. When the groynes were erected most of them had five to seven planks above the beach at the dune end, but by September 1876, five of the groynes had been covered with shingle to depths of 3 to 4 feet along most of their length. In conclusion, Pickwell states that he "is of the opinion that there is now an outer belt of beach in addition to the high bent-covered sands, at least 100 yards wide, 7 feet in average thickness, and $2\frac{1}{2}$ miles in length, equal to 1,250,000 tons of shingle, entirely due tothe construction of the works of Sir John Coode, and the prohibition of the removal of shingle; and that the works have been a great success and have rapidly reduced the chances of the sea outflanking Spurn Point".

Since 1878, many more groynes have been added along the seaward side of the spit, and concrete revetments have been built in parts. These have successfully guarded the spit against further breaching.

Attention will now be turned to the two earlier cycles of development of the spit, and the earliest will be considered first.

After the mention of Ravenser (meaning Hrafn's sandbank) as the place from which the defeated Scandinavians sailed, after the Battle of Stamford Bridge in 1066, nothing else was heard of it for two centuries. In 1099[7] there are records of widespread storm damage on November 11th, especially severe around the Thames estuary. This probably resulted from a major storm surge which would have had a considerable effect on the Yorkshire coast, even though it was probably less severe than further south. It may be that this marked the end of one cycle of development of the spit and the beginning of the next. Boyle[8] quotes the men of Grimsby in the Hundred Rolls as saying, "that forty years ago and more (about or before 1235) by the casting up of the sea, sands and stones accumulated, on which accumulation William de Fortibus, then earl of Albemarle, began to build a certain town which is called Ravenesodd (odd means promontary); and is an island: the sea surrounds it." It was further described in the same papers as, "a certain encroachment (which) has been made in the county of York by ~~Wilhain~~ William de Fortibus, at one time earl of Albemarl, at Ravensher". Abbot Burton, the chronicler of Meaux Abbey explains that the former town of Ravenser, of which only a manor house was left some distance from the sea and the Humber, was called Ald Ravenser, whereas the new Ravenser, 1½ miles from the mainland, and linked to it by a narrow sandy road, was usually called Ravenserodd". The previous reference to Ravenserodd as being on an island can mean only that the neck was perhaps awash in one place at high spring tides, for to establish a town, which by later references was clearly a port, good connections with the mainland would be vital. In 1251, Henry III granted William de Fortibus the right to hold a weekly market and a fair of 16 days in Ravenserodd. Five years later the first reference to Ravenserodd as a port is made by the king in a charter to the burgesses of Scarborough, in which he promised that no port or quay should be built between Scarborough and Ravenserodd. Many complaints were made subsequently by the men of Grimsby about the men of Ravenserodd leading ships there with their merchandise, which were originally bound for

Grimsby. As Ravenserodd was nearer the sea, it had a more advantageous site as a port, than Grimsby.

Ravenserodd enjoyed a period of considerable prosperity after 1290. In 1299, a royal charter was granted to make it a free borough. Two markets were subsequently held there every week, and a fair of thirty days duration, each year. Two burgesses represented Ravenserodd in parliament, in 1304 and 1326 to 1327. During the struggle between Edward II of England and Robert Bruce of Scotland, Ravenserodd played a part, by several times supplying a fully manned and equiped warship, and by sending food supplies for the English army.

The destruction of Ravenserodd began about 1334 to 1335 at the time of great floods. In 1346 an inquisition was held to ascertain the nature and extent of the destruction of the port. It appeared that two-thirds of the town had been destroyed and it was daily being diminished. Many of the inhabitants left because of the danger of living there. Shortly afterwards, "Ravenserodd, by the inundation of the sea and of the Humber, was completely blotted out and consumed" according to the chronicle of Meaux Abbey. About 1360 it states that scarcely a vestige remained of the site.

The building of the town and port of Ravenserodd clearly reflects the development of a new spit, and the importance of the settlement in relation to other ports of its day suggests it must have attained a considerable size. For this to be possible the bulbous end of the spit must have been well developed. That it was linked to the mainland by a narrow sandy road is stated in the Meaux Chronicles, and therefore the form of the spit must have been similar to that which developed in the last cycle. If it is correct to assume that this first cycle of which there is evidence began early in the 12th century, it lasted about 250 years until the destruction of Ravenserodd.

The next mention of Spurn is as "Ravenser Spurn", and this marks the beginning of a new cycle of development. In June, 1399[8], Henry Duke of Lancaster landed at Ravenser Spurn before deposing Richard II and being declared Henry IV. When Henry landed he was met by a hermit, Matthew Danthorpe, who had been attracted there by the remoteness and loneliness of the place. He had begun to build himself a chapel and an anchorage into which Henry and his followers had sailed. Shakespeare's "Henry VI" Part III, and "Richard II" both contain references to Henry's landing at Ravenser Spurn. The day after Henry was proclaimed king he granted a royal license to Matthew Danthorpe to continue and complete the hermitage and chapel which he had started. By 1428 another hermit, Richard Reedbarrow had come to Ravenser Spurn. In that year he addressed a petition to parliament for permission to levy tolls on all ships entering the river Humber, so that he might finish a tower in which a beacon was to be lit every night to guide ships safely into the Humber. By this time the spit must have developed to such a size that it became a danger to shipping, for Reedbarrow was concerned with saving the "Christian people and the goods and merchandise coming into that river". The patent was granted and Richard Reedbarrow's beacon thus became the first lighthouse at Spurn. During the Wars ofthe Roses, Edward IV was forced to flee to Holland and on his return in 1471 he was reconnoitering the coast of Norfolk, when a severe storm carried the little fleet towards the Humber. Edward himself landed at Ravenspurgh where "king Henry the fourth landed". Two 16th century charts, one of 1540, and Lord Burleigh's Chart of 1579, reproduced by Sheppard[9] show the spit with a long thin neck and bulbous tip. Reference has already been made to Callis' statement (see page 258) that a little before 1622 Spurn Head was turned into an island as it was torn from the mainland.

The period from the end of the 14th century to the beginning of 17th century appears to have witnessed yet another cycle of development of Spurn Head, and the form of the spit appears to have been similar to that in the earlier and later cycles.

Figure 8.2 attempts to correlate the three cycles which have been described. It assumes that as the physical circumstances controlling the development of Spurn Head have repeated themselves in a similar form in each cycle, each will have followed a similar course. Spurn has been drawn in three positions using the outline of Spurn as it was in 1830 in the final stage of the last cycle. The physiographical processes which produced this were little interfered with by man. The position of the outlines has been determined by assuming an average rate of coastal erosion of $2\frac{1}{2}$ yards per year. The date lines, intersecting these three outlines at right angles, indicate how with each cycle, similar events seem to have happened at the corresponding phase. Thus, the building of Justinian Angell's lighthouse in the early 1670's corresponds to that of Richard Reedbarrow in 1428, 70 years from the beginning of a cycle. The date line 120 years from the beginning is based on a map of Spurn in its last cycle; if Ravenser Spurn was growing out at a similar rate a very likely place is suggested for the landing of Edward IV. Contemporary evidence gives this as $2\frac{1}{2}$ miles from Kilnsea. The same line shows that the most probable site for Ravenserodd would not have come into existence by the corresponding phase of an earlier cycle. However, the evidence available from the building of Smeaton's lighthouses in the 1770's indicates a course of development, which, had it operated 500 years earlier on similar lines would have caused the site of Ravenserodd to appear in a position which would be reasonable for a sea port and agrees with the slight indications of its position which are available. The date line further fits the time of the appearance of Ravenserodd well. The considerable thinning of Spurn Head indicated between 1830 and 1850 compares with that suggested on 16th century charts between 1545 and 1588, and the erosion which began to be felt about 1340 at Ravenserodd and soon afterwards led to its destruction.

How can the cyclic development of Spurn Head be related to geomorphological processes, some at least of which have been observed during the last three years?

As the spit begins to form it is turned south-westwards from the south-east corner of Holderness. The orientation of the boulder clay coast is probably related to storm waves from the north, refracted westwards to break at a low angle on this rapidly eroding coast, where they cause major destruction, especially when a low section of beach is present. Spurn Head, a depositional feature, built of material from the Holderness coast suffers only destruction by these storm waves. Constructive action takes place under all wind conditions except when strong north to north-west winds blow. The waves causing con~~de~~struction approach the shore either parallel to it or at a low angle to the south, and as the wave orthogonal diagrams (Figures 3.1, 3.2, 3.3 and 3.4) show, they will most probably have come from an easterly to south-easterly direction. The orientation of the spit to face approximately south-east is probably in response to these waves. As it grows, it curves more gradually towards the south-west as it develops a neck. This is probably due to the energy of the storm waves from the north being concentrated more on the north-east facing coast to which the spit is attached, than on the south-east facing coast of the spit itself. It must be remembered, however, that boulder clay cliffs will not retreat as rapidly as sand dunes when open to strong wave attack, but despite this, the net loss is probably greater on the north-east facing coast.

The more rapid rate of growth of the spit in the earlier stages of the cycle were noted on page 262. As the rate of longshore movement of material along the Holderness coast towards Spurn is not likely to have varied greatly over the years, some other factor must account for this. The most probable is the channels of the tidal streams. Unfortunately there is no direct evidence about these. If it may be assumed that the main ebb channel has never moved much further north than its present position, the development of the spit may be explained in the following way.

When the spit is only short and its tip is not very close to the ebb channel material will be carried to the tip where the coarser part will be deposited as the larger waves of the North Sea cease to be effective. Much of the finer material is likely to be carried round the tip and deposited along the western shore to form the bulbous end of the spit. This material is probably moved very slowly northwards along the southern end of the riverside, by the small waves which form in the estuary. Even if the main ebb stream does not wash the shore of the tip there is likely to be a very slow movement of shingle eastwards, which would explain why shingle is shown off the south-east corner of the tip on Greenvile Collins' chart of 1684. However if there is no mass movement of shingle eastwards by the ebb stream and the waves are too small to move it westwards the spit will obviously lengthen rapidly.

The neck must be built of previous bulbous ends and if the rate of lengthening is relatively constant, as probably is the case in the first part of the cycle, the question arises as to why the neck is thin in relation to the end. It seems almost certain that the seaward side is suffering constant erosion throughout the cycle, as low sections of beach will be passing southwards from the Holderness coast towards the tip. The further south the spit extends, the further west the bulbous end will form in relation to the position of the seaward side of the spit further north, which will be moving west of the position it occupied, when it first developed. Whilst material is probably carried to the western side of the bulbous end it is not likely to be carried to the west of the neck in any large quantity. Thus the neck becomes thinner as it is eroded from the east. This theory is substantiated by the fact that Angell's lighthouses were built originally on the end of the bulbous part. That this section was suffering erosion from the east is shown in the reported washing away of several low lights, and the site of Angell's last low light in 1776. If the spit was growing fast as appears to be the case in the early stages, there would be no reason to expect the northern part of the neck to be much thinner than the southern at this time.

As the spit lengthens it will be approaching closer and closer to the main ebb channel. The rate of lengthening will decrease as more coarse material is carried away from the tip eastwards to build the Binks. At the same time the amount of fine material passing to the west of the bulbous end is likely to decrease. Gradually, as the spit grows slowly longer and pushes almost into the ebb channel, these conditions will be accentuated.

When virtually no material is passing round the tip westwards there will be no compensation for the erosion of the seaward side anywhere along the spit. The whole of it, both neck and bulbous end will narrow as was seen in the last few years of the two most recent cycles, and the neck being the thinnest part after much erosion has taken place along it when the spit was extending its bulbous end only slowly, will be breached. The position of Angell's lights originally sited at the bulbous end of Spurn Head is known to be opposite the northern end of Old Den at present, where in fact one of the minor breaches occurred in 1852, and slightly to the north of the major breach of 1849. The bulbous end of Angell's day had so thinned by the middle of the 19th century. The cycle will be ended as the material from the spit at the breach will be carried westwards by the flood stream and deposited in the estuary, and as the island into which the bulbous tip is turned is eroded by the flood stream to the north and the ebb stream to the south until it ceases to exist. The Binks will most likely be destroyed by the ebb stream which will prbably swing slightly northwards to the position it occupied before the spit began to push into it.

The present conditions of the spit, as it appears in Plate 8.A, is artifically maintained by groynes and revetments. Despite the rapid eastward growth of the dune edge on the seaward side after the first groynes were built, this development was only short-lived, before erosion recommenced, and now that the artificial defenses are in a poor state of repair it is increasing markedly. The present length of the spit is probably greater than ever before and the Binks are probably most fully formed because of man's intefvention in the natural geomorphological development.

The theory of the evolution of Spurn, outlined above, depends for substantiation upon its amount of agreement with the historical evidence, and as has been shown, this agreement seems good. Furthermore the present investigation shows clearly that the geomorphological processes required by the theory of evolution are in operation at the present time, and in the manner which the theory requires. To this extent therefore the present investigation provides a contribution to the study of the history and evolution of Spurn Head.

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APPENDIX 1

The Relative Value of the Different Methods of Analysis Used in Chapter 3

1. A preliminary study of the beach profiles and beach feature plans which gave a three dimensional picture of beach conditions revealed that there were two major types of beach form, a built up form, and a smooth form resulting from the break down of the former. The built up form consisted of a convex-profiled upper beach with an even sloping lower beach. The smooth form showed an even slope from the top of the upper beach to low water mark.

2. The composite diagram, figure 2.1 showed the profile changes in relation to differing conditions of winds, waves and tides and clearly revealed the combination of factors which produced the major changes, in general terms. A detailed analysis of all the data collected was then begun.

3. The winds were considered first. The predominant direction between beach surveys was taken from the wind roses and the gain or loss of material from each Point was noted. From this information Tables 3.I, 3.II, 3.III and 3.IV were compiled. These all revealed one fact, above all else, that build up of the top part of the beach was most common with offshore winds. It yielded nothing about conditions producing break down of the built up form, therefore the data was considered in another way. The wind roses revealed that for a number of periods between observations winds blew almost solely from

one direction. The wind roses in addition to showing predominant direction linked wind speed to it. Eight periods were selected, two for when the wind blew mainly from each of the four cardinal points. The two periods were so chosen that winds were lighter in one and stronger in the other. In the light of this, beach conditions at the end of each of the eight periods were considered. This analysis showed that the break down of the beach form occurred with strong north or north-west winds, whereas build up occurred with all other combinations of wind direction and speed. This showed the vital importance of taking direction and speed together in this analysis.

4. Winds affect the beaches primarily through the waves, and may modify the tidal regime. The waves were considered next. The maximum fetch was found to be between 350° and 010° from Spurn Head and the largest waves to reach the shore there might be expected from between these two bearings. The wave energy and steepness, and the angle of wave approach were considered with the wind direction and speed during the preceeding 24 hours, in Tables 3.V and 3.VI. This showed that waves with the highest energy content, the longest period and greatest height (although not the greatest s teepness) were generated by strong winds from between north and north-west. Wave orthogonal diagrams showed where energy was concentrated under varying wave conditions.

5. The tides were considered finally. The occasions when the recorded tides differed in height from those predicted were taken from the composite diagram, Figure 2.1 and were considered together with the wind direction and speed during the preceeding 24 hours. It was found that a storm surge occurred with strong north to north-west winds, and a depression of tidal level with strong winds from between south and west.

Thus the analysis of wave and tide data showed why the break down of the built up form of the beach occurred with strong north to north-west winds and why build up was possible under all other wind conditions.

APPENDIX 2 WAVE DATA

	Point A				Point I			
Date	T.Secs	Hb ft	Breaker Type	Direction of Approach	T.Secs	Hb ft	Breaker Type	Direction of approach
13.4.60	5.0	2.0	P	-	-	-	-	-
18.4.60	-	-	-	-	-	-	-	-
25.4.60	5.0	0.5	S	-	-	-	-	-
4.5.60	3.0	0.5	P	-	2.5	0.5	S	-
11.5.60	-	-	-	-	-	-	-	-
18.5.60	-	1.0	P	-	3.0	1.0	S	-
25.5.60	4.0	1.0	P	-	-	-	-	-
30.5.60	3.0	1.0	P	-	-	0.25	S	-
10.6.60	-	0.5	P	-	-	-	-	-
15.6.60	4.0	0.5	P	-	2.5	0.1	S	-
23.6.60	5.0	1.5	P	-	-	-	-	-
29.6.60	-	3.0	P	-	-	-	-	-
7.7.60	2.5	1.5	P	-	3.0	0.5	S	-
14.7.60	-	0.25	P	-	3.0	0.5	S	-
20.7.60	2.5	0.5	P	-	-	-	-	-
31.7.60	4.0	0.5	P	-	-	-	-	-
5.8.60	7.5	0.5	P	-	-	-	-	-
10.8.60	3.0	0.5	P	-	-	-	-	-
18.8.60	-	0.5	P	-	-	-	-	-
27.8.60	-	0.5	P	-	-	-	-	-
3.9.60	-	0.5	P	-	-	-	-	-

Appendix 2 continued

	Point A				Point I			
Date	T.Secs	Hb ft	Breaker Type	Direction of Approach	T.Secs	Hb Ft	Breaker Type	Direction of Approach
7.9.60	-	0.25	P	-	-	-	-	-
21.9.60	-	1.0	P	-	-	-	-	-
27.9.60	4.0	1.0	P	-	-	-	-	-
7.10.60	4.0	1.0	P	-	-	-	-	-
12.10.60	-	1.0	P	-	-	-	-	-
21.10.60	-	0.5	P	-	-	-	-	-
26.10.60	6.0	0.5	P	-	-	-	-	-
4.11.60	-	1.0	P	-	-	-	-	-
9.11.60	-	0.5	P	-	-	-	-	-
18.11.60	-	0.5	P	-	3.5	0.25	P	-
23.11.60	-	-	-	-	-	-	-	-
30.11.60	-	1.0	P	-	-	-	-	-
7.12.60	-	1.0	P	-	-	-	-	-
17.12.60	-	0.5	P	-	-	-	-	-
22.12.60	-	0.5	P	-	-	-	-	-
1.1.61	-	1.0	P	-	-	-	-	-
14.1.61	-	0.75	P	-	-	-	-	-
19.1.61	-	1.0	P	-	-	-	-	-
29.1.61	3.5	3.0	P	-	-	-	-	-
4.2.61	-	2.0	P	-	-	-	-	-
13.2.61	-	1.5	P	-	-	-	-	-
20.2.61	-	0.5	P	-	-	-	-	-

Appendix 2 continued

	Point A				Point I			
Date	T.Secs	Hb ft	Breaker Type	Direction of Approach	T.Secs	Hb ft	Breaker Type	Direction of Approach
27.2.61	-	1.0	P	-	2.5	0.5	S	-
8.3.61	-	0.25	P	-	-	-	-	-
16.3.61	2.5	0.5	P	-	-	-	-	-
18.3.61	-	-	-	-	-	-	-	-
19.3.61	-	2.0	P	-	-	-	-	-
22.3.61	-	0.5	P	-	2.0	0.5	S	-
23.3.61	-	1.0	P/S	-	-	-	-	-
29.3.61	-	2.0	P	-	-	-	-	-
5.4.61	-	1.0	P	-	-	-	-	-

Appendix 2 continued

WAVE DATA

	Point B				Point C			
Date	T.Secs	Hb ft	Breaker Type	Direction of Approach°	T.Secs	Hb ft	Breaker Type	Direction of Approach°
13.4.60	-	-	-	-	-	-	-	-
18.4.60	-	-	-	-	-	-	-	-
25.4.60	-	-	-	-	-	-	-	-
4.5.60	-	-	-	-	8.5	1.0	P	-
11.5.60	-	-	-	-	5.0	1.5	S	115
18.5.60	-	-	-	-	5.0	2.5	S	130
25.5.60	-	-	-	-	10.0	2.5	S	105
30.5.60	-	-	-	-	6.0	1.5	S	120
10.6.60	-	-	-	-	4.5	1.0	P	-
15.6.60	-	-	-	-	-	1.0	S	-
23.6.60	-	-	-	-	5.0	2.0	S	-
29.6.60	-	-	-	-	10.0	4.0	S	110
7.7.60	7.5	1.0	P	-	7.5	1.5	P	-
14.7.60	6.0	0.5	S	-	5.0	1.0	S	110
20.7.60	6.0	1.0	P	-	6.0	1.0	S/P	-
31.7.60	3.0	0.5	P	-	3.0	1.0	S	-
5.8.60	7.5	1.0	S	110	7.5	2.0	S	115
10.8.60	6.0	0.5	S	-	-	0.5	S	-
18.8.60	7.5	1.0	P	-	6.0	1.0	P	130
27.8.60	6.0	0.5	S	140	7.5	0.5	S	-
3.9.60	7.5	1.0	S	120	8.5	1.0	S/P	120

Appendix 2 continued

	Point B				Point C			
Date	T.Secs	Hb ft	Breaker Type	Direction of Approach °	T.Secs	Hb ft	Breaker Type	Direction of Approach °
7.9.60	6.0	0.5	S	130	6.0	0.5	S	115
21.9.60	10.0	5.0	S	110	10.0	4.0	S	110
27.9.60	8.5	1.5	S	100	10.0	2.0	S	110
7.10.60	8.5	2.0	P	-	8.5	1.0	S	110
12.10.60	10.0	7.0	S	100	10.0	7.0	S	100
21.10.60	7.5	1.0	S	105	7.5	3.0	S	110
26.10.60	-	-	-	-	-	2.0	S	-
4.11.60	6.6	1.0	S	-	6.0	1.5	S	-
9.11.60	10.0	0.5	P	-	10.0	0.5	S	125
18.11.60	6.6	1.5	P	125	6.6	0.5	S	-
23.11.60	7.5	2.0	S	120	7.5	2.0	S	-
30.11.60	10.0	1.0	S	-	8.5	1.0	S	120
7.12.60	8.5	2.5	S	115	10.0	3.0	S	110
17.12.60	-	0.5	S	-	-	0.5	P	-
22.12.60	8.5	1.0	S	110	8.5	3.0	S	120
1.1.61	-	0.5	S	-	-	0.5	S	-
14.1.61	7.5	1.5	S	115	7.5	1.0	S	-
19.1.61	5.5	2.0	S	120	-	2.0	S	-
29.1.61	-	1.0	S	-	-	-	-	-
4.2.61	10.0	2.0	S	110	8.5	2.0	P	130

Appendix 2 continued

	Point B				Point C			
Date	T.Secs	Hb ft	Breaker Type	Direction of Approach°	T.Secs	Hb ft	Breaker Type	Direction of Approach°
13.2.61	8.5	0.5	S	120	8.5	1.0	S	-
20.2.61	-	0.5	S	-	-	0.5	S	-
27.2.61	4.0	0.5	P	-	-	1.0	S	-
8.3.61	6.0	1.0	S	120	6.6	1.0	P	120
16.3.61	12.0	0.5	S	-	8.5	1.0	P	-
18.3.61	-	-	-	-	-	-	-	-
19.3.61	10.0	2.0	S	95	10.0	3.0	S	110
22.3.61	10.0	2.0	S	110	8.5	3.0	P	120
23.3.61	10.0	3.0	P	120	10.0	2.0	P	120
29.3.61	12.0	3.0	S	110	12.0	3.0	P	110
5.4.61	6.0	1.0	S	125	7.5	1.0	P	-

Appendix 2 continued

	Point D				Point E			
Date	T.Secs	Hb ft	Breaker Type	Direction of Approach°	T.Secs	Hb ft	Breaker Type	Direction of Approach°
13.4.60	6.0	2.0	S	160	-	-	-	-
18.4.60	7.5	1.0	P	90	-	-	-	-
25.4.60	7.5	2.5	S	100	-	-	-	-
4.5.60	8.5	1.0	P	-	8.5	2.0	P	-
13.5.60	-	-	-	-	6.6	3.0	S	90
18.5.60	5.0	4.0	S/P	95	5.0	4.0	S	85
25.5.60	10.0	3.0	S	100	7.5	3.0	S	80
30.5.60	6.0	2.0	P	90	6.0	2.0	S/P	80
10.6.60	5.0	1.0	P	-	5.0	1.0	S	-
15.6.60	6.6	1.0	P	-	6.0	1.0	S	-
23.6.60	5.0	2.5	P	115	5.0	2.5	S	-
29.6.60	10.0	4.0	S	110	10.0	4.0	S	50
7.7.60	7.5	2.5	S	110	7.5	2.5	P	-
14.7.60	5.0	1.0	S	110	5.0	1.0	S	-
20.7.60	6.0	1.5	S	105	6.0	1.5	S	-
31.7.60	-	-	-	-	3.5	1.5	S	-
5.8.60	8.0	2.5	S	105	7.5	2.5	S	85
10.8.60	6.0	0.5	S	120	-	0.5	S	-
18.8.60	6.0	1.5	S/P	-	6.0	1.5	S	-
27.8.60	-	-	-	-	-	0.5	S	-
3.9.60	10.0	1.5	S	-	10.0	1.5	P	90

Appendix 2 continued

	Point D				Point E			
Date	T.Secs	Hb ft	Breaker Type	Direction of Approach°	T.Secs	Hb ft	Breaker Type	Direction of Approach°
7.9.60	6.0	1.0	S	-	6.0	1.0	S	-
21.9.60	10.0	5.0	S	100	12.0	5.0	S	80
27.9.60	8.5	3.0	S	105	8.5	3.0	S	80
7.10.60	8.5	1.0	S	110	8.5	1.0	S	80
12.10.60	10.0	7.0	S	120	10.0	7.0	S	60
21.10.60	7.5	3.0	S	120	7.5	3.0	S	90
26.10.60	8.5	3.0	S	120	7.5	3.0	S	85
4.11.60	6.6	2.0	S	-	6.6	2.0	S	-
9.11.60	7.5	1.0	S/P	115	8.5	1.0	S	-
18.11.60	6.6	3.0	S	110	6.6	1.0	P	-
23.11.60	7.5	2.0	S	100	7.5	2.0	P	-
30.11.60	10.0	1.0	S	110	10.0	1.0	S	-
7.12.60	8.5	3.5	S	110	6.6	3.5	S	80
17.12.60	4.3	0.5	P	-	-	0.5	P	-
22.12.60	8.5	3.0	S	110	8.5	4.0	S/P	80
1.1.61	5.0	1.0	P	-	5.0	1.0	S	-
14.1.61	-	1.5	S	-	6.0	1.5	S	-
19.1.61	6.6	3.0	S	100	6.6	3.0	S	90
29.1.61	-	2.5	S	-	5.0	2.5	S	-

Appendix 2 continued

	Point D				Point E			
Date	T.Secs	Hb ft	Breaker Type	Direction of Approach°	T.Secs	Hb ft	Breaker Type	Direction of Approach°
4.2.61	8.5	2.5	P	-	8.5	2.0	P	80
13.2.61	-	1.5	S/P	-	5.5	2.0	P	-
20.2.61	6.6	1.0	S	-	4.0	1.0	P	-
27.2.61	-	1.5	S	-	6.0	1.5	S	-
8.3.61	10.0	1.0	S	-	10.0	1.0	P	-
16.3.61	10.0	1.0	S	-	10.0	2.0	P	-
18.3.61	7.5	5.0	P	-	-	-	-	-
19.3.61	8.5	6.0	P	100	10.0	5.0	S	70
22.3.61	10.0	4.0	S	90	10.0	4.0	P	85
23.3.61	10.0	3.0	P	110	10.0	3.0	P	90
29.3.61	12.0	3.0	P	110	12.0	4.0	P	85
5.4.61	7.5	2.0	S/P	-	7.5	2.0	P	-

T is wave period

Hb is wave height at breaker point

THE UNIVERSITY OF HULL

Some Aspects of the Coastal Geomorphology of Spurn Head, Yorkshire

being a Thesis submitted for the Degree of

Doctor of Philosophy

in the University of Hull

by

Ada Waddon Phillips, B.A.

September, 1962

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VOLUME 2

F I G U R E S

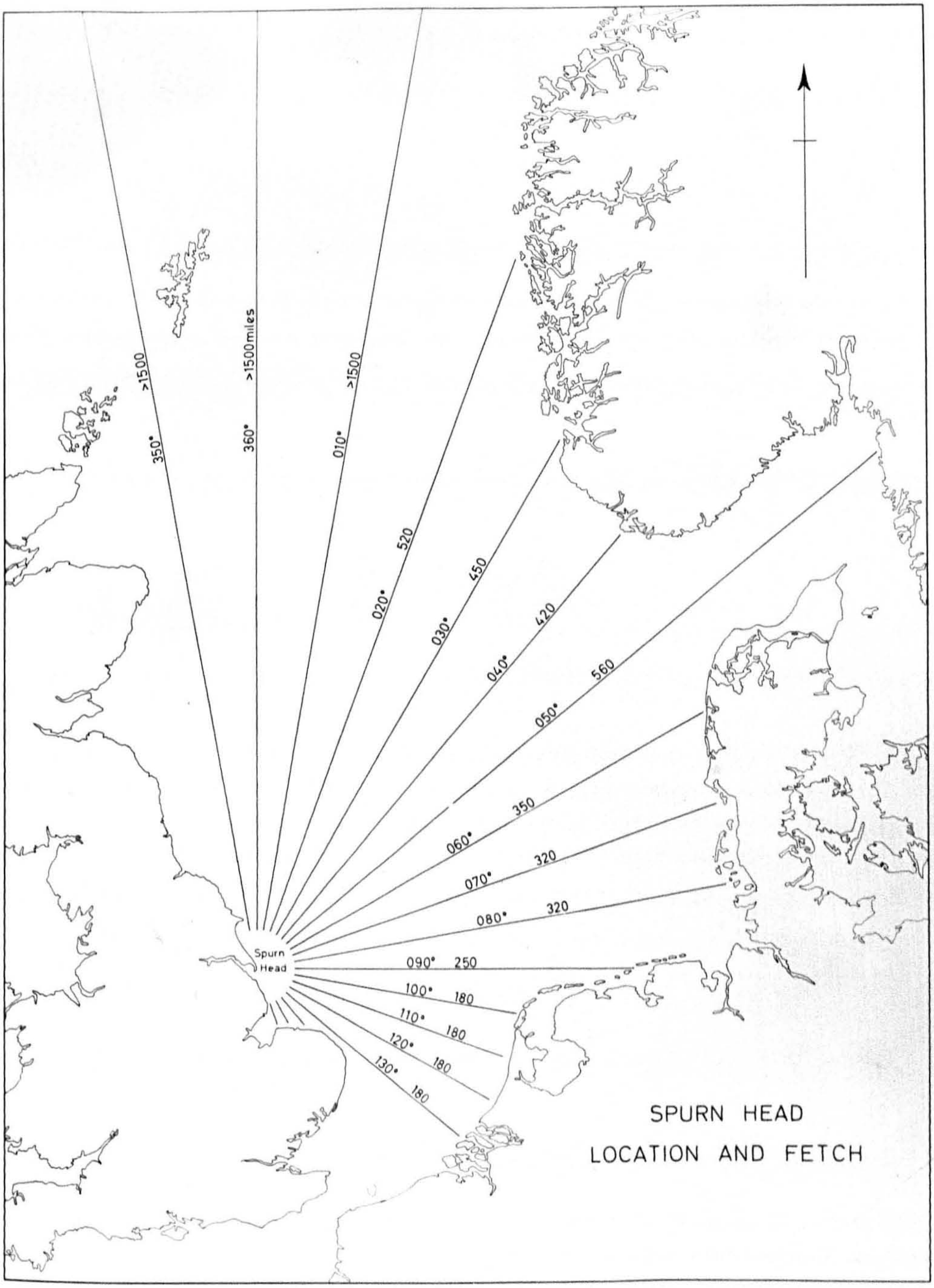
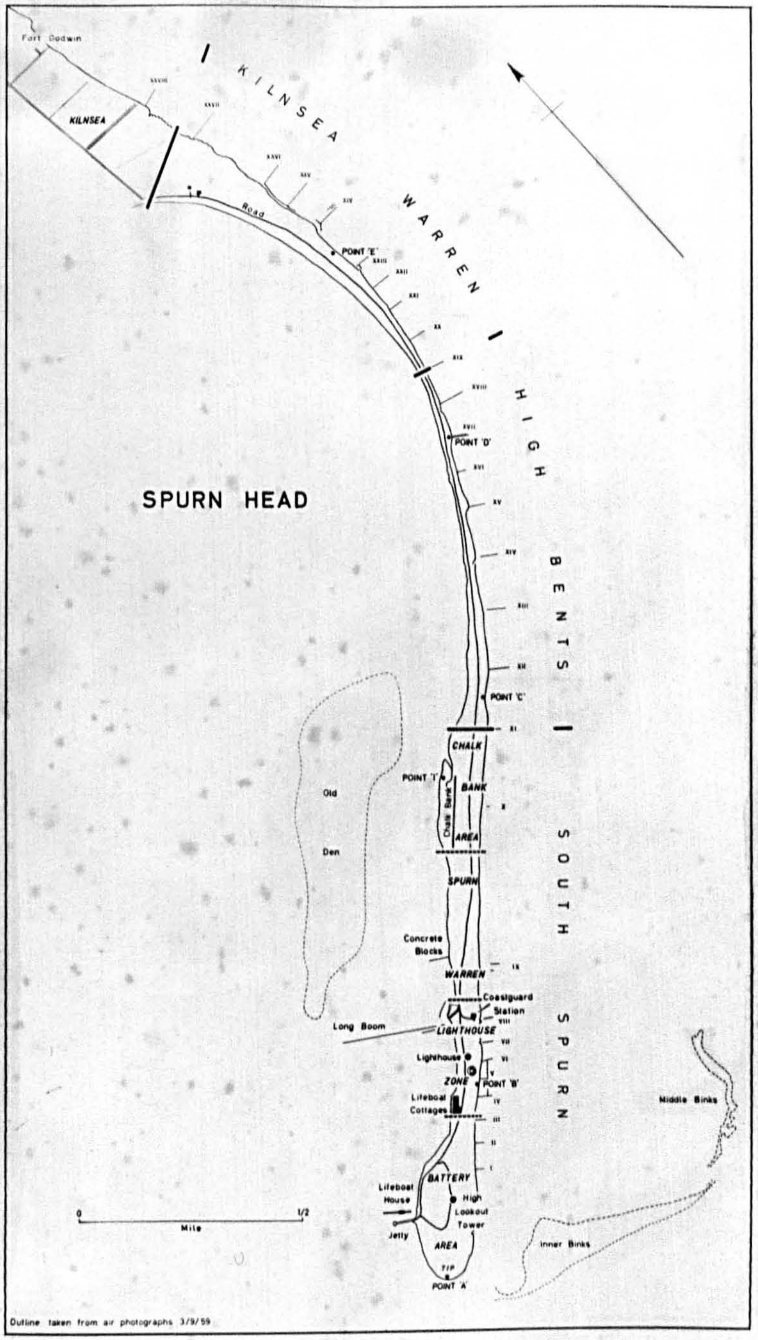

SPURN HEAD
LOCATION AND FETCH
Spurn Head
350° >1500
360° >1500 miles
010° >1500
020° 520
030° 450
040° 420
050° 560
060° 350
070° 320
080° 320
090° 250
100° 180
110° 180
120° 180
130° 180

Fig.1.1



SPURN HEAD
Fort Godwin
KILNSEA
KILNSEA WARREN
HIGH BENTS
SOUTH SPURN
Road
POINT 'E'
POINT 'D'
POINT 'C'
POINT 'B'
POINT 'A'
CHALK BANK AREA
SPURN WARREN
LIGHTHOUSE ZONE
BATTERY AREA
TIP
Chalk Bank
Old Den
Concrete Blocks
Coastguard Station
Long Boom
Lighthouse
Lifeboat Cottages
Lifeboat House
Jetty
High Lookout Tower
Middle Binks
Inner Binks
0
1/2
Mile
Outline taken from air photographs 3/9/59

Fig.1.2

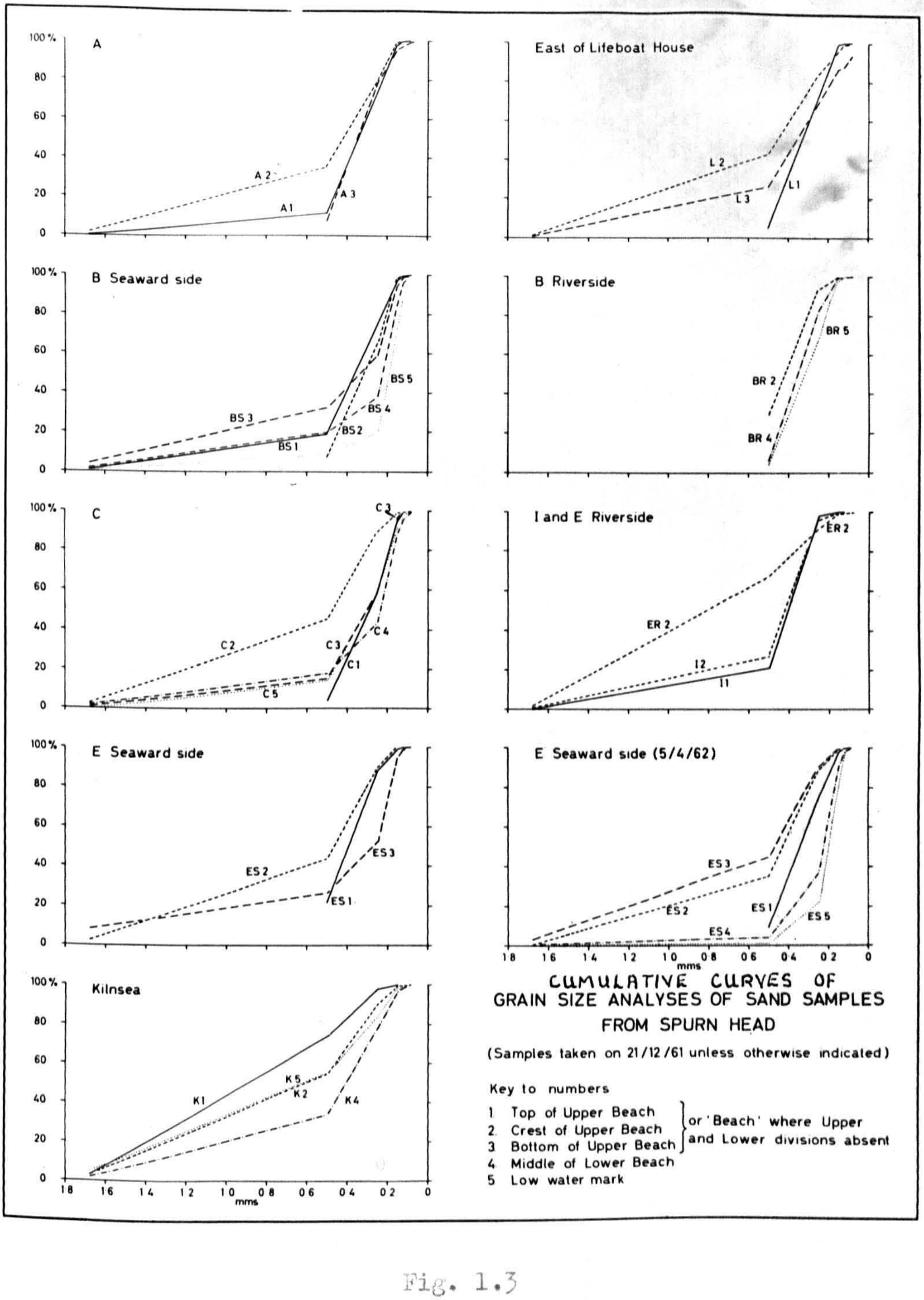

A
A 1
A 2
A 3
East of Lifeboat House
L 1
L 2
L 3
B Seaward side
BS 1
BS 2
BS 3
BS 4
BS 5
B Riverside
BR 2
BR 4
BR 5
C
C 1
C 2
C 3
C 4
C 5
I and E Riverside
ER 2
I 1
I 2
E Seaward side
ES 1
ES 2
ES 3
E Seaward side (5/4/62)
ES 1
ES 2
ES 3
ES 4
ES 5
Kilnsea
K 1
K 2
K 4
K 5
100 %
80
60
40
20
0
1 8
1 6
1 4
1 2
1 0
0 8
0 6
0 4
0 2
0
mms
CUMULATIVE CURVES OF
GRAIN SIZE ANALYSES OF SAND SAMPLES
FROM SPURN HEAD
(Samples taken on 21/12/61 unless otherwise indicated)
Key to numbers
1 Top of Upper Beach
2 Crest of Upper Beach
3 Bottom of Upper Beach
4 Middle of Lower Beach
5 Low water mark
or 'Beach' where Upper and Lower divisions absent

Fig. 1.3

BEACH CHANGES AT SPURN HEAD AND THEIR INFLUENCING FACTORS
APRIL 1960 TO APRIL 1961

BEACH PROFILES

Vertical Exaggeration x10

Ps - pebbles <2ins long diameter	S - sand	D - dunes
Pm - pebbles 2-4ins long diameter	/W - surface water	M - mud
Pl - pebbles >4ins long diameter	S&S/W - sand hummocks and water-filled hollows	C - chalk rubble
		BCl - boulder clay

MOVEMENT OF BEACH MATERIAL

gain above axial line *   loss below axial line

end of comparative profile

WAVES

S - spilling   P - plunging

TIDES

—— converted recorded tides   - - - Admiralty predicted tides

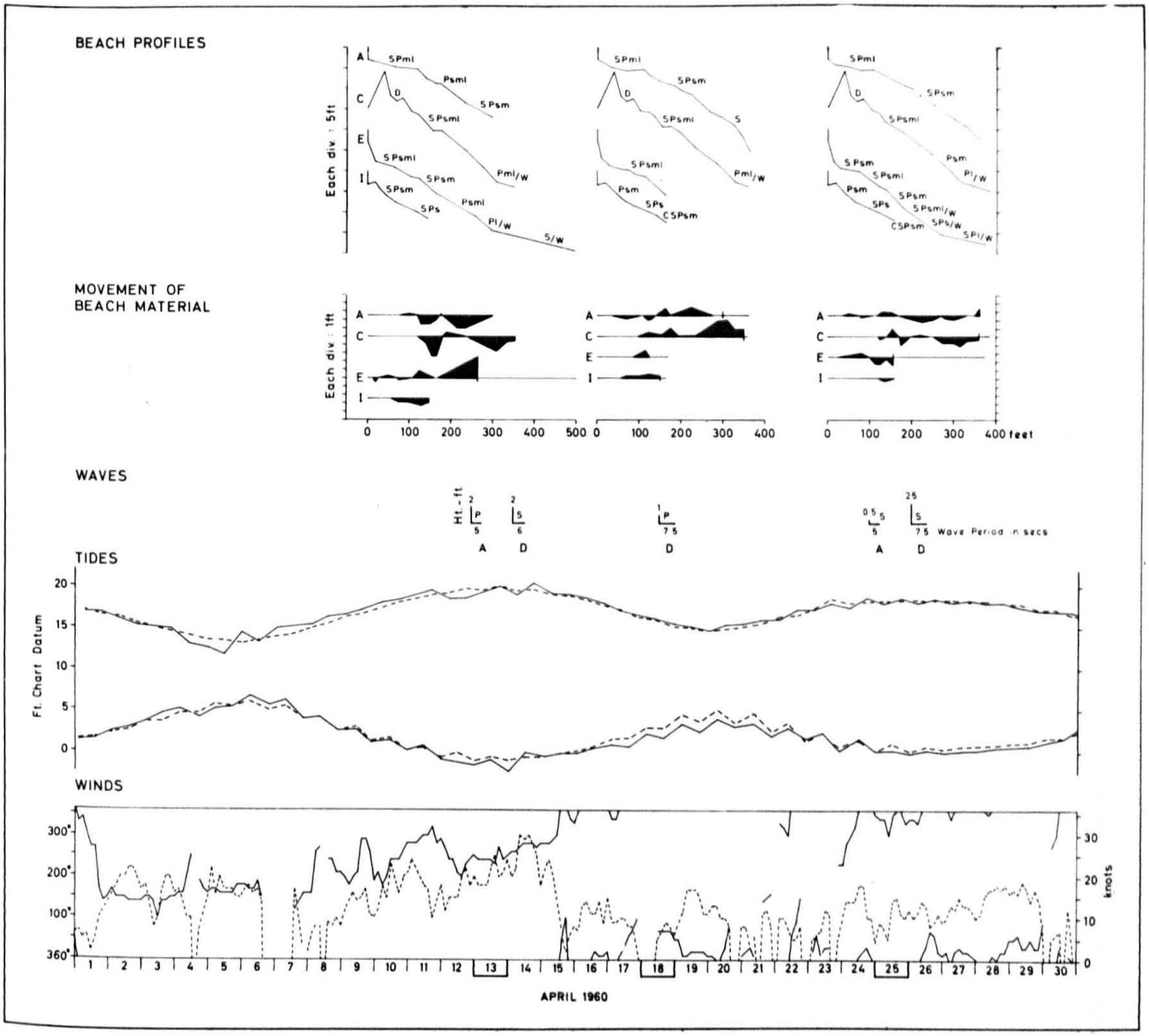
WINDS

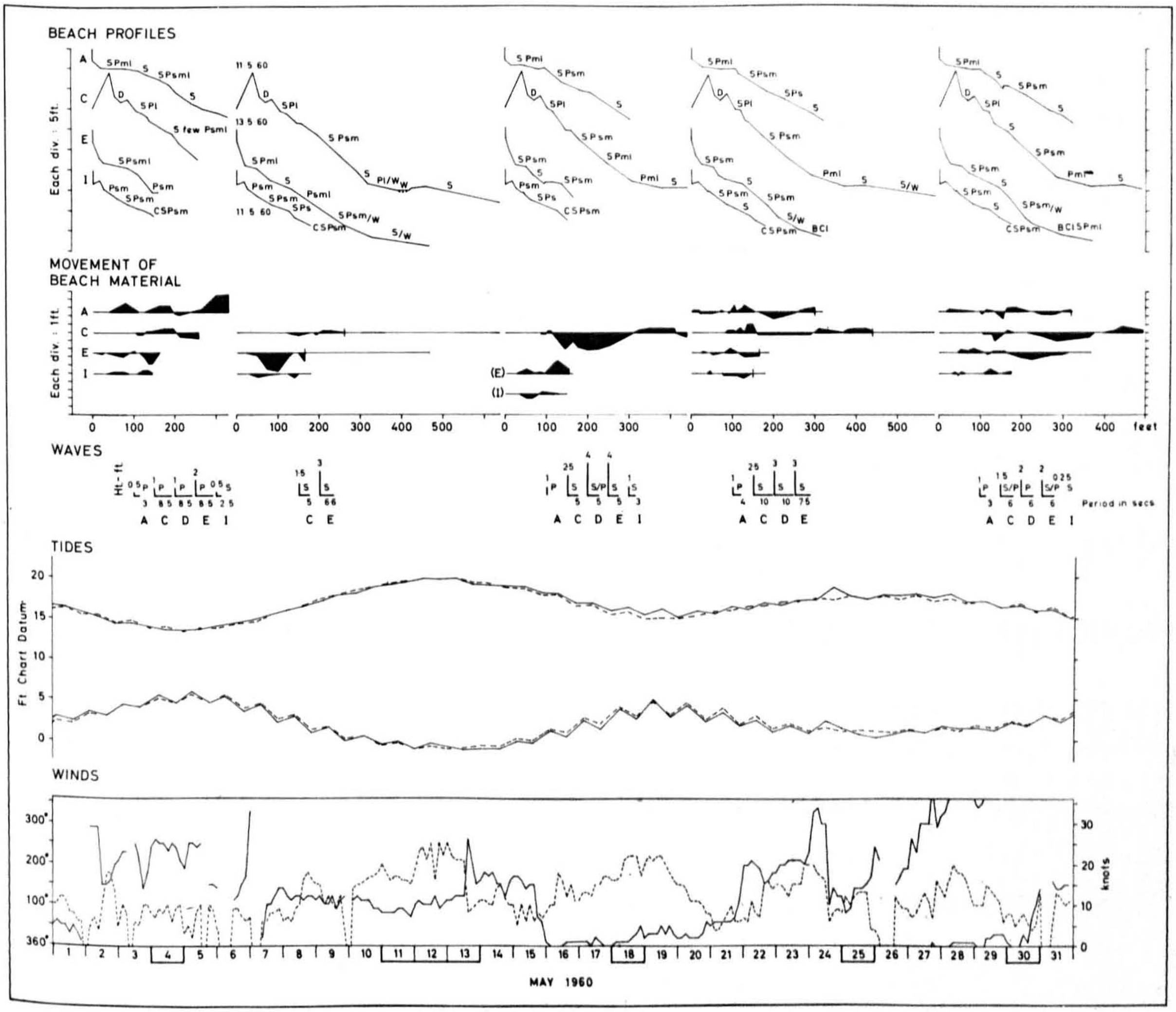
—— direction   ----- speed

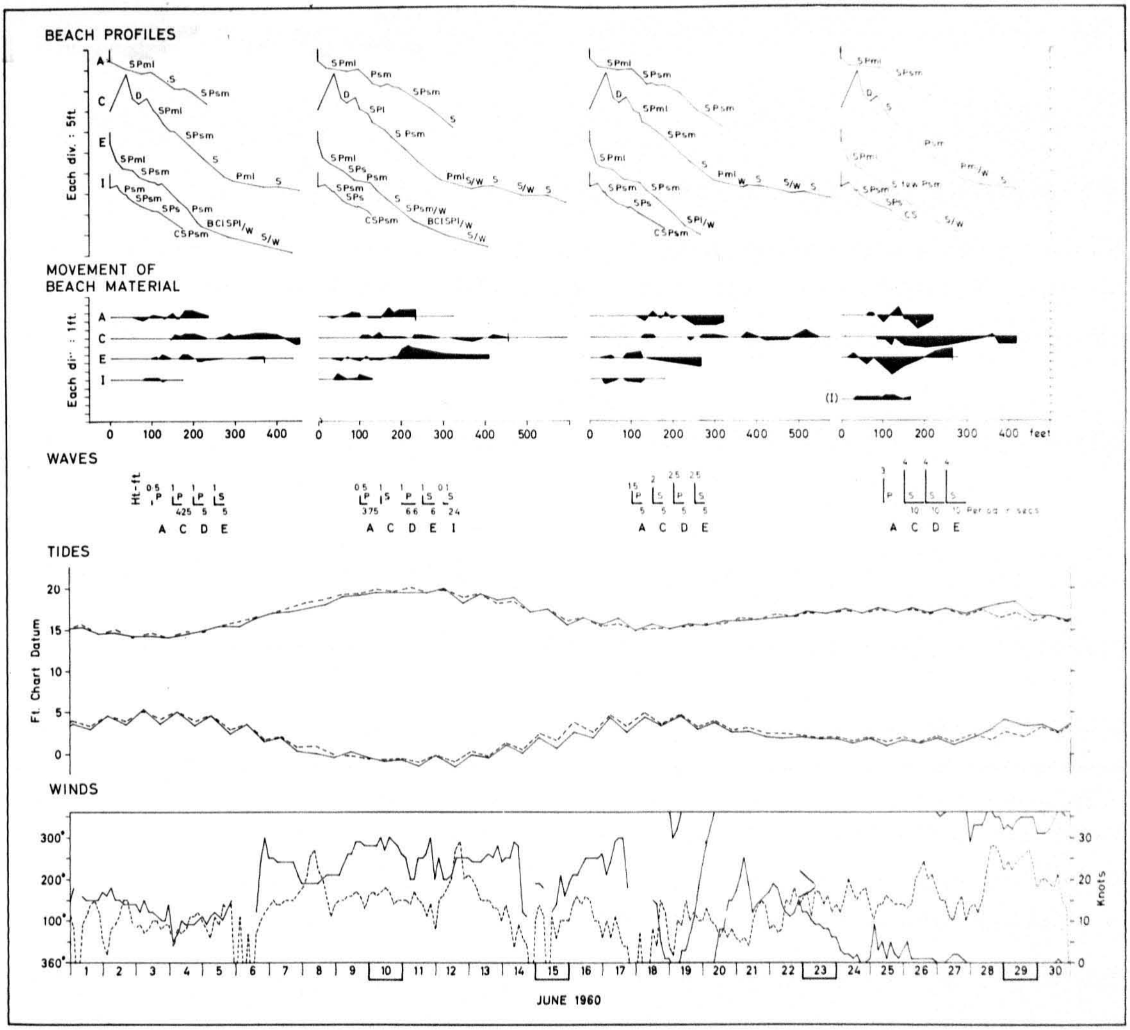
Date of beach and wave observations shown thus [3]

Fig.2.1

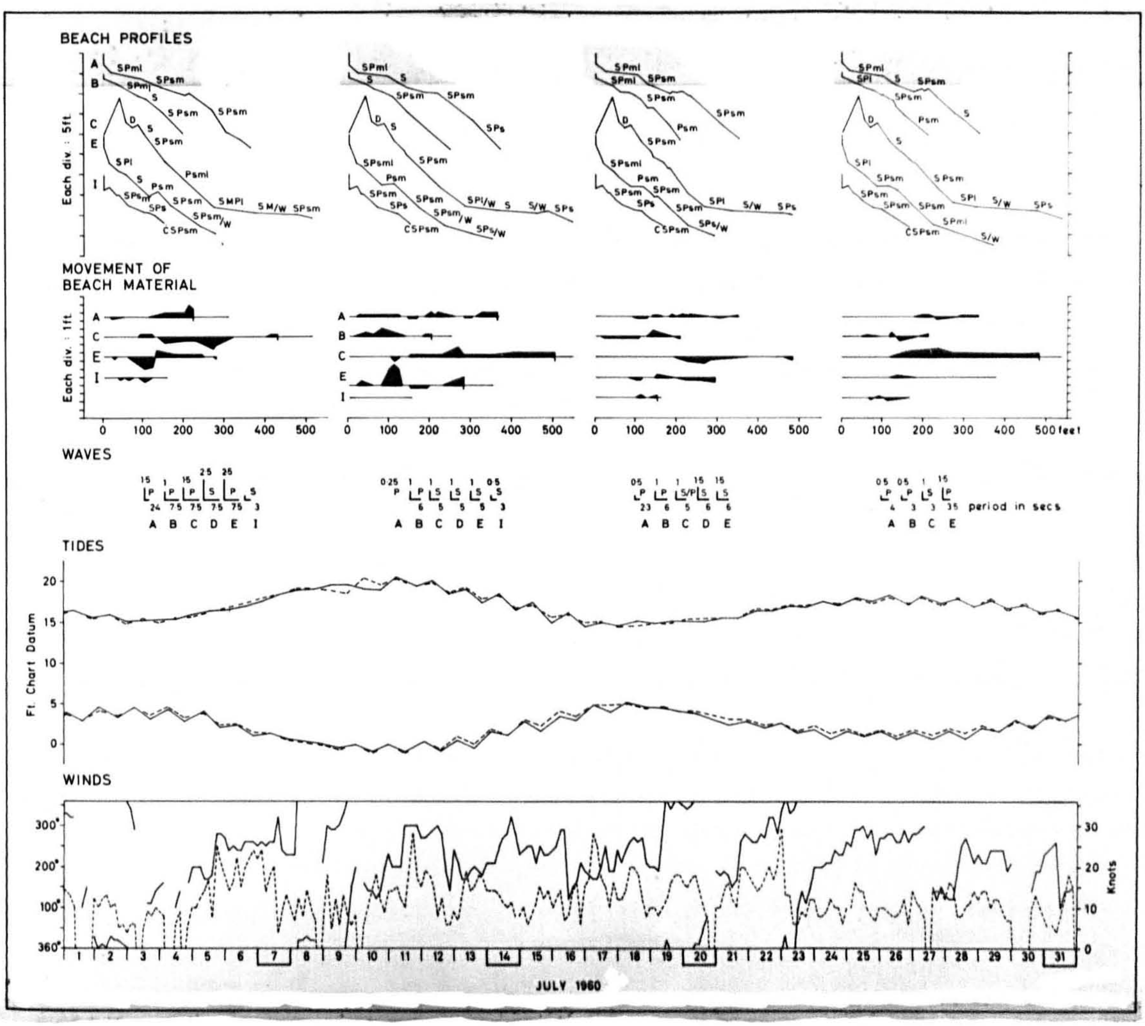
* Central "axial" line represents profile on previous date of observations in straightened form

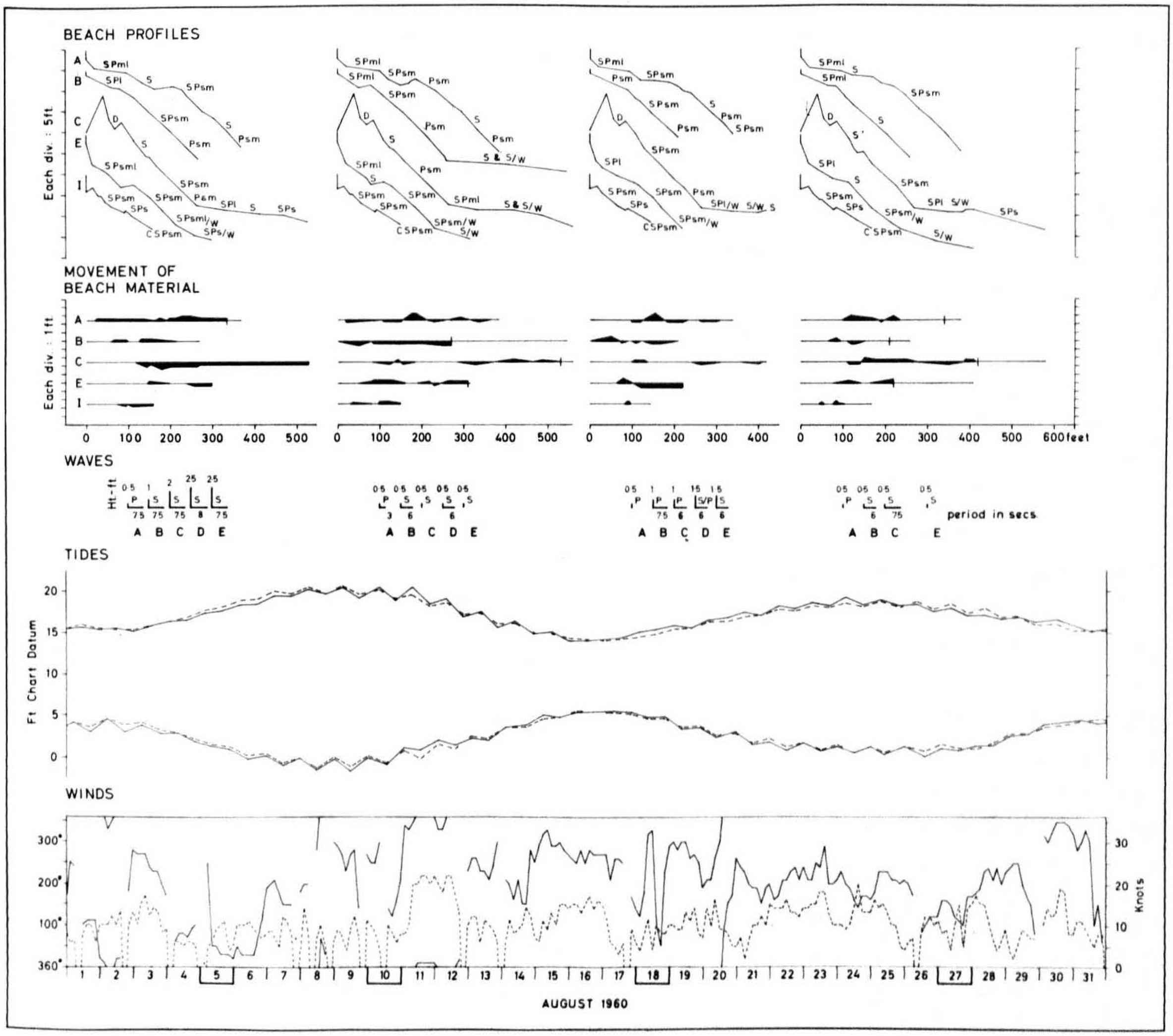

BEACH PROFILES
Each div : 5ft
A
C
E
I
SPml
Psml
SPsm
D
SPsml
Pml/w
SPsm
Psml
SPs
Pl/w
S/w
S
Psm
CSPsm
Pl/w
SPsml/w
SPs/w
SPl/w
MOVEMENT OF BEACH MATERIAL
Each div : 1ft
0
100
200
300
400
500
feet
WAVES
Ht.-ft
Wave Period in secs
TIDES
Ft. Chart Datum
WINDS
knots
APRIL 1960

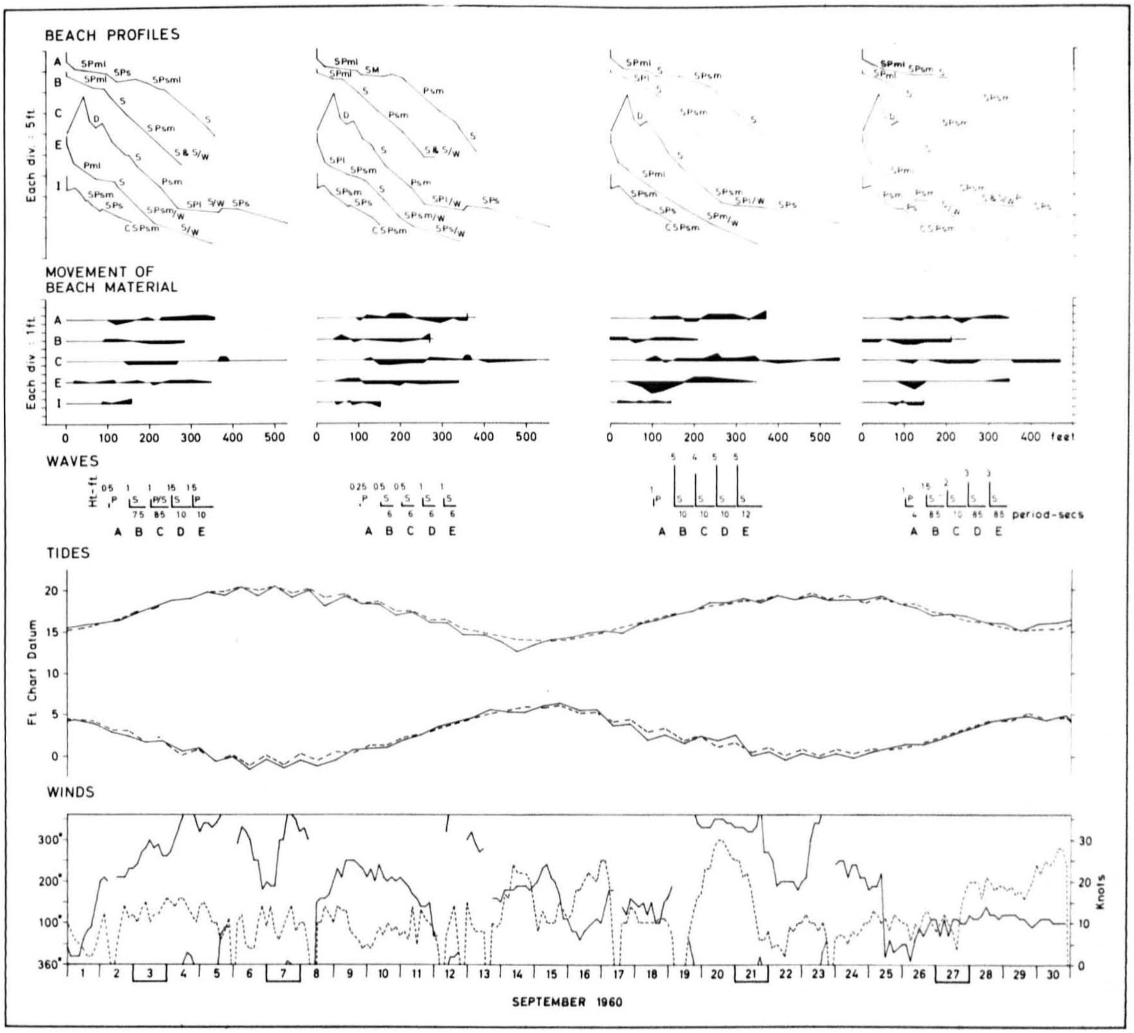

BEACH PROFILES
Each div. : 5 ft.
MOVEMENT OF BEACH MATERIAL
Each div. : 1 ft.
feet
WAVES
Ht. ft.
Period in secs
TIDES
Ft Chart Datum
WINDS
knots
MAY 1960



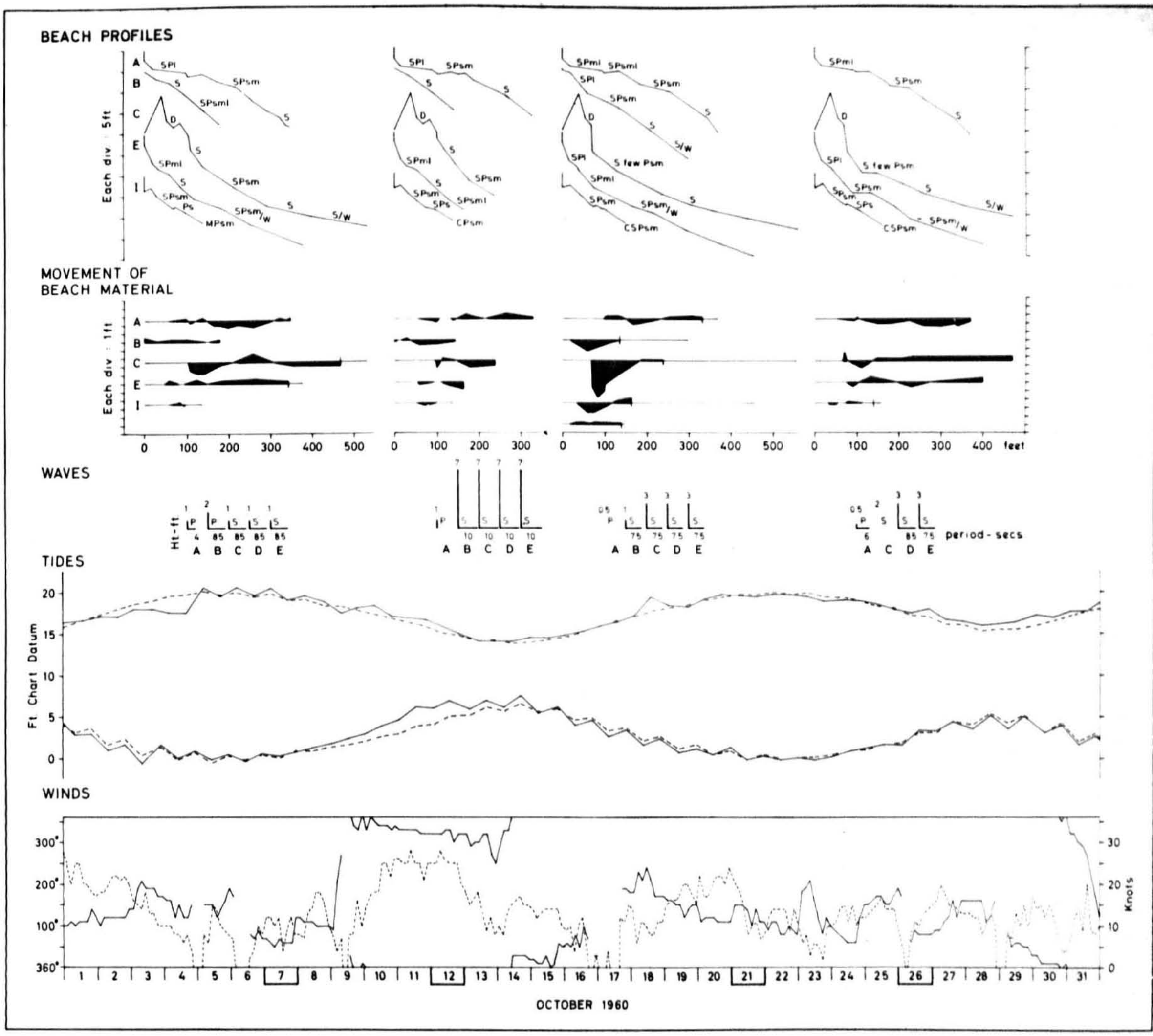
BEACH PROFILES
Each div. : 5ft.
MOVEMENT OF BEACH MATERIAL
Each div. : 1ft.
feet
WAVES
Ht-ft
Period in secs
TIDES
Ft. Chart Datum
WINDS
Knots
JUNE 1960


BEACH PROFILES
Each div. : 5ft.
MOVEMENT OF BEACH MATERIAL
Each div. : 1ft.
WAVES
period in secs
TIDES
Ft. Chart Datum
WINDS
Knots
JULY 1960

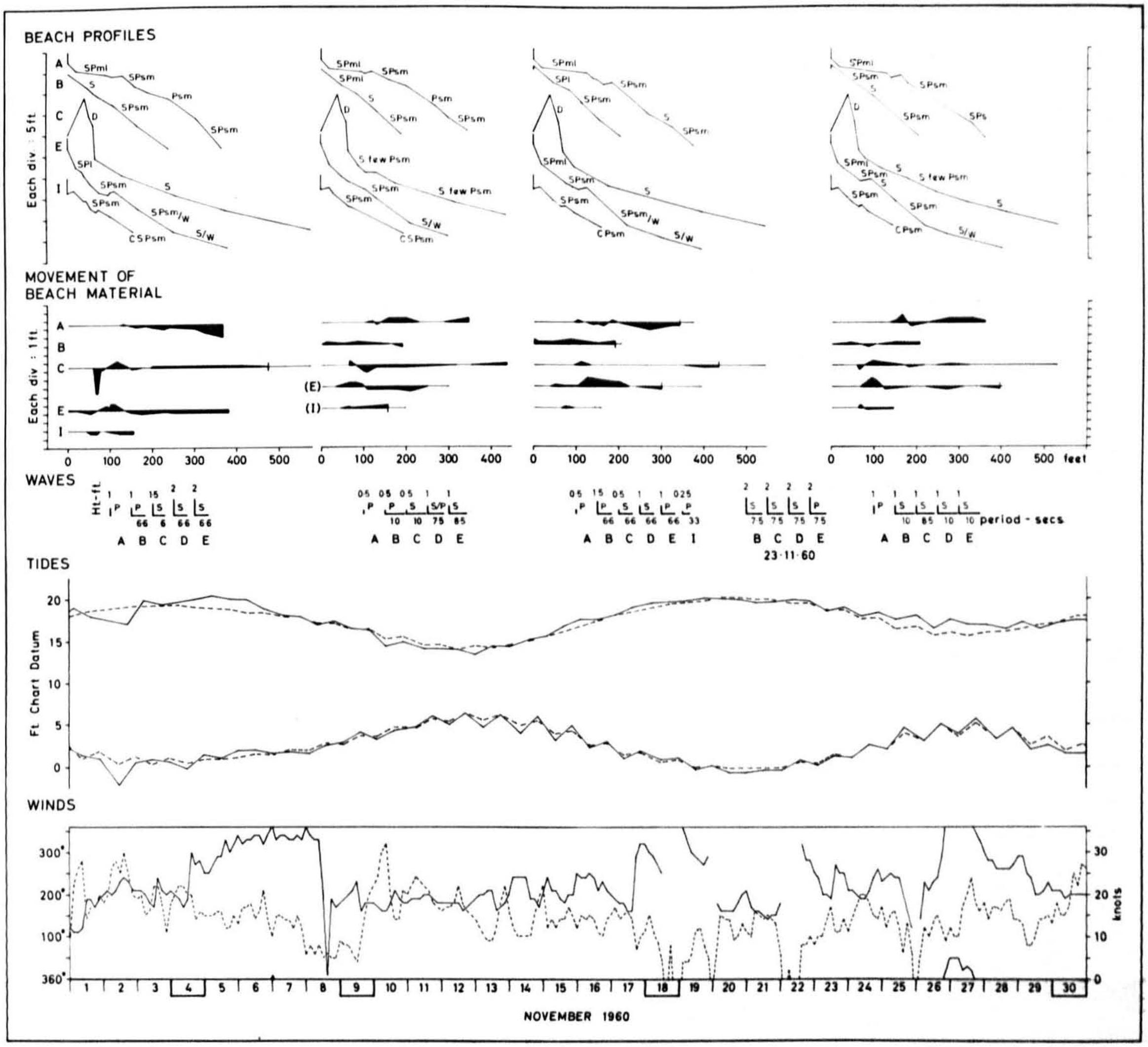

BEACH PROFILES
Each div.: 5 ft.
MOVEMENT OF BEACH MATERIAL
Each div.: 1 ft.
WAVES
Ht-ft
period in secs.
TIDES
Ft Chart Datum
WINDS
Knots
AUGUST 1960



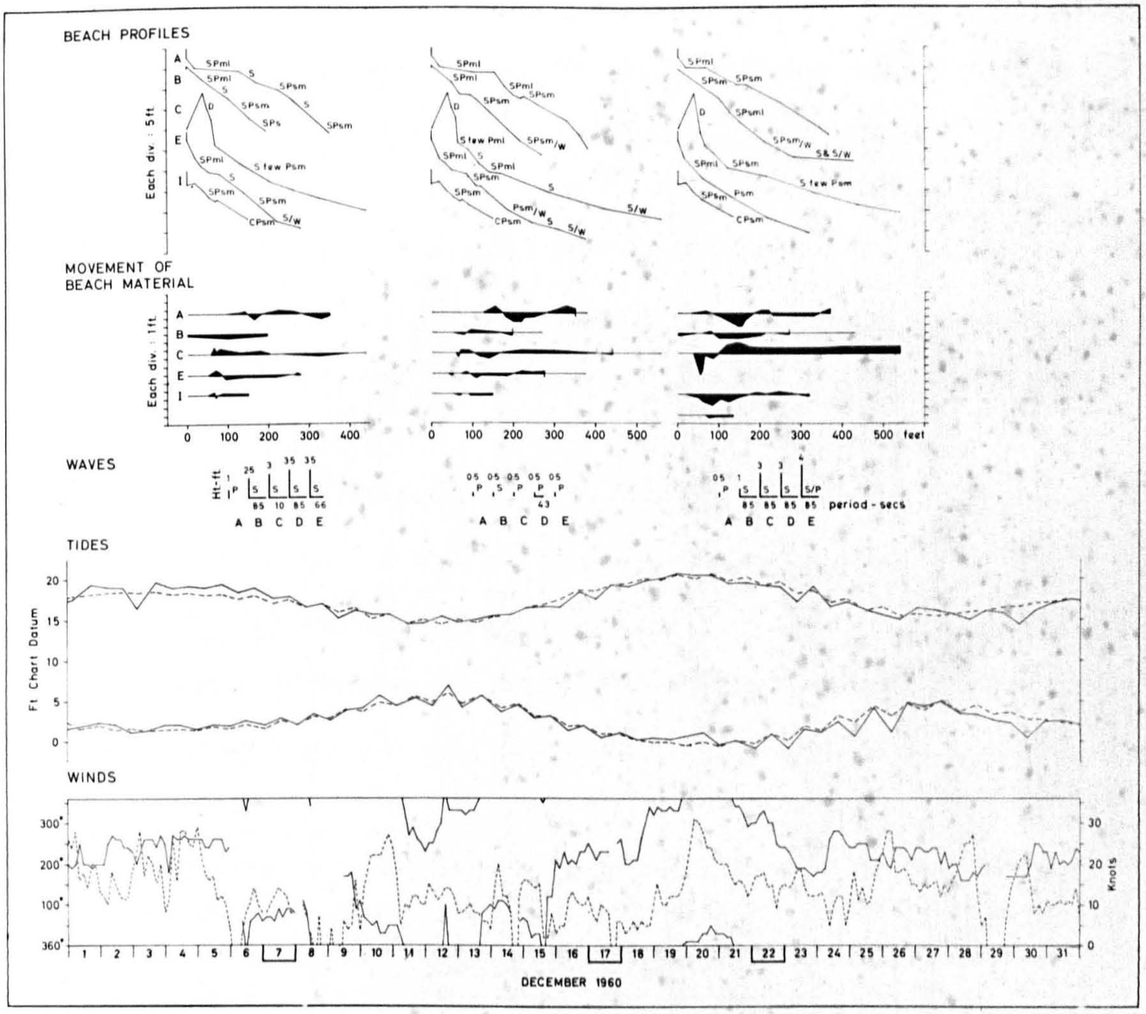
BEACH PROFILES
Each div : 5 ft.
MOVEMENT OF BEACH MATERIAL
Each div : 1 ft.
feet
WAVES
Ht-ft
period-secs
TIDES
Ft. Chart Datum
WINDS
Knots
SEPTEMBER 1960



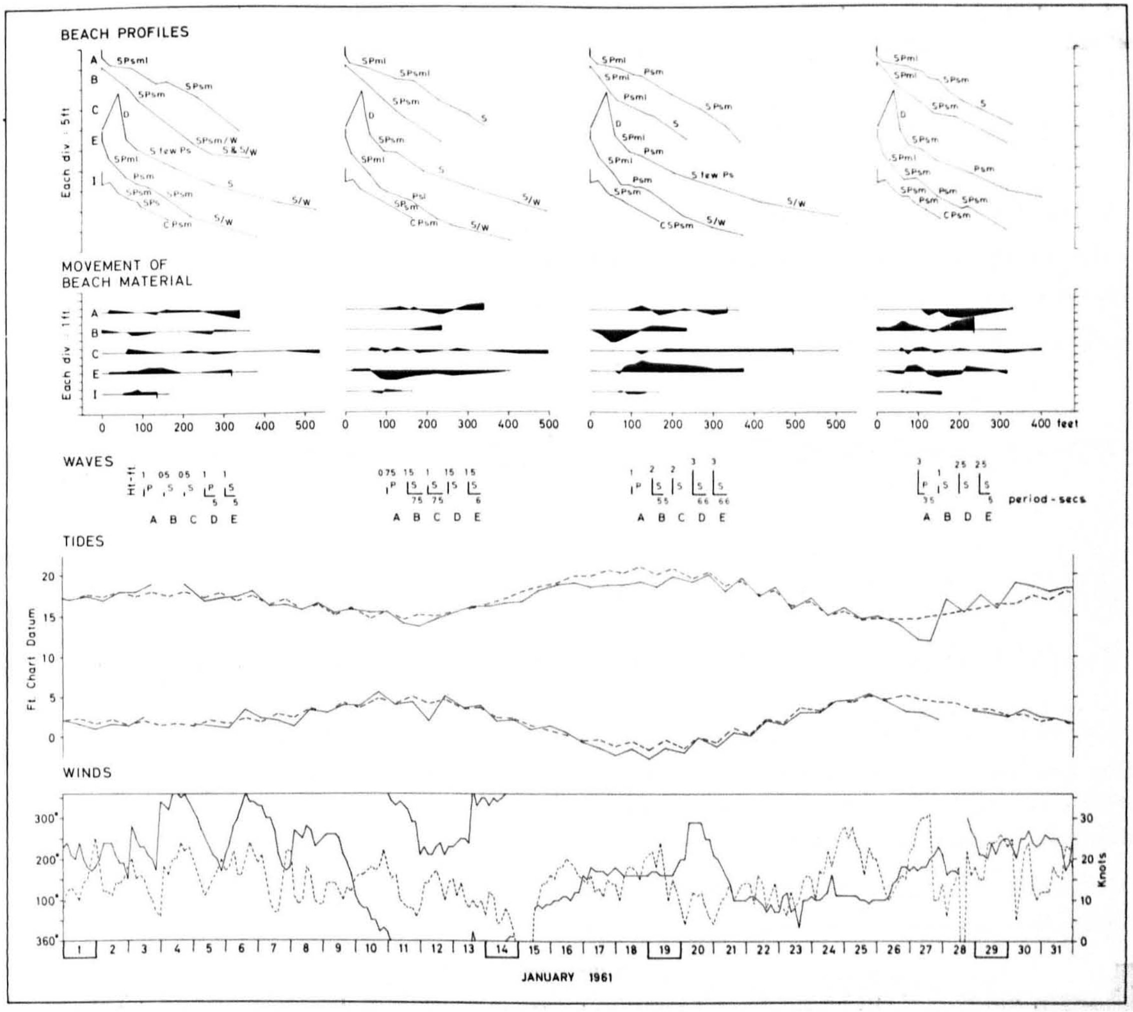
BEACH PROFILES
Each div : 5 ft
MOVEMENT OF BEACH MATERIAL
Each div : 1 ft
feet
WAVES
Ht - ft
period - secs
TIDES
Ft. Chart Datum
WINDS
Knots
OCTOBER 1960



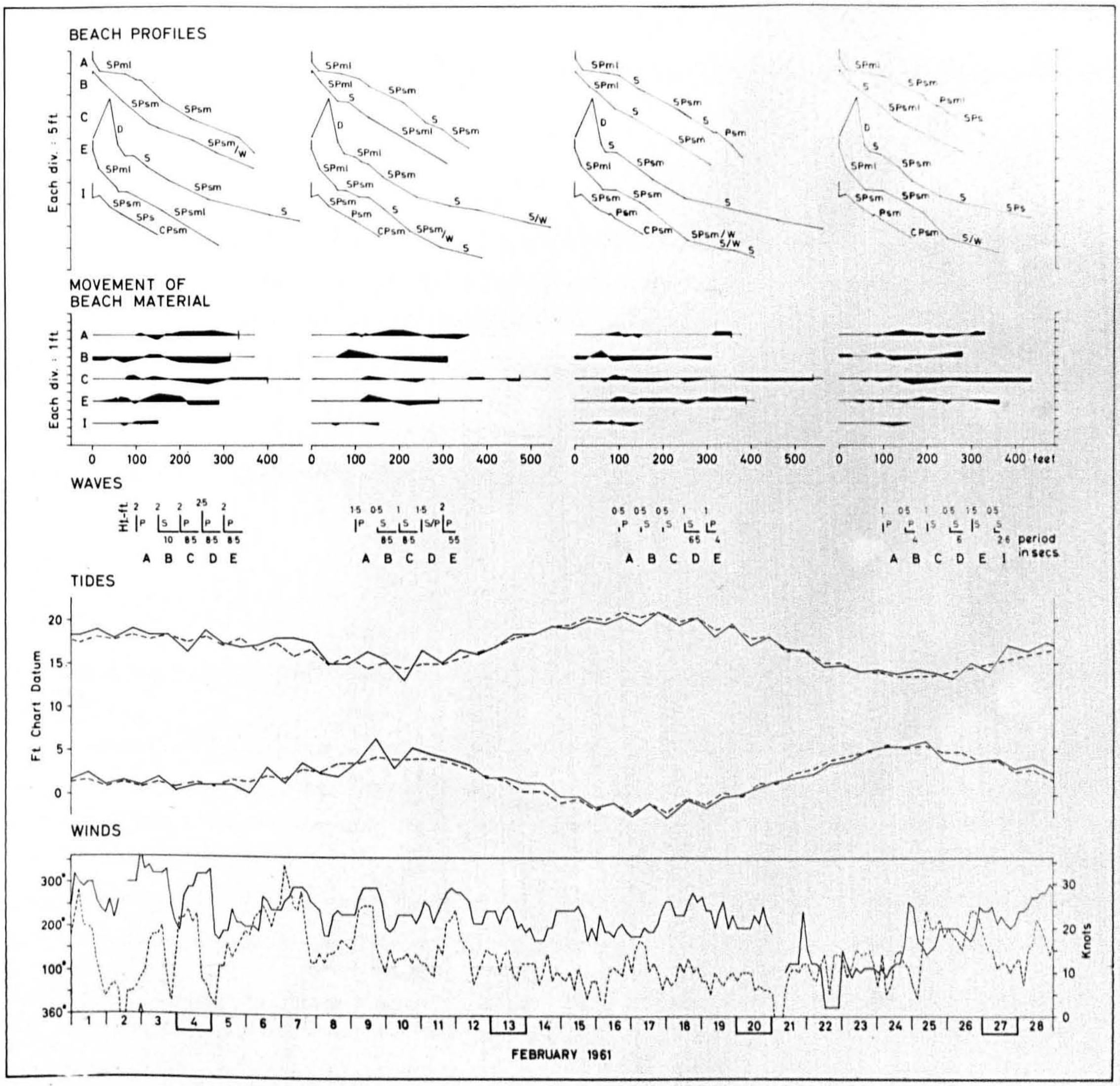
BEACH PROFILES
Each div : 5 ft.
MOVEMENT OF BEACH MATERIAL
Each div : 1 ft.
0 100 200 300 400 500 feet
WAVES
Ht-ft.
period - secs
23·11·60
TIDES
Ft. Chart Datum
WINDS
knots
NOVEMBER 1960



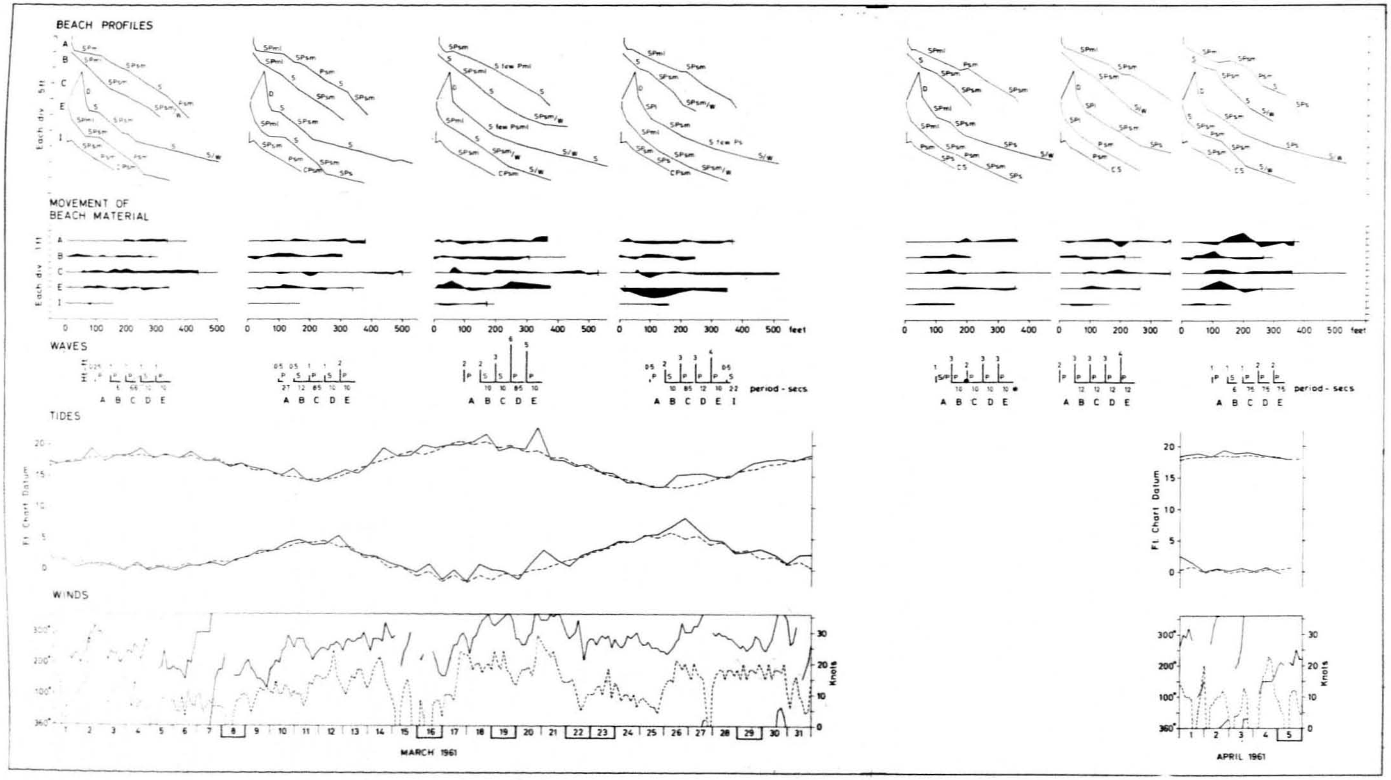
BEACH PROFILES
Each div. : 5 ft.
MOVEMENT OF BEACH MATERIAL
Each div. : 1 ft.
0 100 200 300 400 500 feet
WAVES
Ht-ft
period - secs
A B C D E
TIDES
Ft Chart Datum
WINDS
Knots
DECEMBER 1960



BEACH PROFILES
Each div : 5 ft
MOVEMENT OF BEACH MATERIAL
Each div : 1 ft
0 100 200 300 400 500
400 feet
WAVES
Ht-ft
period - secs
A B C D E
A B D E
TIDES
Ft. Chart Datum
WINDS
Knots
JANUARY 1961



BEACH PROFILES
Each div. : 5 ft.
MOVEMENT OF BEACH MATERIAL
Each div. : 1 ft.
0 100 200 300 400 feet
WAVES
Ht-ft
period in secs
A B C D E
TIDES
Ft. Chart Datum
WINDS
Knots
FEBRUARY 1961



BEACH PROFILES
MOVEMENT OF BEACH MATERIAL
WAVES
period - secs
TIDES
Ft. Chart Datum
WINDS
Knots
MARCH 1961
APRIL 1961

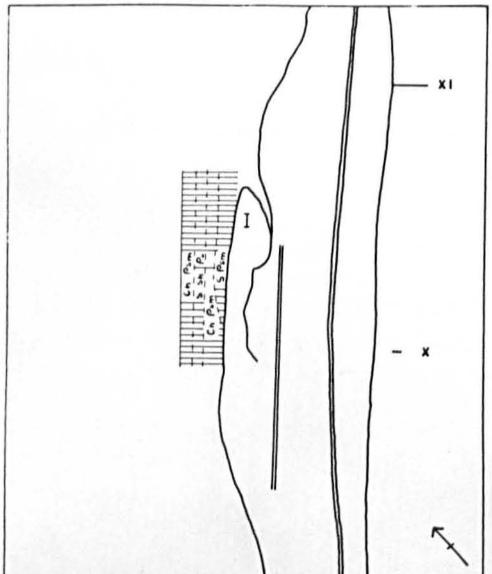
BEACH FEATURES AT POINTS A,B,C,E, and I

APRIL 1960 TO APRIL 1961

	Direction of slope of upper beach
	Convex break of slope on upper beach
	Concave break of slope on upper beach
	Cliff
	Upper / lower beach division
	Rises on lower beach
S	Sand
Sh	Fine shingle
Ps	Pebbles $<$ 2 ins. long diameter
Pm	Pebbles 2 - 4 ins. long diameter
Pl	Pebbles $>$ 4 ins. long diameter
BC	Boulder clay
M	Mud
- - -	Low water mark

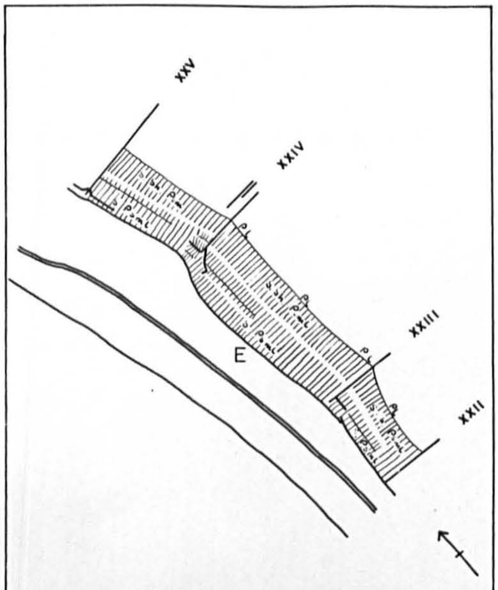
0 — 2000 feet

Fig. 2.2



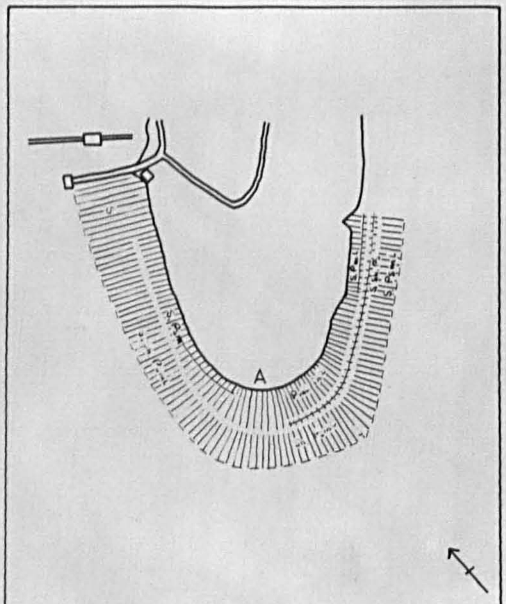
A PLAN OF BEACH FEATURES 13·4 60

SCALE 300 200 100 0 300 600 FEET



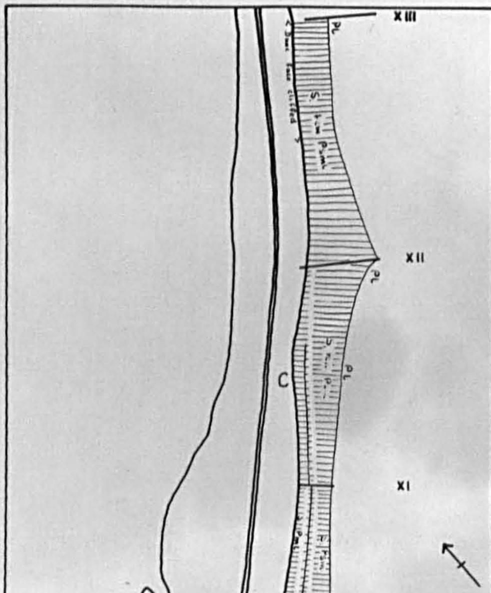
A PLAN OF BEACH FEATURES 13·4·60

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 13·4·60

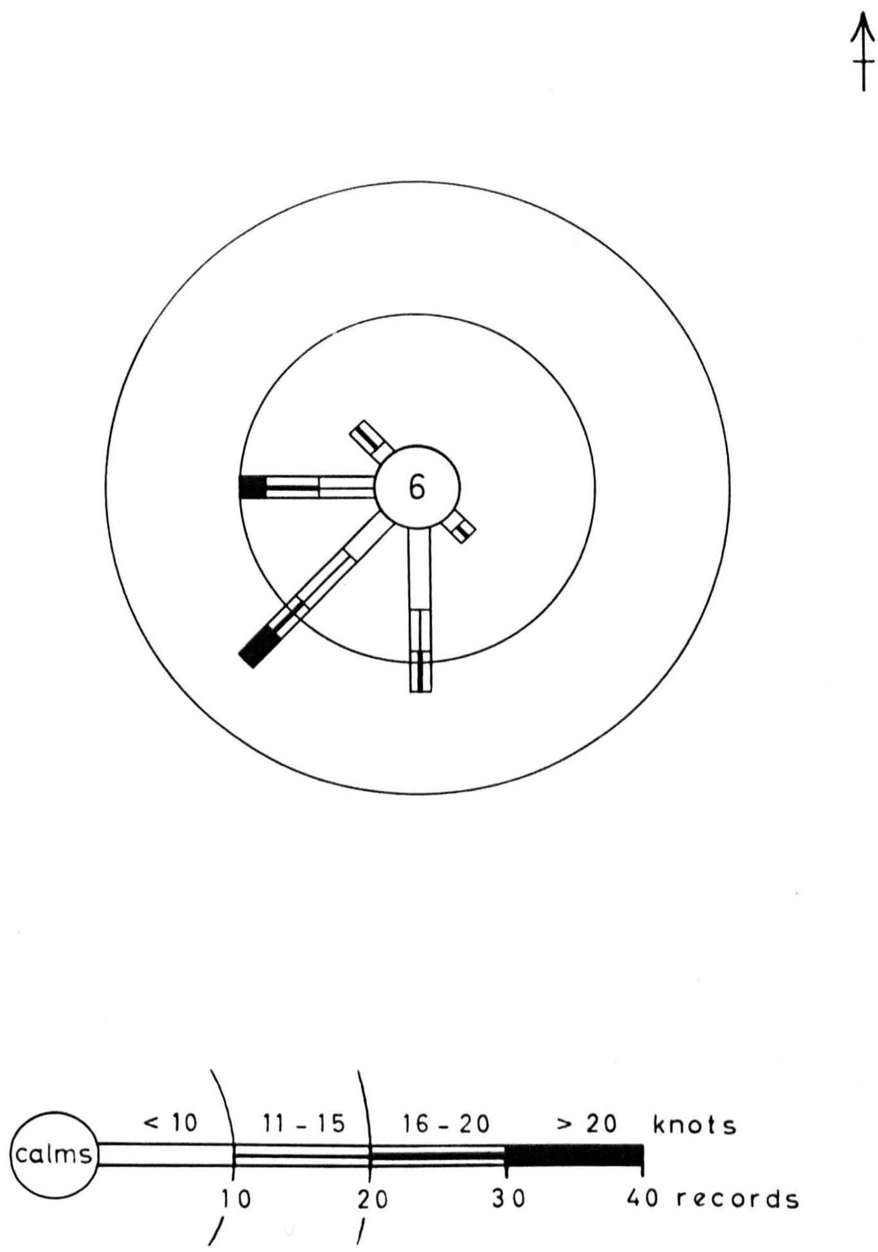
SCALE 300 200 100 0 300 600 FEET

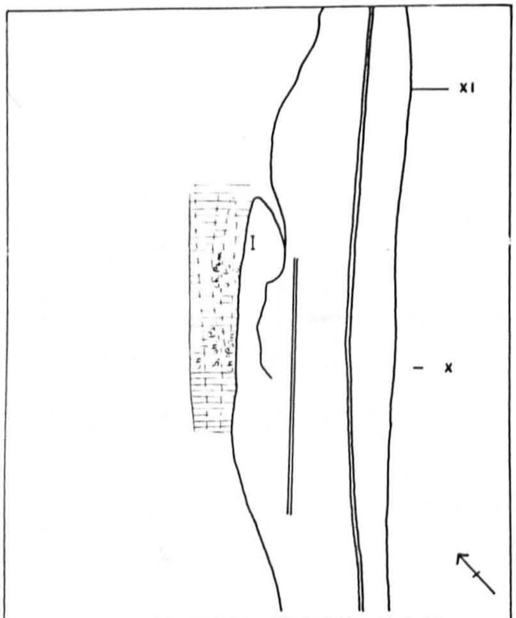


A PLAN OF BEACH FEATURES 13·4·60

SCALE 300 200 100 0 300 600 FEET

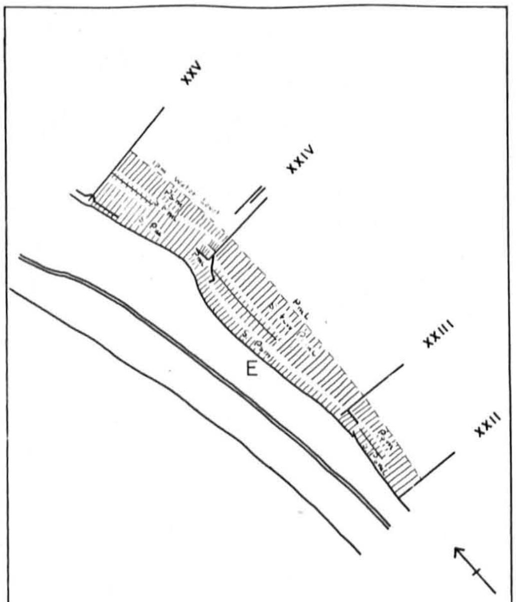
WIND ROSE FOR SPURN HEAD. 7·4·60 — 12·4·60





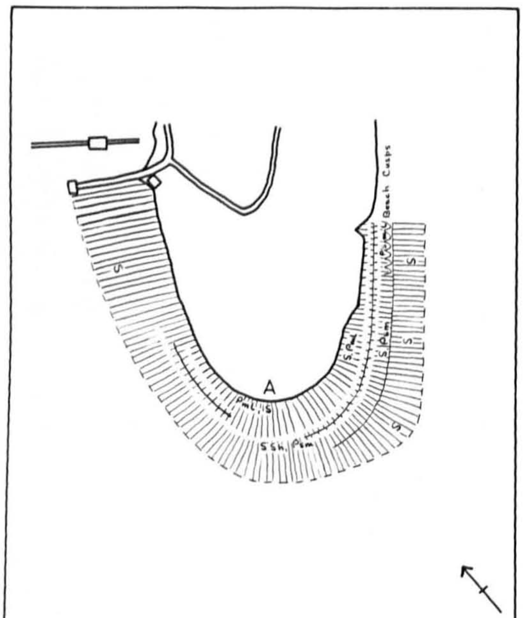
A PLAN OF BEACH FEATURES 18·4·60

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 18·4·60

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 18·4·60

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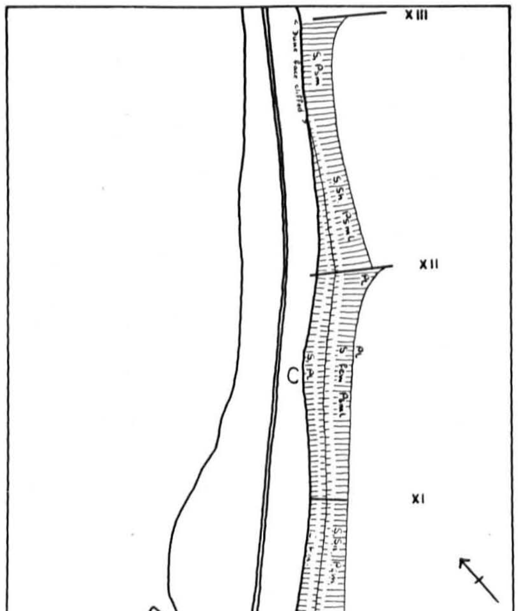
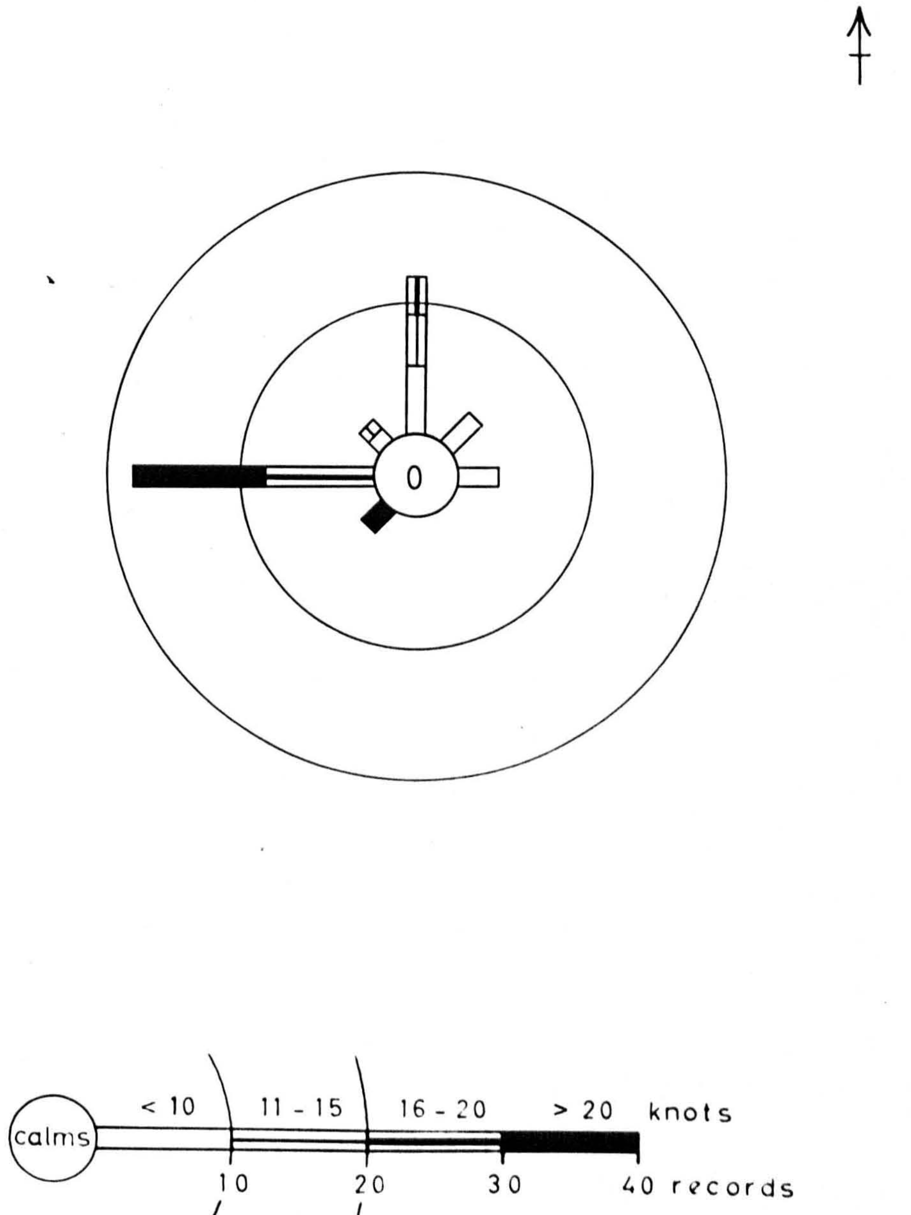
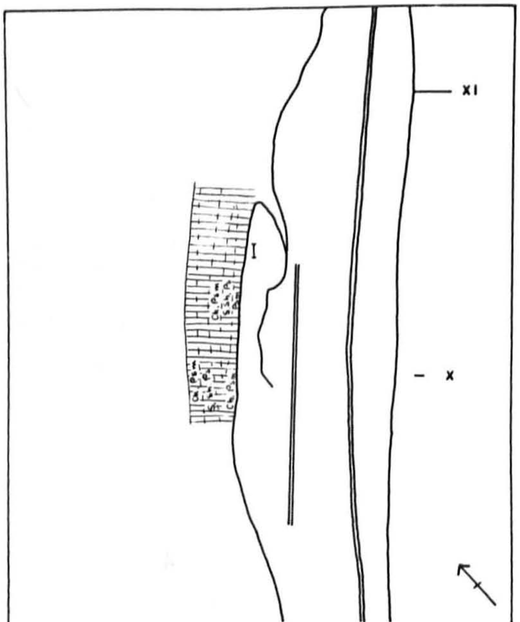


A PLAN OF BEACH FEATURES 18·4·60

SCALE 300 200 100 0 300 600 FEET

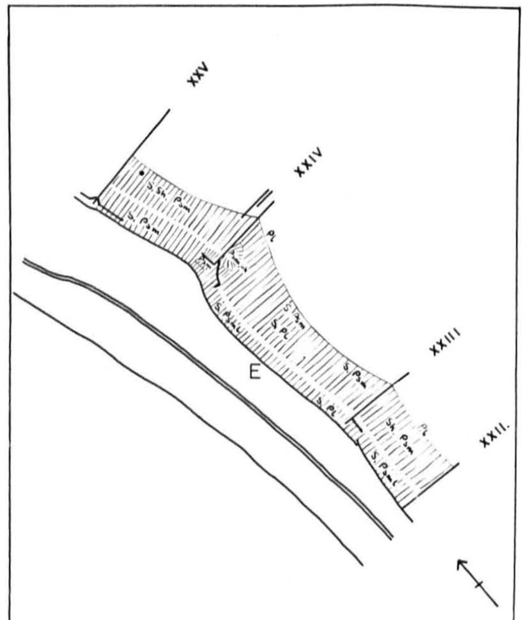
WIND ROSE FOR SPURN HEAD. 13·4·60 — 17·4·60





A PLAN OF BEACH FEATURES 25·4·60

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 25·4·60

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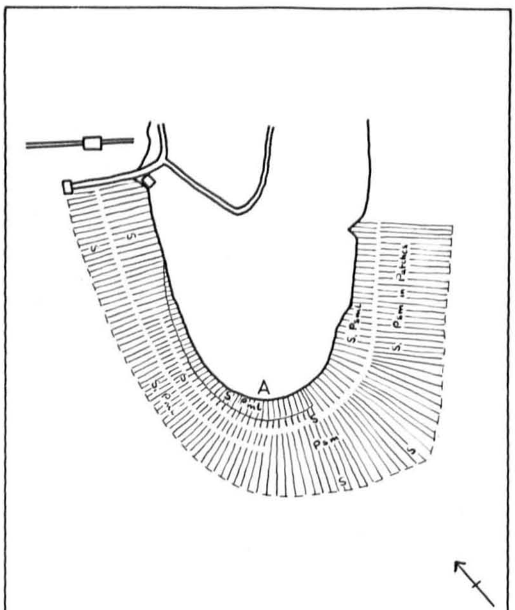

A PLAN OF BEACH FEATURES 25·4·60

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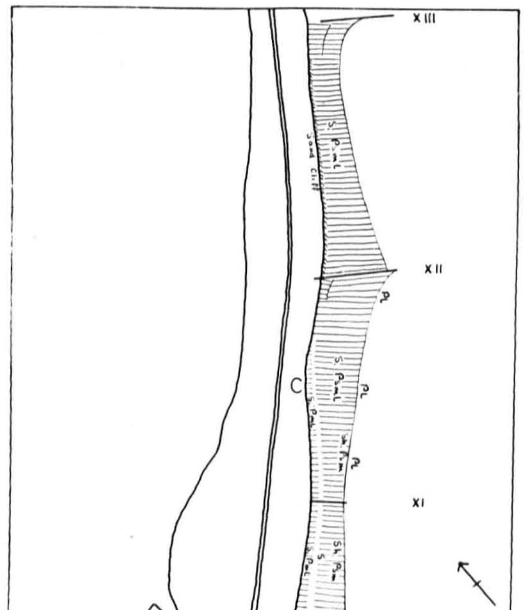
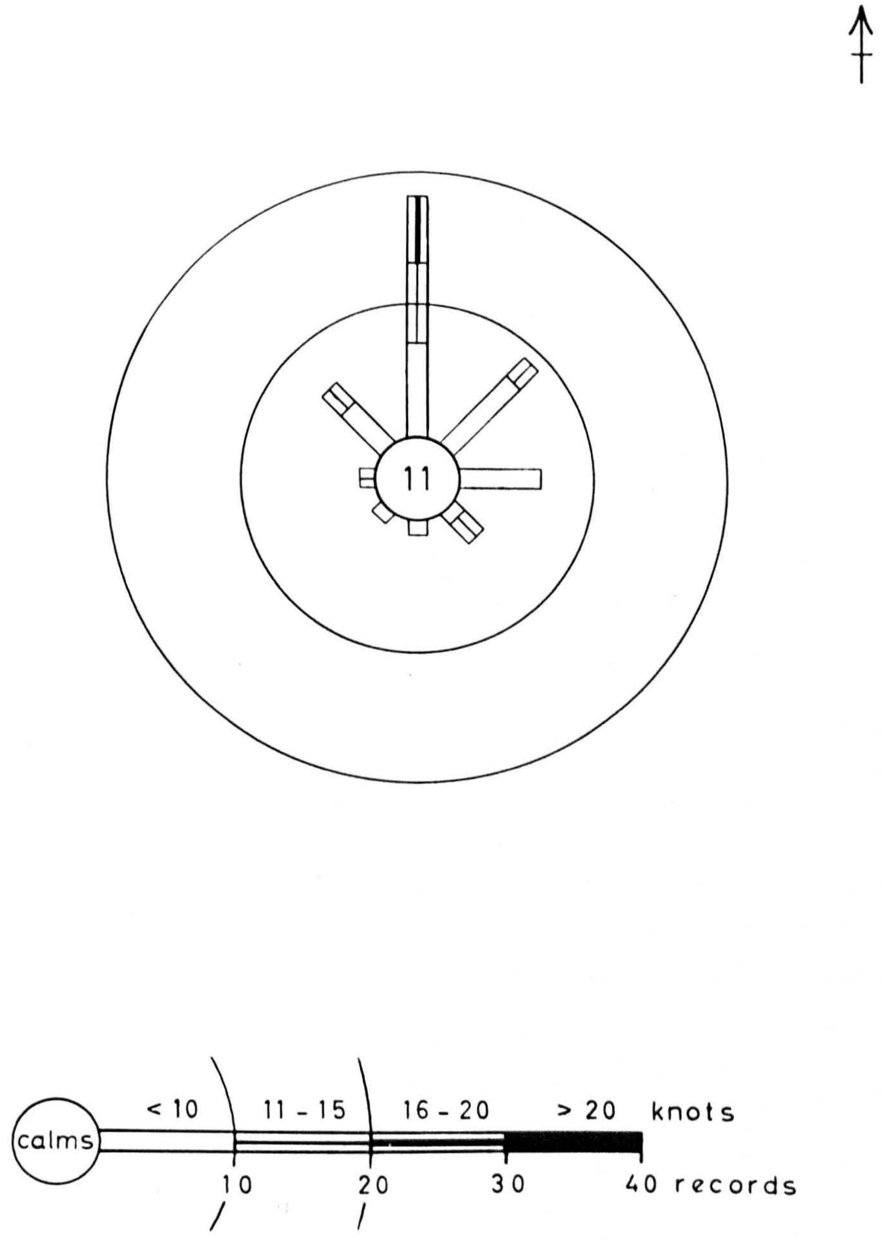
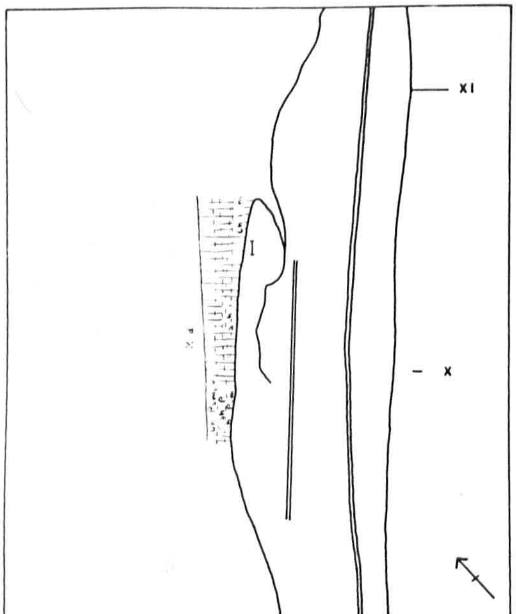


A PLAN OF BEACH FEATURES 25·4·60

SCALE 300 200 100 0 300 600 FEET

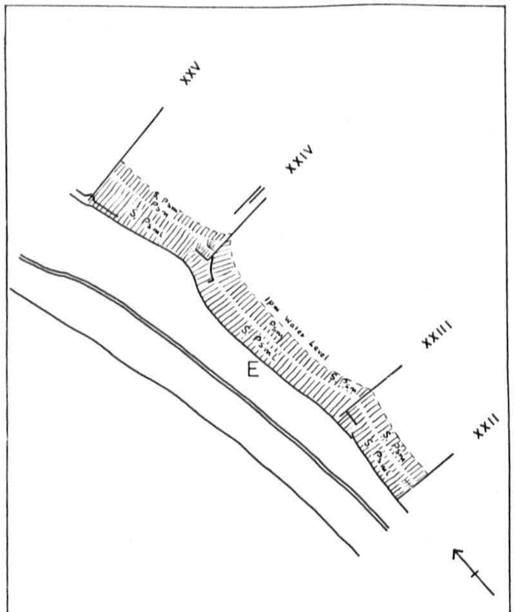
WIND ROSE FOR SPURN HEAD 18·4·60 — 24·4·60





A PLAN OF BEACH FEATURES 4·5·60

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 4·5·60

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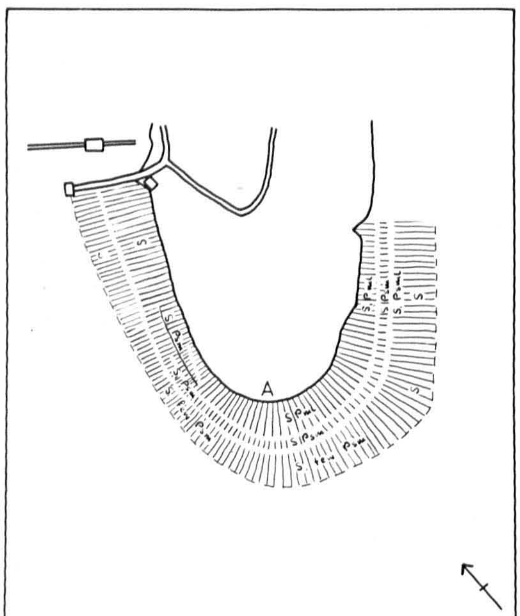

A PLAN OF BEACH FEATURES 4·5·60

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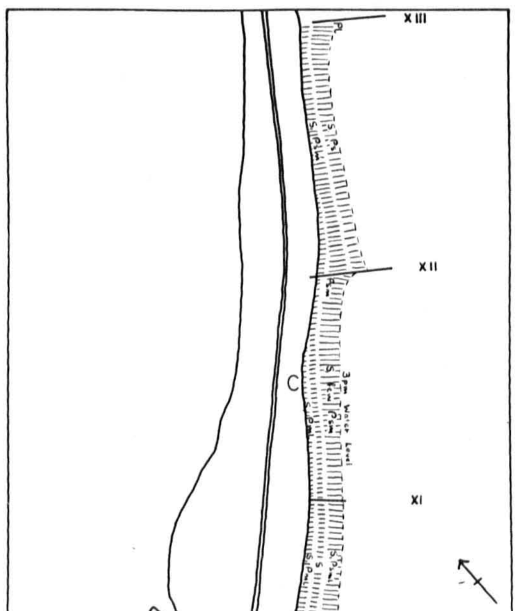
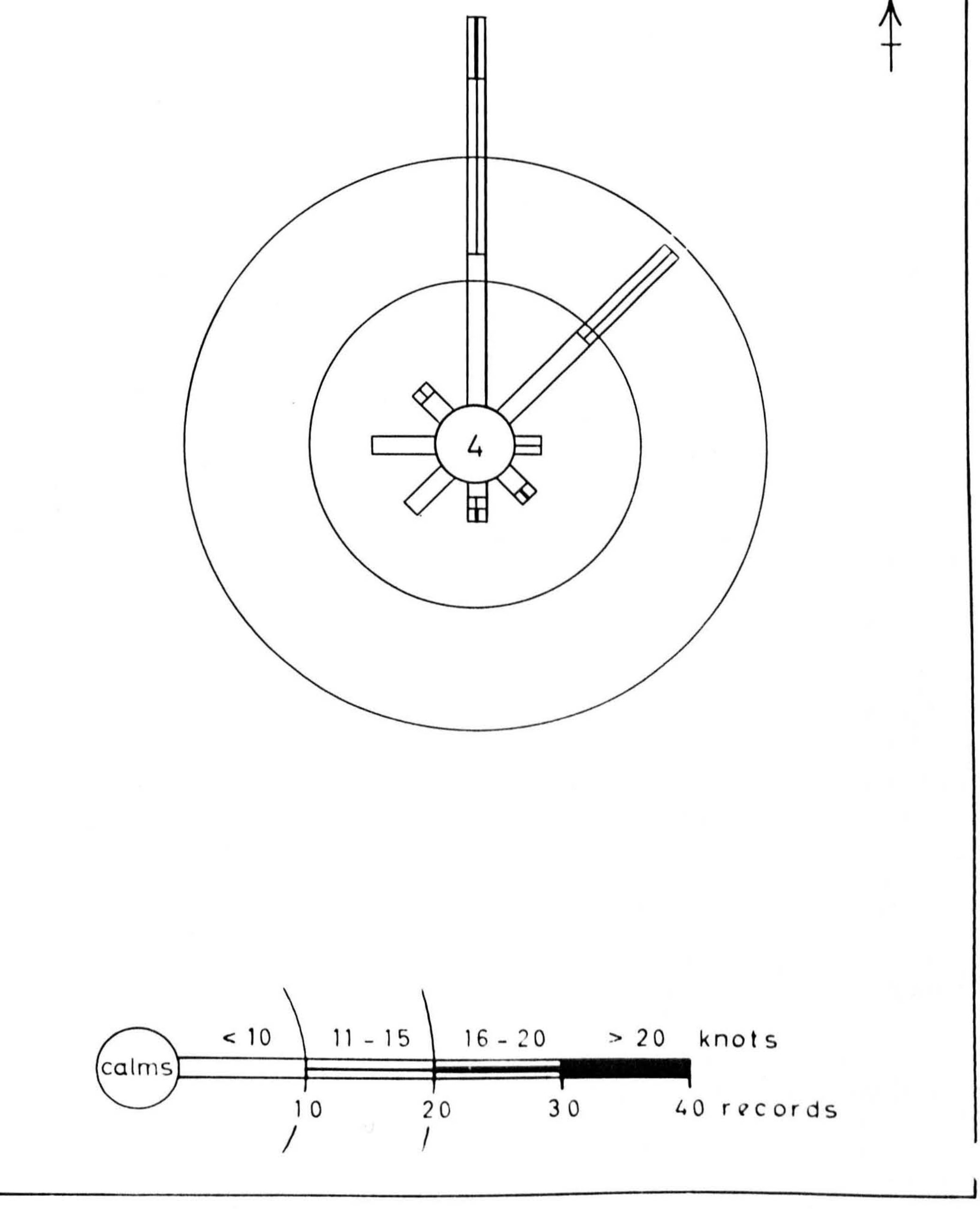


A PLAN OF BEACH FEATURES 4·5·60

SCALE 300 200 100 0 300 600 FEET

WIND ROSE FOR SPURN HEAD 25·4·60 — 3·5·60



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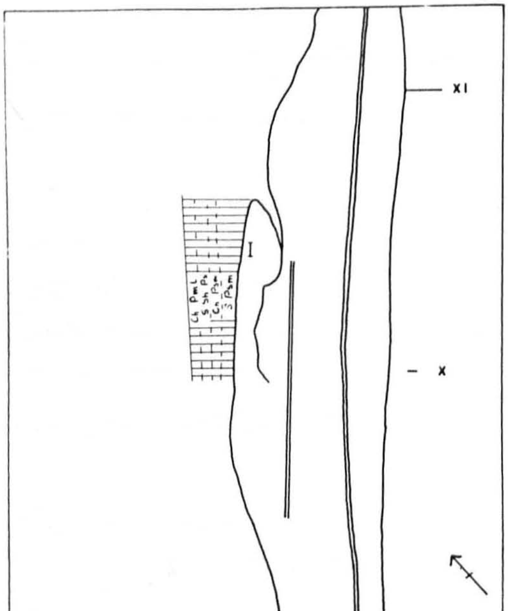

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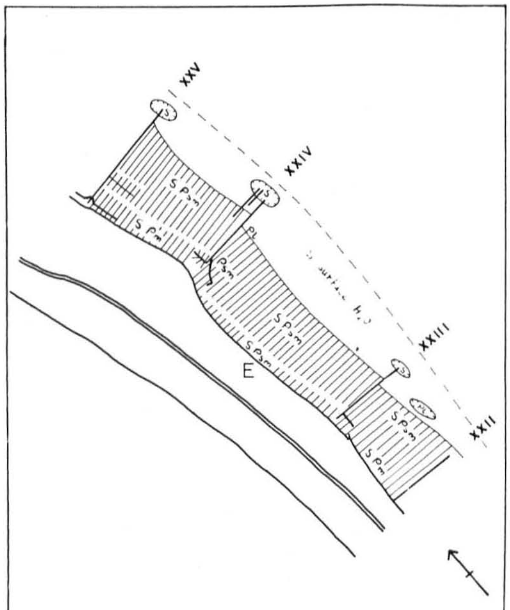
SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 12·5·60

SCALE 300 200 100 0 300 600 FEET

A PLAN OF BEACH FEATURES 12·5·60

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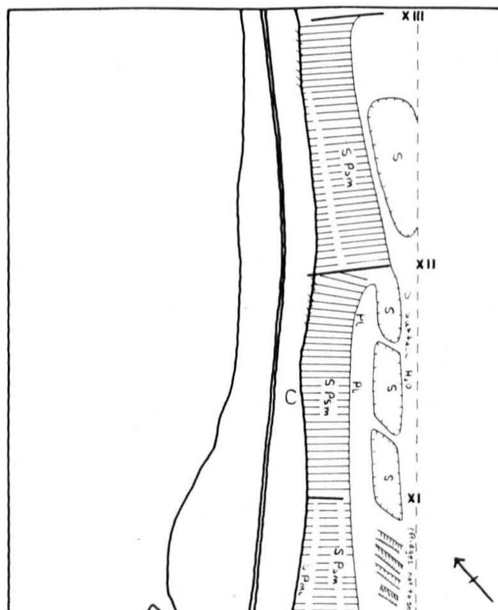
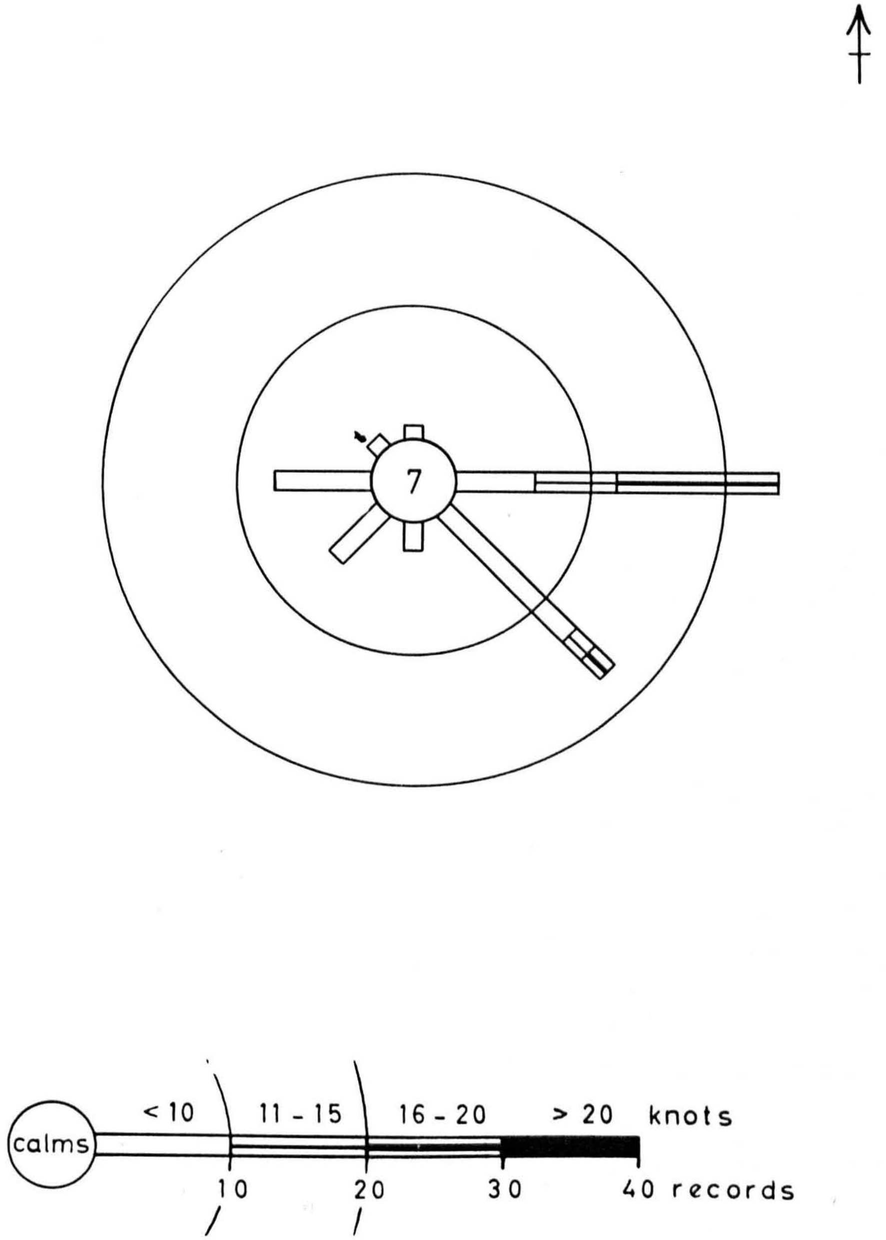
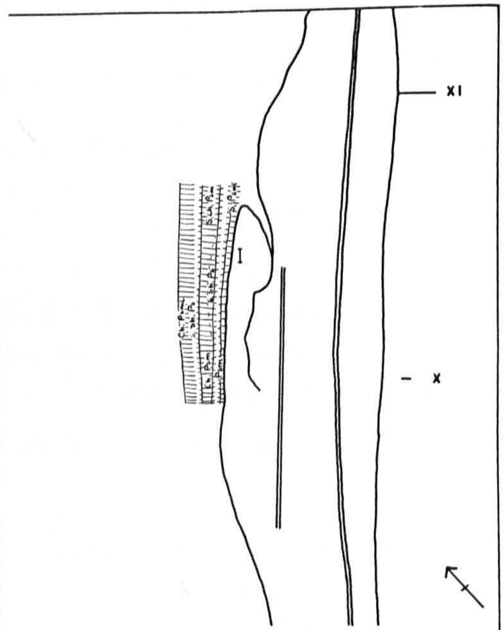


A PLAN OF BEACH FEATURES 12·5·60

SCALE 300 200 100 0 300 600 FEET

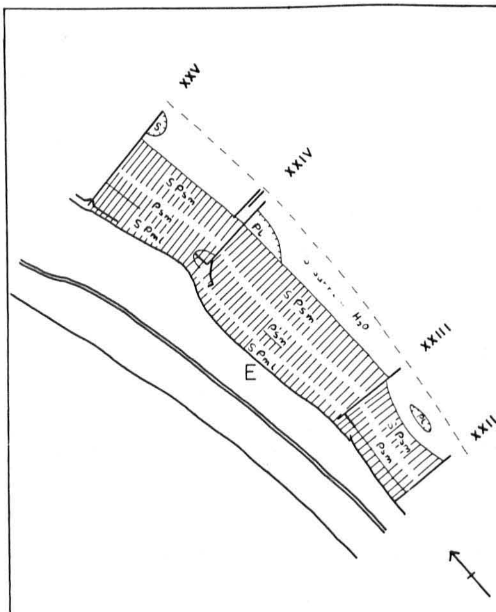
WIND ROSE FOR SPURN HEAD 4·5·60 — 11·5·60





A PLAN OF BEACH FEATURES 18·5·60

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 18·5·60

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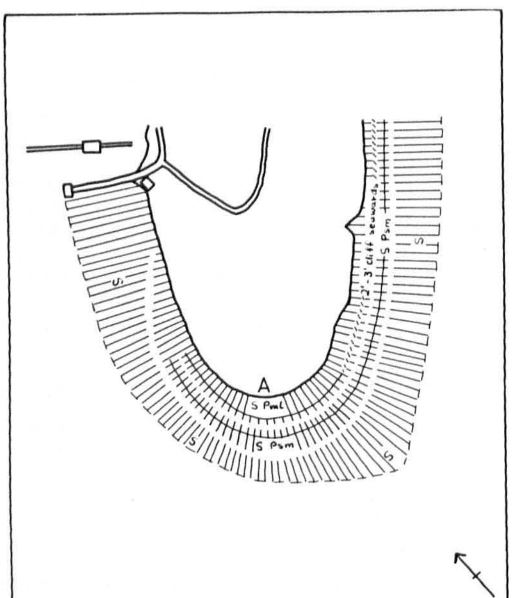

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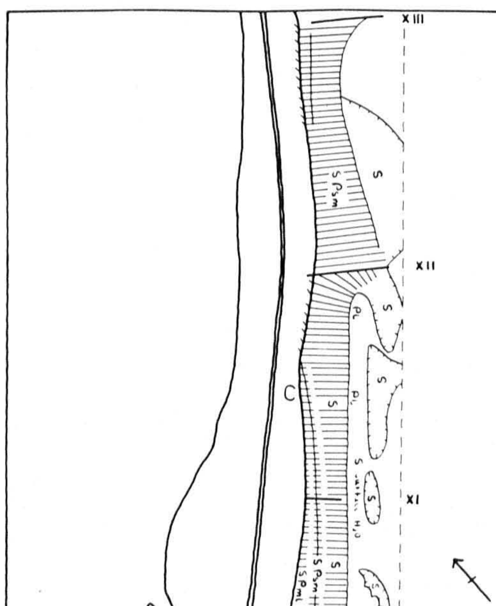
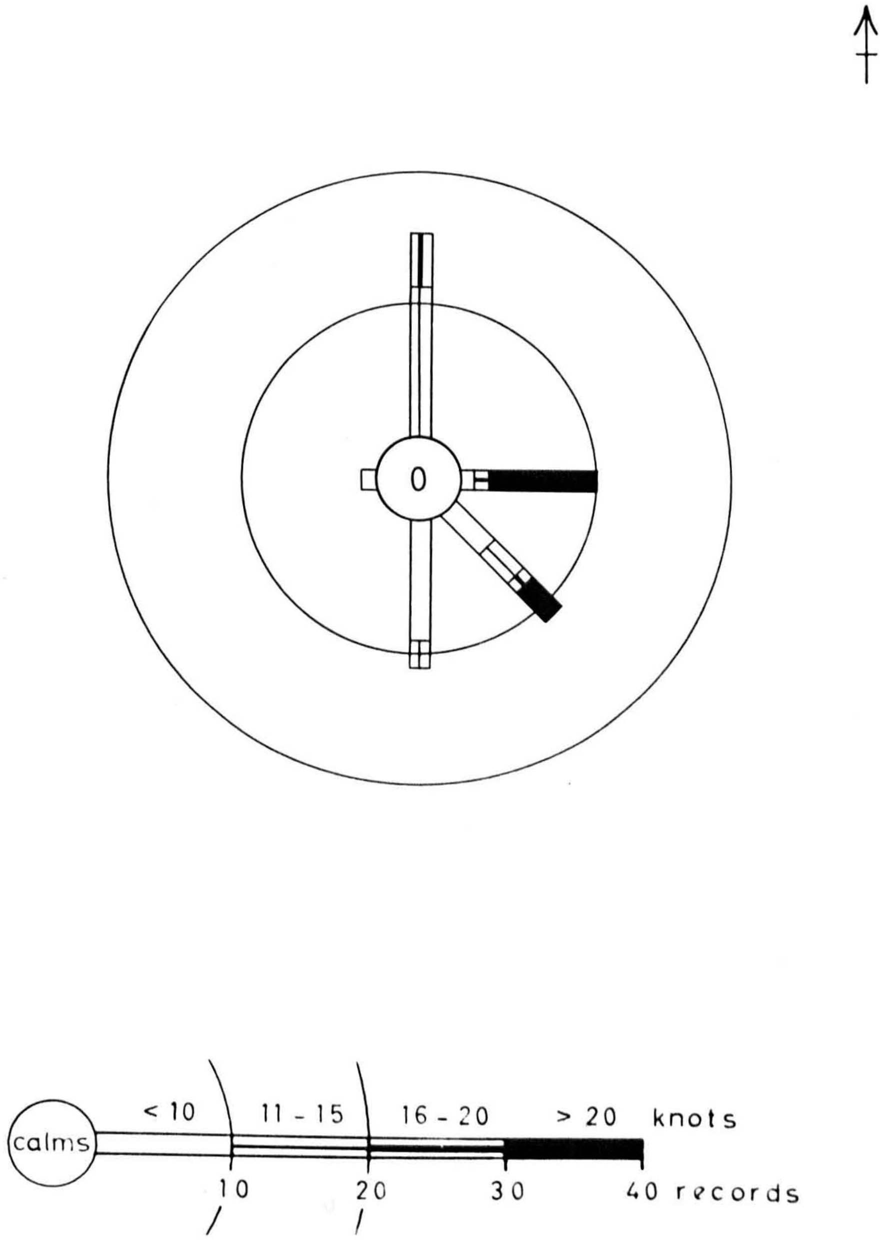
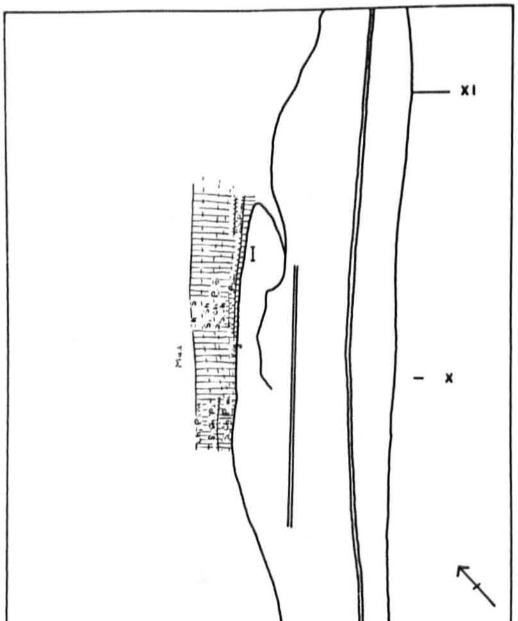


A PLAN OF BEACH FEATURES 18·5·60

SCALE 300 200 100 0 300 600 FEET

WIND ROSE FOR SPURN HEAD 12·5·60 — 17·5·60





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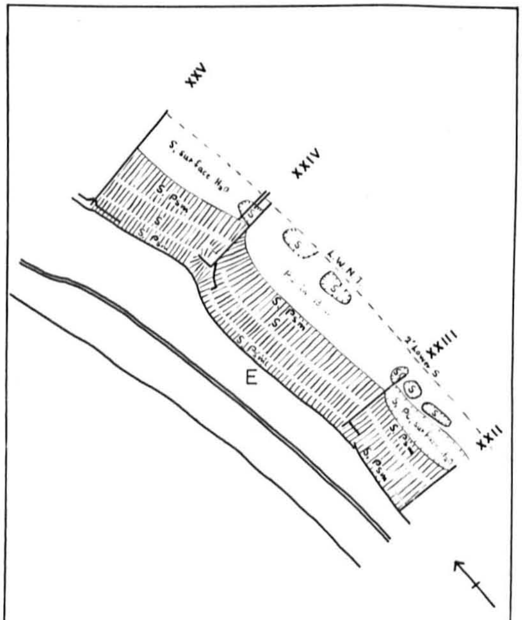

A PLAN OF BEACH FEATURES 30·5·60

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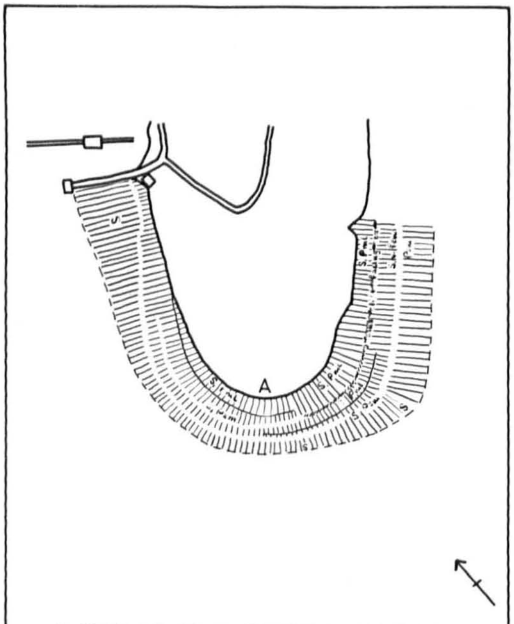

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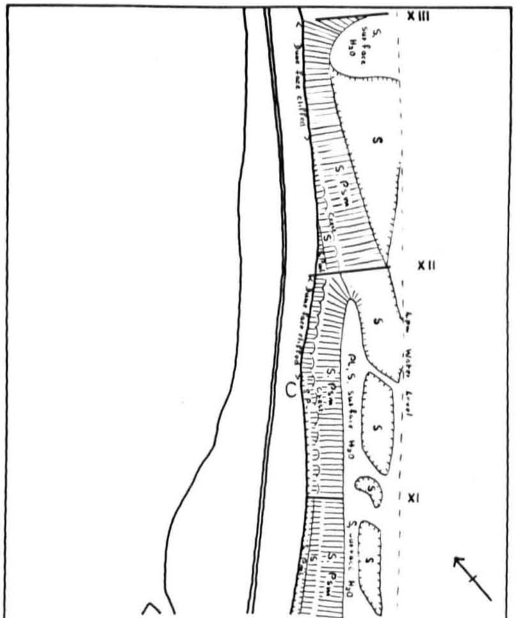

A PLAN OF BEACH FEATURES 30·5·60

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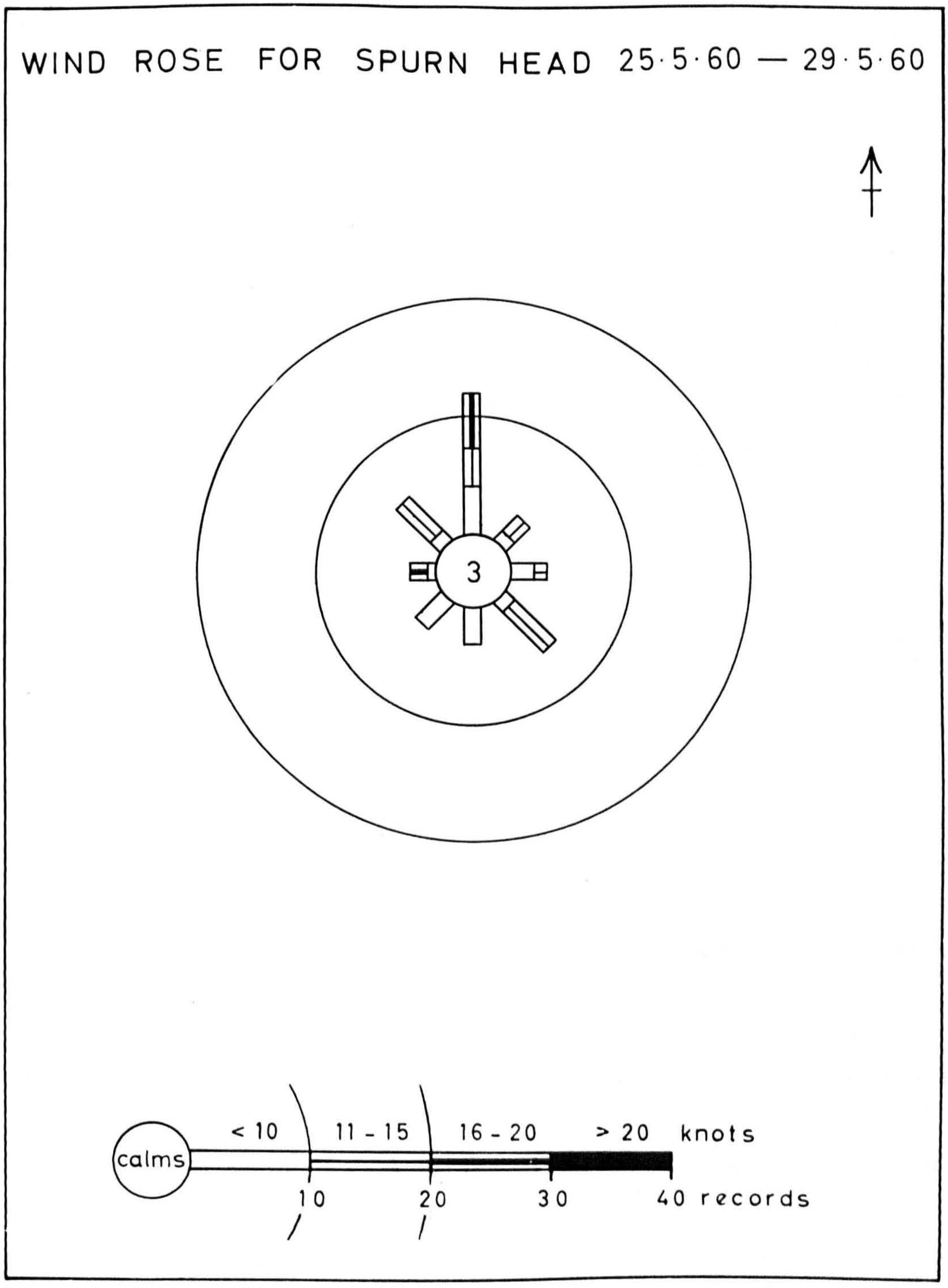
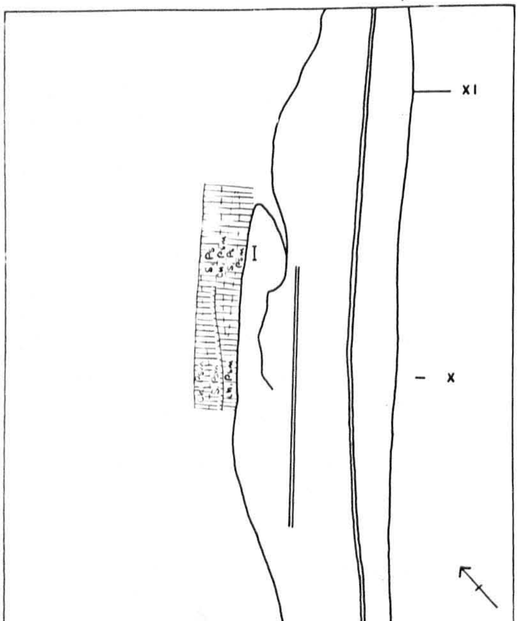
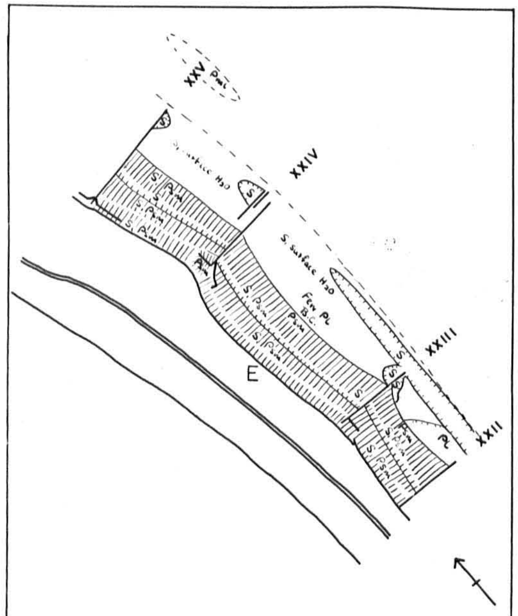

WIND ROSE FOR SPURN HEAD 25·5·60 — 29·5·60
3
calms
< 10
11 - 15
16 - 20
> 20 knots
10
20
30
40 records



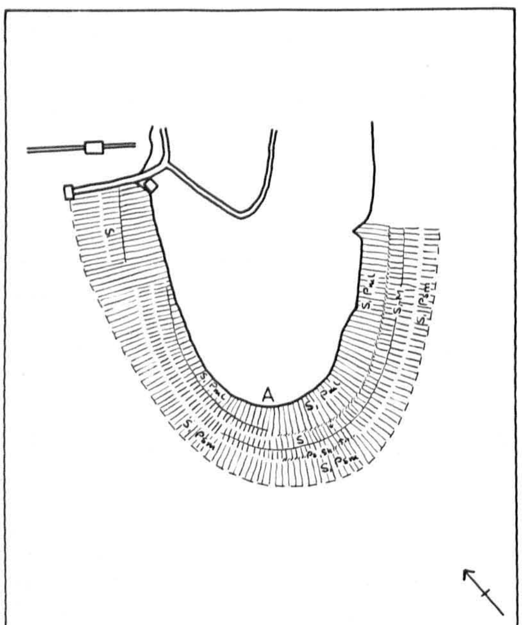
A PLAN OF BEACH FEATURES 10·6·60

SCALE 300 200 100 0 300 600 FEET



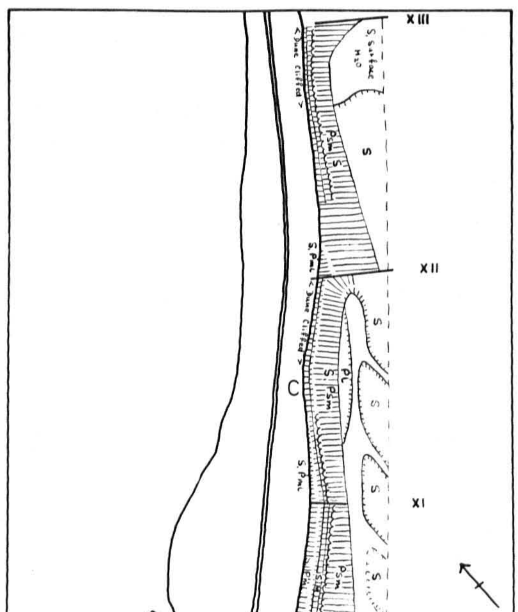
A PLAN OF BEACH FEATURES 10·6·60

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 10·6·60

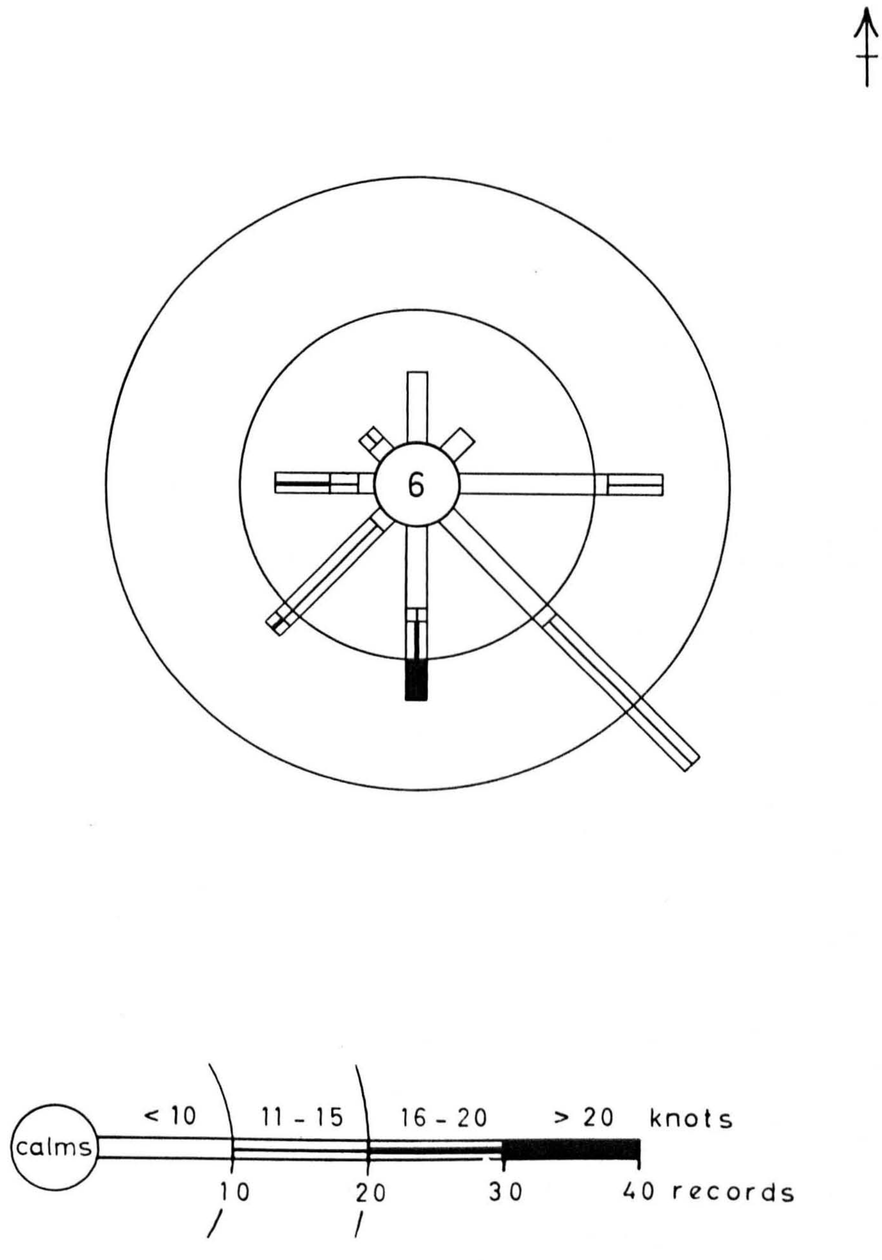
SCALE 300 200 100 0 300 600 FEET

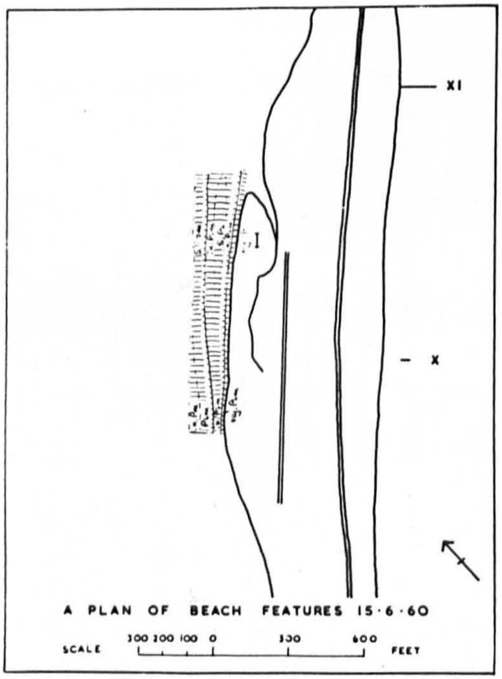


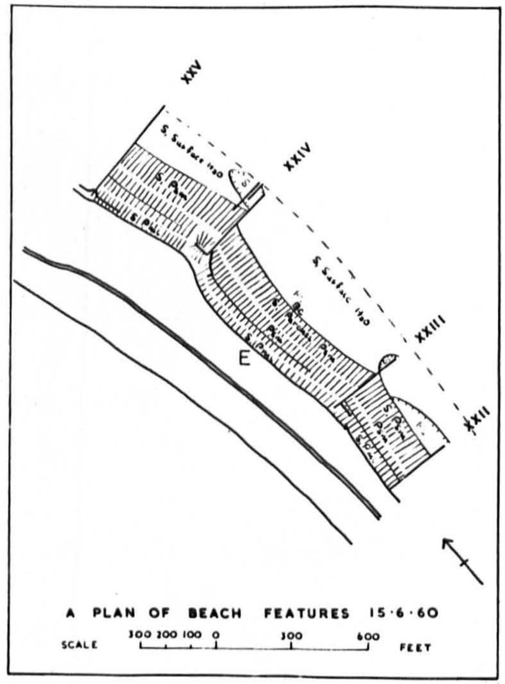
A PLAN OF BEACH FEATURES 10·6·60

SCALE 300 200 100 0 300 600 FEET

WIND ROSE FOR SPURN HEAD 30·5·60 — 9·6·60




XI
X
I
A PLAN OF BEACH FEATURES 15·6·60
SCALE 300 200 100 0 300 600 FEET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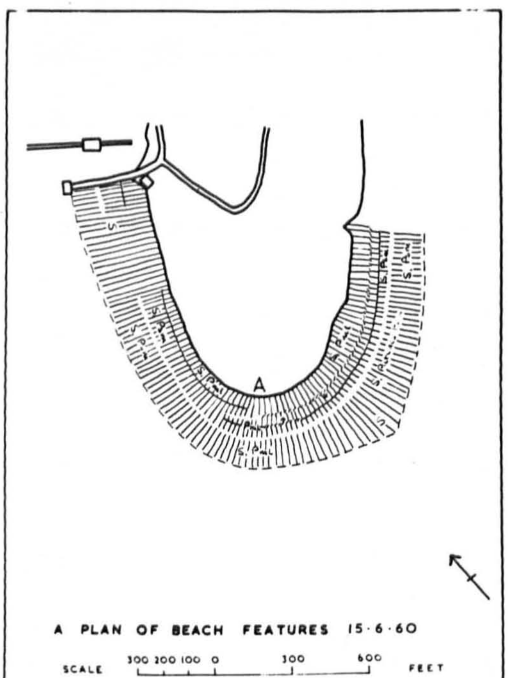
XXIV
XXIII
XXII
E
A PLAN OF BEACH FEATURES 15·6·60
SCALE 300 200 100 0 300 600 FEET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A PLAN OF BEACH FEATURES 15·6·60
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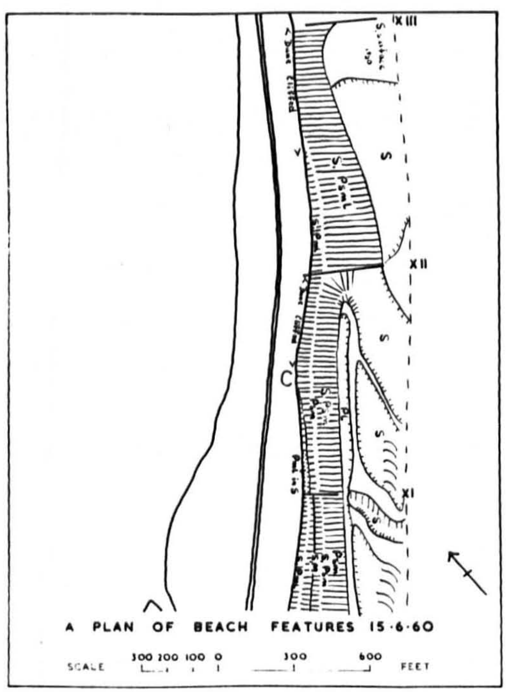
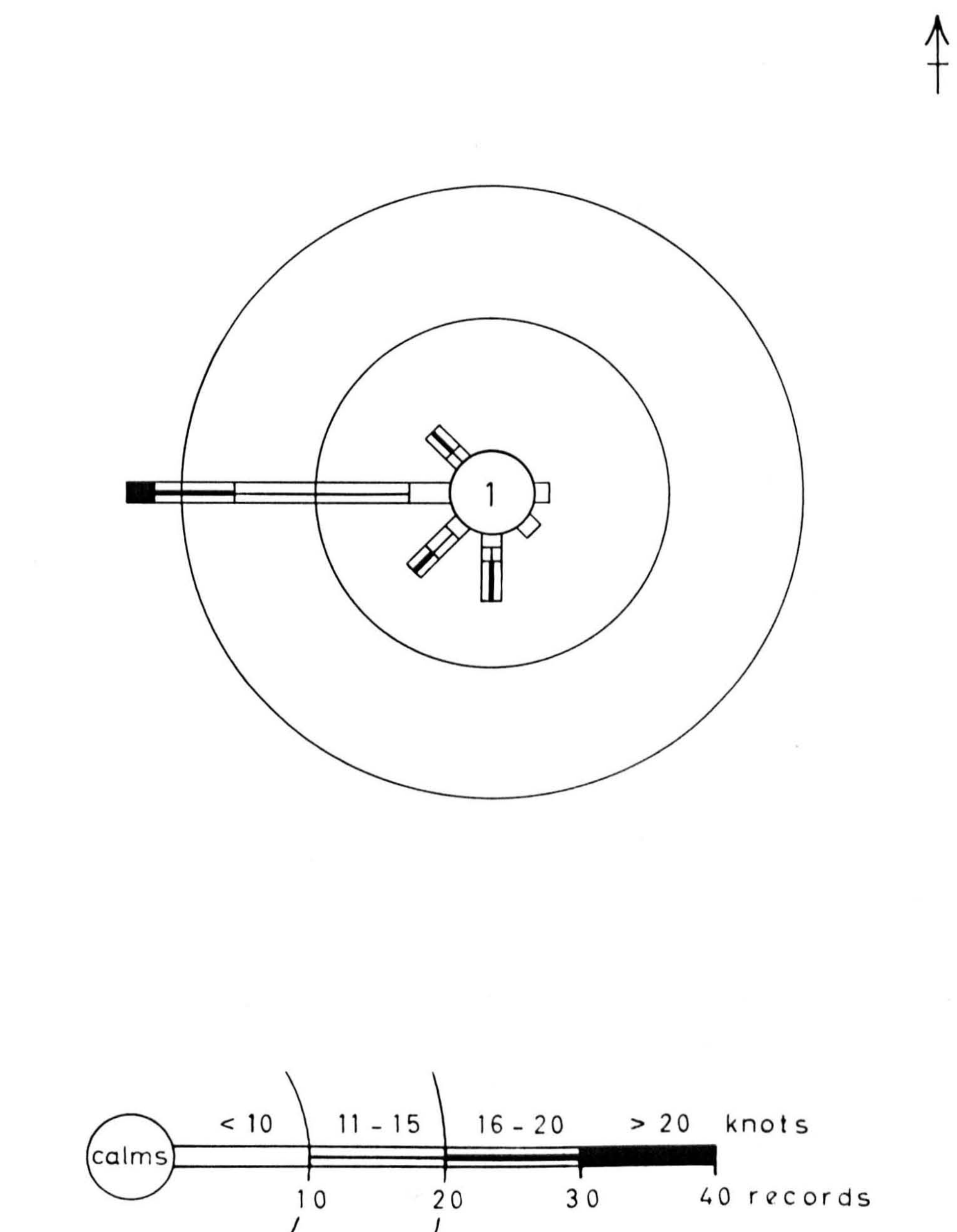
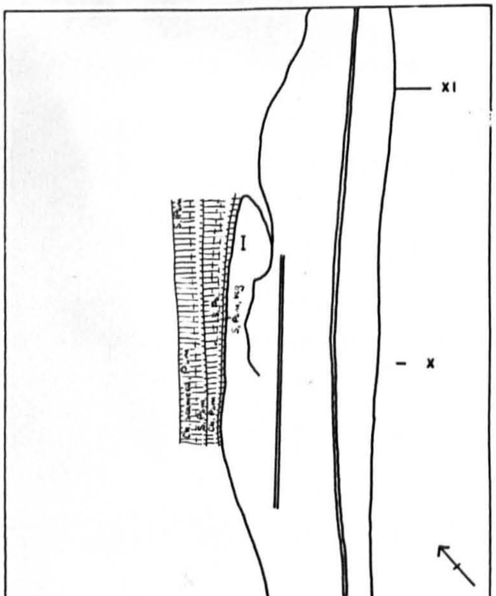

XIII
S
XII
S
C
S
XI
A PLAN OF BEACH FEATURES 15·6·60
SCALE 300 200 100 0 300 600 FEET

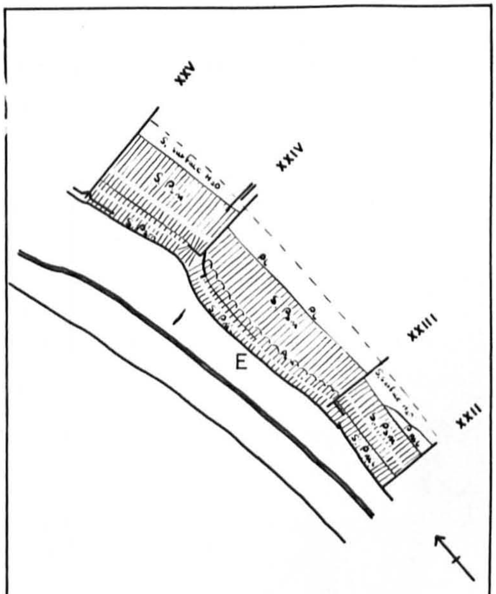
WIND ROSE FOR SPURN HEAD 10·6·60 — 14·6·60





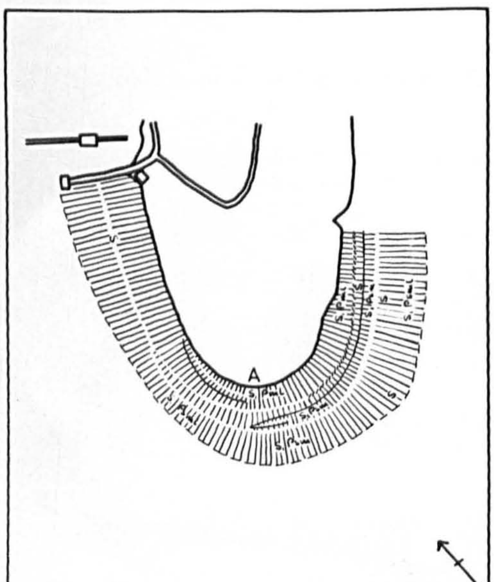
A PLAN OF BEACH FEATURES 23·6·60

SCALE 300 200 100 0 300 600 FEET



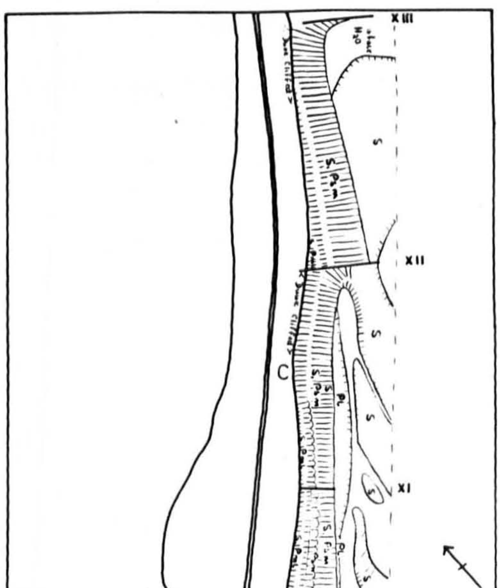
A PLAN OF BEACH FEATURES 23·6·60

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 23·6·60

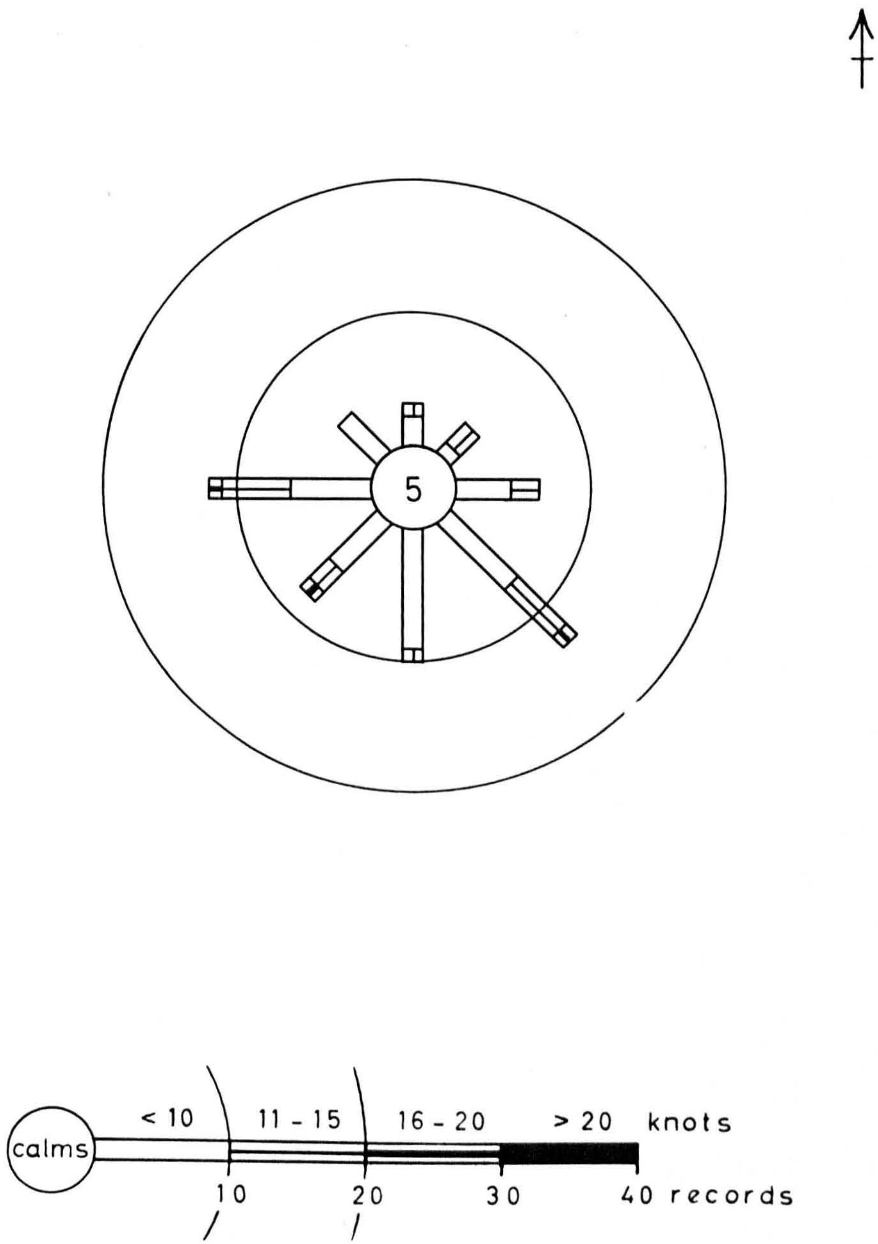
SCALE 300 200 100 0 300 600 FEET

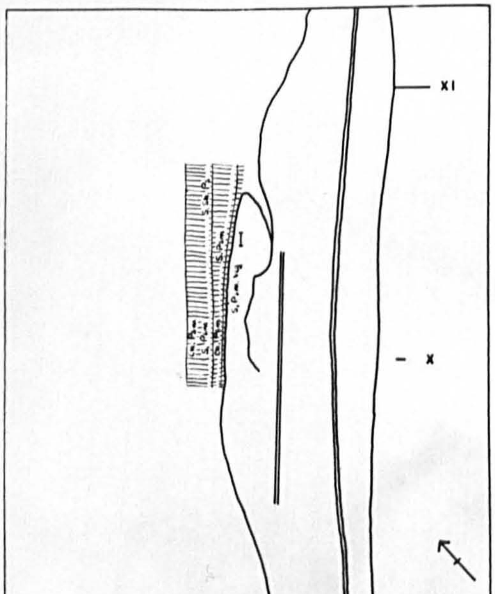


A PLAN OF BEACH FEATURES 23·6·60

SCALE 300 200 100 0 300 600 FEET

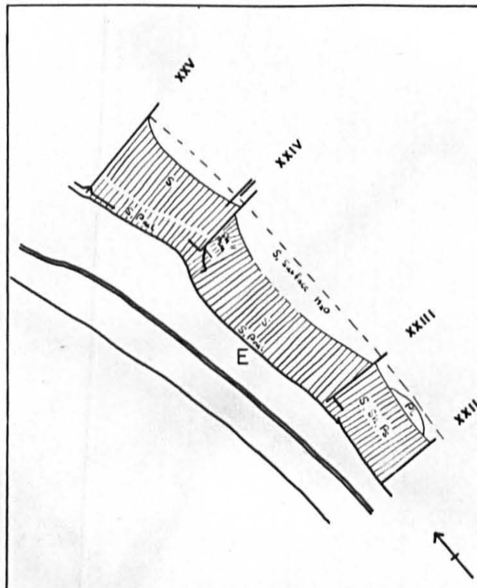
WIND ROSE FOR SPURN HEAD 15·6·60 — 22·6·60





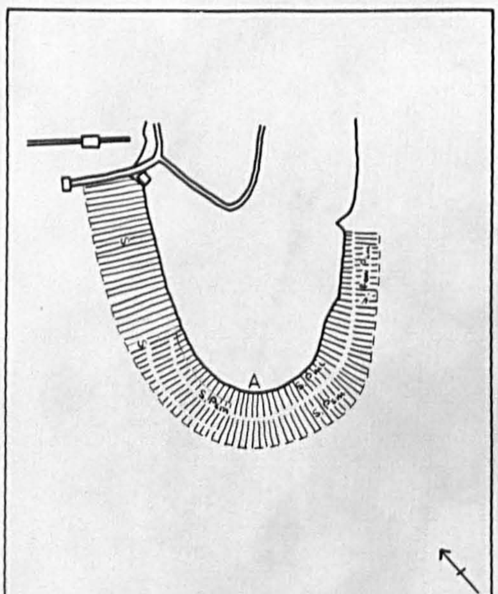
A PLAN OF BEACH FEATURES 29·6·60

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 29·6·60

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 29·6·60

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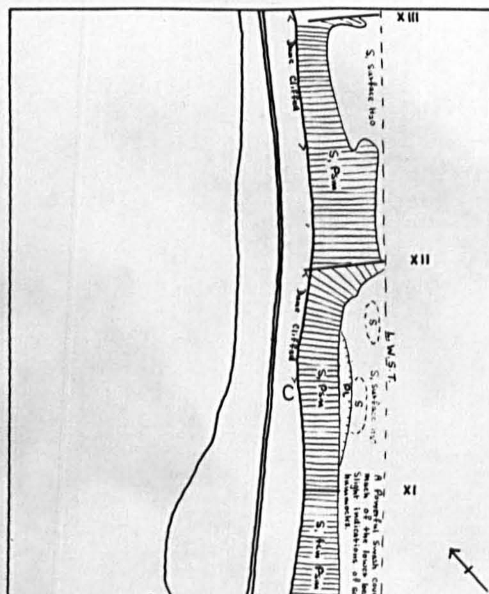
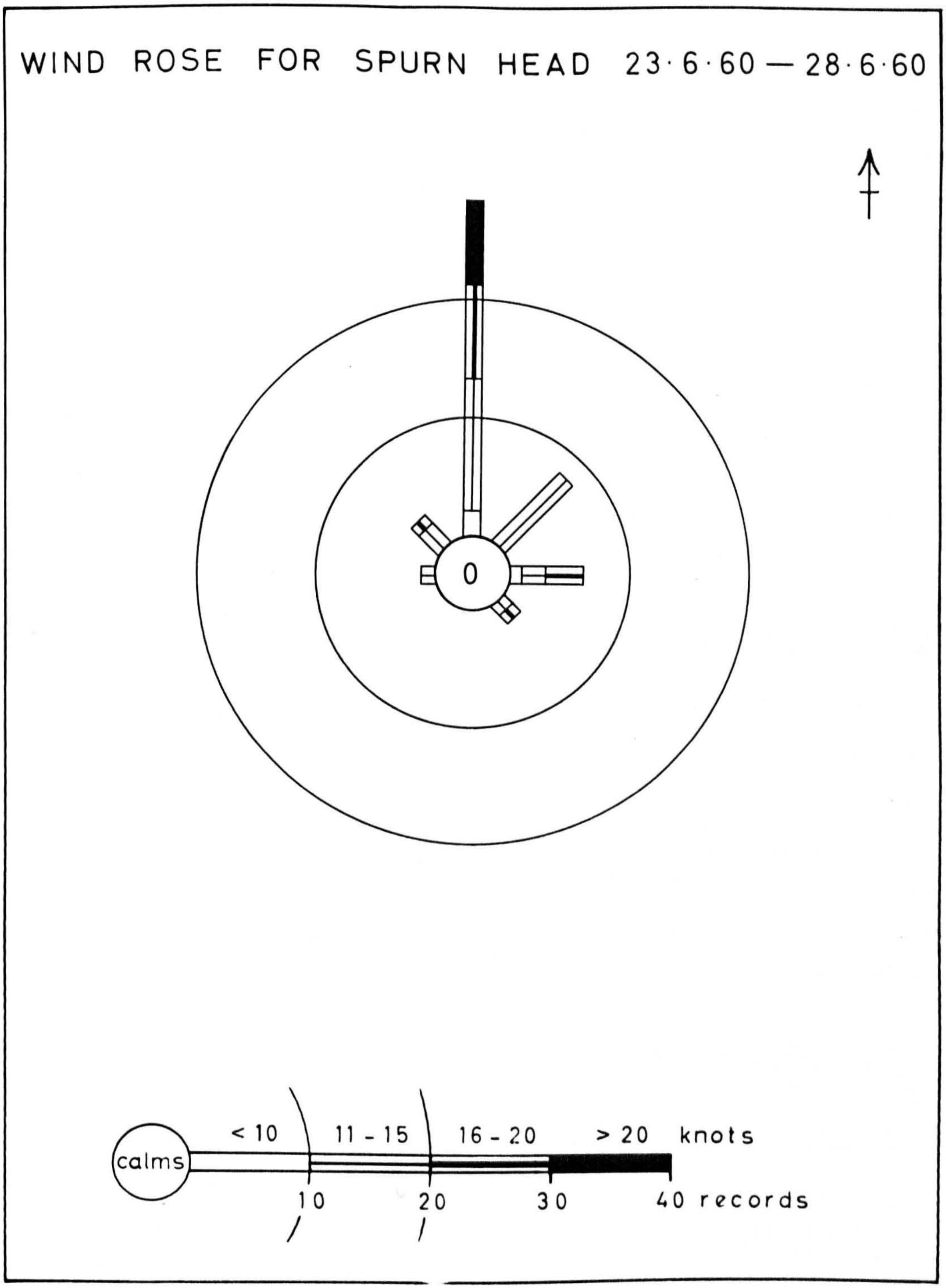
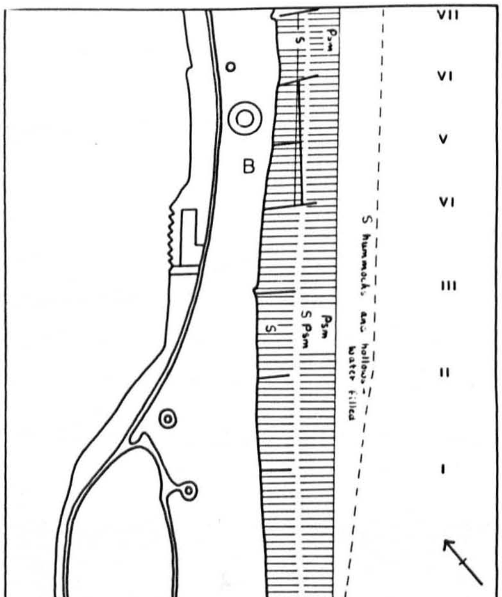


A PLAN OF BEACH FEATURES 29·6·60

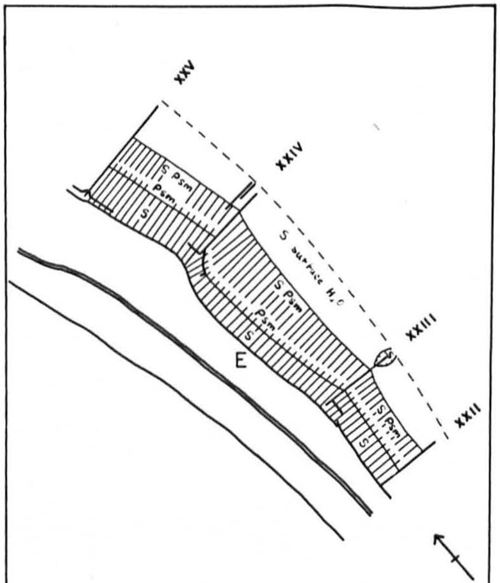
SCALE 300 200 100 0 300 600 FEET


WIND ROSE FOR SPURN HEAD 23·6·60 — 28·6·60
0
calms
< 10
11 - 15
16 - 20
> 20 knots
10
20
30
40 records



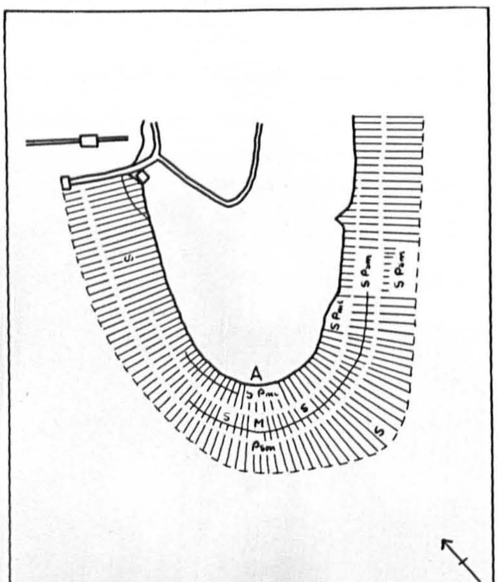
A PLAN OF BEACH FEATURES 8·7·60

SCALE 300 200 100 0 300 600 FEET



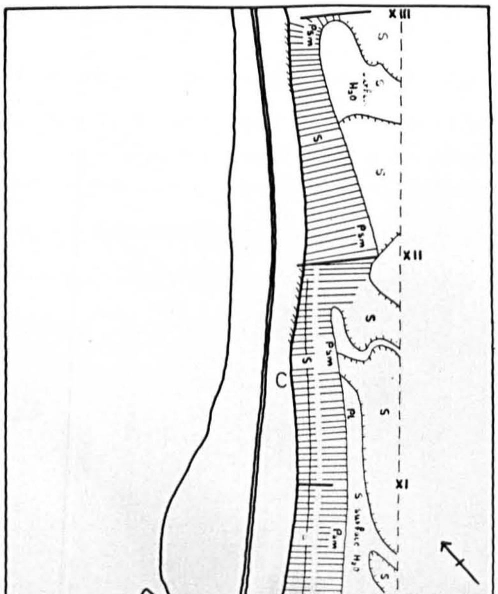
A PLAN OF BEACH FEATURES 8·7·60

SCALE 300 200 100 0 300 600 FEET



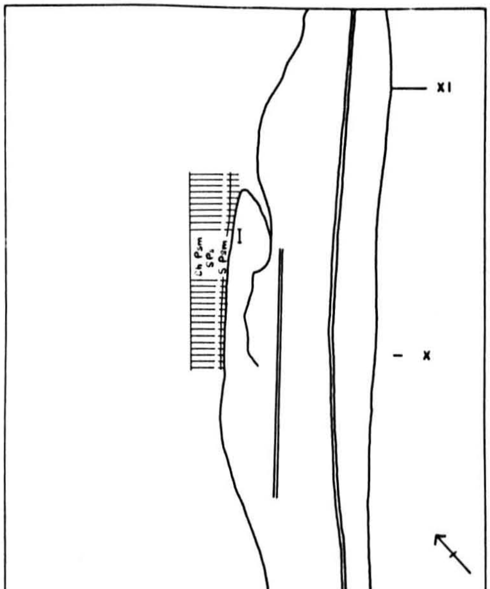
A PLAN OF BEACH FEATURES 8·7·60

SCALE 300 200 100 0 300 600 FEET

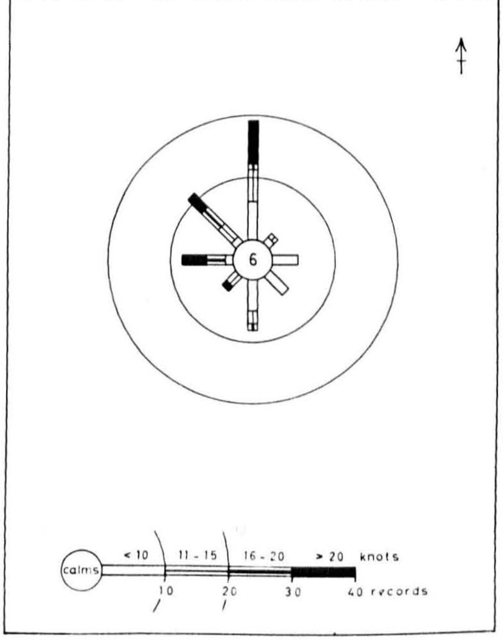


A PLAN OF BEACH FEATURES 8·7·60

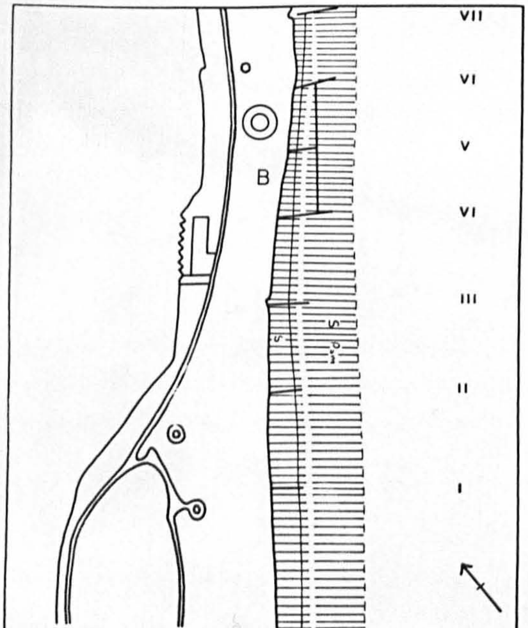
SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 8·7·60



WIND ROSE FOR SPURN HEAD 29·6·60 — 6·7·60



A PLAN OF BEACH FEATURES 14 · 7 · 60

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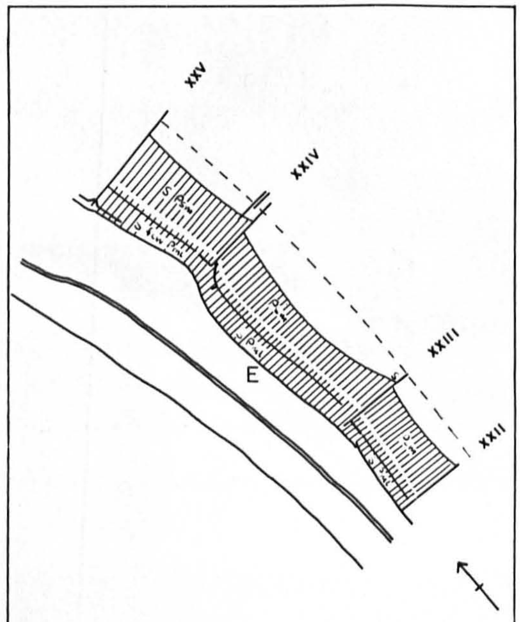

A PLAN OF BEACH FEATURES 14 · 7 · 60

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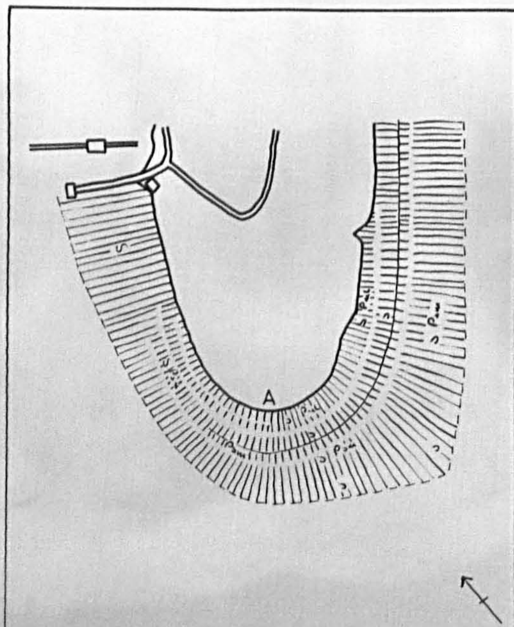
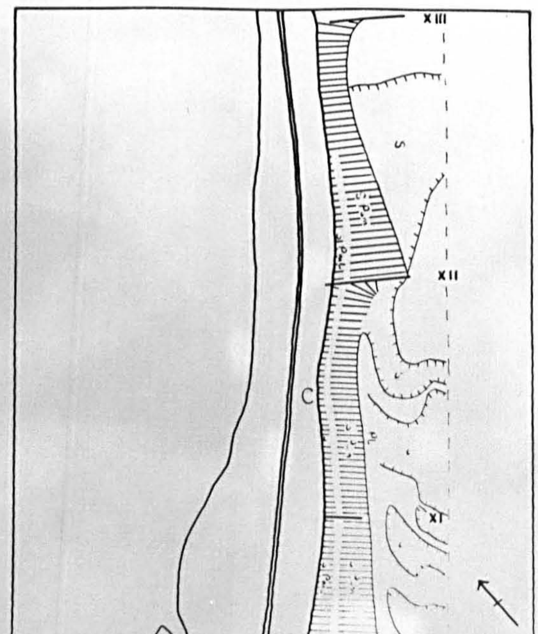


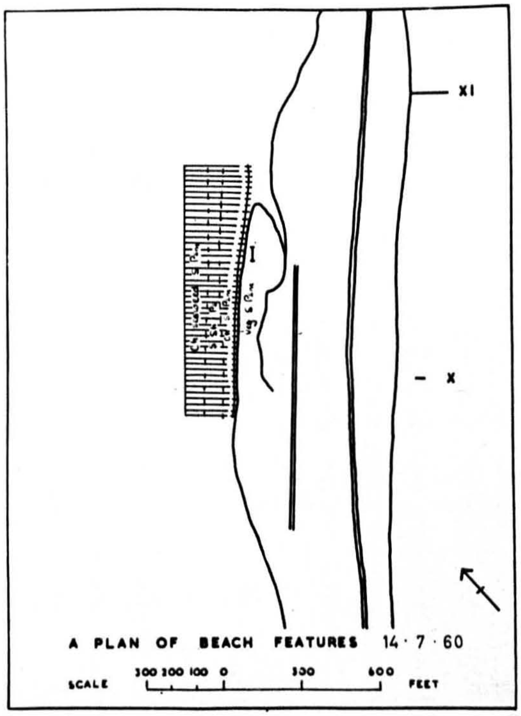
A PLAN OF BEACH FEATURES 14 7 60

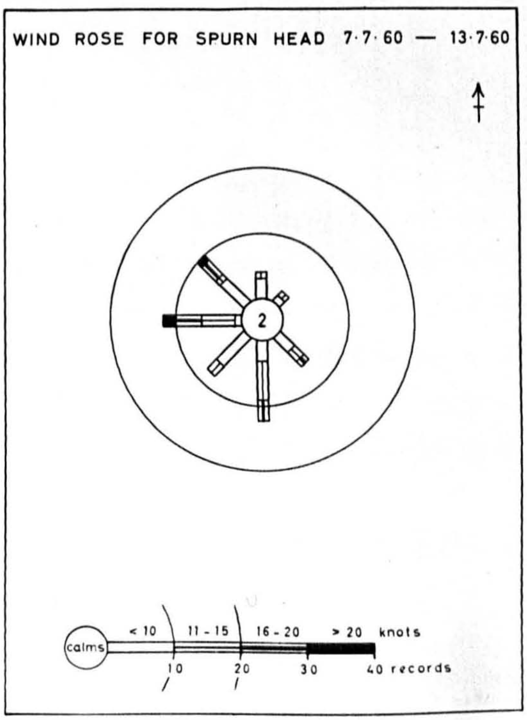
SCALE 300 200 100 0 300 600 FEET

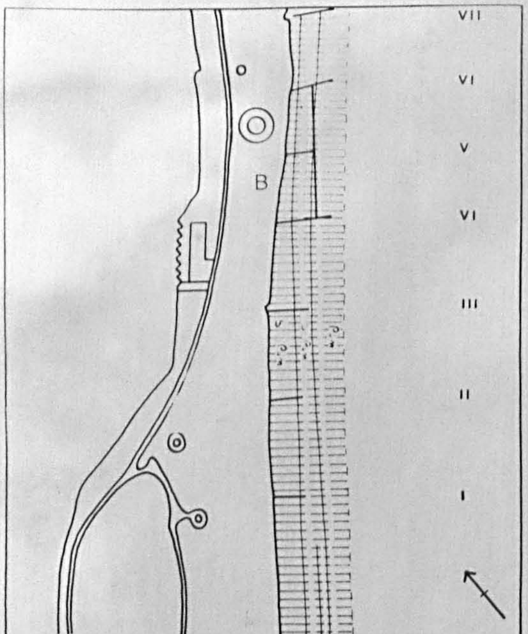


A PLAN OF BEACH FEATURES 14 7 60

SCALE 300 200 100 0 300 600 FEET

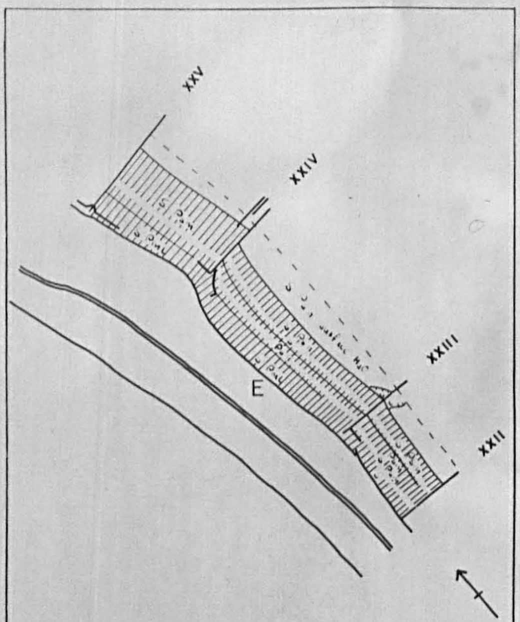

XI
I
X
A PLAN OF BEACH FEATURES 14 · 7 · 60
SCALE
300 200 100 0
300
600
FEET


WIND ROSE FOR SPURN HEAD 7·7·60 — 13·7·60
2
calms
< 10
11 - 15
16 - 20
> 20 knots
10
20
30
40 records



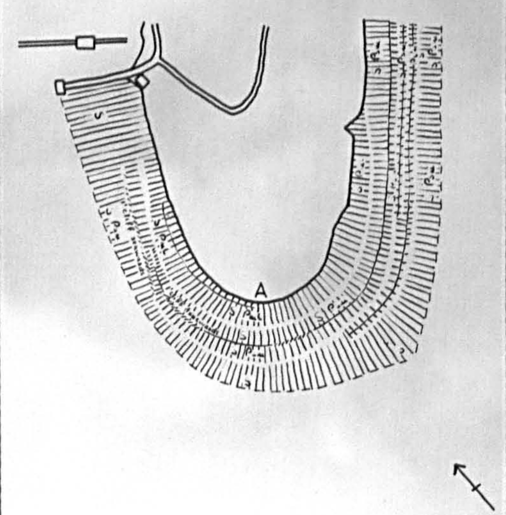
A PLAN OF BEACH FEATURES 20·7·60

SCALE 300 200 100 0 300 600 FEET



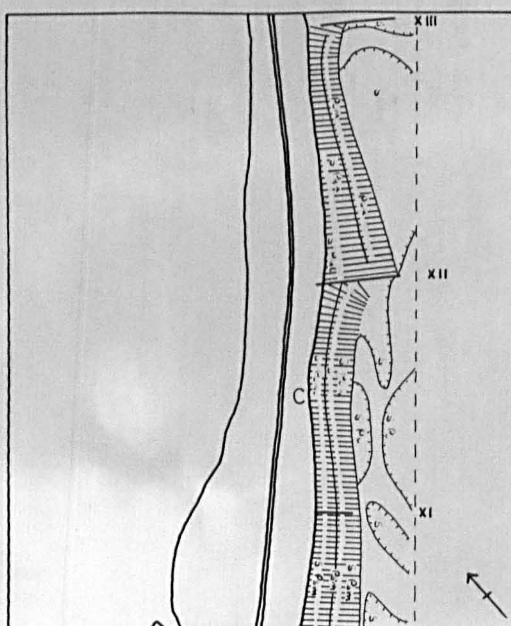
A PLAN OF BEACH FEATURES 20·7·60

SCALE 300 200 100 0 300 600 FEET



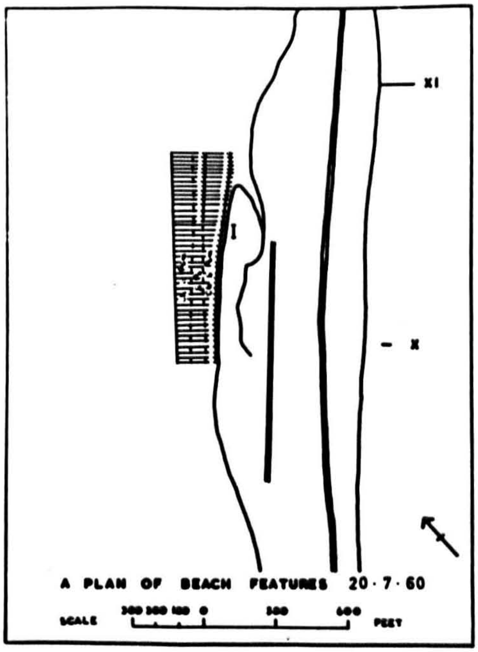
A PLAN OF BEACH FEATURES 20·7·60

SCALE 300 200 100 0 300 600 FEET



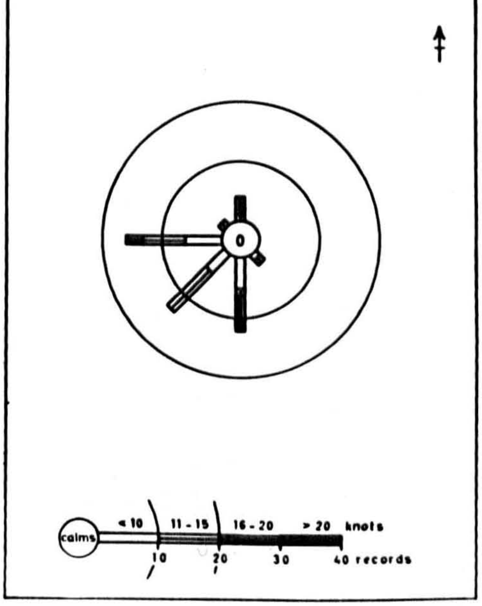
A PLAN OF BEACH FEATURES 20·7·60

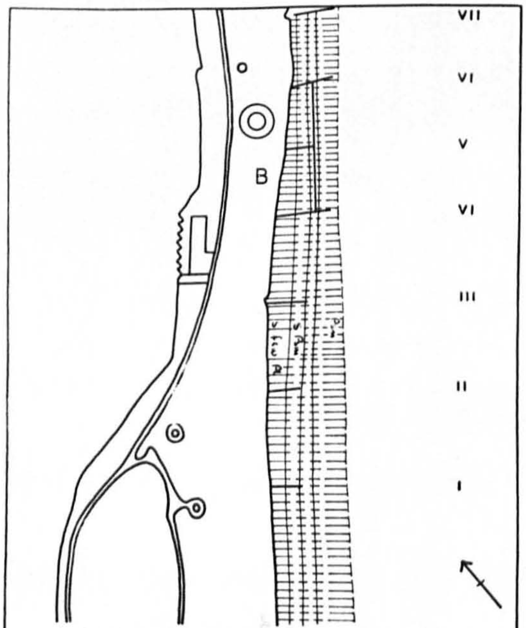
SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 20 · 7 · 60

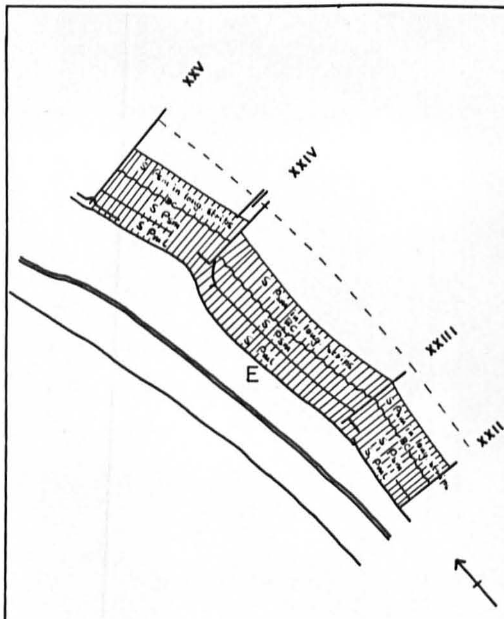
WIND ROSE FOR SPURN HEAD 14·7·60 — 19·7·60





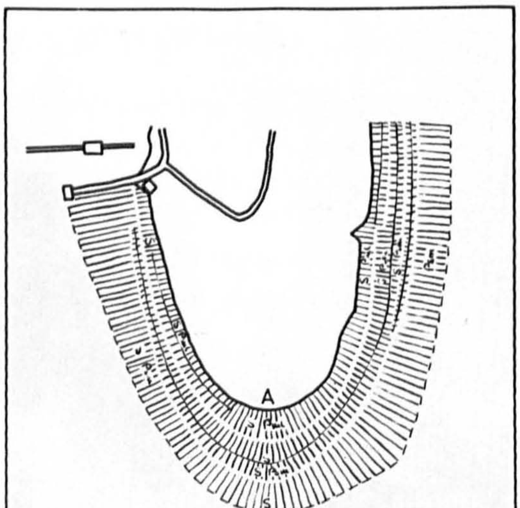
A PLAN OF BEACH FEATURES 31 · 7 · 60

SCALE 300 200 100 0 300 600 FEET



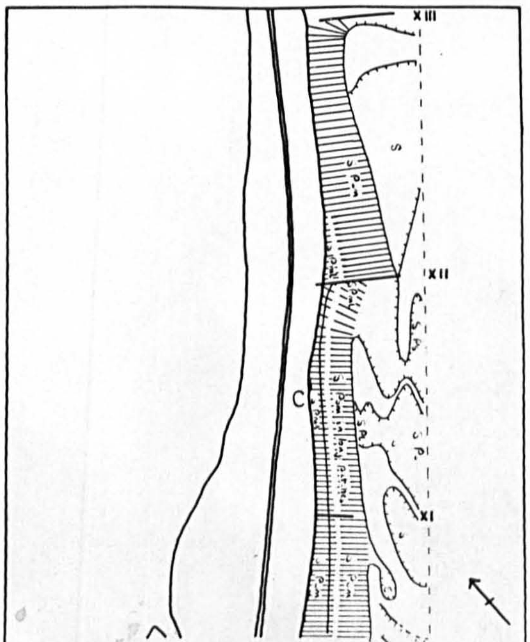
A PLAN OF BEACH FEATURES 31 · 7 · 60

SCALE 300 200 100 0 300 600 FEET



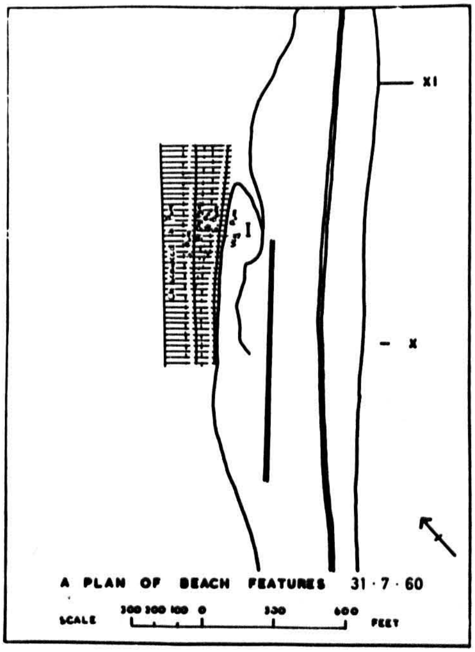
A PLAN OF BEACH FEATURES 31 · 7 · 60

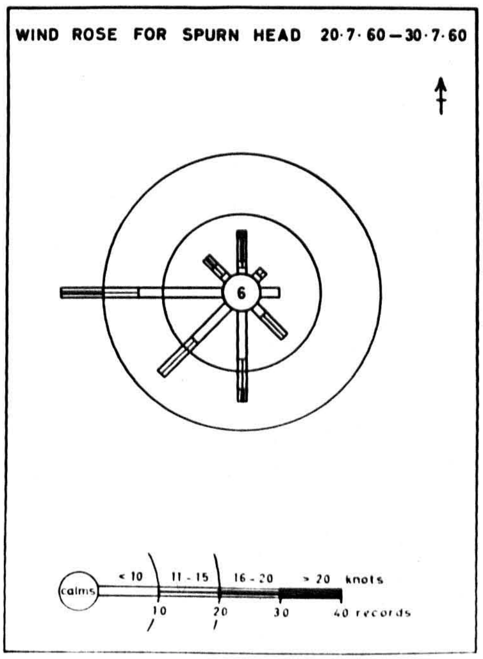
SCALE 300 200 100 0 300 600 FEET

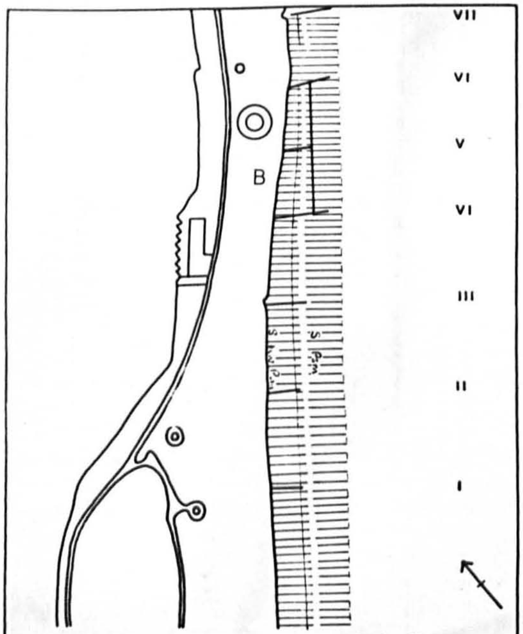


A PLAN OF BEACH FEATURES 31 · 7 · 60

SCALE 300 200 100 0 300 600 FEET

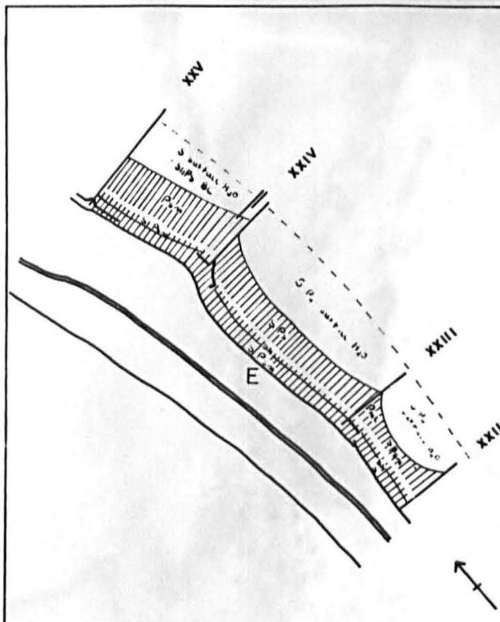

XI
X
I
A PLAN OF BEACH FEATURES 31·7·60
SCALE
300 200 100 0 300 600
FEET


WIND ROSE FOR SPURN HEAD 20·7·60—30·7·60
6
calms
< 10
11 - 15
16 - 20
> 20 knots
10
20
30
40 records



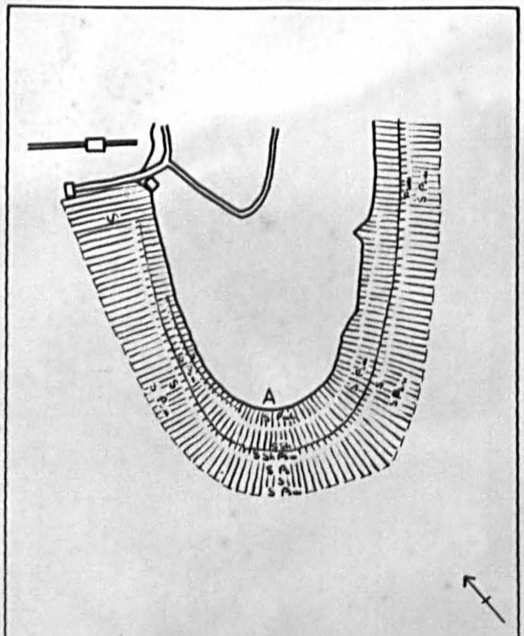
A PLAN OF BEACH FEATURES 5·8·60

SCALE 300 200 100 0 300 600 FEET



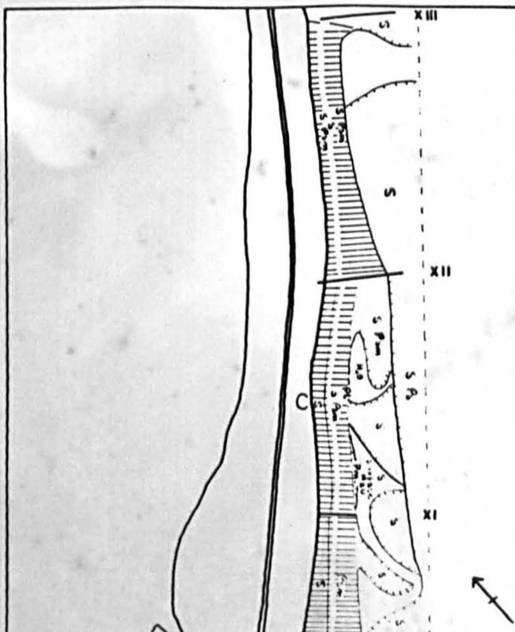
A PLAN OF BEACH FEATURES 5·8·60

SCALE 300 200 100 0 300 600 FEET



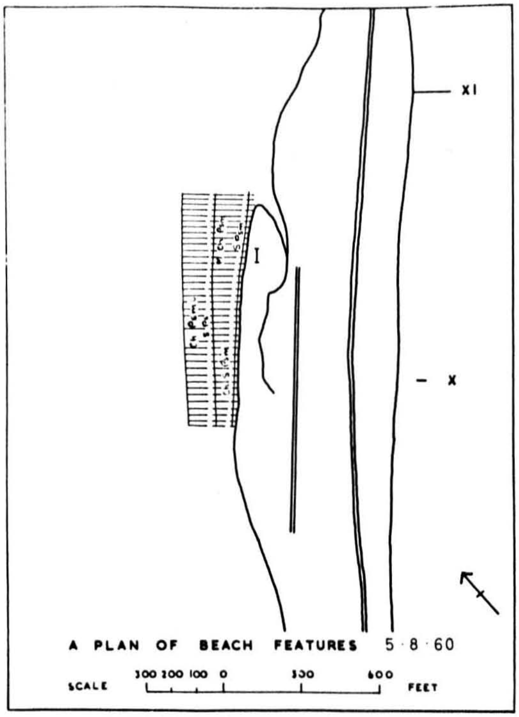
A PLAN OF BEACH FEATURES 5 8 60

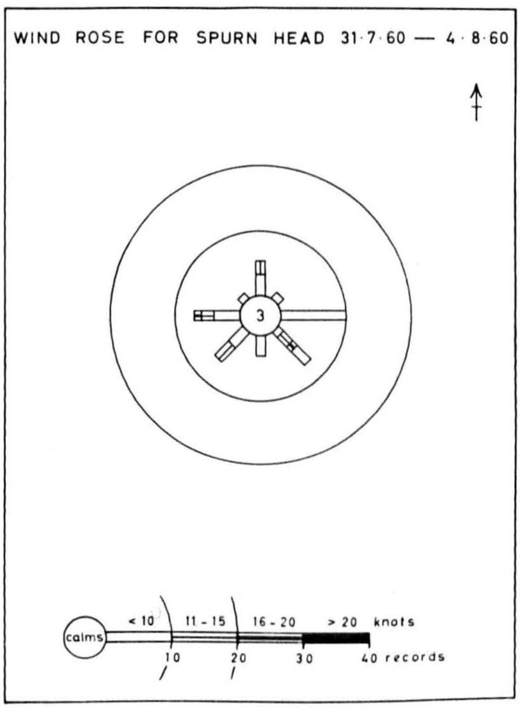
SCALE 300 200 100 0 300 600 FEET

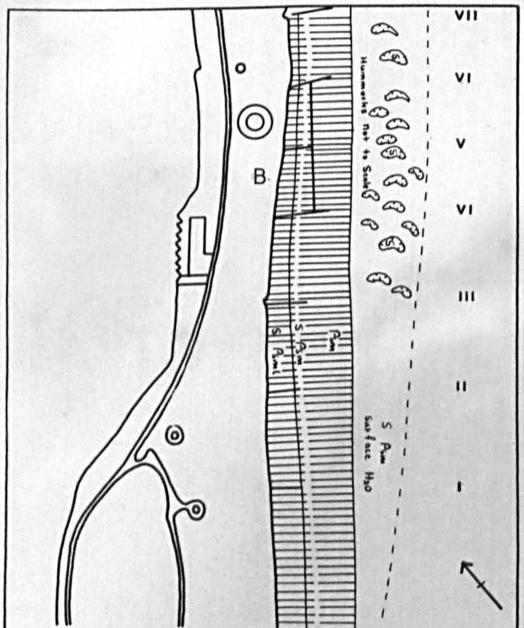


A PLAN OF BEACH FEATURES 5 8 60

SCALE 300 200 100 0 300 600 FEET

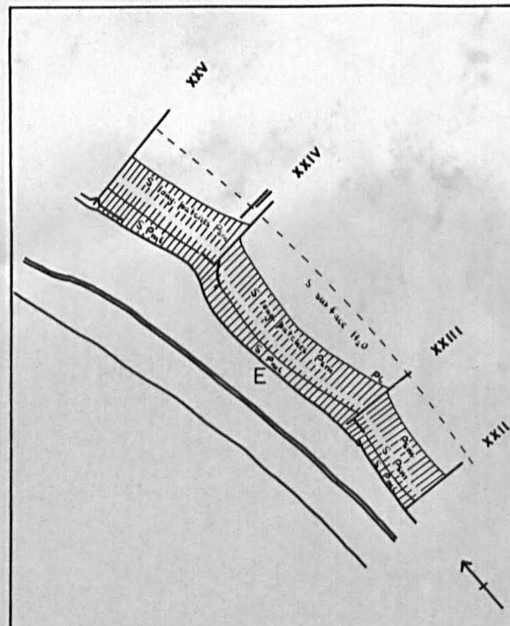

XI
I
X
A PLAN OF BEACH FEATURES 5·8·60
SCALE
300 200 100 0
300
600
FEET


WIND ROSE FOR SPURN HEAD 31·7·60 — 4·8·60
3
calms
< 10
11 - 15
16 - 20
> 20 knots
10
20
30
40 records



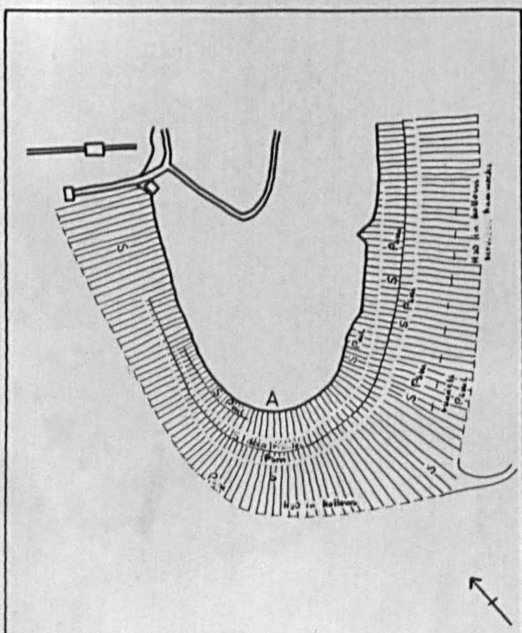
A PLAN OF BEACH FEATURES 10·8·60

SCALE 300 200 100 0 300 600 FEET



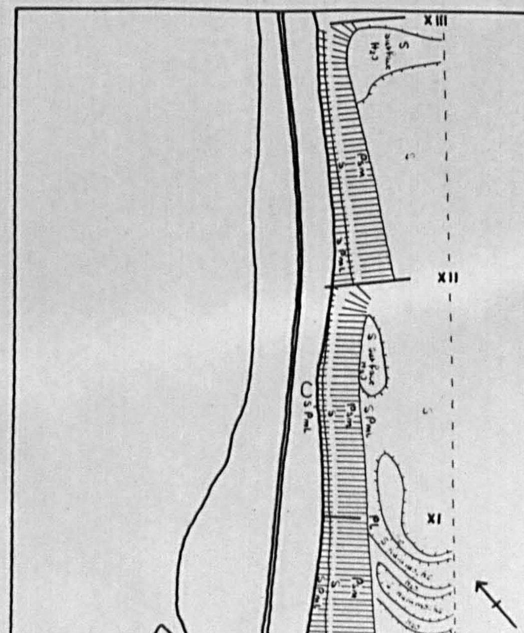
A PLAN OF BEACH FEATURES 10·8·60

SCALE 300 200 100 0 300 600 FEET



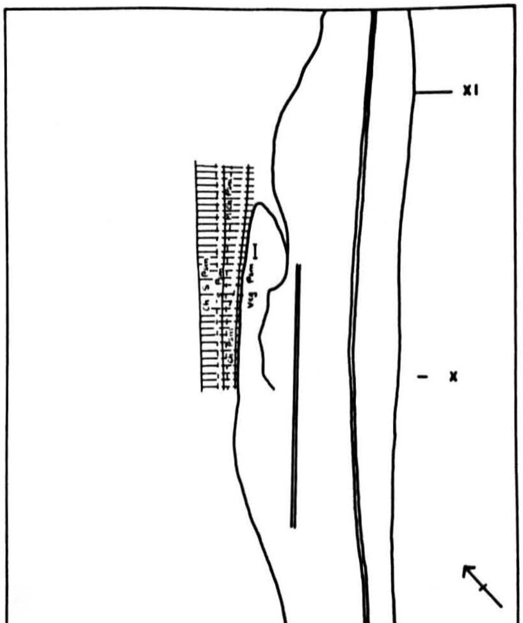
A PLAN OF BEACH FEATURES 10·8·60

SCALE 300 200 100 0 300 600 FEET



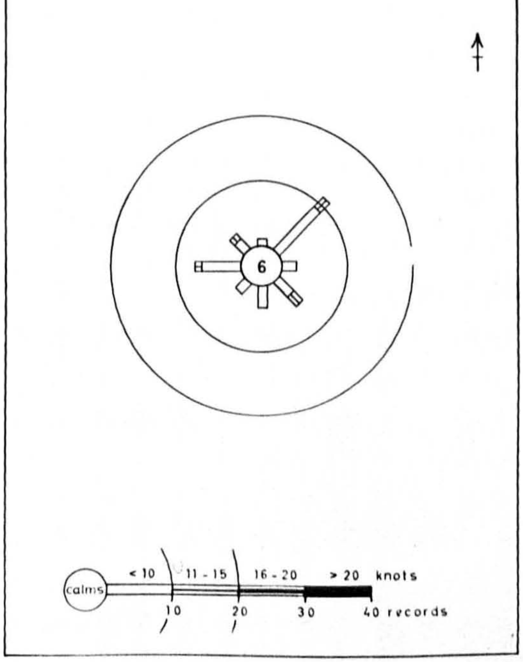
A PLAN OF BEACH FEATURES 10·8·60

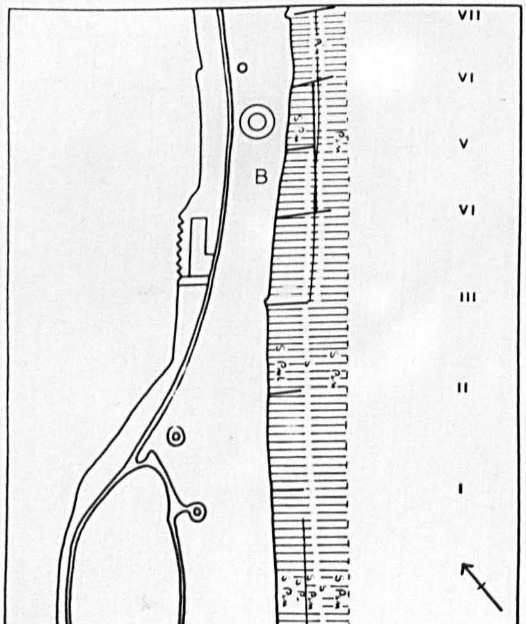
SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 10·8·60

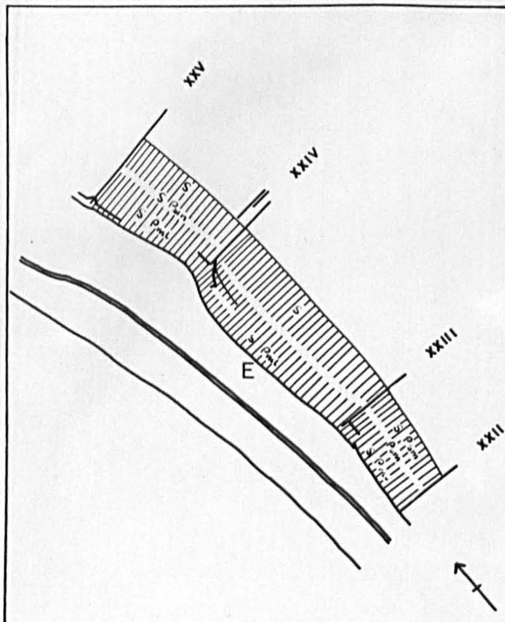
WIND ROSE FOR SPURN HEAD 5·8·60 — 9·8·60





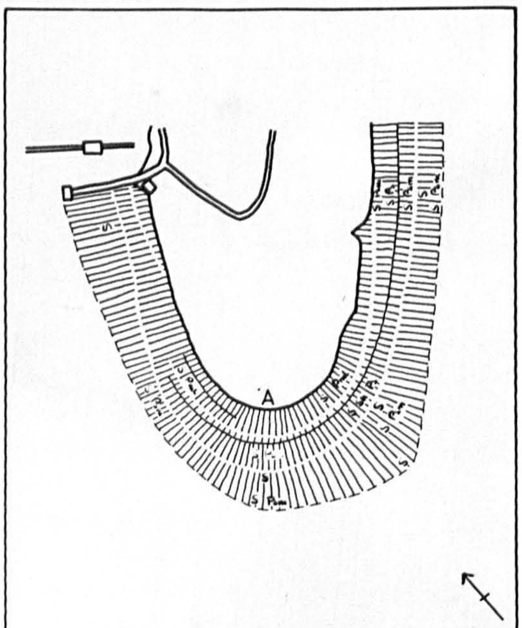
A PLAN OF BEACH FEATURES 18 · 8 · 60

SCALE 300 200 100 0 300 600 FEET



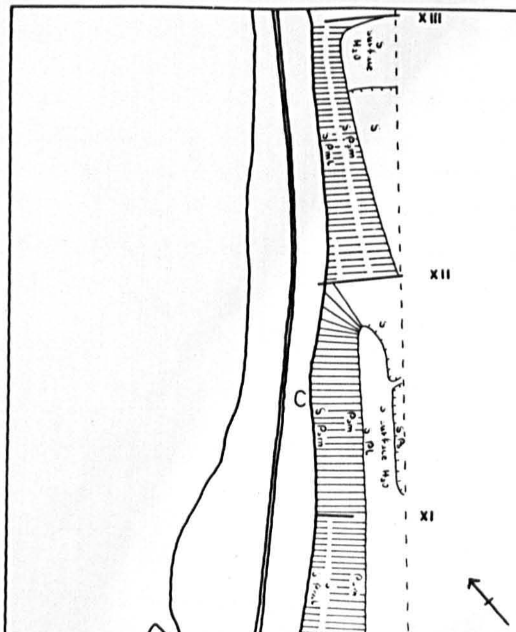
A PLAN OF BEACH FEATURES 18 · 8 · 60

SCALE 300 200 100 0 300 600 FEET



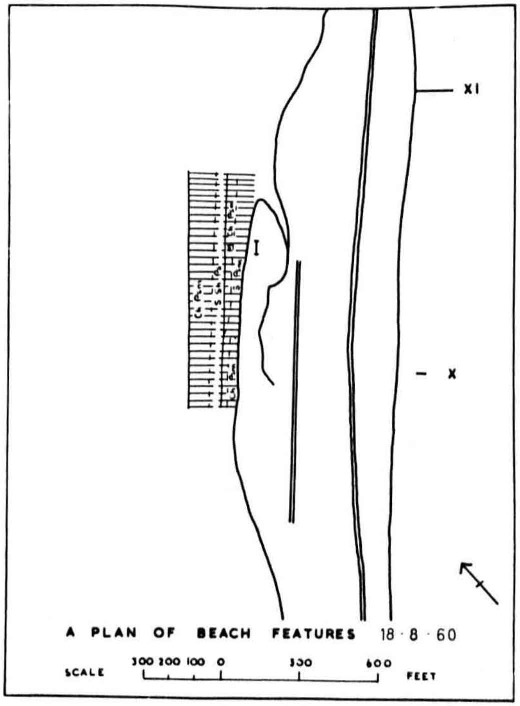
A PLAN OF BEACH FEATURES 18 · 8 · 60

SCALE 300 200 100 0 300 600 FEET



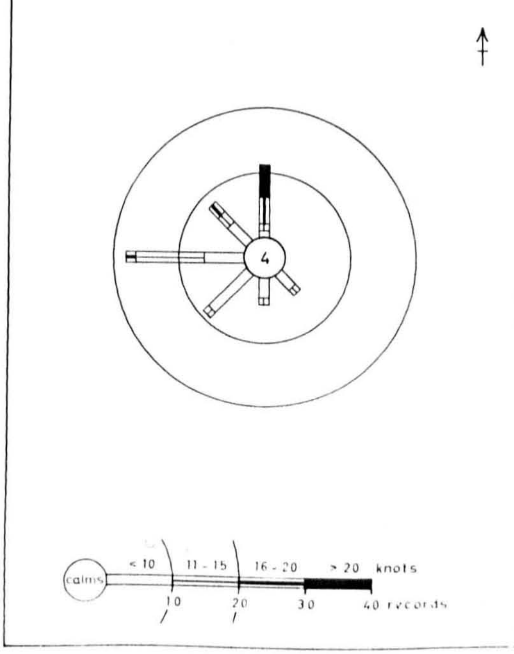
A PLAN OF BEACH FEATURES 18 · 8 · 60

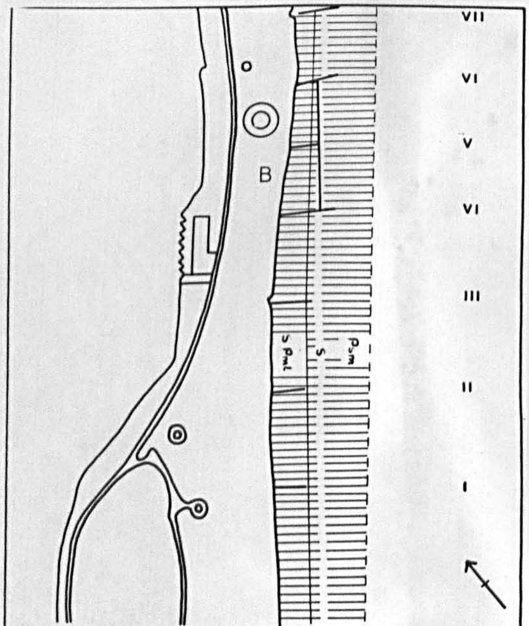
SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 18·8·60

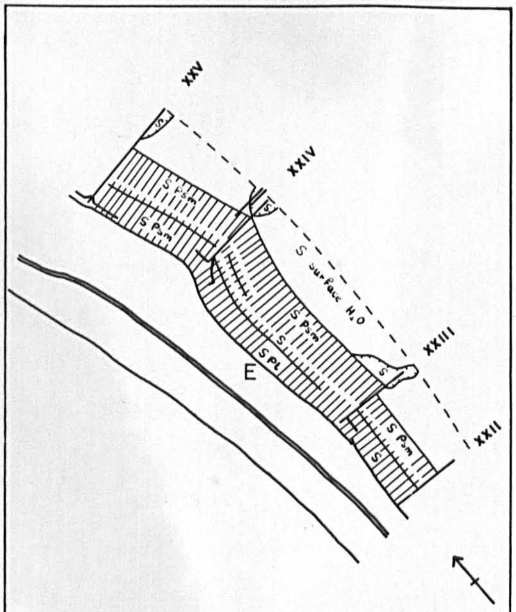
WIND ROSE FOR SPURN HEAD 10·8·60 — 17·8·60





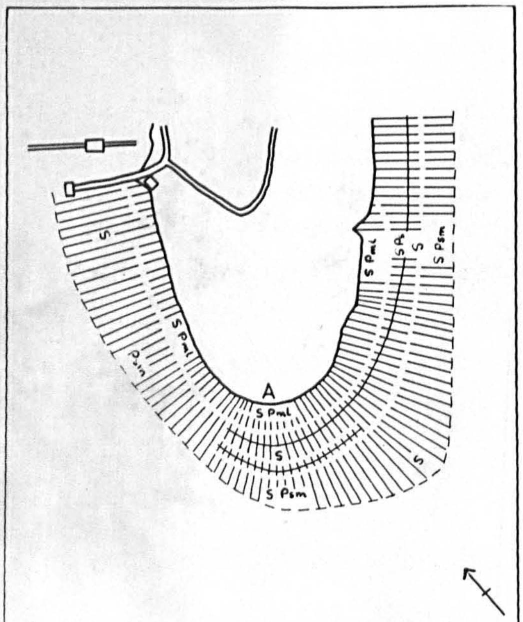
A PLAN OF BEACH FEATURES 28·8·60

SCALE 300 200 100 0 300 600 FEET



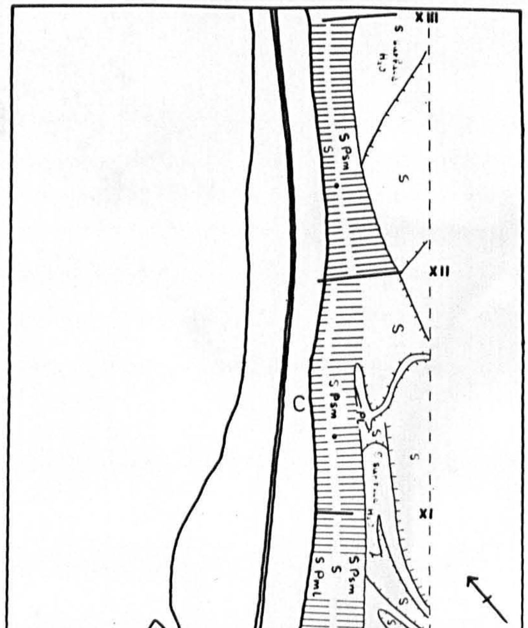
A PLAN OF BEACH FEATURES 28·8·60

SCALE 300 200 100 0 300 600 FEET



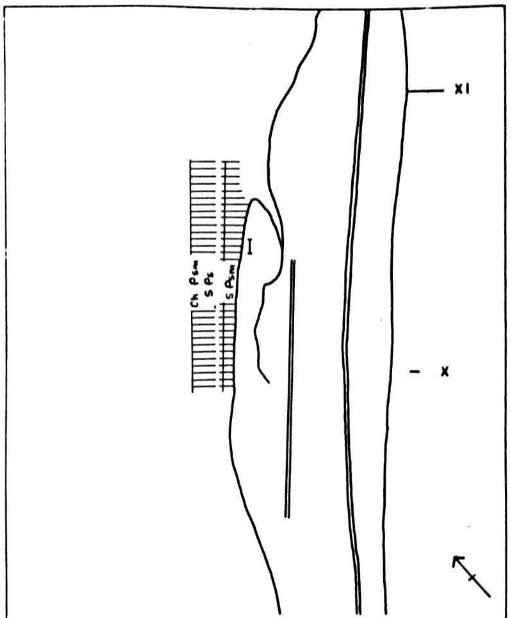
A PLAN OF BEACH FEATURES 28·8·60

SCALE 300 200 100 0 300 600 FEET



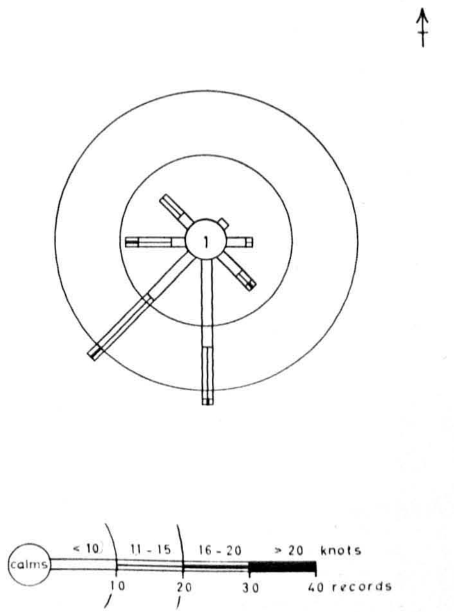
A PLAN OF BEACH FEATURES 28·8·60

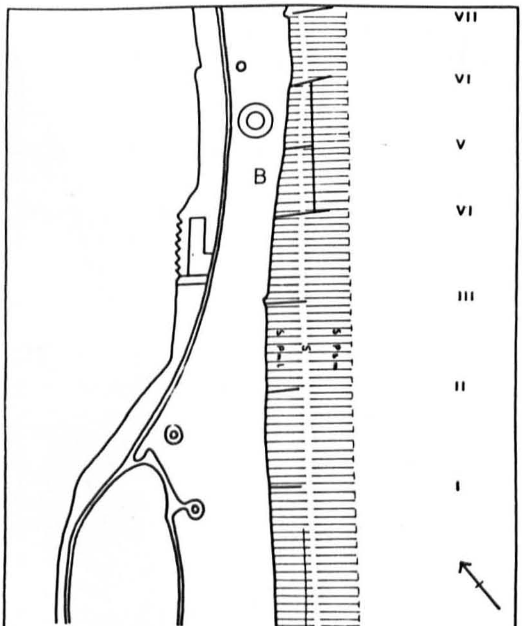
SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 28·8·60

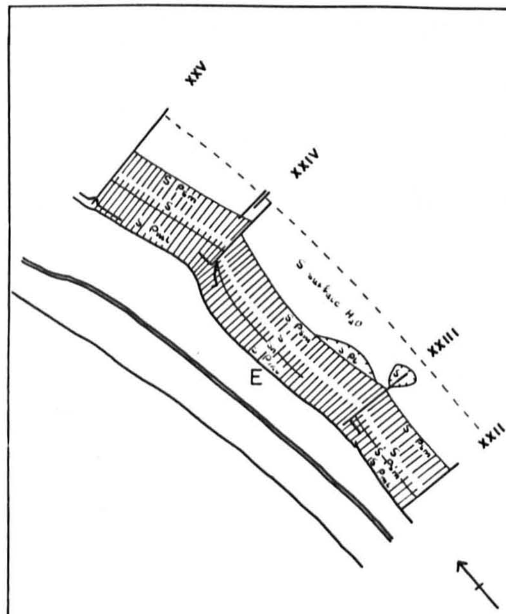
WIND ROSE FOR SPURN HEAD 18·8·60 — 26·8·60





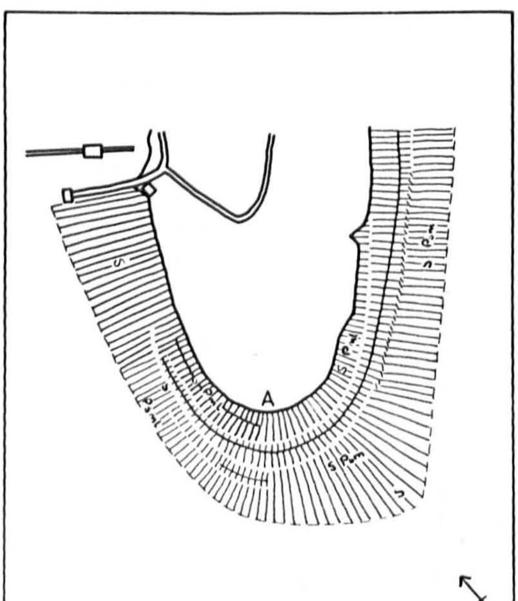
A PLAN OF BEACH FEATURES 3·9·60

SCALE 300 200 100 0 300 600 FEET



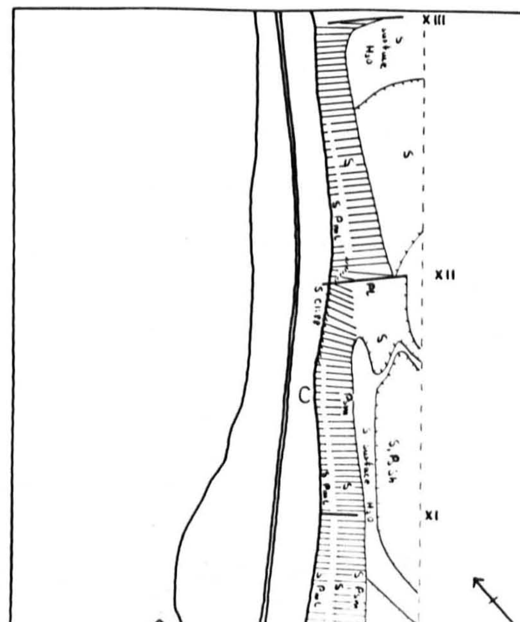
A PLAN OF BEACH FEATURES 3·9·60

SCALE 300 200 100 0 300 600 FEET



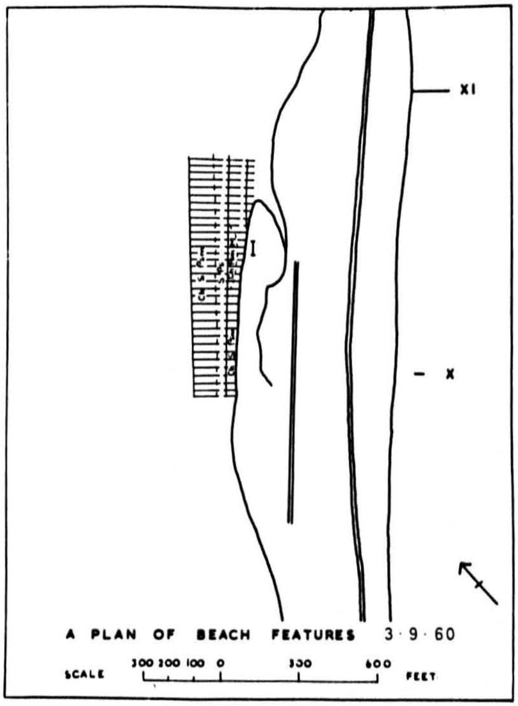
A PLAN OF BEACH FEATURES 3 9 60

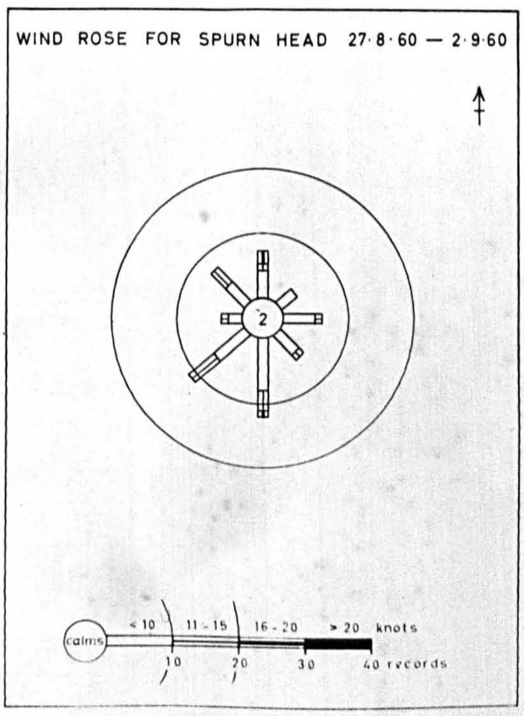
SCALE 300 200 100 0 300 600 FEET

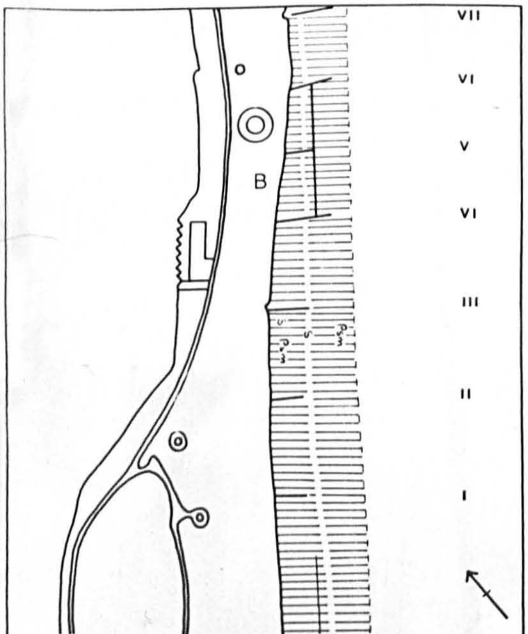


A PLAN OF BEACH FEATURES 3 9 60

SCALE 300 200 100 0 300 600 FEET

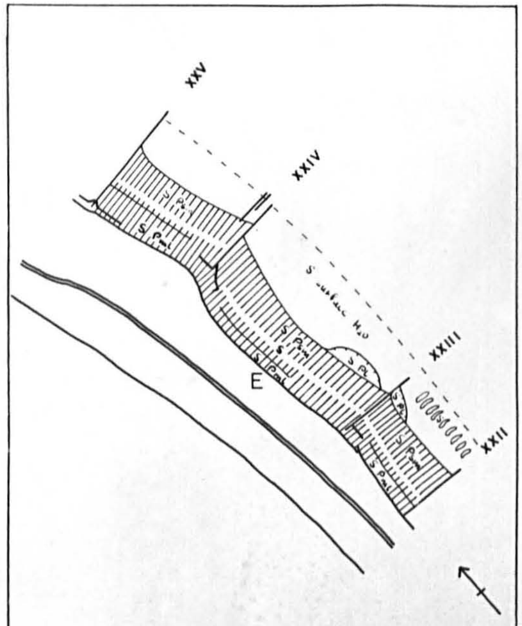

XI
I
X
A PLAN OF BEACH FEATURES 3·9·60
SCALE 300 200 100 0 300 600 FEET


WIND ROSE FOR SPURN HEAD 27·8·60 — 2·9·60
2
calms
< 10
11 - 15
16 - 20
> 20 knots
10
20
30
40 records



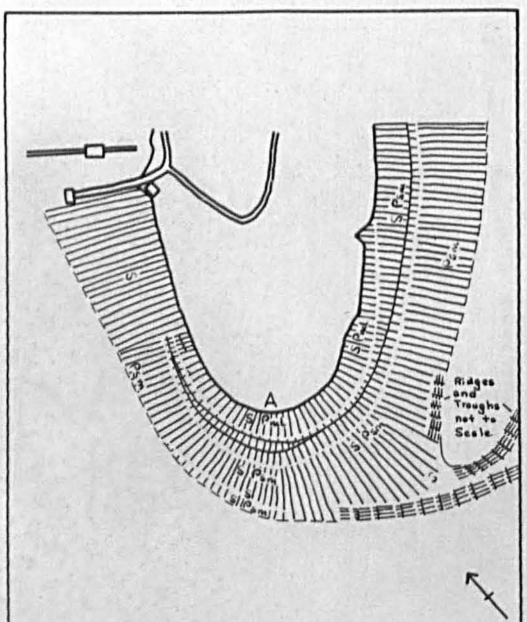
A PLAN OF BEACH FEATURES 7·9·60

SCALE 300 200 100 0 300 600 FEET



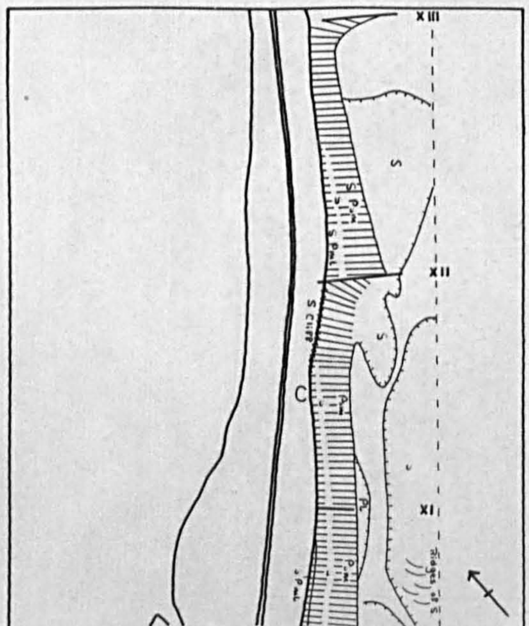
A PLAN OF BEACH FEATURES 7·9·60

SCALE 300 200 100 0 300 600 FEET



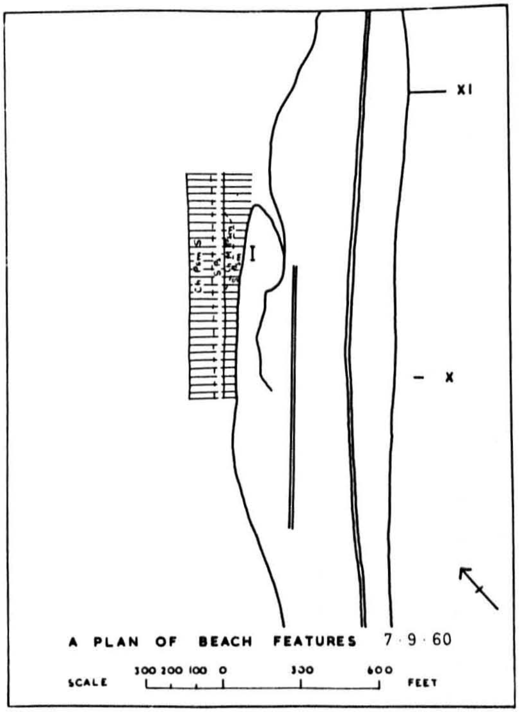
A PLAN OF BEACH FEATURES 7·9·60

SCALE 300 200 100 0 300 600 FEET

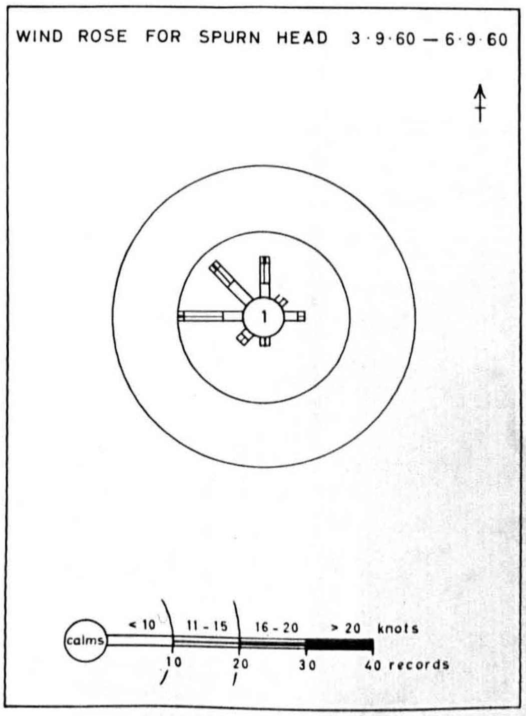


A PLAN OF BEACH FEATURES 7·9·60

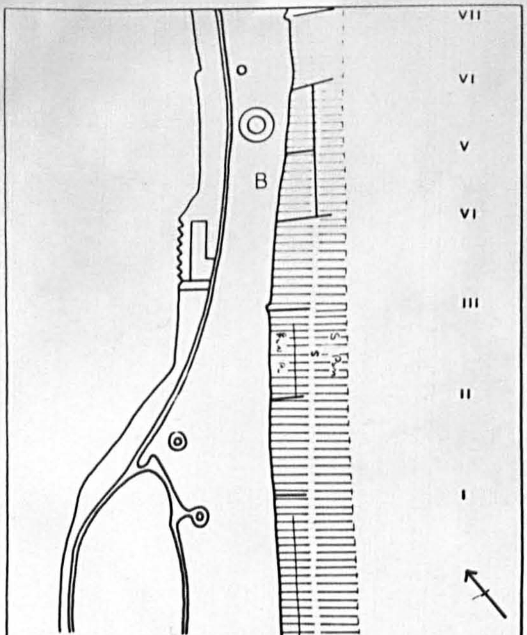
SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 7·9·60

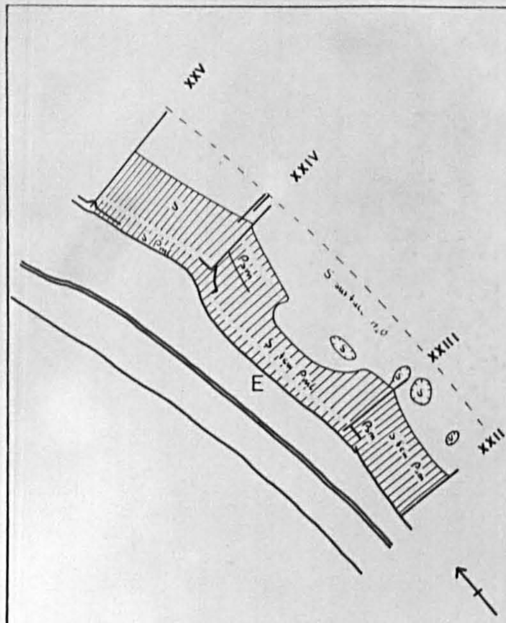


WIND ROSE FOR SPURN HEAD 3·9·60 — 6·9·60



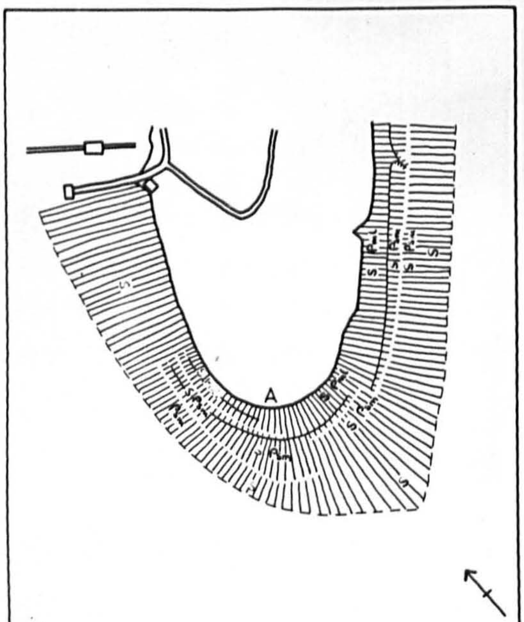
A PLAN OF BEACH FEATURES 21·9·60

SCALE 300 200 100 0 300 600 FEET



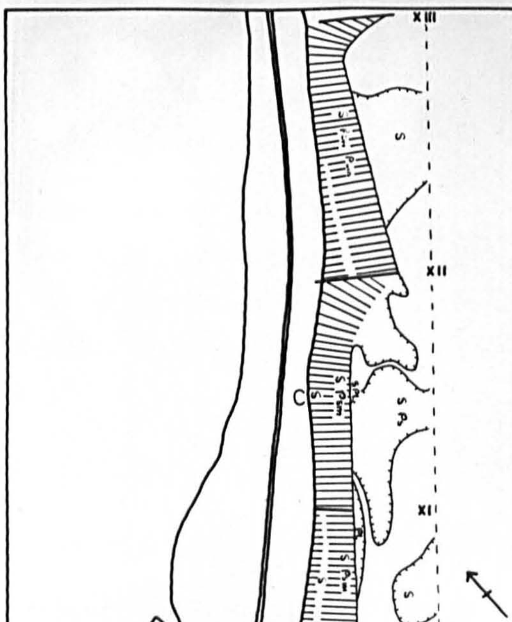
A PLAN OF BEACH FEATURES 21·9·60

SCALE 300 200 100 0 300 600 FEET



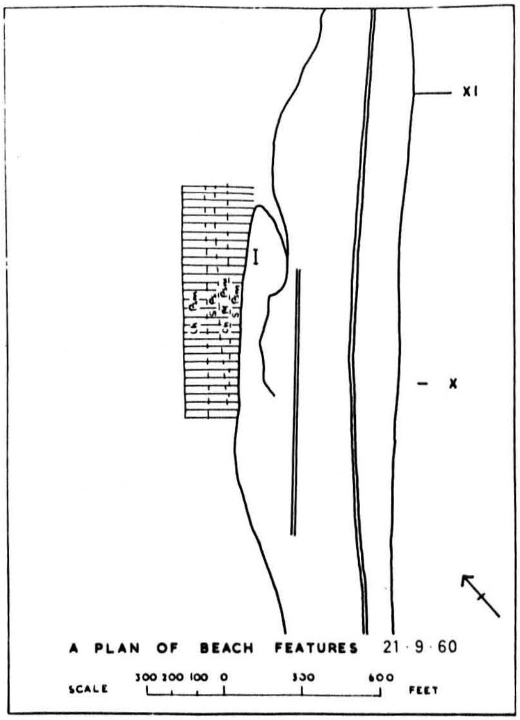
A PLAN OF BEACH FEATURES 21·9·60

SCALE 300 200 100 0 300 600 FEET

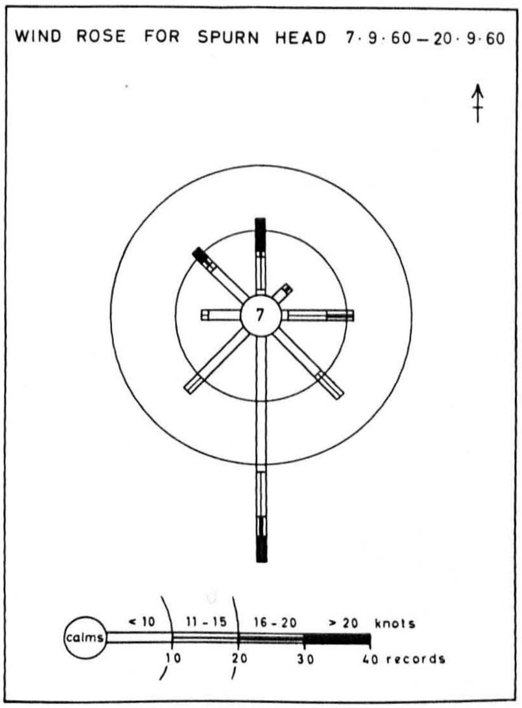


A PLAN OF BEACH FEATURES 21·9·60

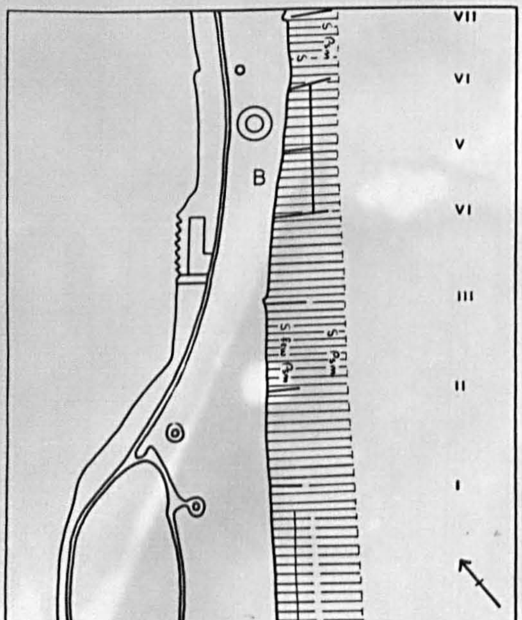
SCALE 300 200 100 0 300 600 FEET



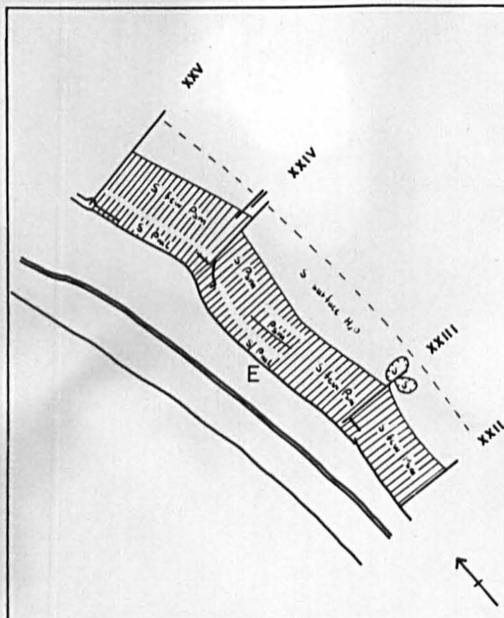
A PLAN OF BEACH FEATURES 21·9·60



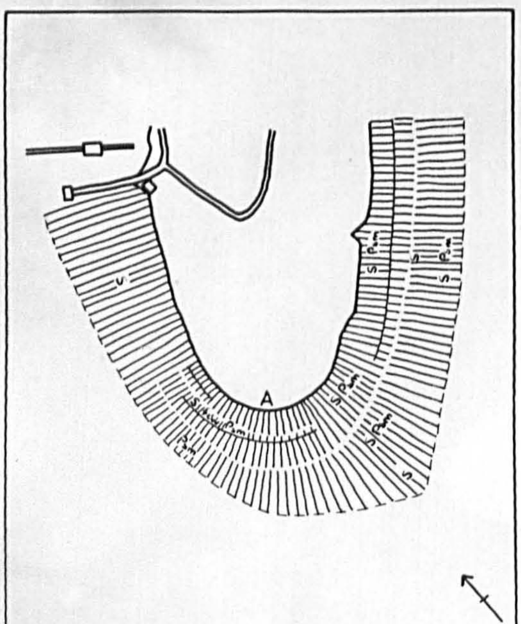
WIND ROSE FOR SPURN HEAD 7·9·60 – 20·9·60



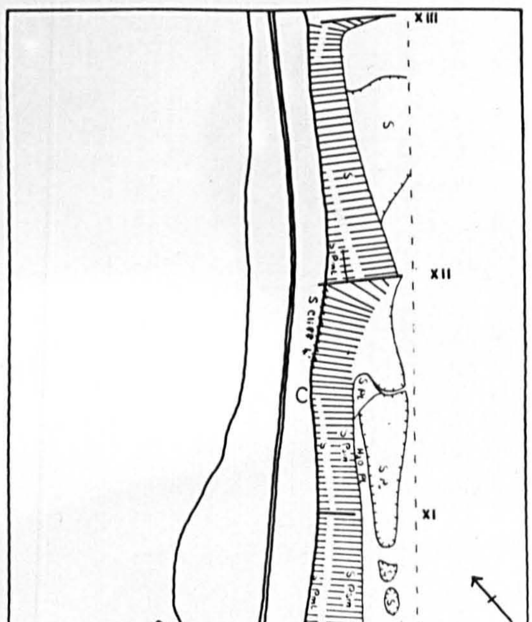
A PLAN OF BEACH FEATURES 27·9·60



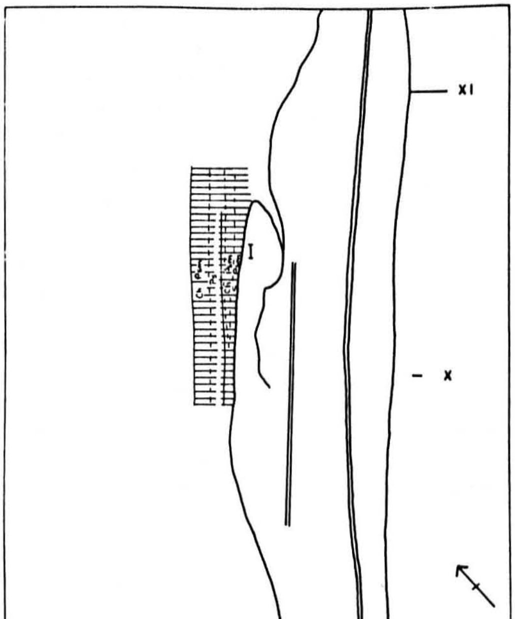
A PLAN OF BEACH FEATURES 27·9·60



A PLAN OF BEACH FEATURES 27 9 60

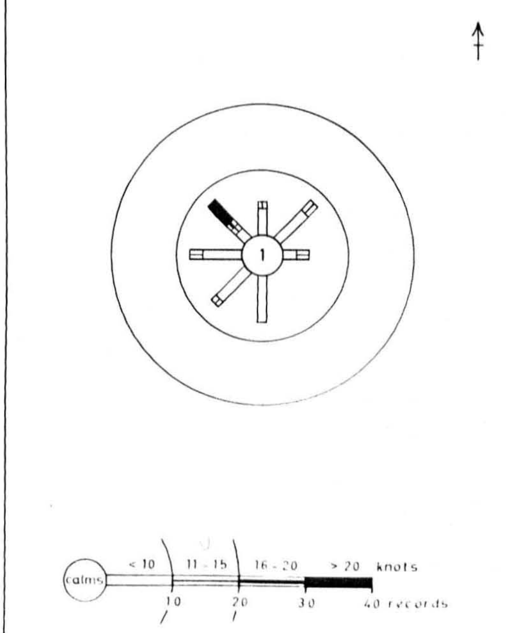


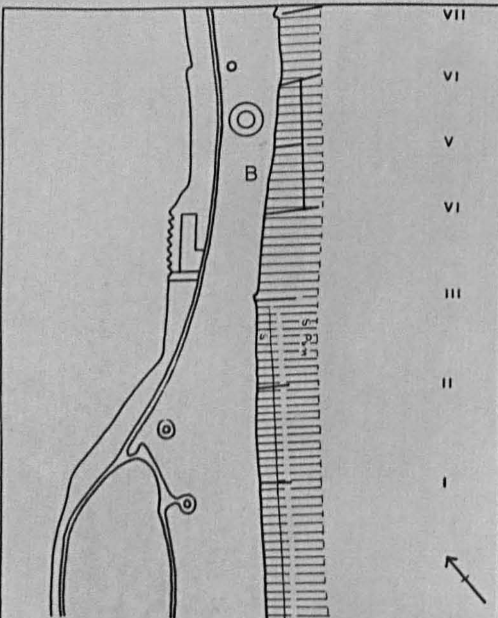
A PLAN OF BEACH FEATURES 27 9 60



A PLAN OF BEACH FEATURES 27·9·60

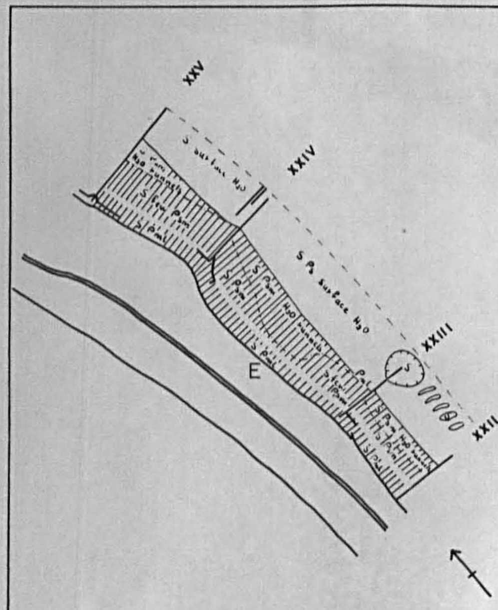
WIND ROSE FOR SPURN HEAD 21·9·60 — 26·9·60





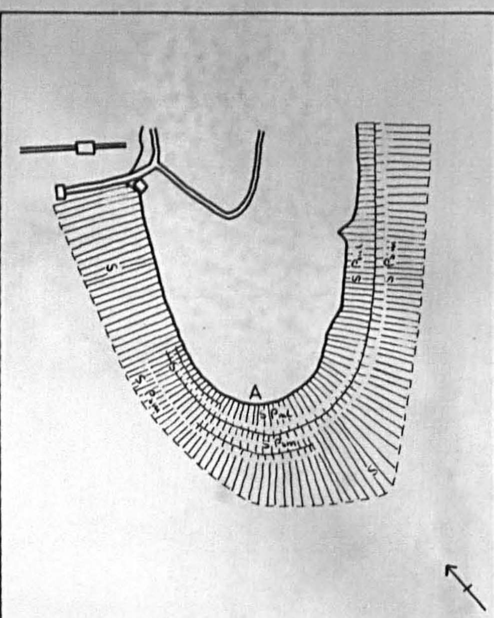
A PLAN OF BEACH FEATURES 7·10·60

SCALE 300 200 100 0 300 600 FEET



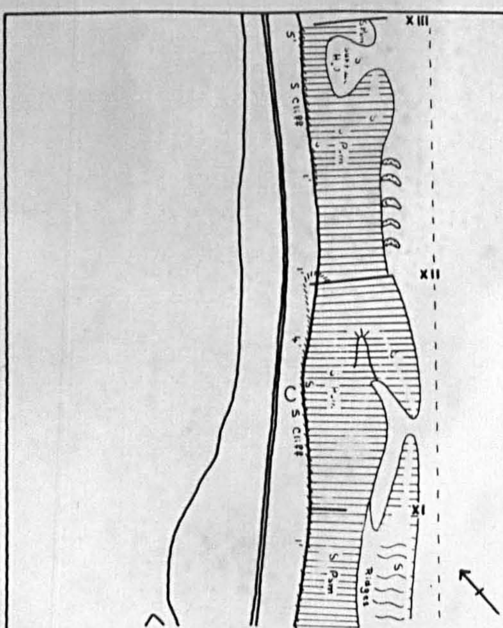
A PLAN OF BEACH FEATURES 7·10·60

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 7·10·60

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 7·10·60

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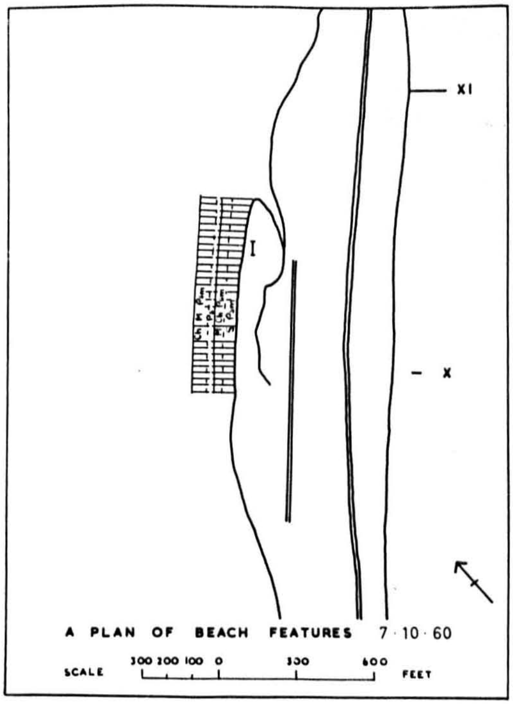
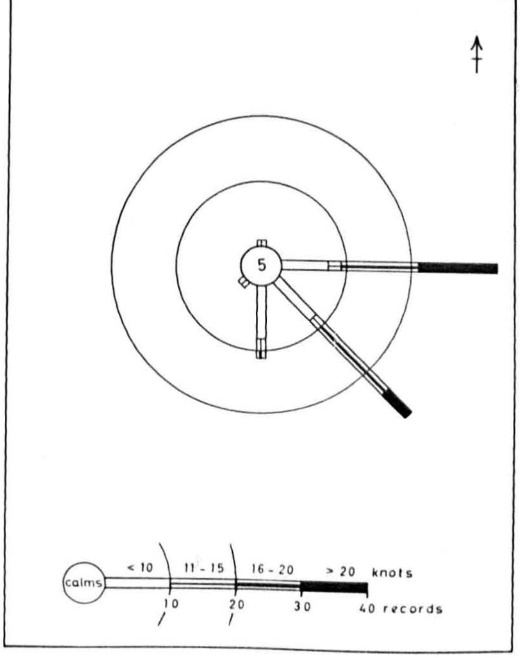
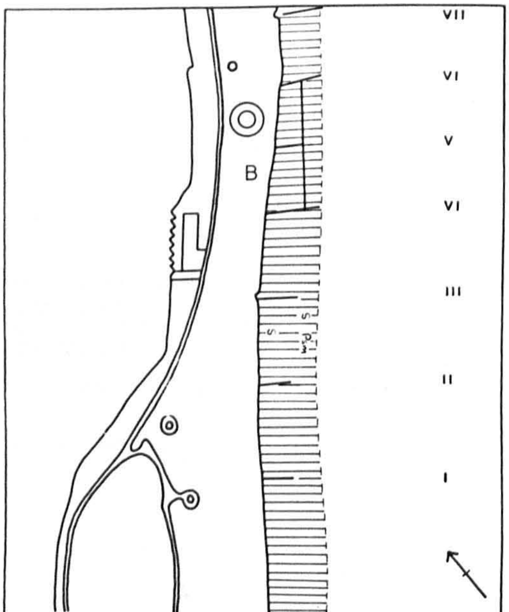


A PLAN OF BEACH FEATURES 7·10·60

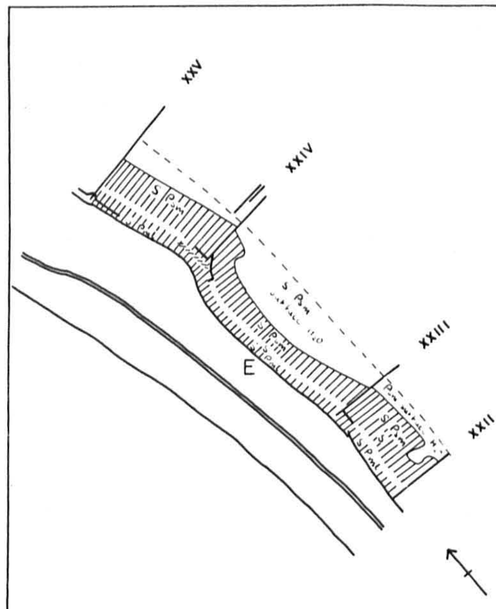
WIND ROSE FOR SPURN HEAD 27·9·60 — 6·10·60





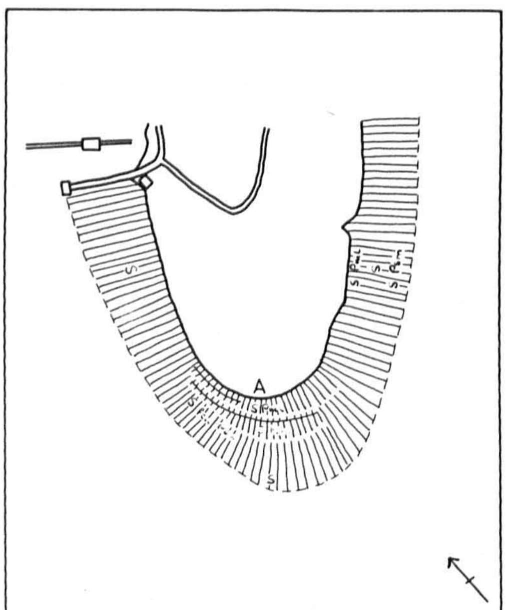
A PLAN OF BEACH FEATURES 12·10·60

SCALE 300 200 100 0 300 600 FEET



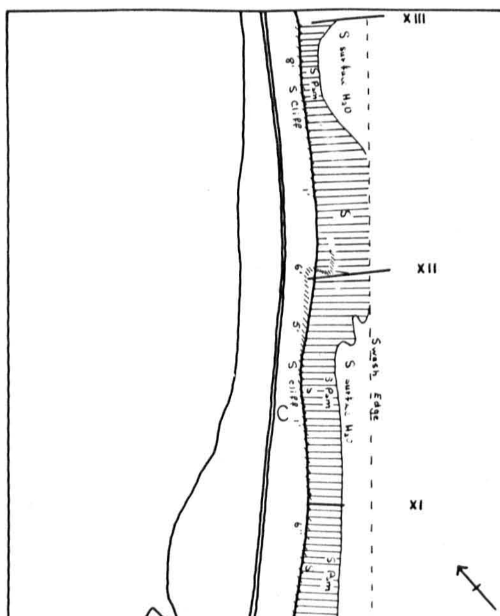
A PLAN OF BEACH FEATURES 12·10·60

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 12·10·60

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 12·10·60

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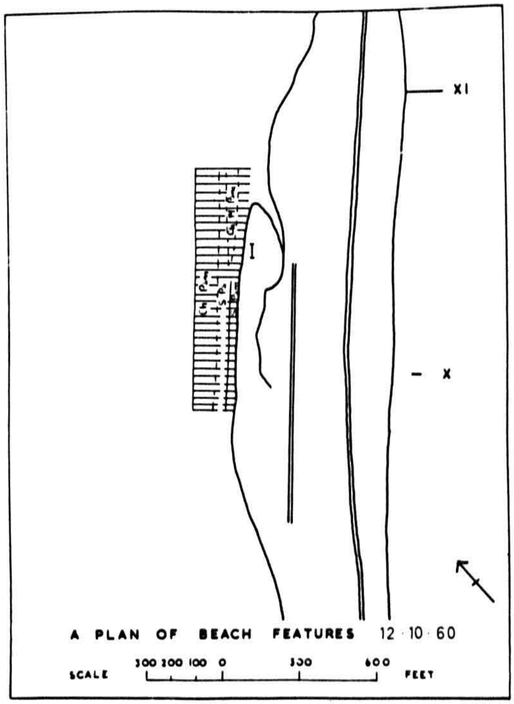
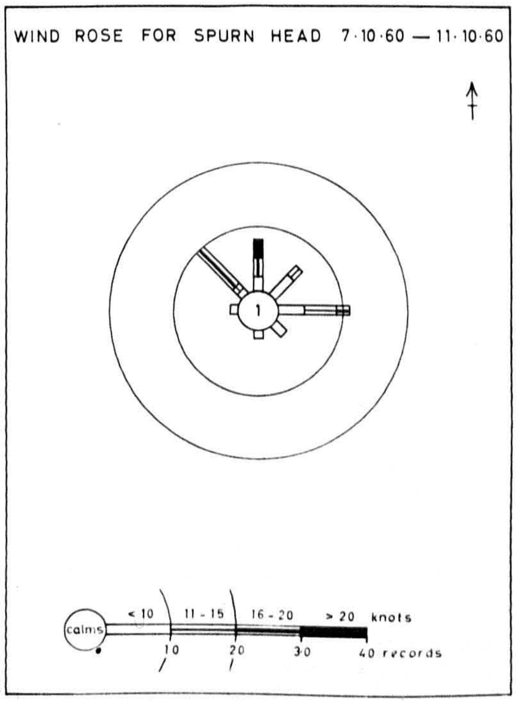
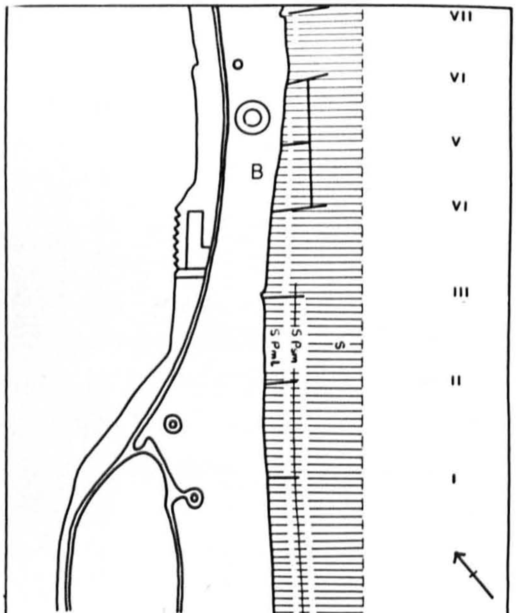


A PLAN OF BEACH FEATURES 12·10·60

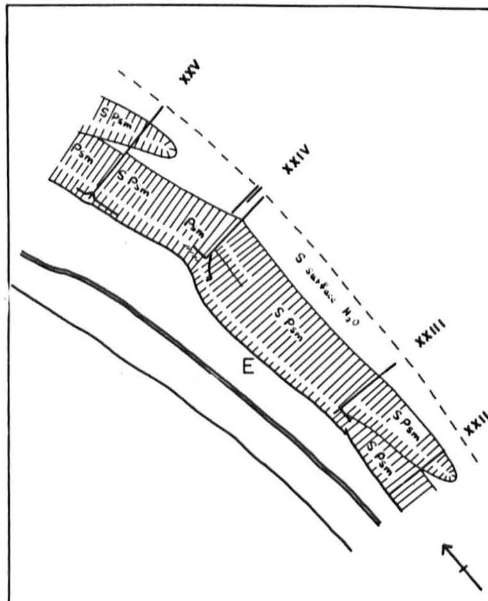


WIND ROSE FOR SPURN HEAD 7·10·60 — 11·10·60



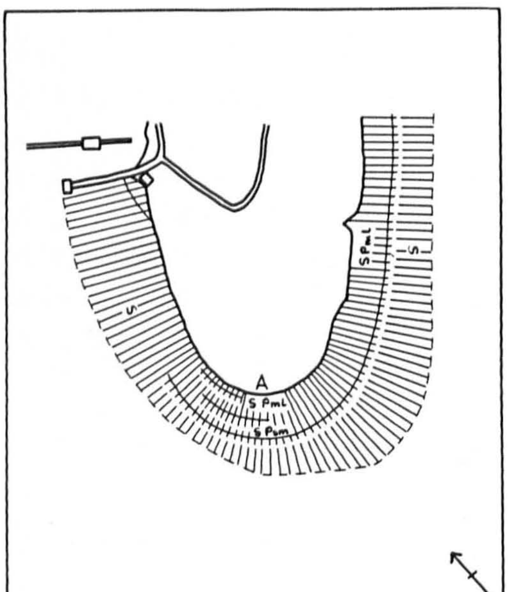
A PLAN OF BEACH FEATURES 22·10·60

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 22·10·60

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 22·10·60

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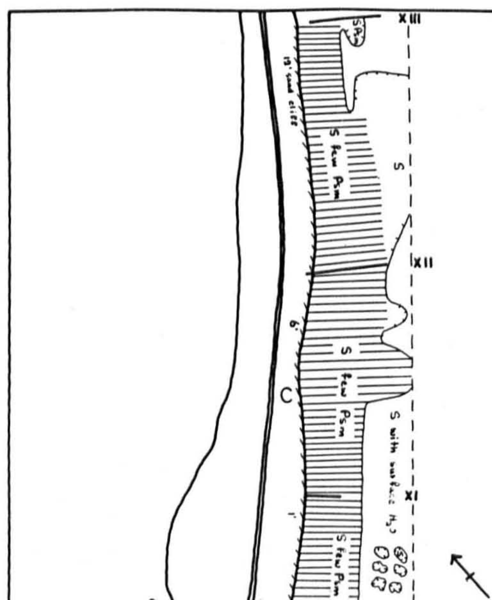
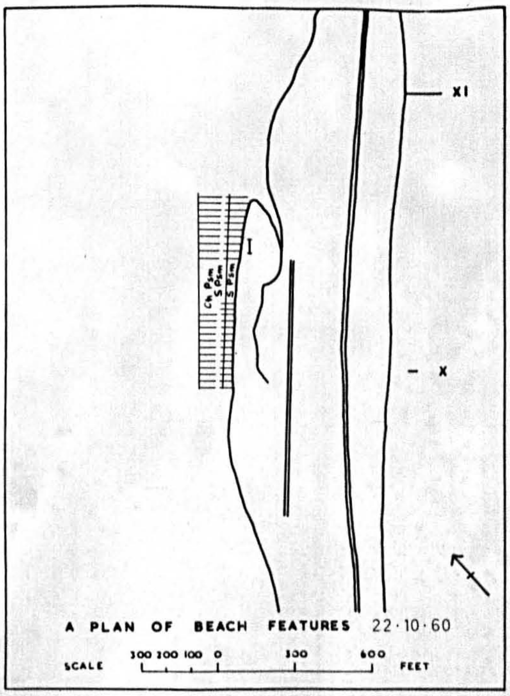
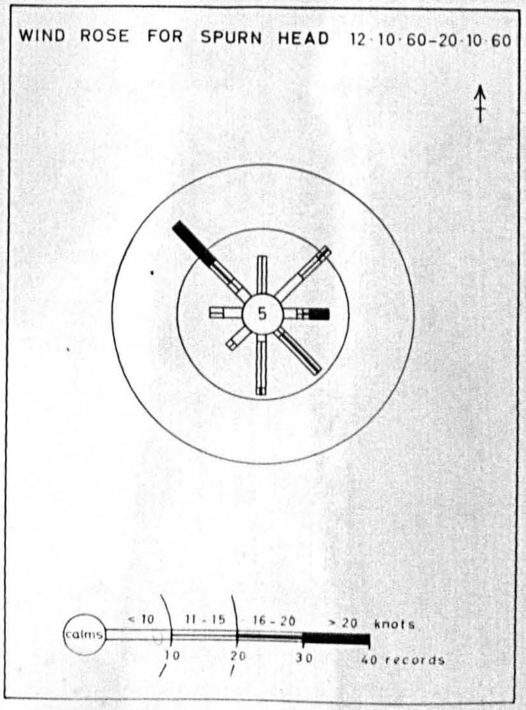
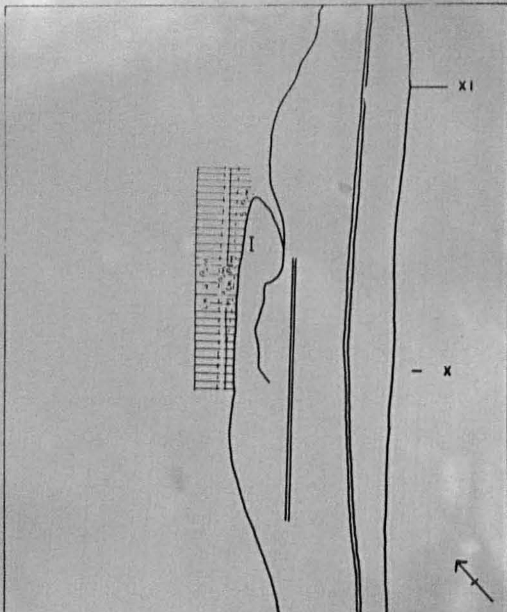


A PLAN OF BEACH FEATURES 22·10·60

SCALE 300 200 100 0 300 600 FEET

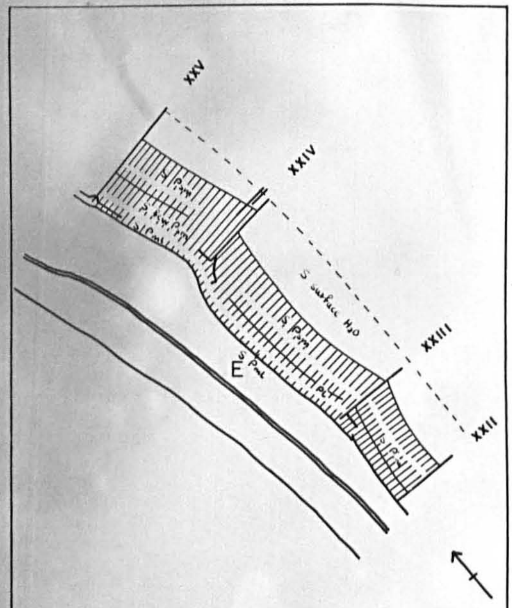

XI
I
Ch Psm
S Psm
S Psm
X
A PLAN OF BEACH FEATURES 22·10·60
SCALE 300 200 100 0 300 600 FEET


WIND ROSE FOR SPURN HEAD 12·10·60–20·10·60
5
calms
< 10
11 - 15
16 - 20
> 20 knots
10
20
30
40 records



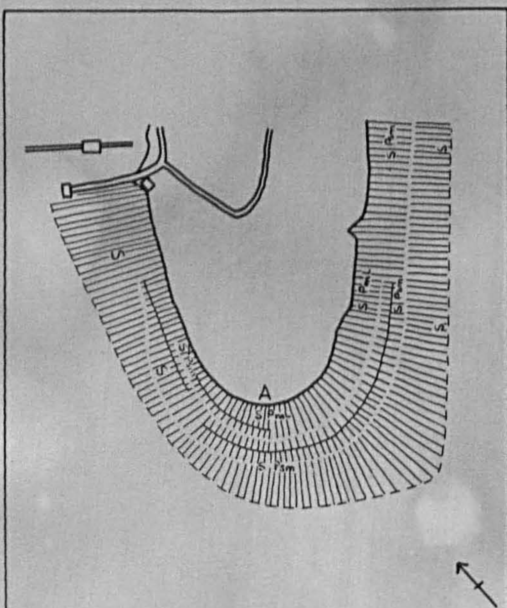
A PLAN OF BEACH FEATURES 26·10·60

SCALE 300 200 100 0 300 600 FEET



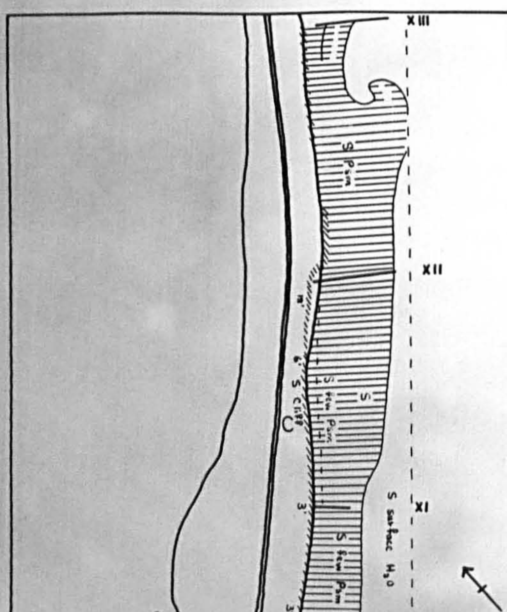
A PLAN OF BEACH FEATURES 26·10·60

SCALE 300 200 100 0 300 600 FEET



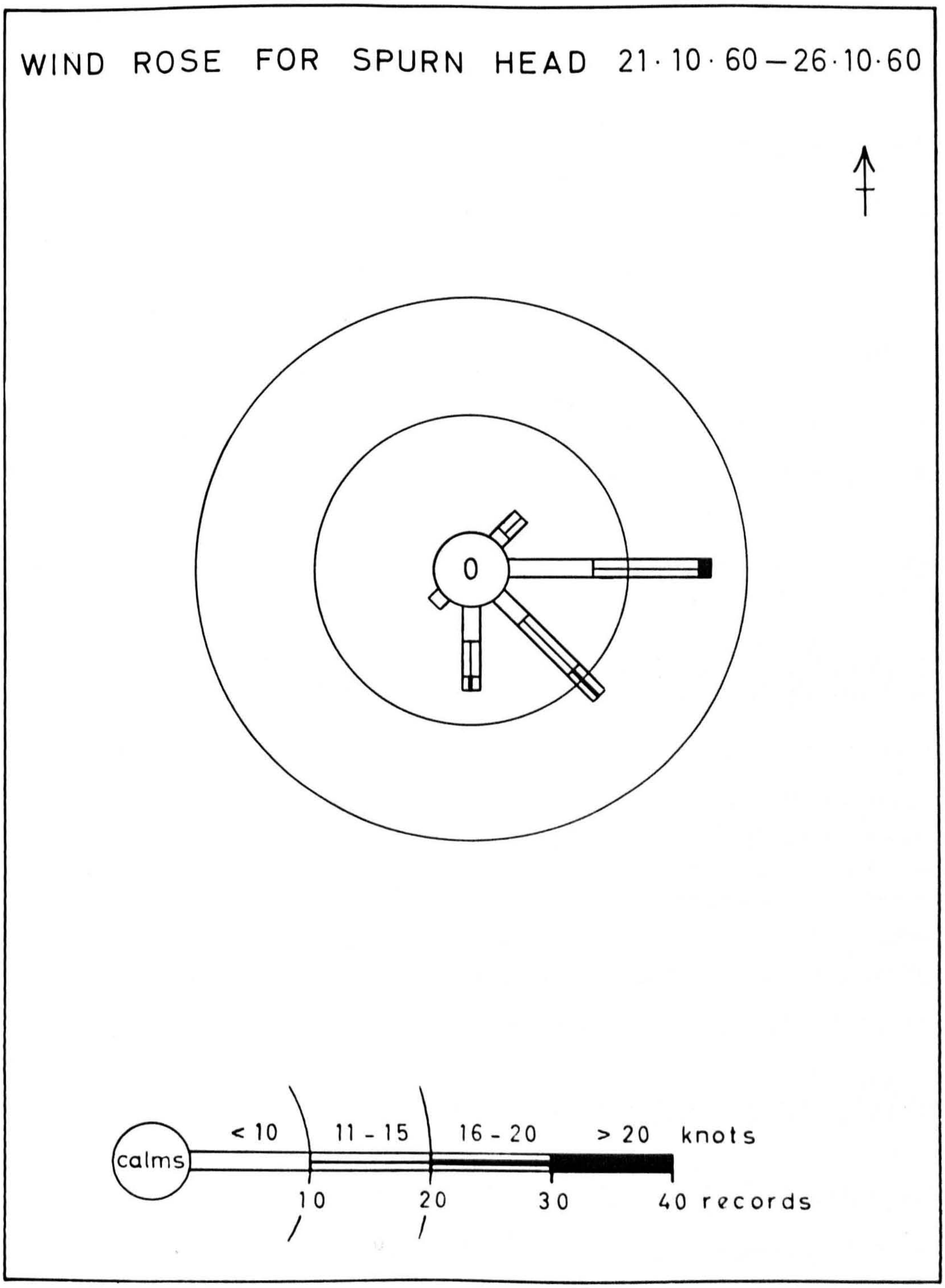
A PLAN OF BEACH FEATURES 26·10·60

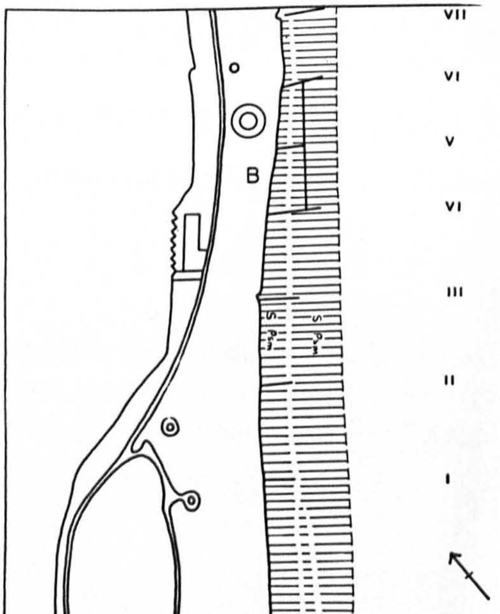
SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 26·10·60

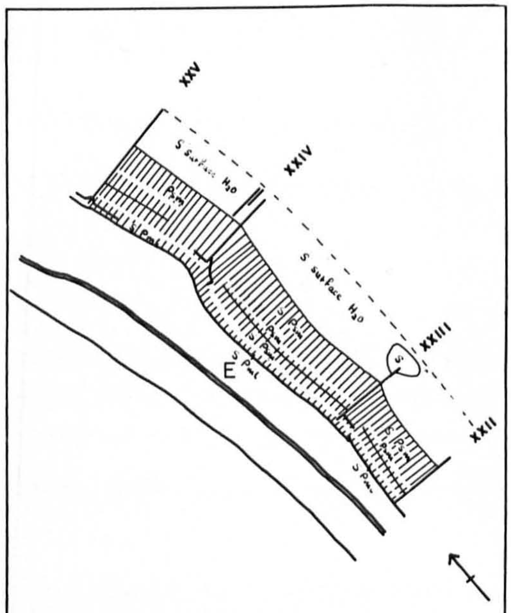
SCALE 300 200 100 0 300 600 FEET


WIND ROSE FOR SPURN HEAD 21·10·60—26·10·60
0
calms
< 10
11 - 15
16 - 20
> 20 knots
10
20
30
40 records



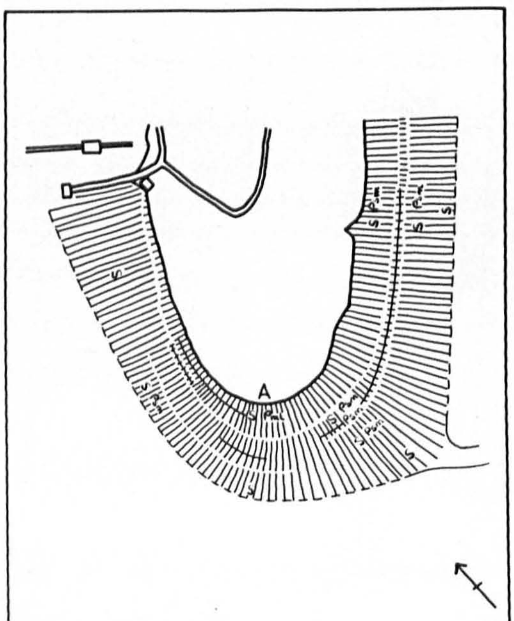
A PLAN OF BEACH FEATURES 4 · 11 · 60

SCALE 300 200 100 0 300 600 FEET



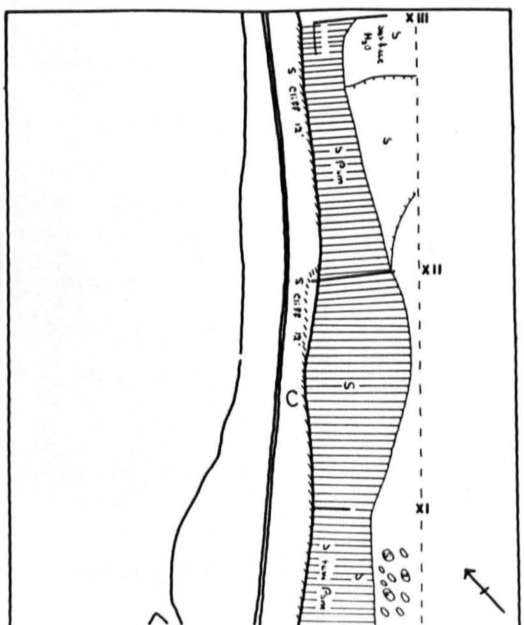
A PLAN OF BEACH FEATURES 4 · 11 · 60

SCALE 300 200 100 0 300 600 FEET



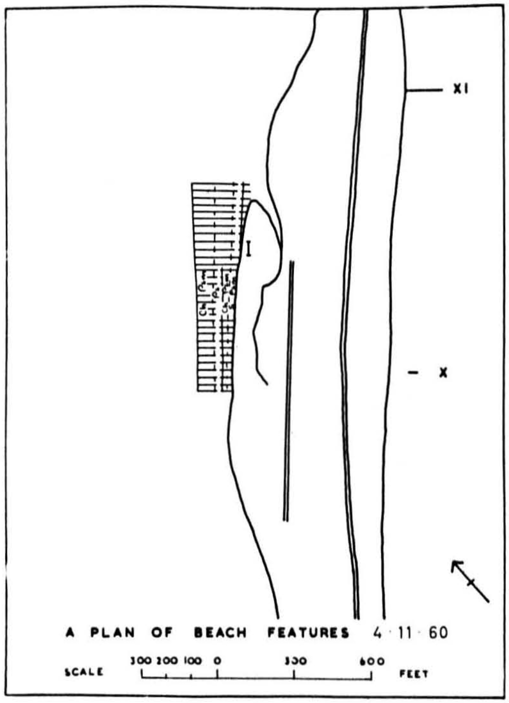
A PLAN OF BEACH FEATURES 4 · 11 · 60

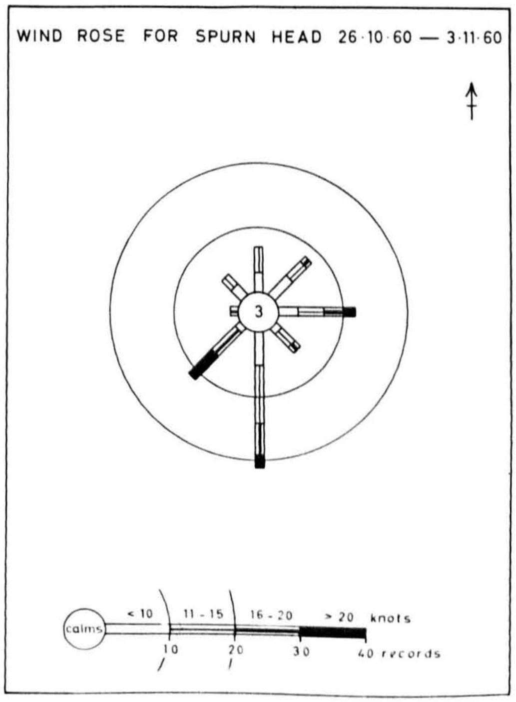
SCALE 300 200 100 0 300 600 FEET

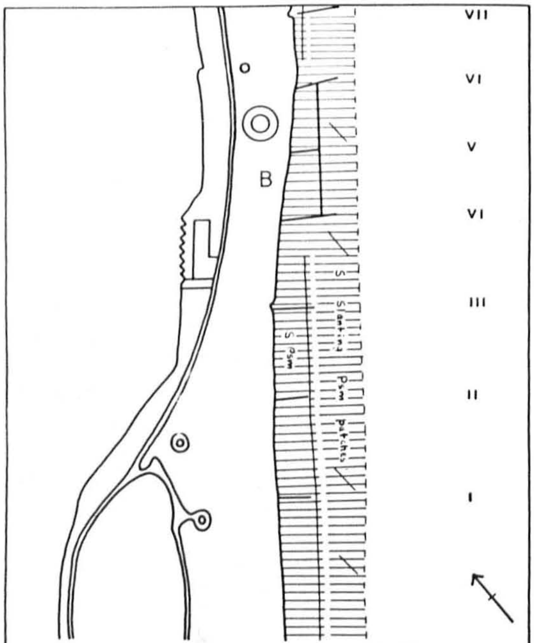


A PLAN OF BEACH FEATURES 4 · 11 · 60

SCALE 300 200 100 0 300 600 FEET

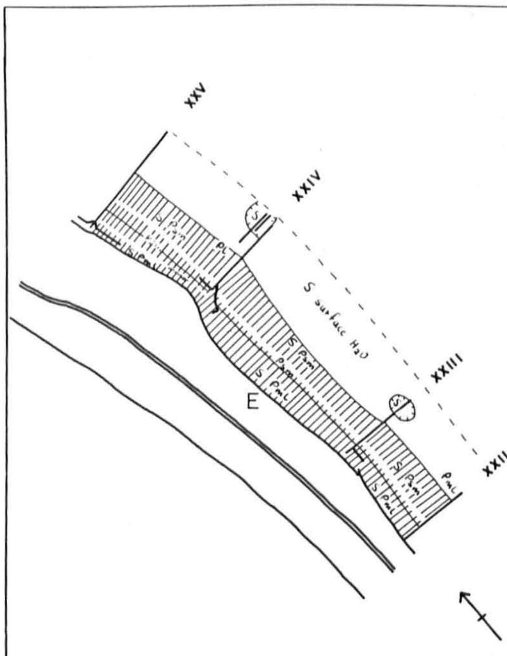

XI
I
X
A PLAN OF BEACH FEATURES 4·11·60
SCALE
300 200 100 0
300
600
FEET


WIND ROSE FOR SPURN HEAD 26·10·60 — 3·11·60
3
calms
< 10
11 - 15
16 - 20
> 20 knots
10
20
30
40 records



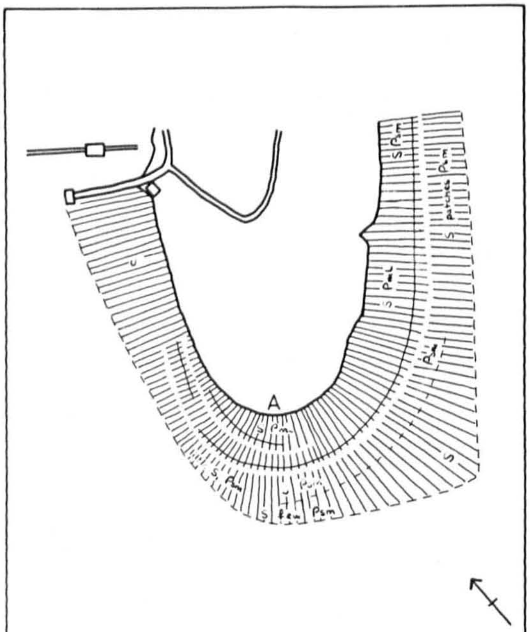
A PLAN OF BEACH FEATURES 18 · 11 · 60

SCALE 300 200 100 0 300 600 FEET



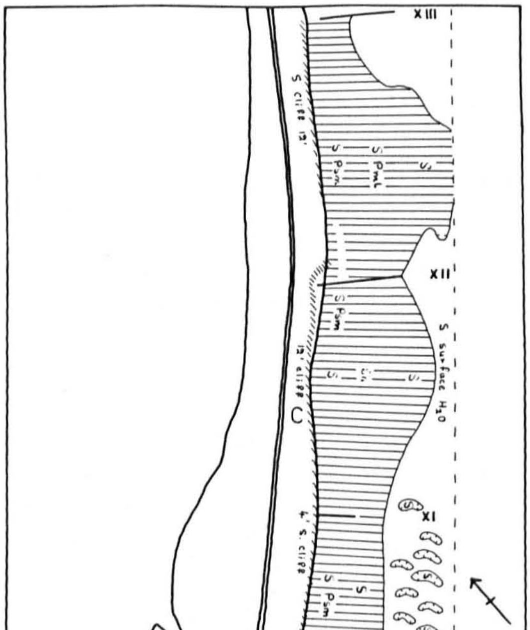
A PLAN OF BEACH FEATURES 18 · 11 · 60

SCALE 300 200 100 0 300 600 FEET



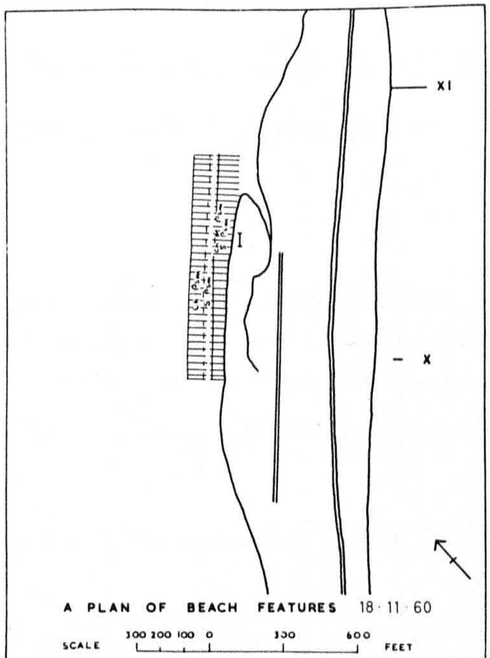
A PLAN OF BEACH FEATURES 18 · 11 · 60

SCALE 300 200 100 0 300 600 FEET



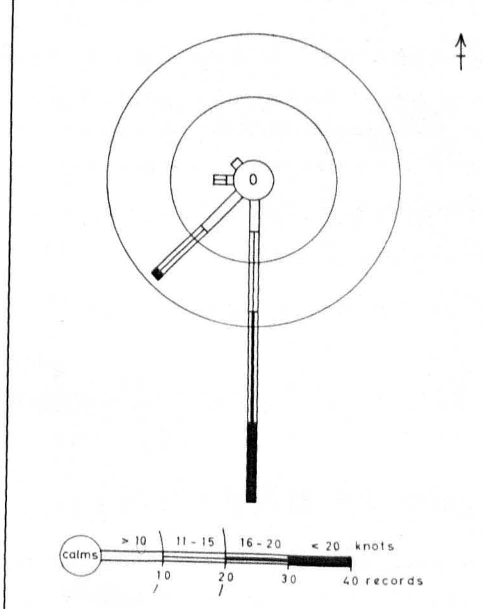
A PLAN OF BEACH FEATURES 18 · 11 · 60

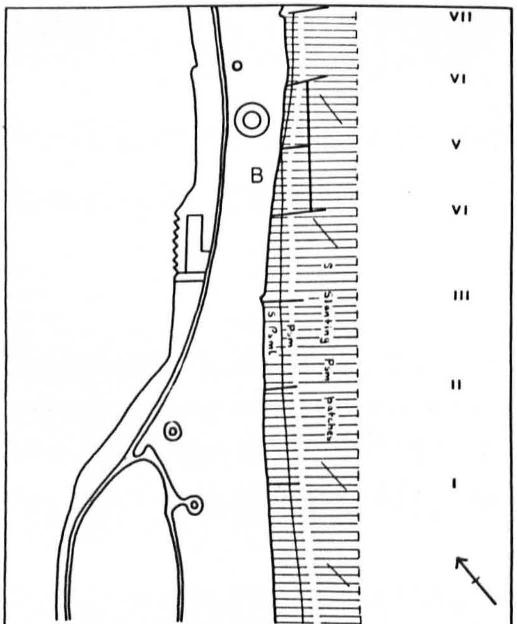
SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 18 · 11 · 60

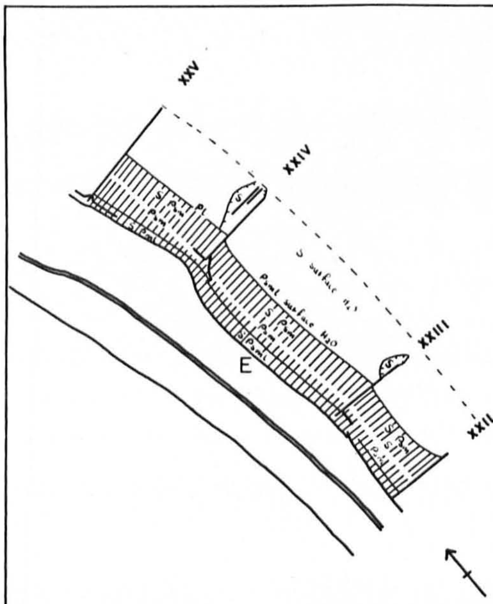
WIND ROSE FOR SPURN HEAD 9 · 11 · 60 — 17 · 11 · 60





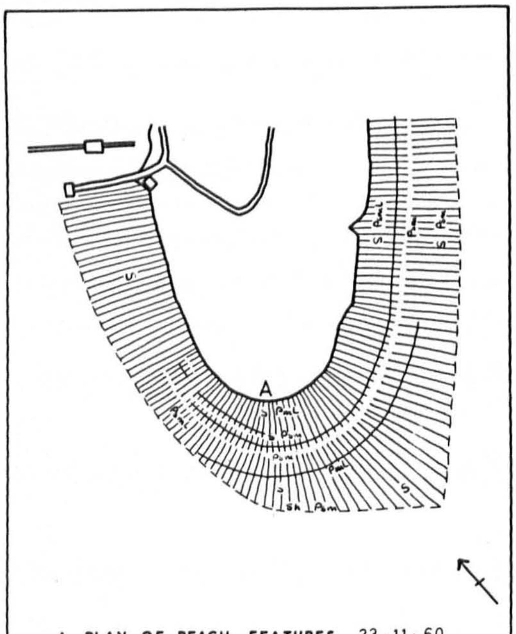
A PLAN OF BEACH FEATURES 23·11·60

SCALE 300 200 100 0 300 600 FEET



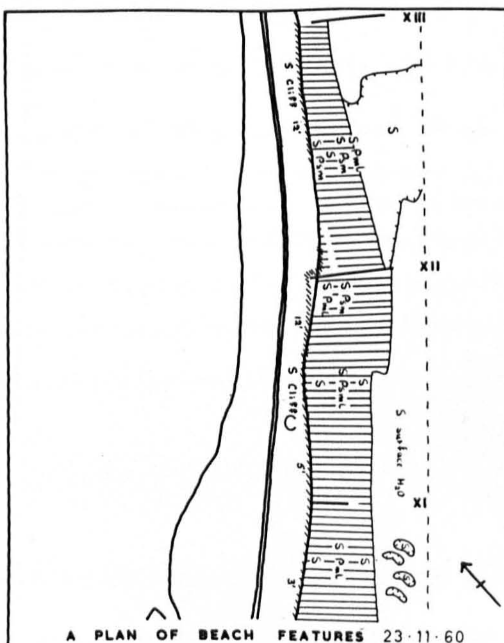
A PLAN OF BEACH FEATURES 23·11·60

SCALE 300 200 100 0 300 600 FEET



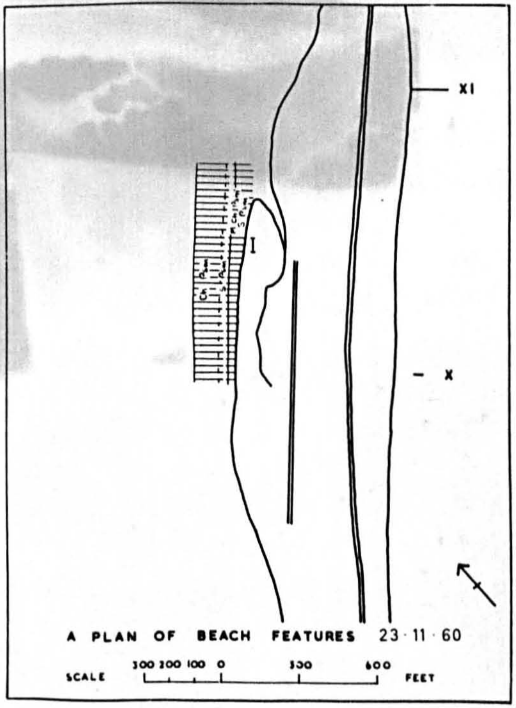
A PLAN OF BEACH FEATURES 23·11·60

SCALE 300 200 100 0 300 600 FEET

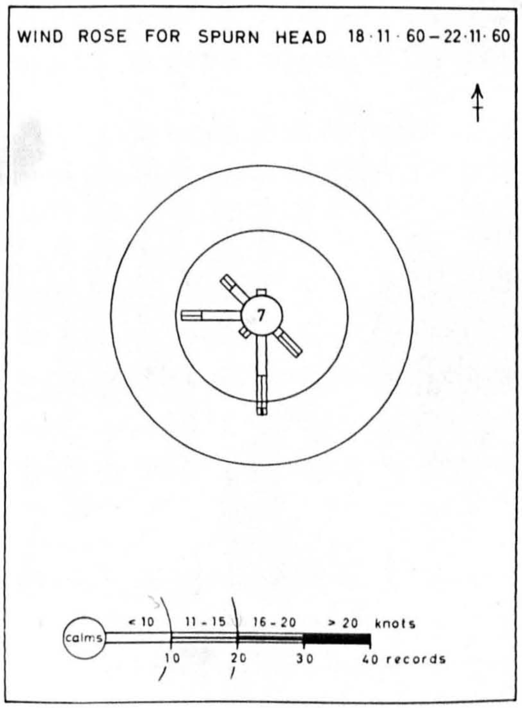


A PLAN OF BEACH FEATURES 23·11·60

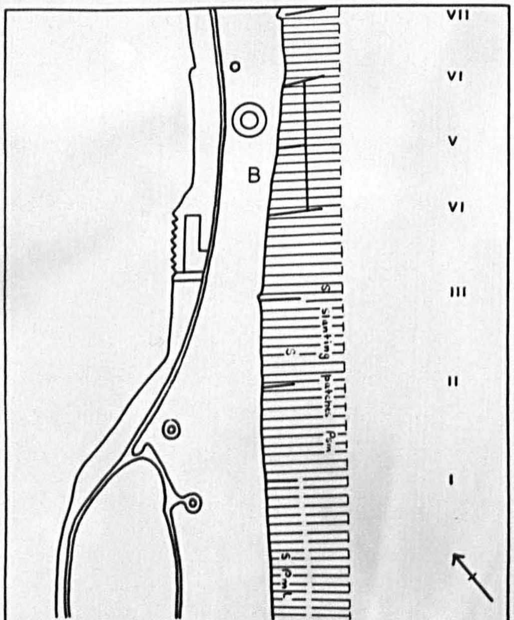
SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 23·11·60

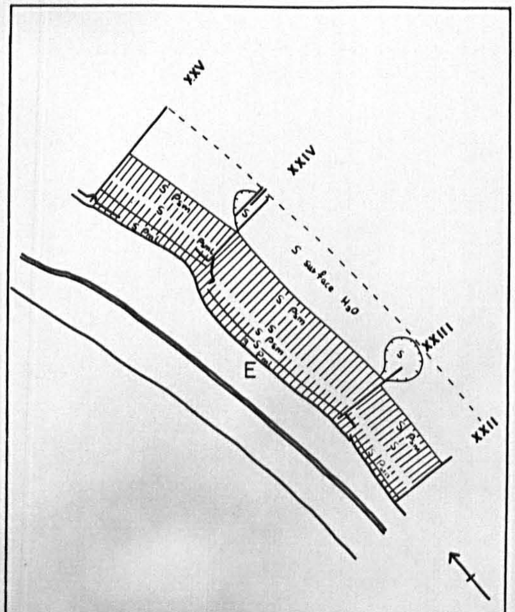


WIND ROSE FOR SPURN HEAD 18·11·60 – 22·11·60



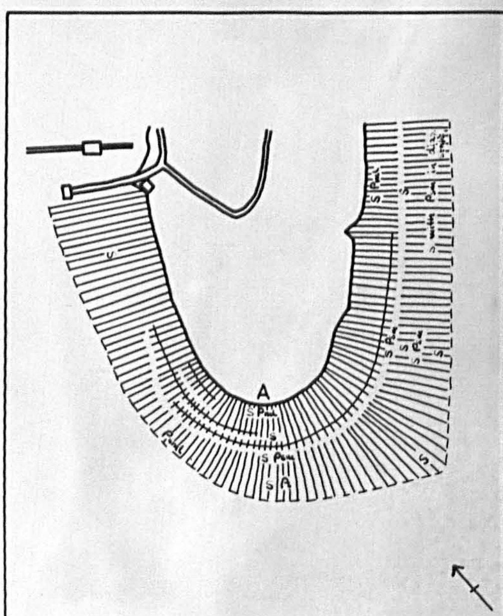
A PLAN OF BEACH FEATURES 30·11·60

SCALE 300 200 100 0 300 600 FEET



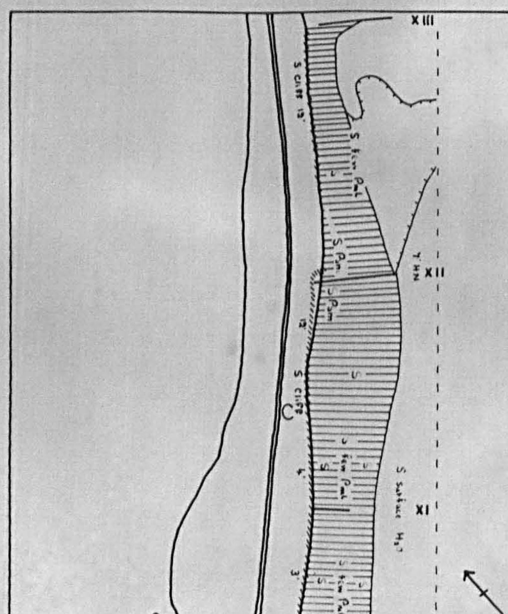
A PLAN OF BEACH FEATURES 30·11·60

SCALE 300 200 100 0 300 600 FEET



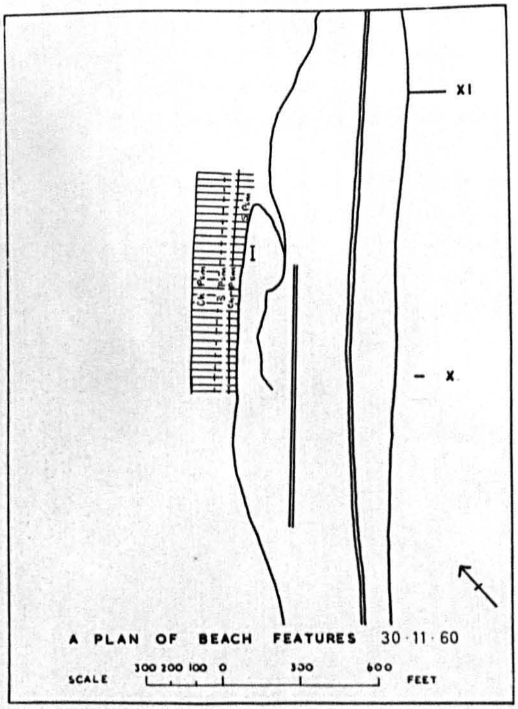
A PLAN OF BEACH FEATURES 30·11 60

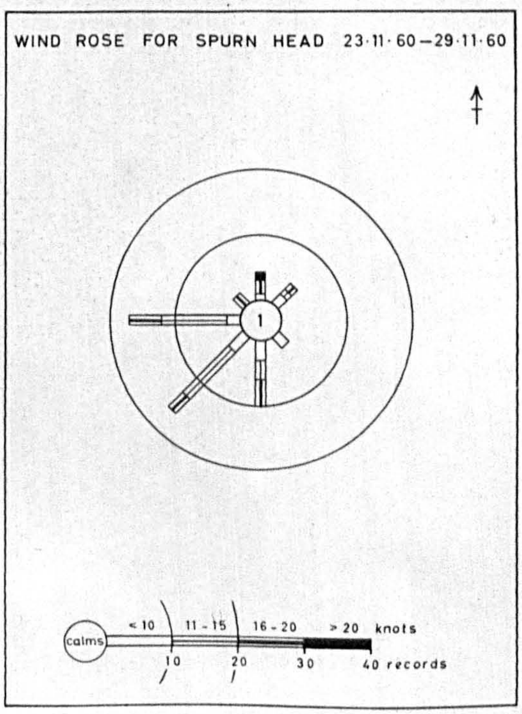
SCALE 300 200 100 0 300 600 FEET

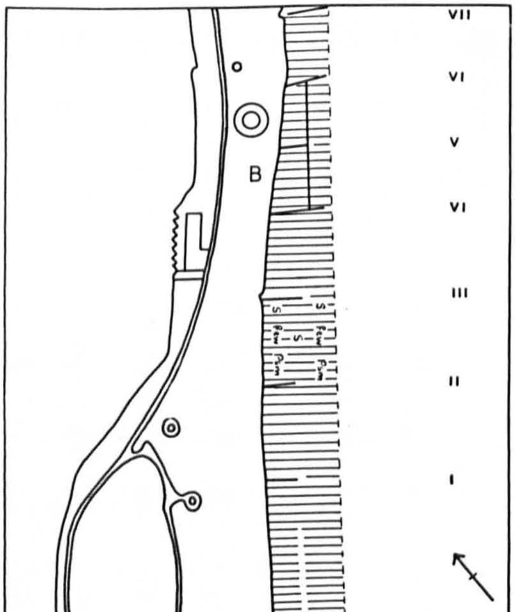


A PLAN OF BEACH FEATURES 30·11 60

SCALE 300 200 100 0 300 600 FEET

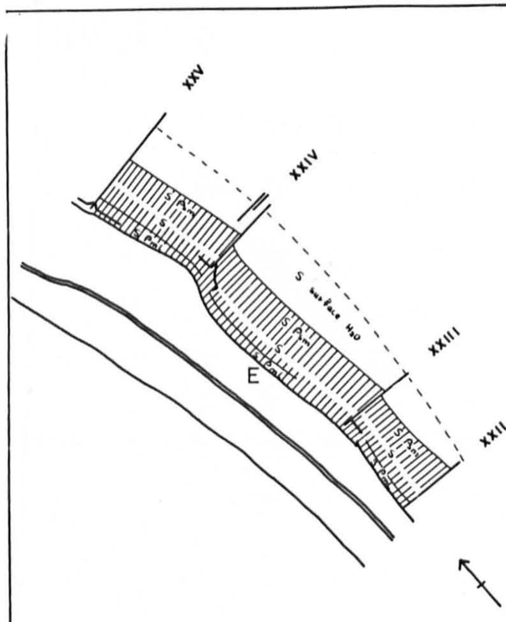

XI
X
I
A PLAN OF BEACH FEATURES 30·11·60
SCALE 300 200 100 0 300 600 FEET


WIND ROSE FOR SPURN HEAD 23·11·60—29·11·60
1
calms
< 10
11 - 15
16 - 20
> 20 knots
10
20
30
40 records



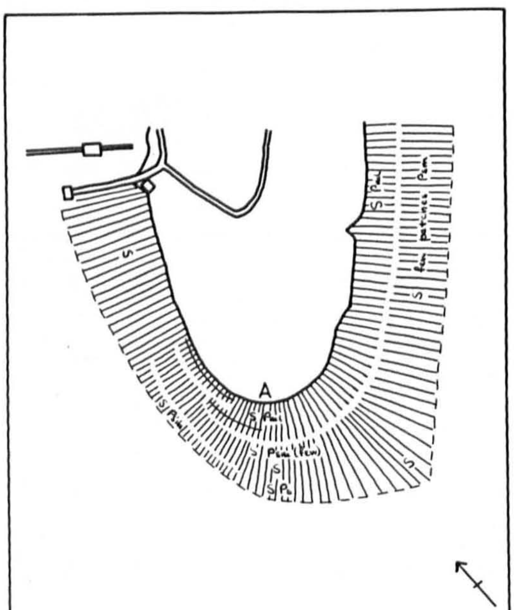
A PLAN OF BEACH FEATURES 7·12·60

SCALE 300 200 100 0 300 600 FEET



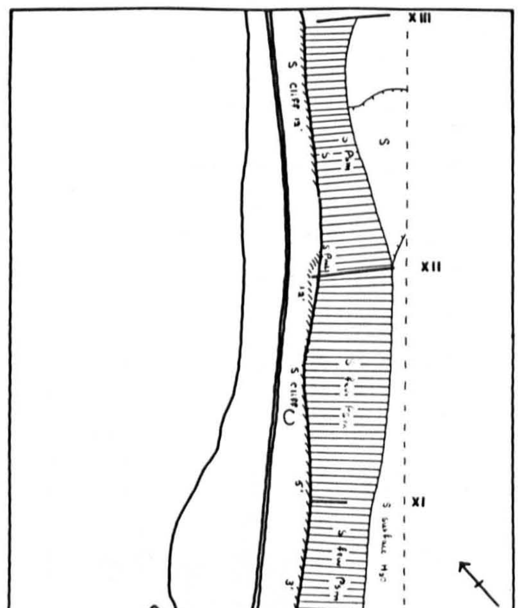
A PLAN OF BEACH FEATURES 7·12·60

SCALE 300 200 100 0 300 600 FEET



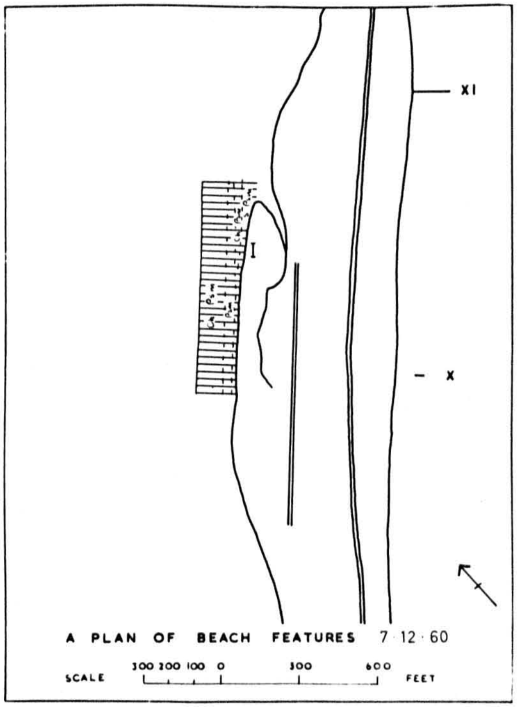
A PLAN OF BEACH FEATURES 7·12·60

SCALE 300 200 100 0 300 600 FEET

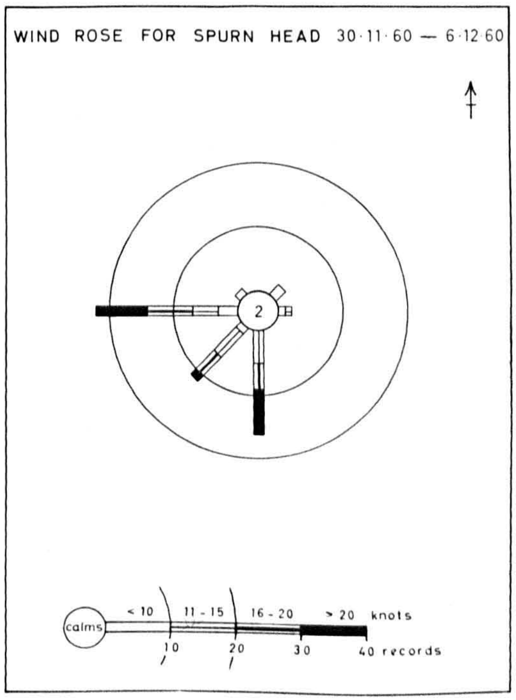


A PLAN OF BEACH FEATURES 7·12·60

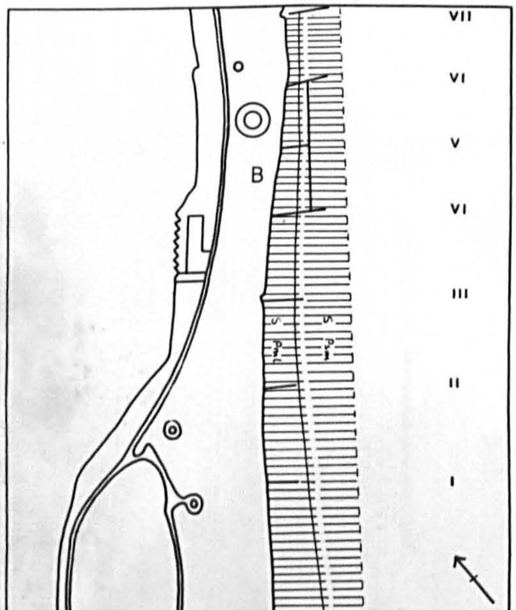
SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 7·12·60

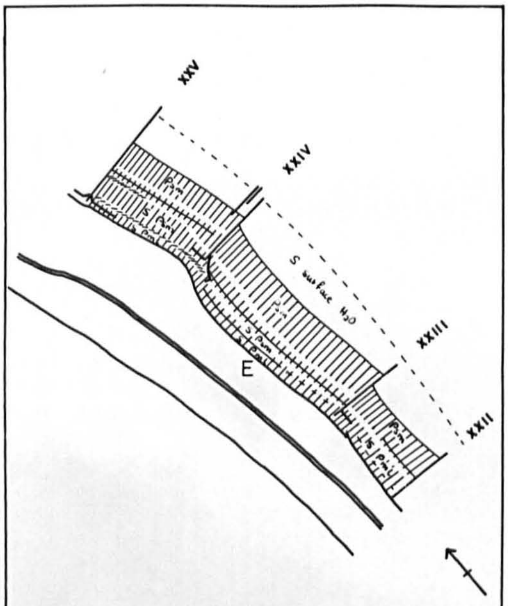


WIND ROSE FOR SPURN HEAD 30·11·60 — 6·12·60



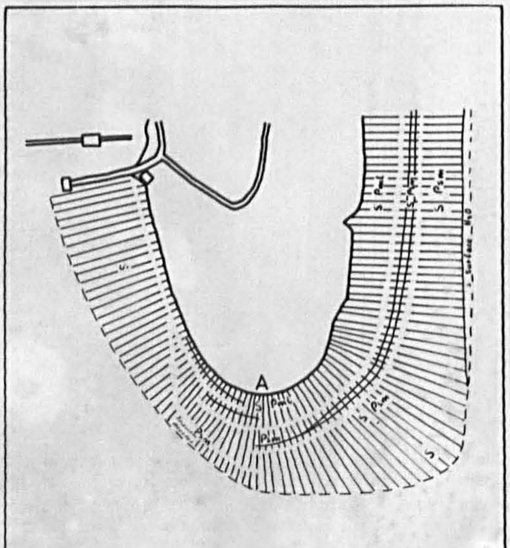
A PLAN OF BEACH FEATURES 17 · 12 · 60

SCALE 300 200 100 0 300 600 FEET



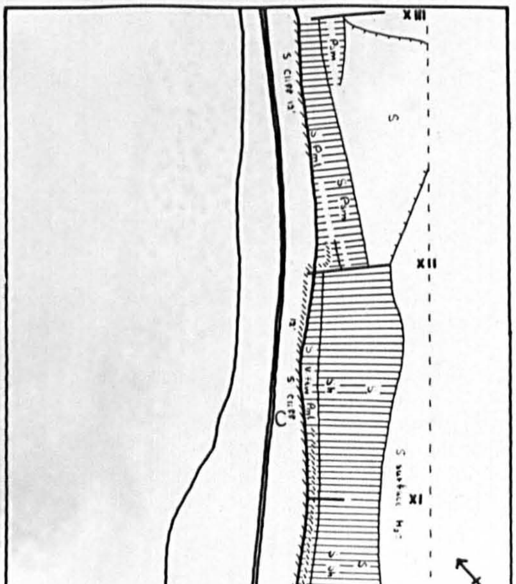
A PLAN OF BEACH FEATURES 17 · 12 · 60

SCALE 300 200 100 0 300 600 FEET



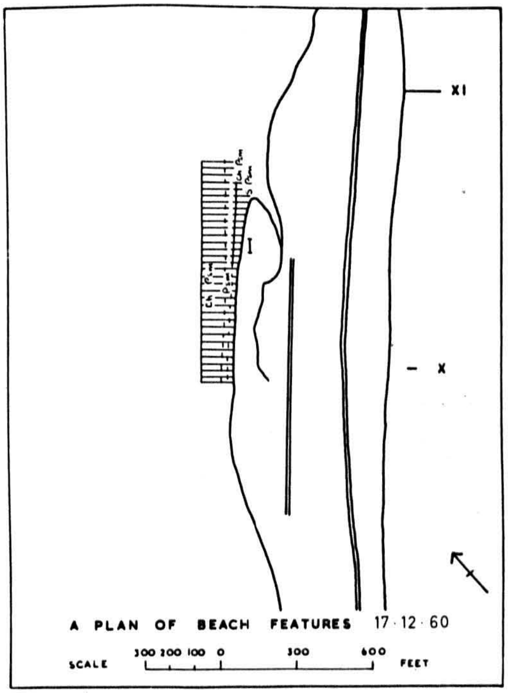
A PLAN OF BEACH FEATURES 17 · 12 · 60

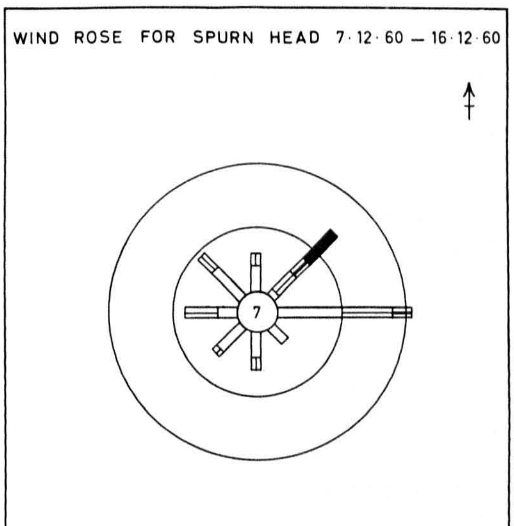
SCALE 300 200 100 0 300 600 FEET

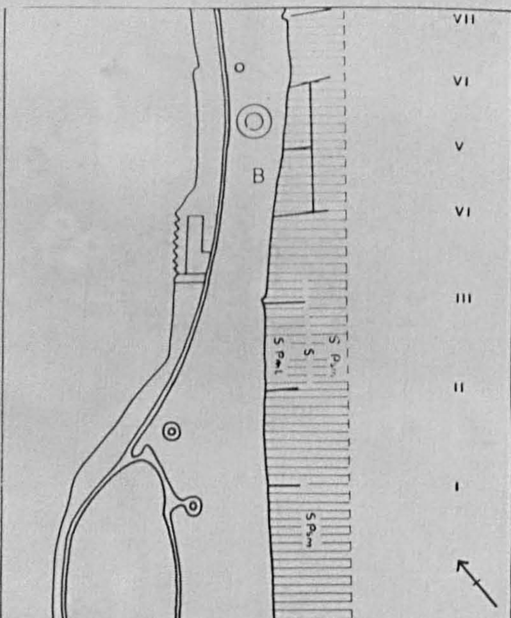


A PLAN OF BEACH FEATURES 17 · 12 · 60

SCALE 300 200 100 0 300 600 FEET

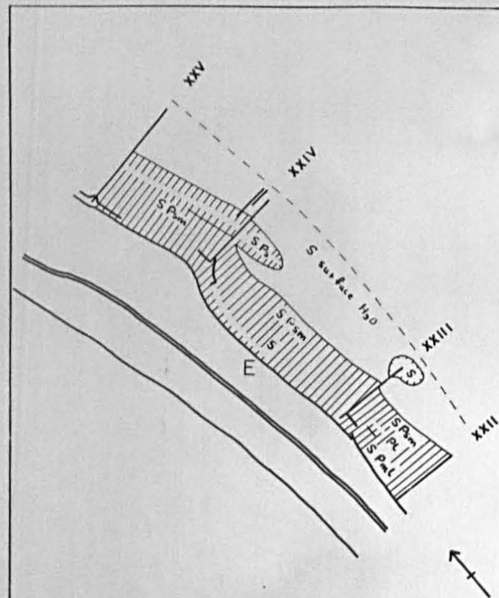

XI
I
X
A PLAN OF BEACH FEATURES 17·12·60
300 200 100 0 300 600
SCALE
FEET


WIND ROSE FOR SPURN HEAD 7·12·60 — 16·12·60
7
calms
< 10
11 - 15
16 - 20
> 20 knots
10
20
30
40 records



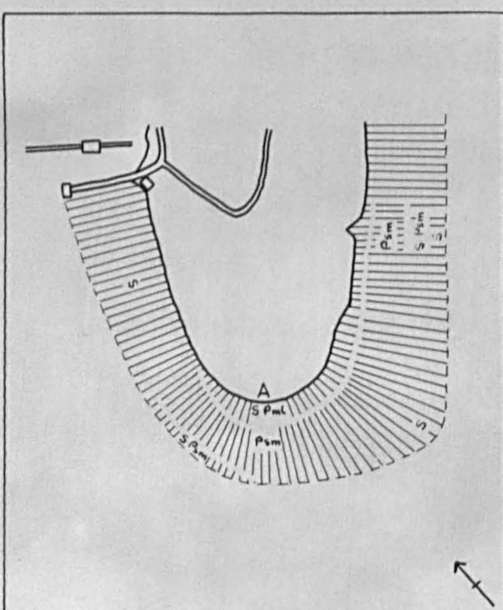
A PLAN OF BEACH FEATURES 21·12·60

SCALE 300 200 100 0 300 600 FEET



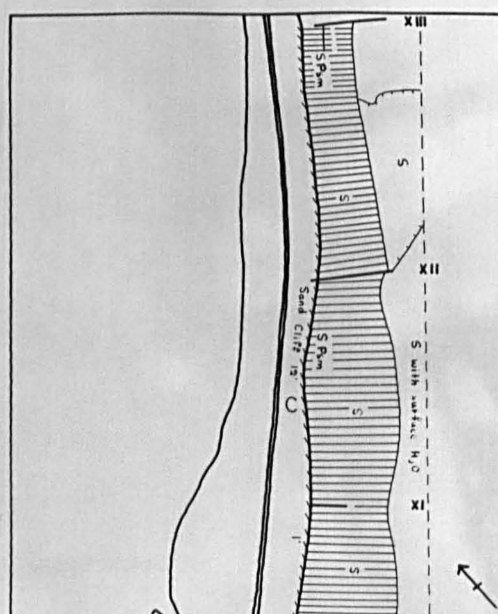
A PLAN OF BEACH FEATURES 21·12·60

SCALE 300 200 100 0 300 600 FEET



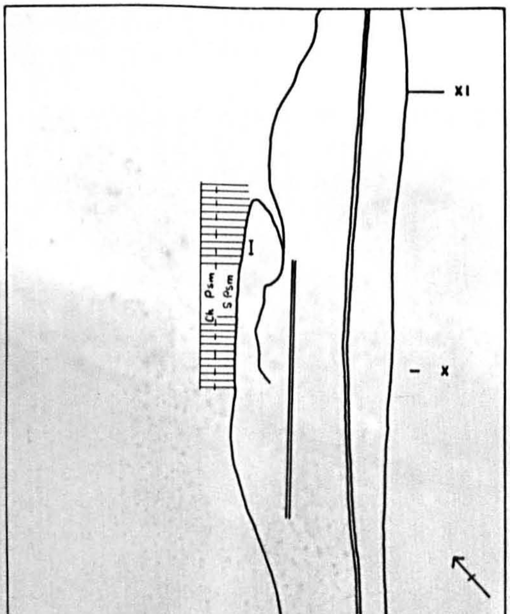
A PLAN OF BEACH FEATURES 21·12·60

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 21·12·60

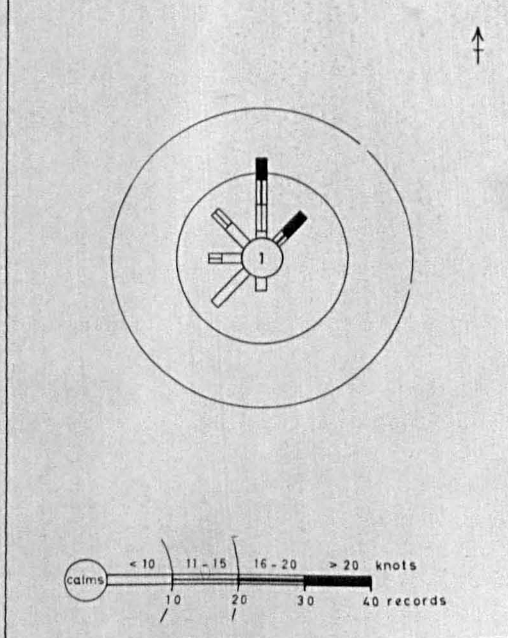
SCALE 300 200 100 0 300 600 FEET

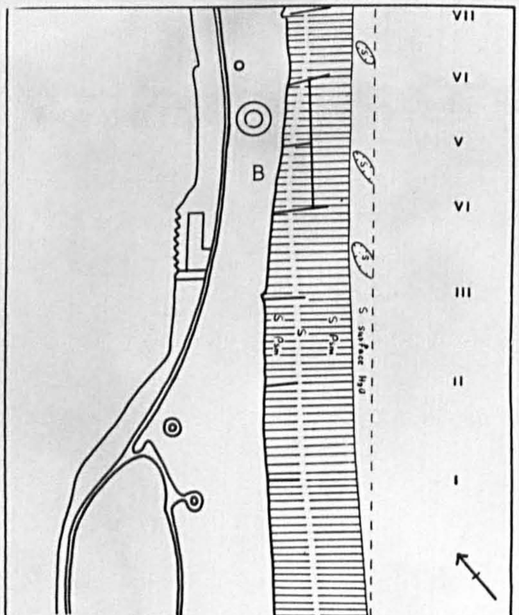


A PLAN OF BEACH FEATURES 21·12·60

SCALE 300 200 100 0 300 600 FEET

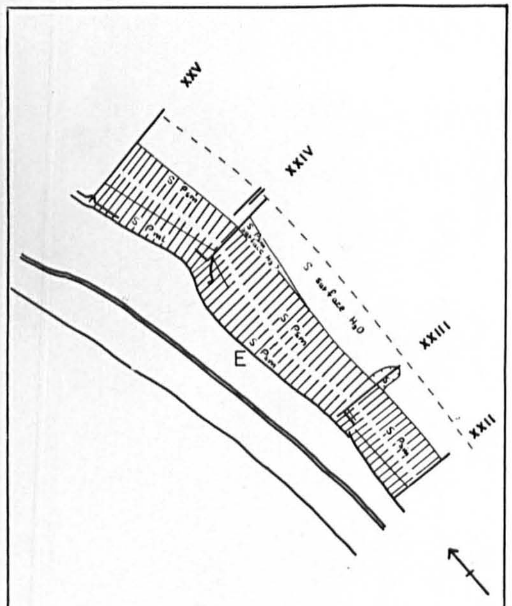
WIND ROSE FOR SPURN HEAD 17·12·60 — 21·12·60





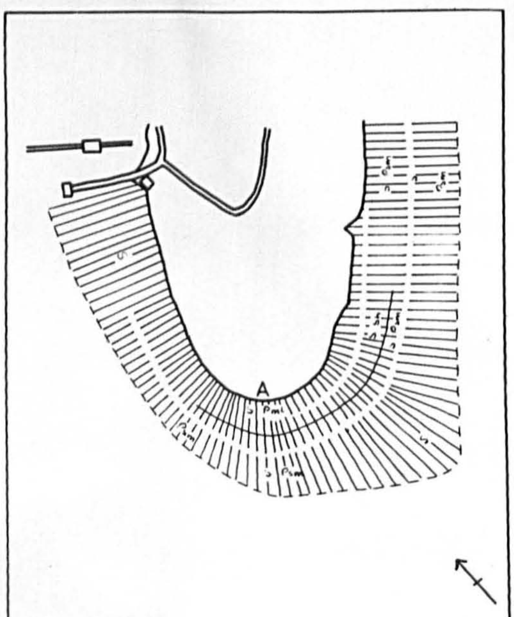
A PLAN OF BEACH FEATURES 1·1·61

SCALE 300 200 100 0 300 600 FEET



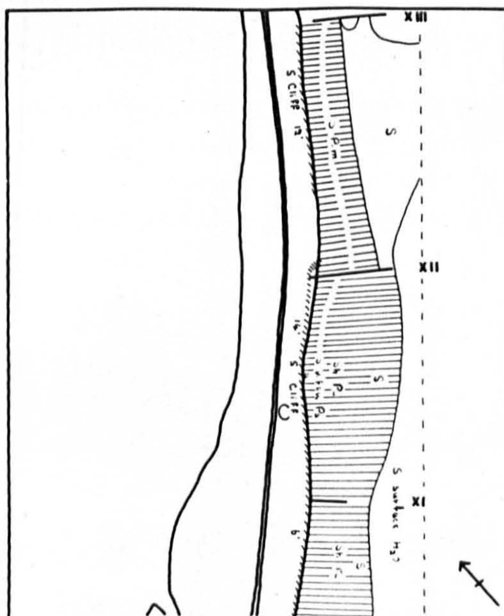
A PLAN OF BEACH FEATURES 1·1·61

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 1·1·61

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 1·1·61

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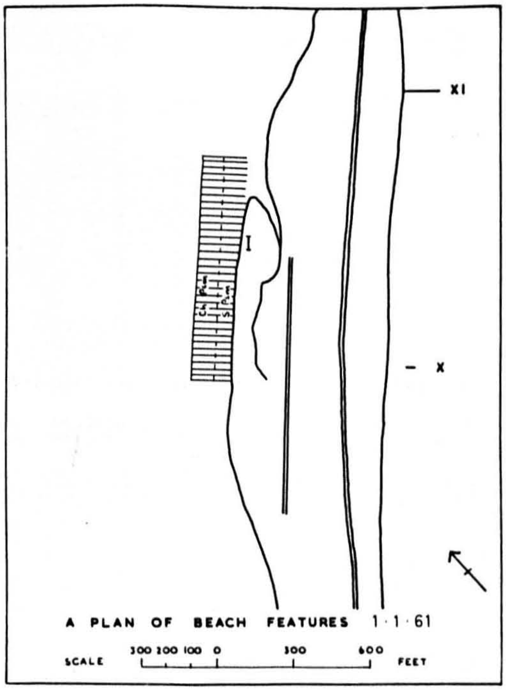
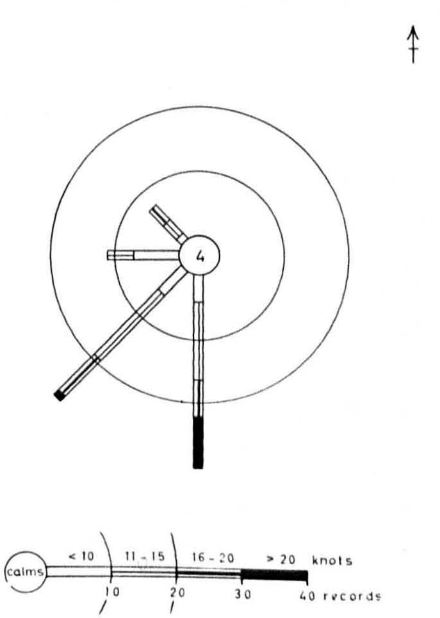
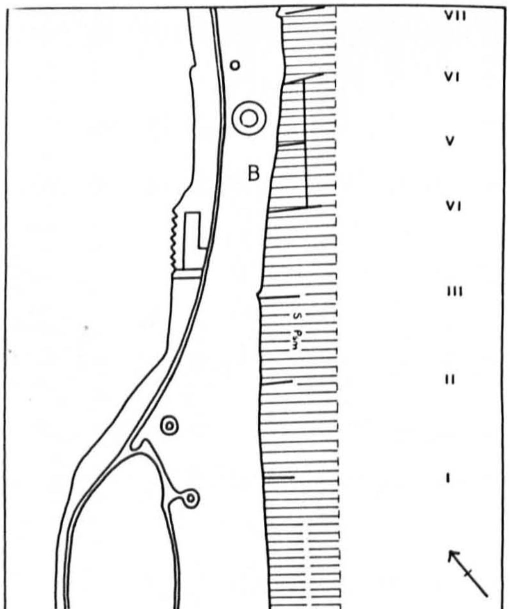


A PLAN OF BEACH FEATURES 1·1·61

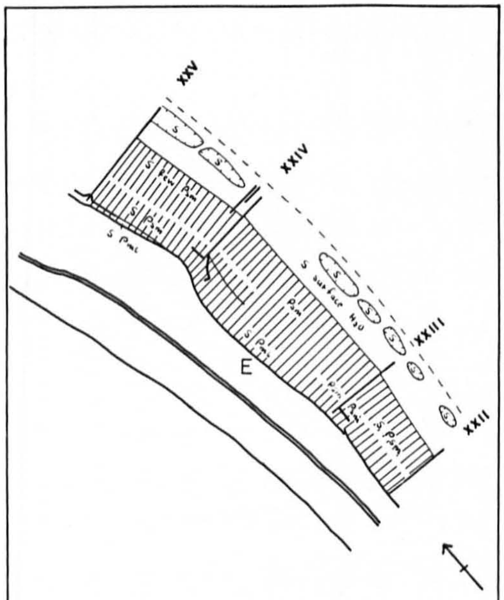
WIND ROSE FOR SPURN HEAD 22·12·60 — 31·12·60





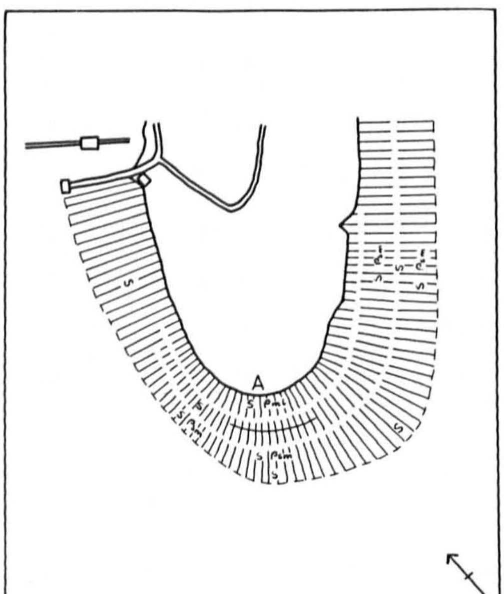
A PLAN OF BEACH FEATURES 14 · 1 · 61

SCALE 300 200 100 0 300 600 FEET



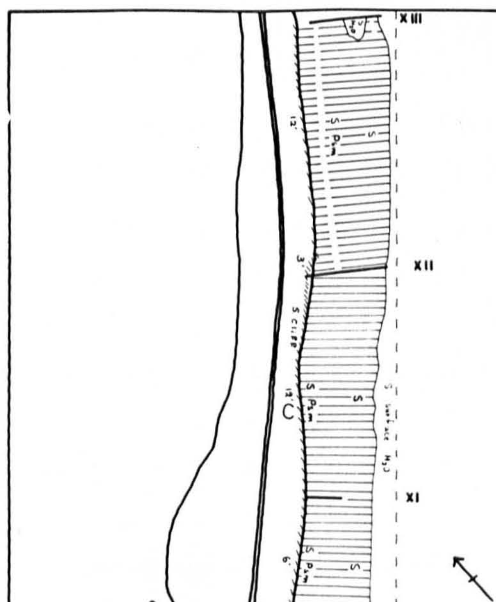
A PLAN OF BEACH FEATURES 14 · 1 · 61

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 14 · 1 · 61

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 14 1 61

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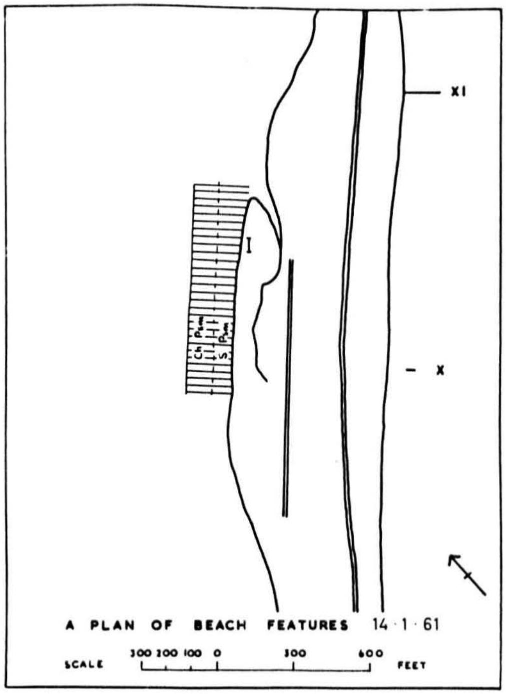
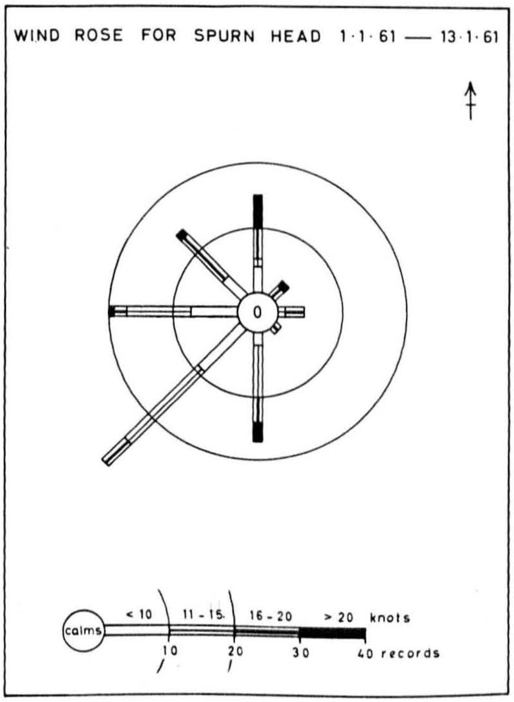
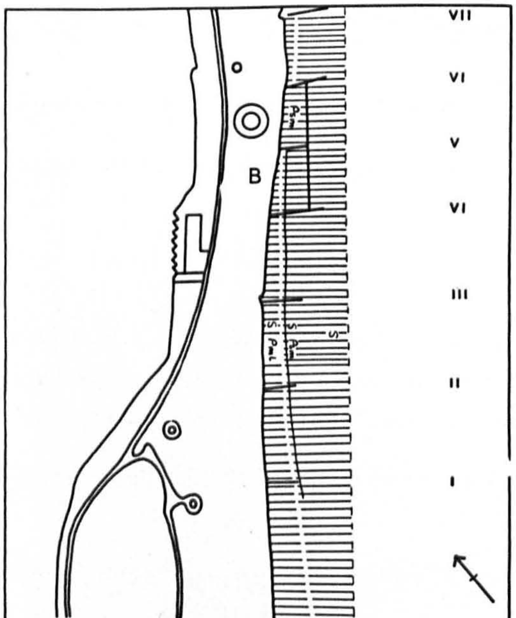


A PLAN OF BEACH FEATURES 14·1·61

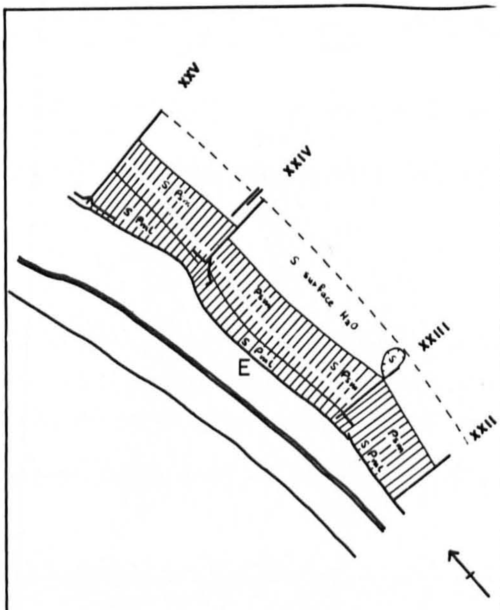


WIND ROSE FOR SPURN HEAD 1·1·61 — 13·1·61



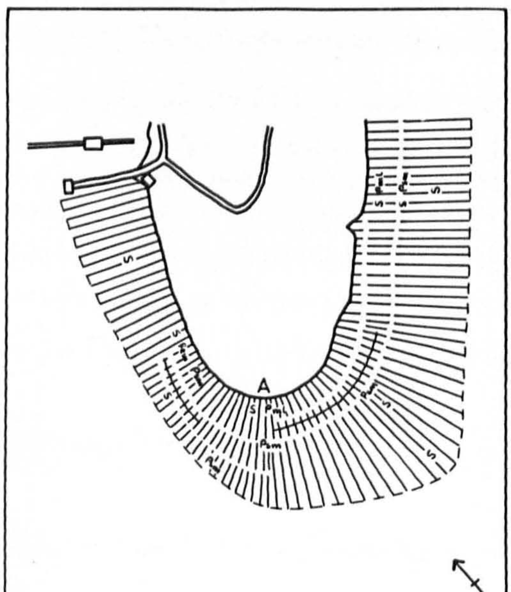
A PLAN OF BEACH FEATURES 19 · 1 · 61

SCALE 300 200 100 0 300 600 FEET



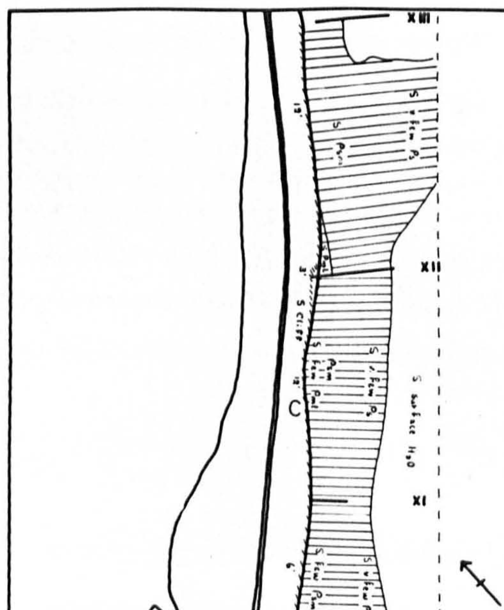
A PLAN OF BEACH FEATURES 19 · 1 · 61

SCALE 300 200 100 0 300 600 FEET



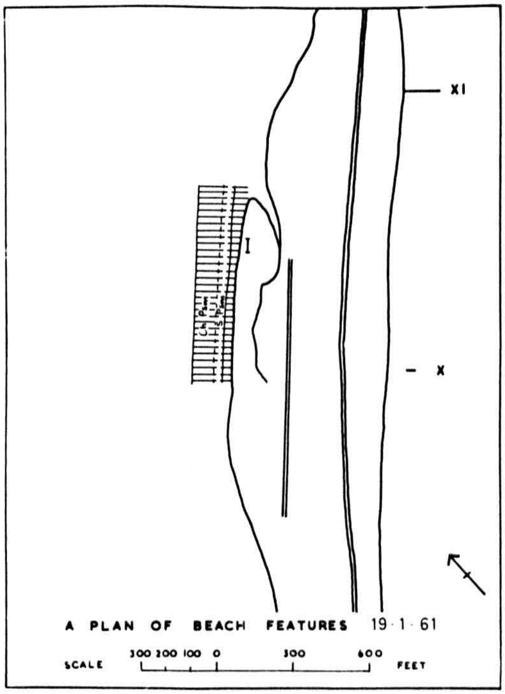
A PLAN OF BEACH FEATURES 19 · 1 · 61

SCALE 300 200 100 0 300 600 FEET



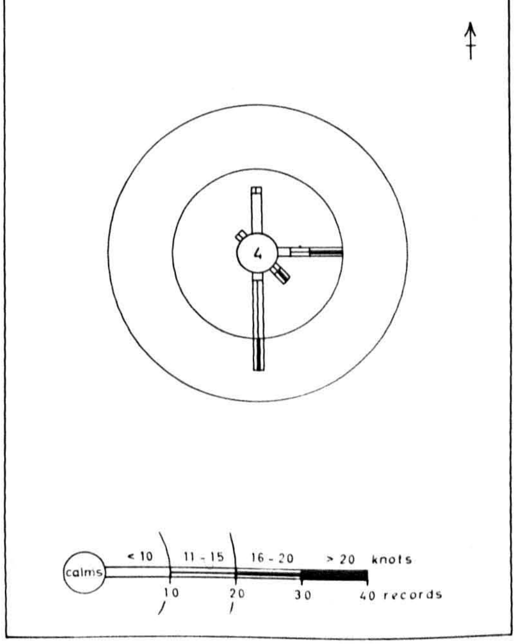
A PLAN OF BEACH FEATURES 19 · 1 · 61

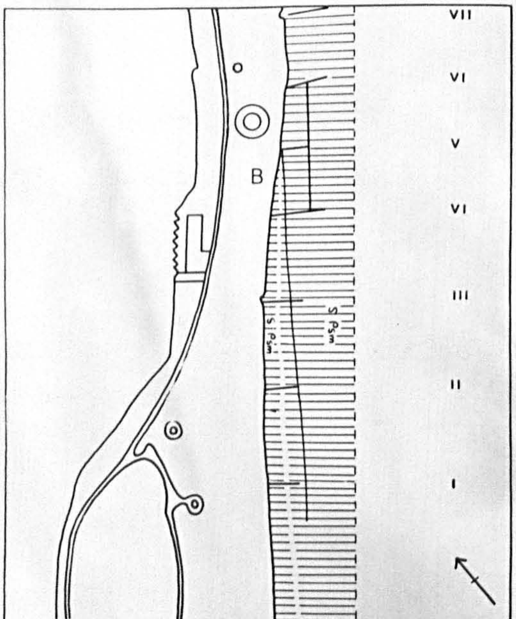
SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 19·1·61

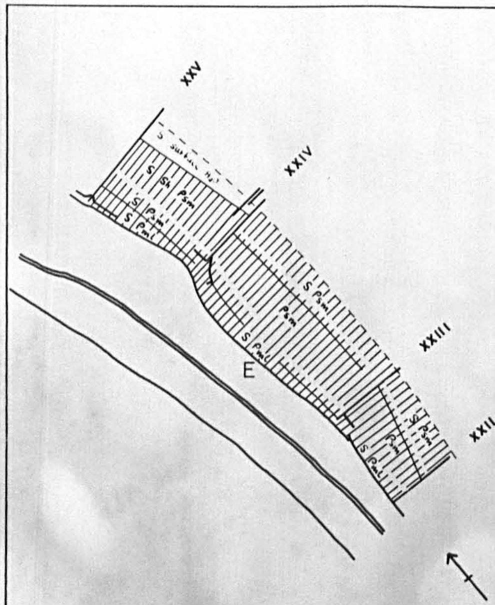
WIND ROSE FOR SPURN HEAD 14·1·61 — 18·1·61





A PLAN OF BEACH FEATURES 29·1·61

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 29·1·61

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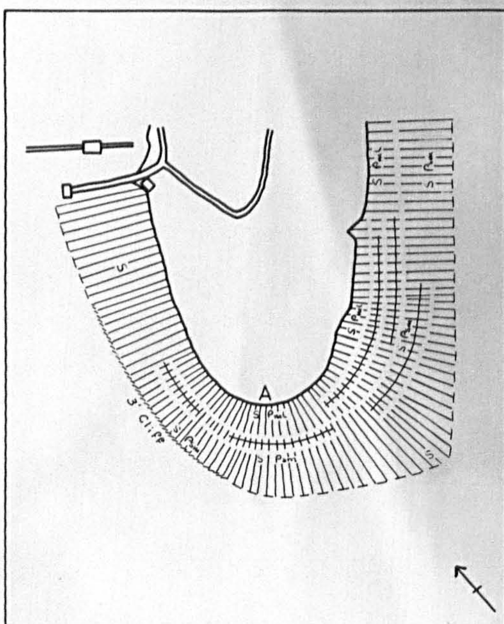

A PLAN OF BEACH FEATURES 29·1·61

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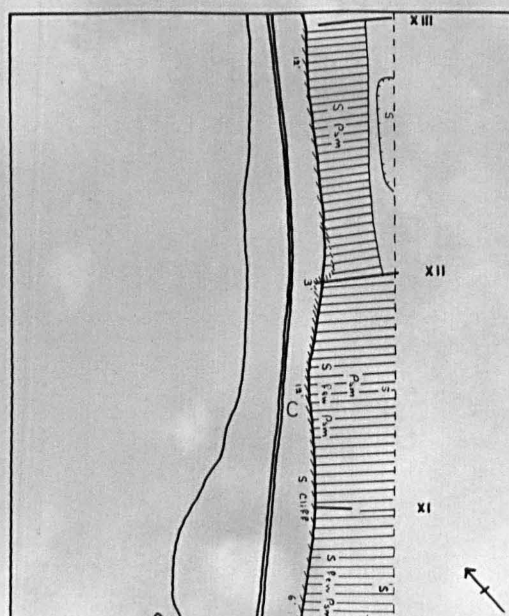

A PLAN OF BEACH FEATURES 29·1·61

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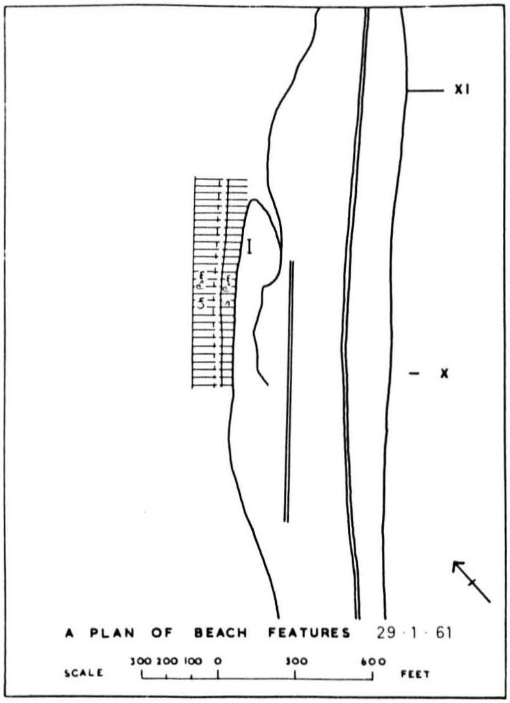
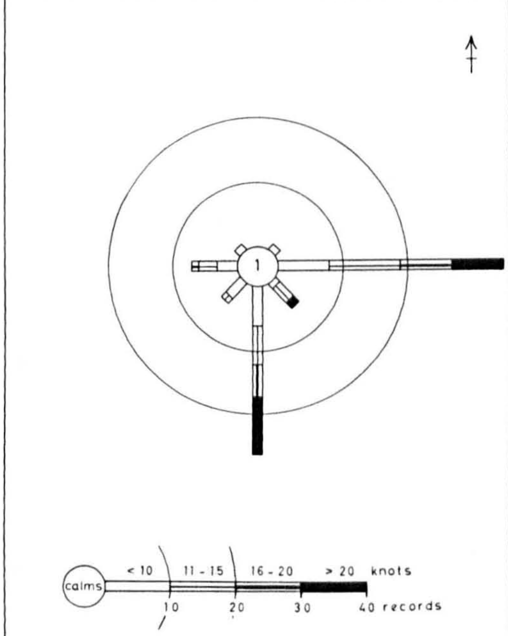
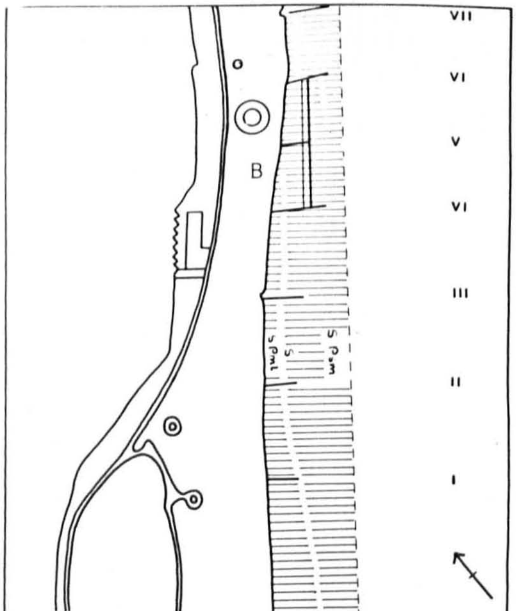


A PLAN OF BEACH FEATURES 29·1·61

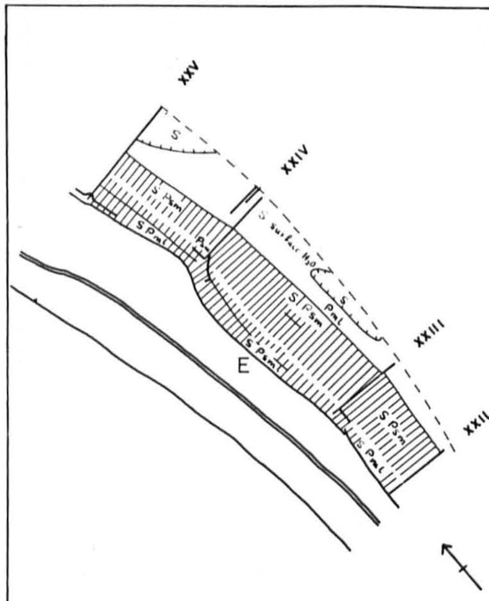
WIND ROSE FOR SPURN HEAD 19·1·61 — 28·1·61





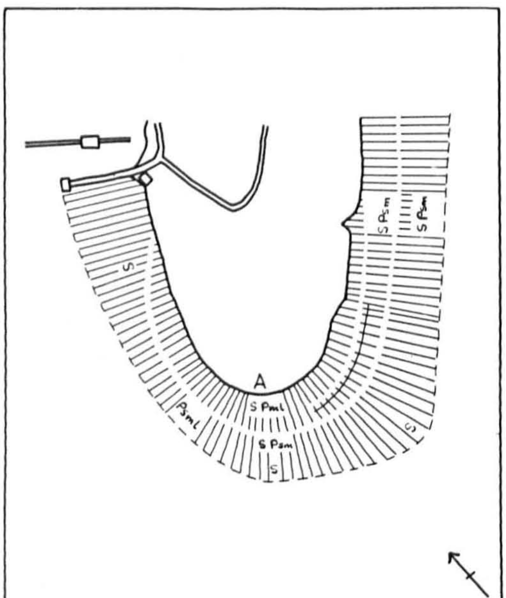
A PLAN OF BEACH FEATURES 3·2·61

SCALE 300 200 100 0 300 600 FEET



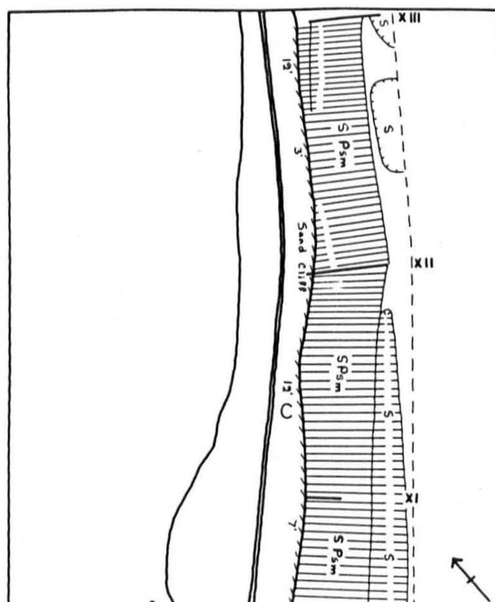
A PLAN OF BEACH FEATURES 3·2·61

SCALE 300 200 100 0 300 600 FEET



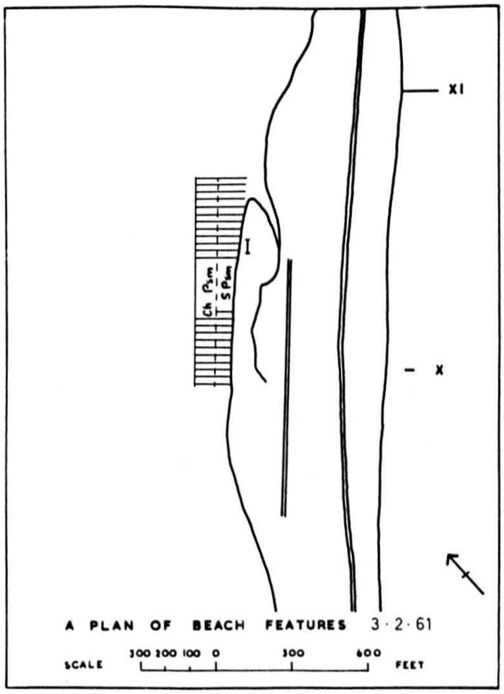
A PLAN OF BEACH FEATURES 3·2·61

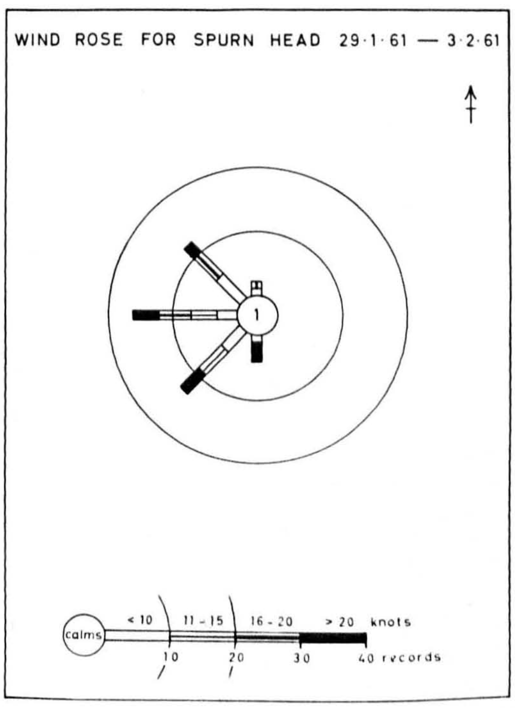
SCALE 300 200 100 0 300 600 FEET

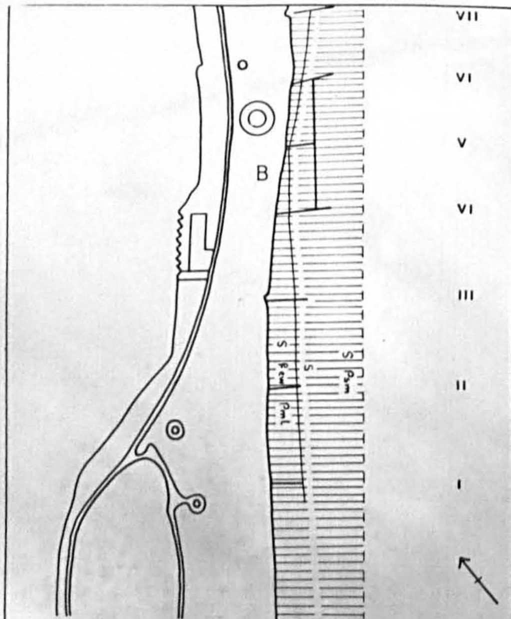


A PLAN OF BEACH FEATURES 3·2·61

SCALE 300 200 100 0 300 600 FEET

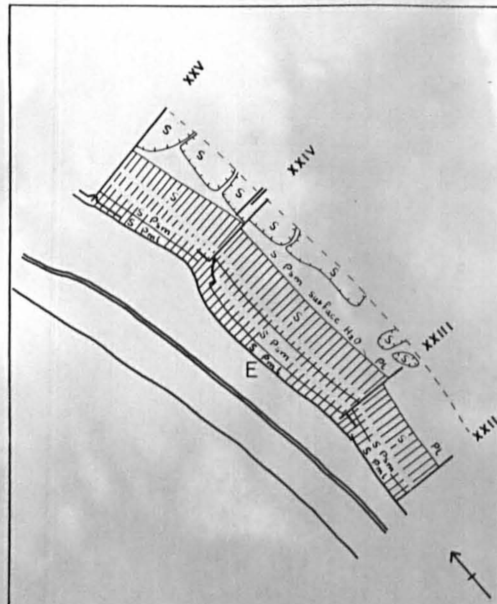

XI
X
I
Ch Psm
T SPsm
A PLAN OF BEACH FEATURES 3·2·61
SCALE
300 200 100 0
300
600
FEET


WIND ROSE FOR SPURN HEAD 29·1·61 — 3·2·61
1
calms
< 10
11 - 15
16 - 20
> 20 knots
10
20
30
40 records



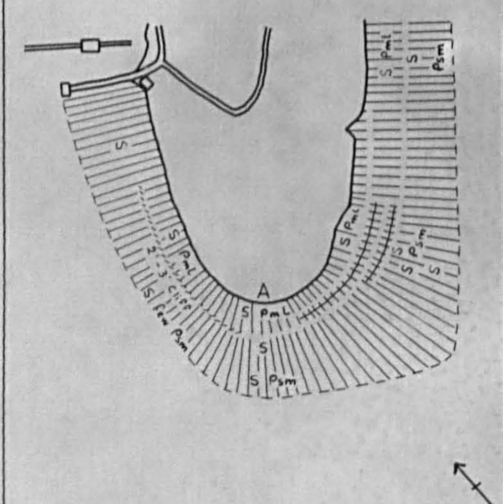
A PLAN OF BEACH FEATURES 13 · 2 · 61

SCALE 300 200 100 0 300 600 FEET



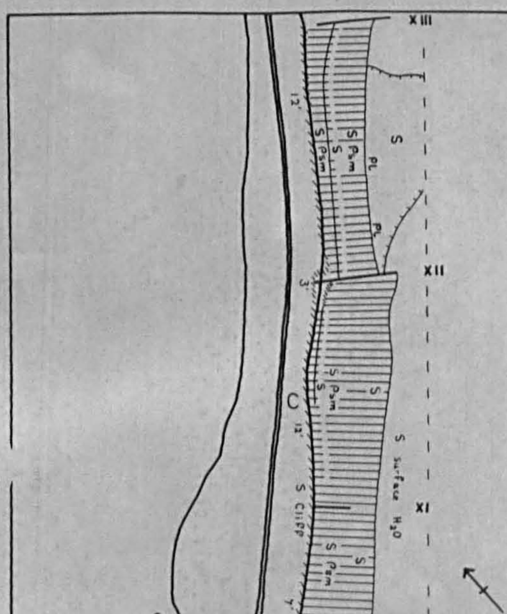
A PLAN OF BEACH FEATURES 13 · 2 · 61

SCALE 300 200 100 0 100 600 FEET



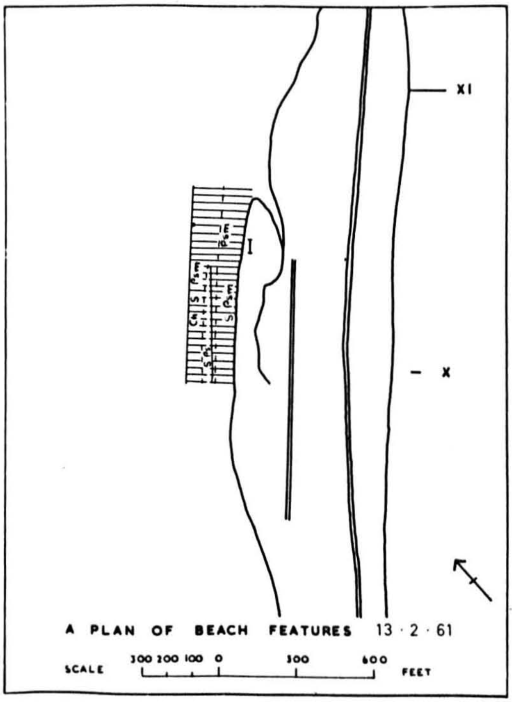
A PLAN OF BEACH FEATURES 13 · 2 · 61

SCALE 300 200 100 0 300 600 FEET

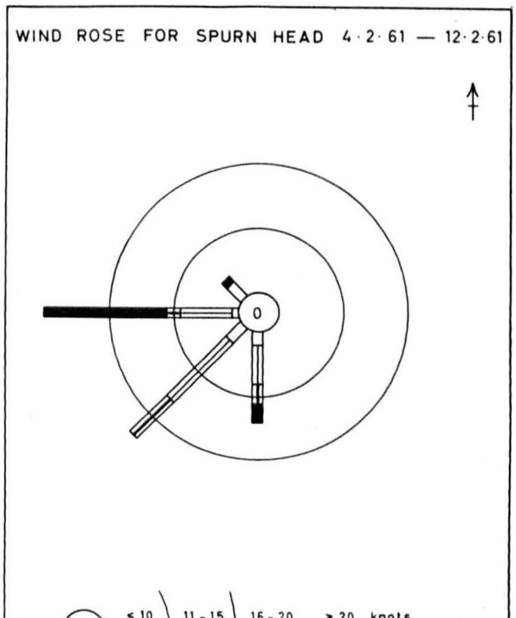


A PLAN OF BEACH FEATURES 13 · 2 · 61

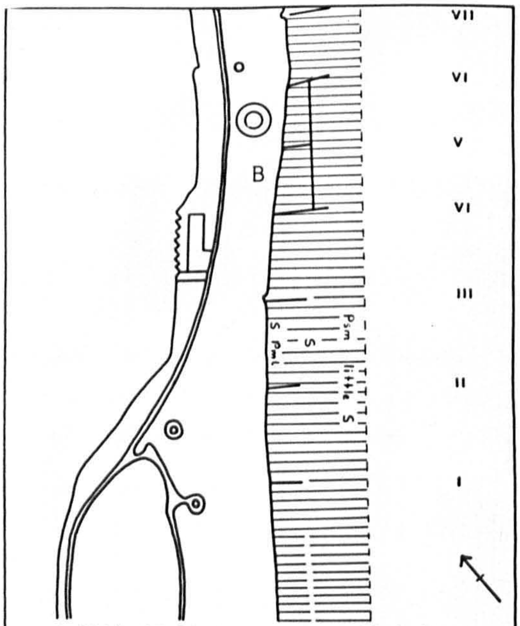
SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 13 · 2 · 61

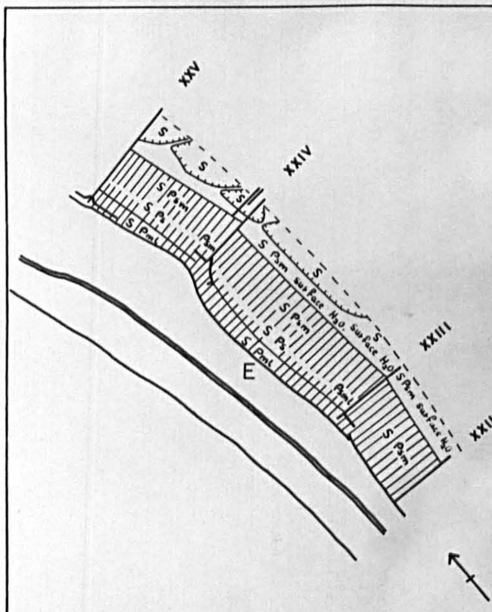


WIND ROSE FOR SPURN HEAD 4 · 2 · 61 — 12 · 2 · 61



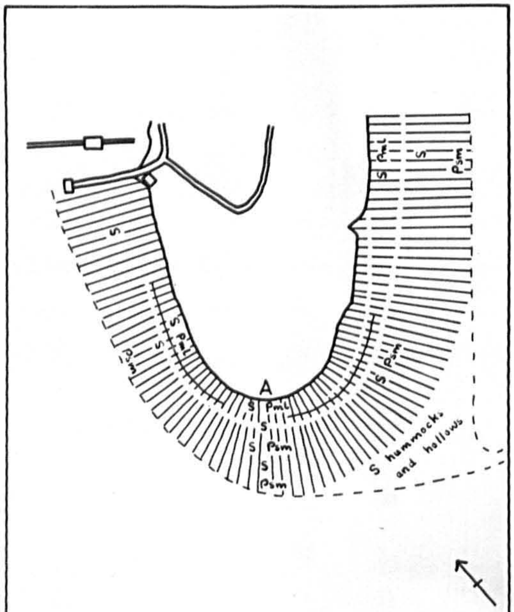
A PLAN OF BEACH FEATURES 20 · 2 · 61

SCALE 300 200 100 0 300 600 FEET



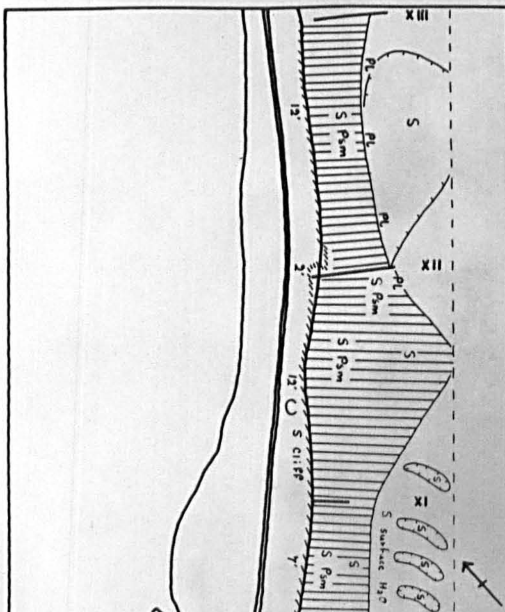
A PLAN OF BEACH FEATURES 20 · 2 · 61

SCALE 300 200 100 0 300 600 FEET



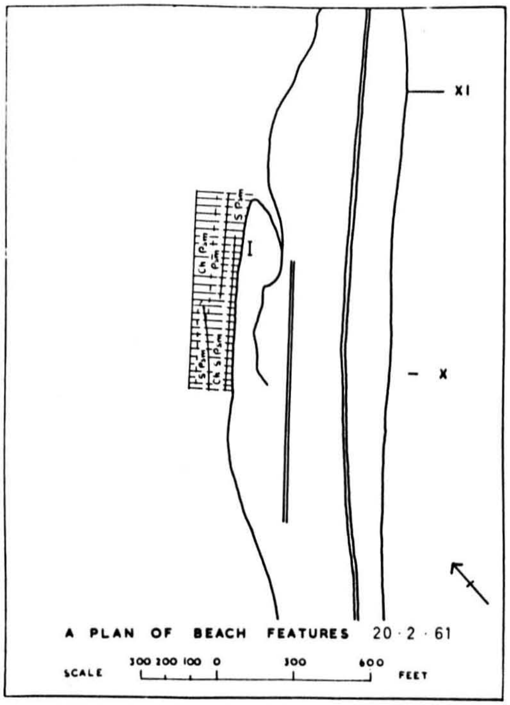
A PLAN OF BEACH FEATURES 20 · 2 · 61

SCALE 300 200 100 0 300 600 FEET

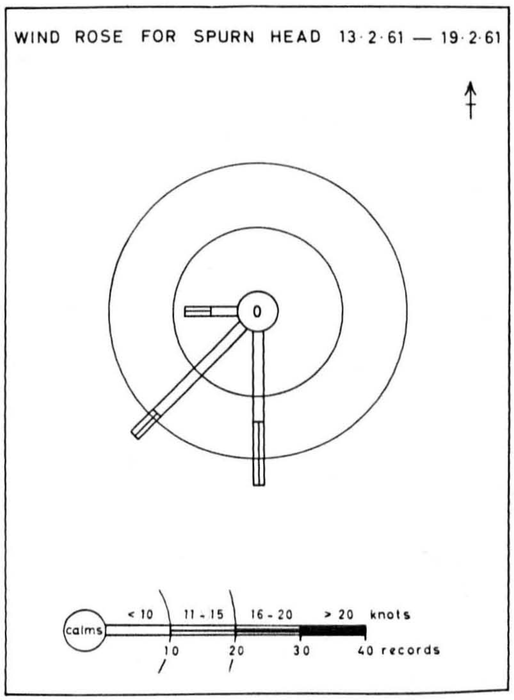


A PLAN OF BEACH FEATURES 20 2 61

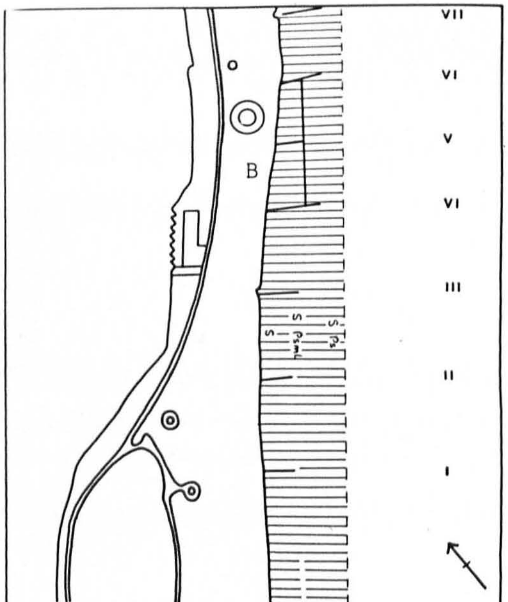
SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 20 · 2 · 61

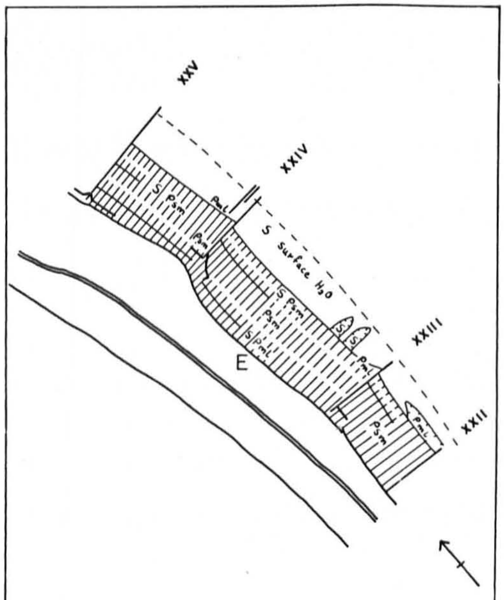


WIND ROSE FOR SPURN HEAD 13·2·61 — 19·2·61



A PLAN OF BEACH FEATURES 27 · 2 · 61

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 27 · 2 · 61

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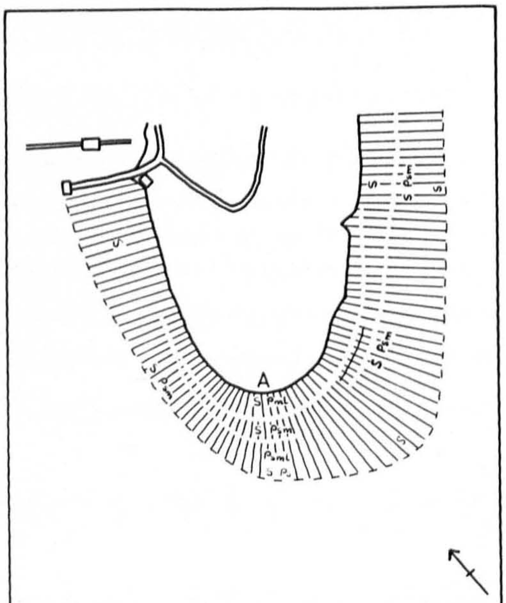

A PLAN OF BEACH FEATURES 27 · 2 · 61

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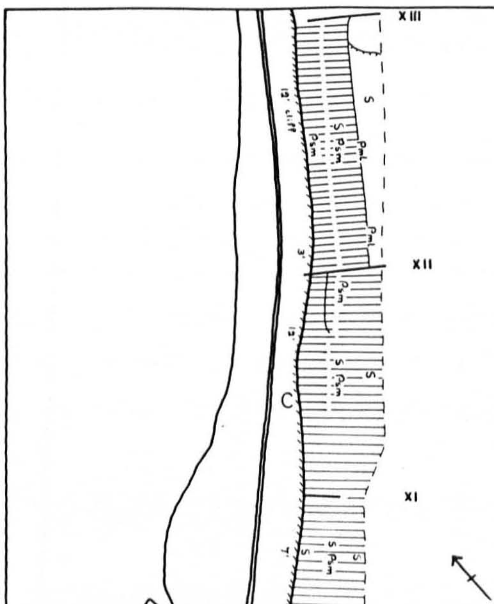

A PLAN OF BEACH FEATURES 27 · 2 · 61

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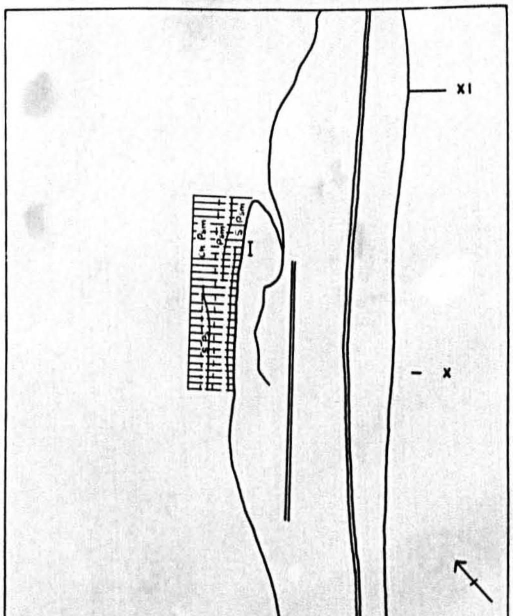
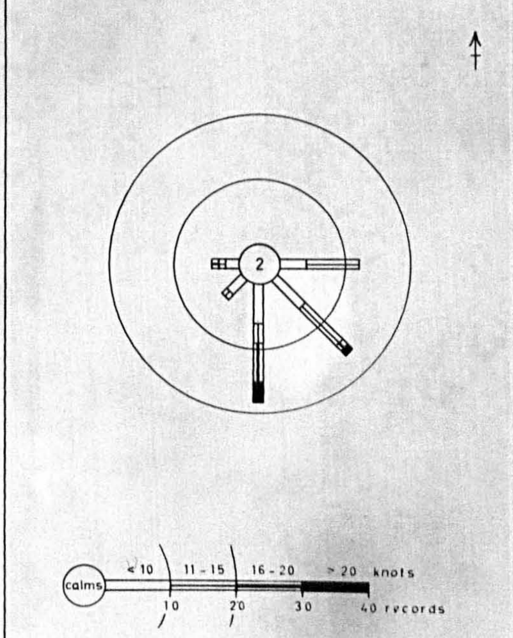
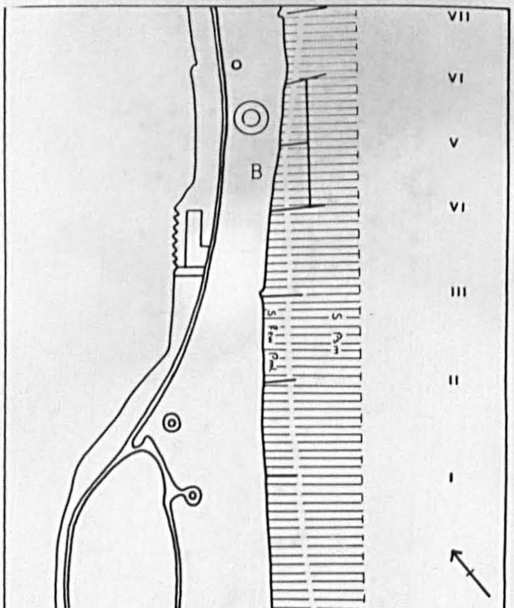


A PLAN OF BEACH FEATURES 27·2·61

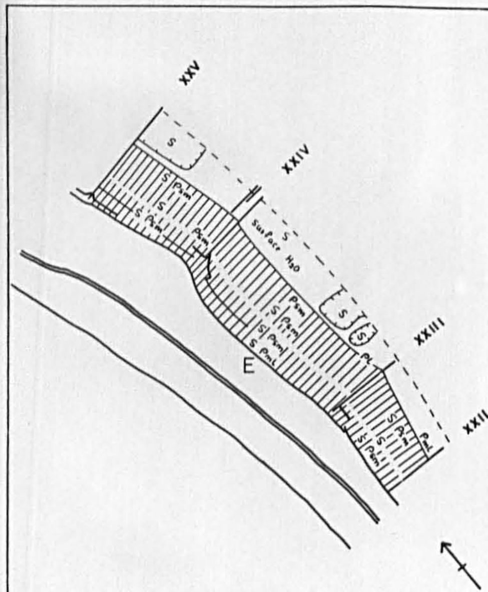


WIND ROSE FOR SPURN HEAD 20·2·61—26·2·61



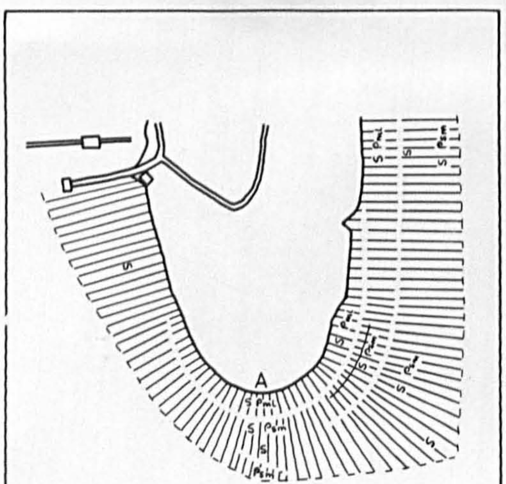
A PLAN OF BEACH FEATURES 8 · 3 · 61

SCALE 300 200 100 0 300 600 FEET



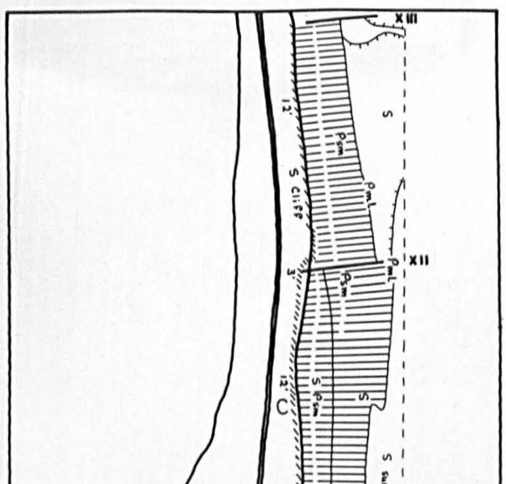
A PLAN OF BEACH FEATURES 8 · 3 · 61

SCALE 300 200 100 0 300 600 FEET



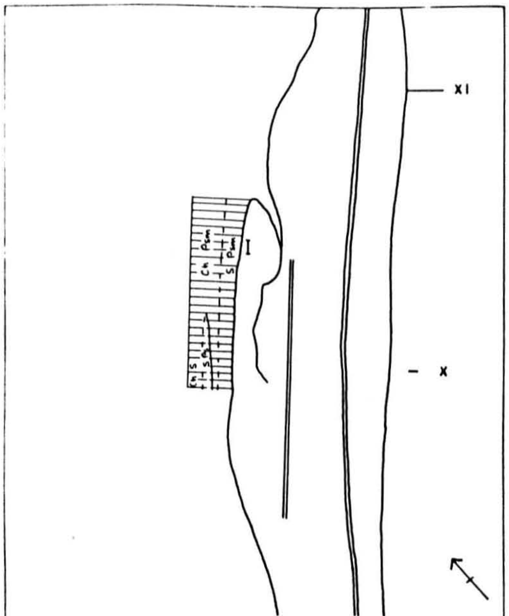
A PLAN OF BEACH FEATURES 8 · 3 · 61

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 8 · 3 · 61

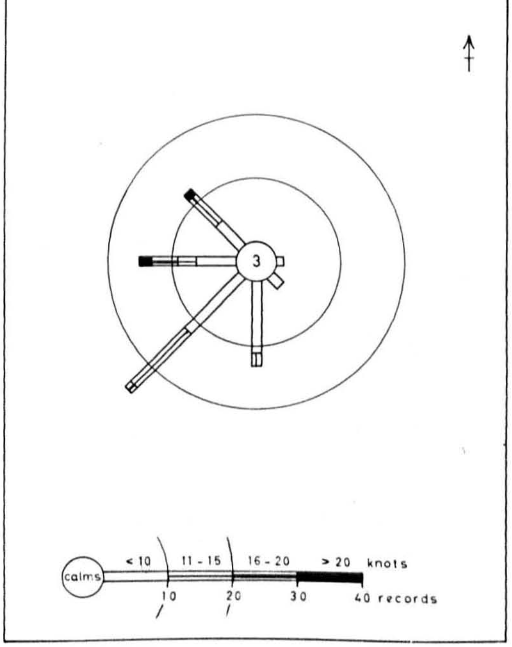
SCALE 300 200 100 0 300 600 FEET

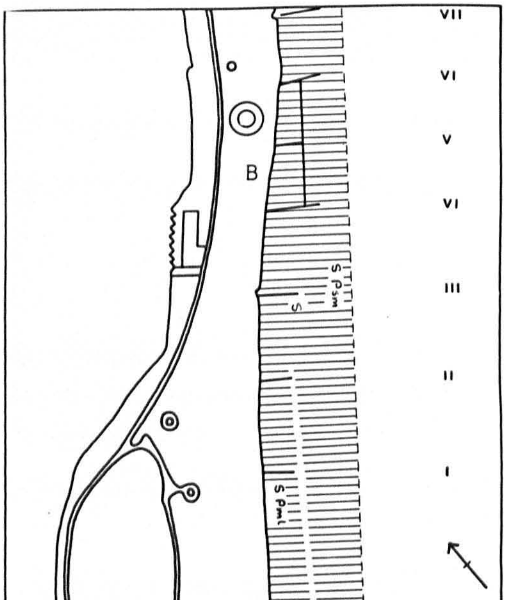


A PLAN OF BEACH FEATURES 8 · 3 · 61

SCALE 300 200 100 0 300 600 FEET

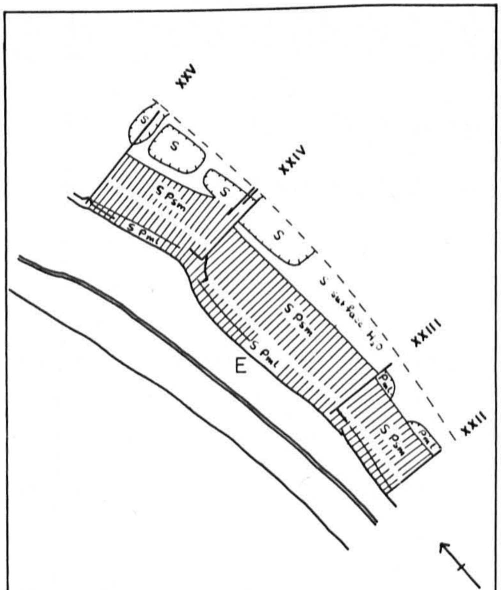
WIND ROSE FOR SPURN HEAD 27·2·61 — 7·3·61





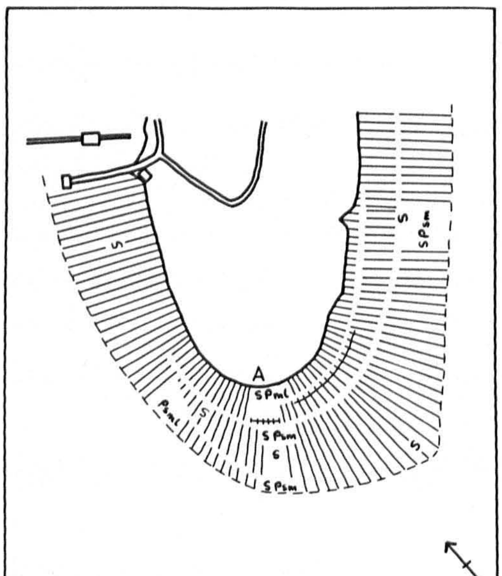
A PLAN OF BEACH FEATURES 17·3·61

SCALE 300 200 100 0 300 600 FEET



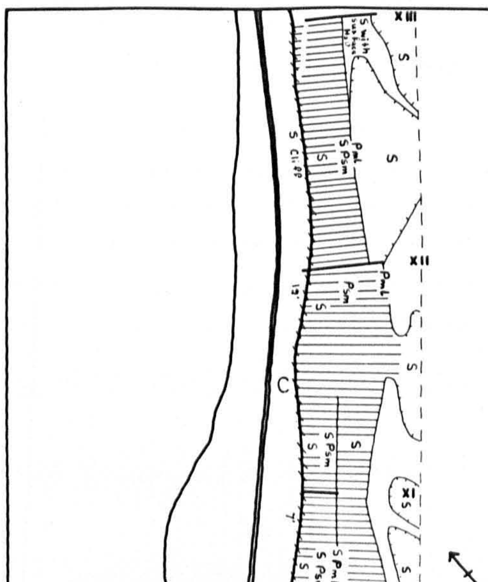
A PLAN OF BEACH FEATURES 17·3·61

SCALE 300 200 100 0 300 600 FEET



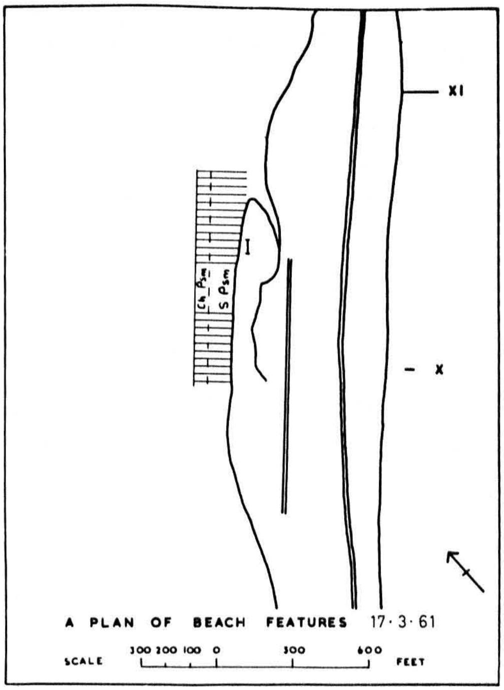
A PLAN OF BEACH FEATURES 17·3·61

SCALE 300 200 100 0 300 600 FEET



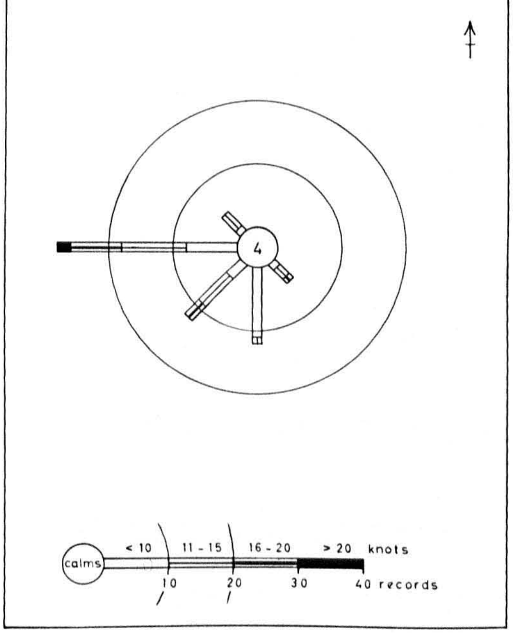
A PLAN OF BEACH FEATURES 17·3·61

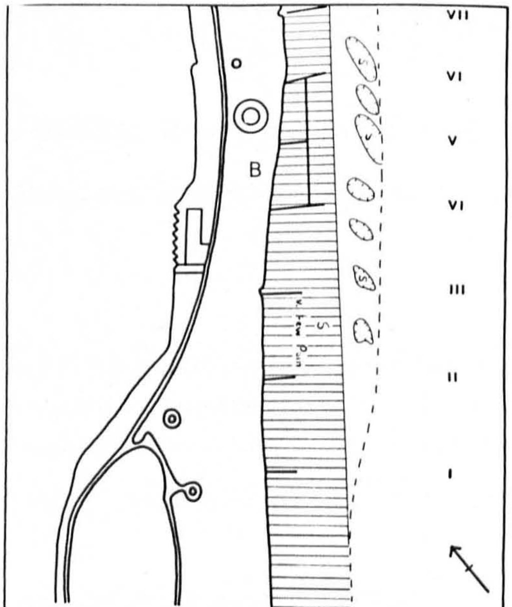
SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 17·3·61

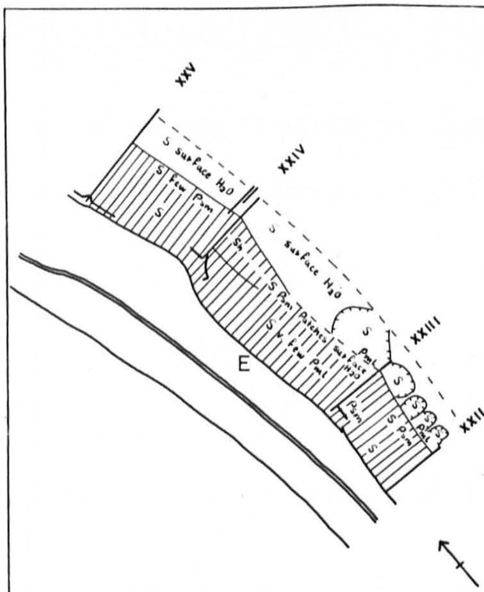
WIND ROSE FOR SPURN HEAD 8·3·61 — 15·3·61





A PLAN OF BEACH FEATURES 19·3·61

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 19·3·61

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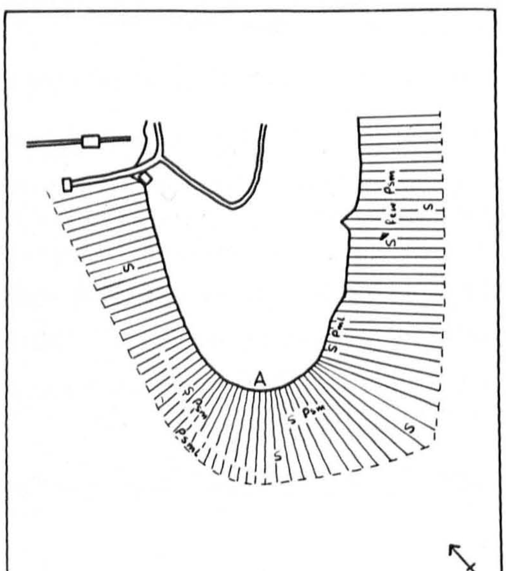
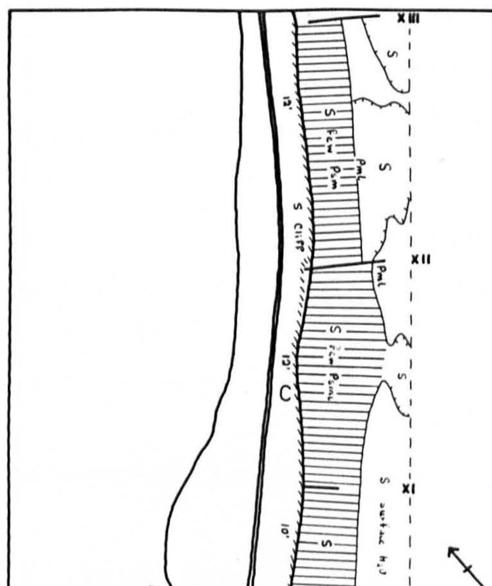


A PLAN OF BEACH FEATURES 19·3·61

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 19·3·61

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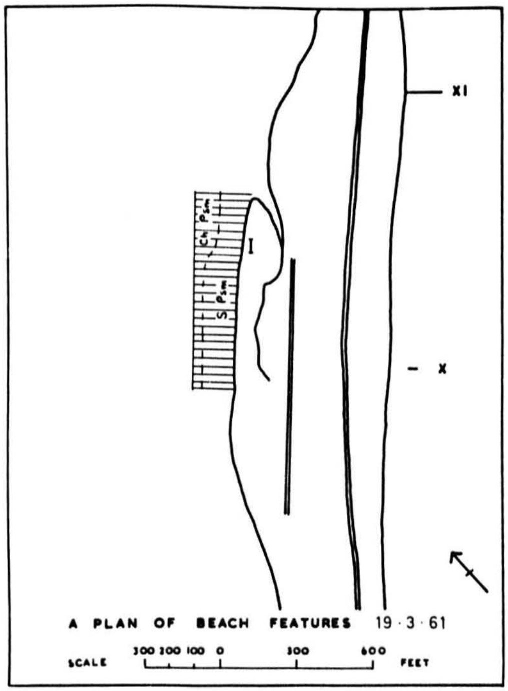
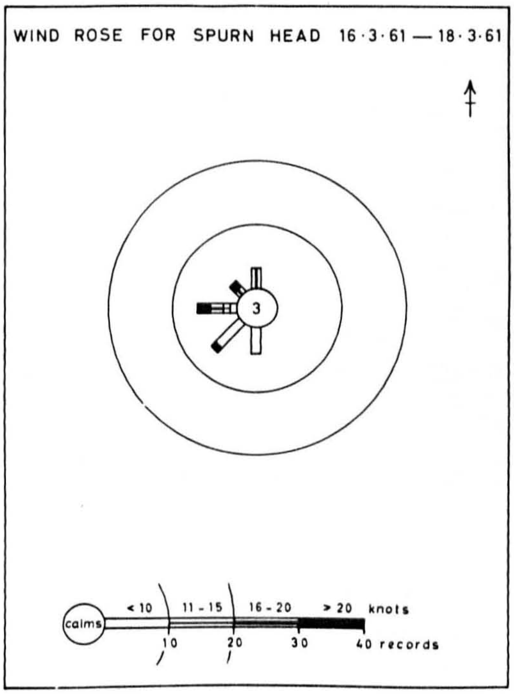
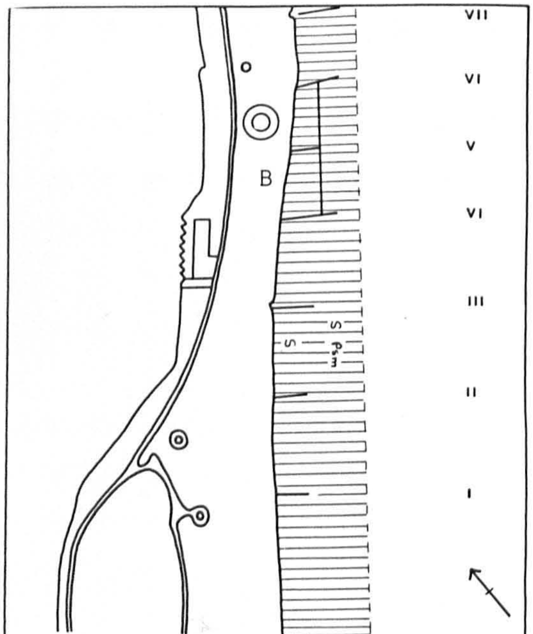


XI
X
Psm
Ch
Psm
S
I
A PLAN OF BEACH FEATURES 19·3·61
SCALE
300 200 100 0 300 600
FEET

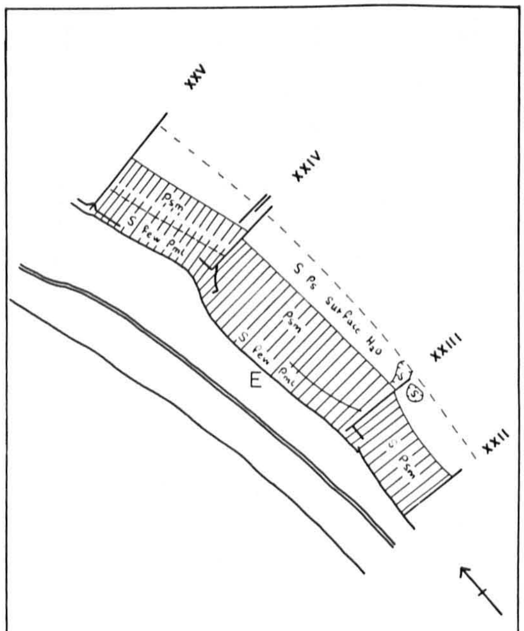


WIND ROSE FOR SPURN HEAD 16·3·61 — 18·3·61
3
calms
< 10
11 - 15
16 - 20
> 20 knots
10
20
30
40 records



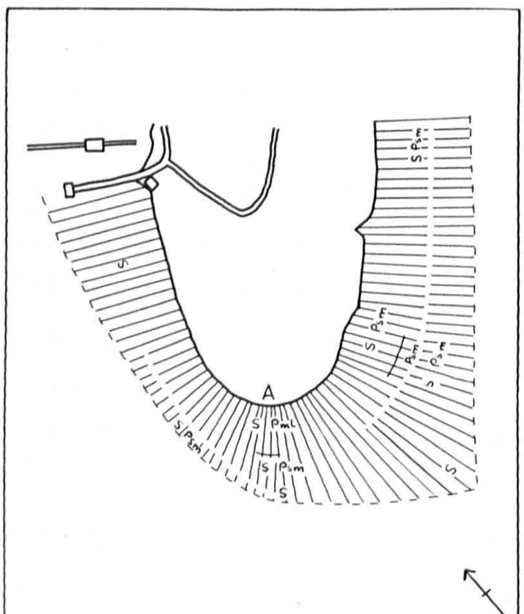
A PLAN OF BEACH FEATURES 22·3·61

SCALE 300 200 100 0 300 600 FEET



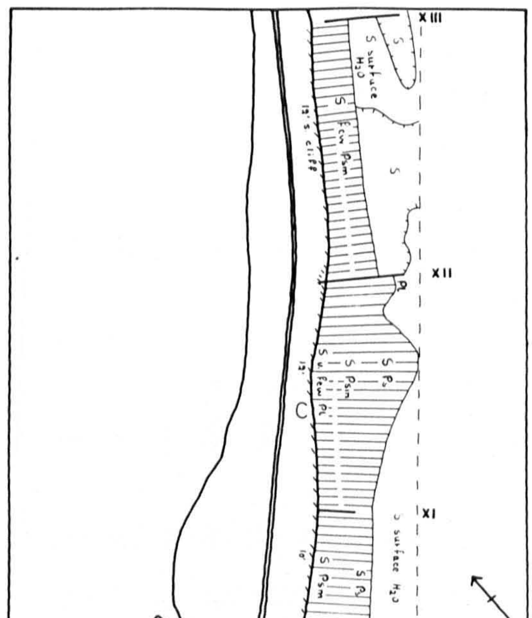
A PLAN OF BEACH FEATURES 22·3·61

SCALE 300 200 100 0 300 600 FEET



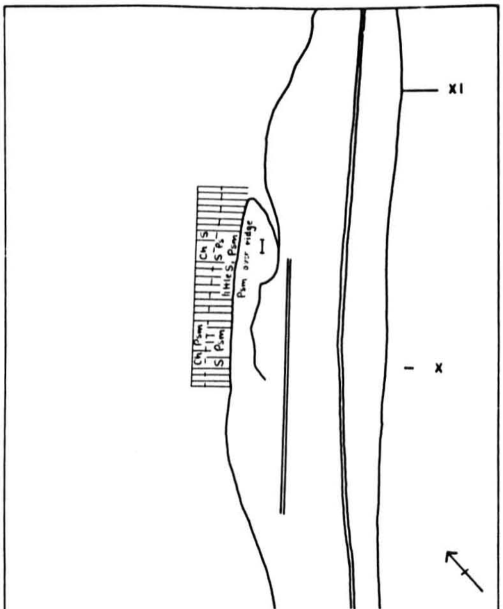
A PLAN OF BEACH FEATURES 22·3·61

SCALE 300 200 100 0 300 600 FEET

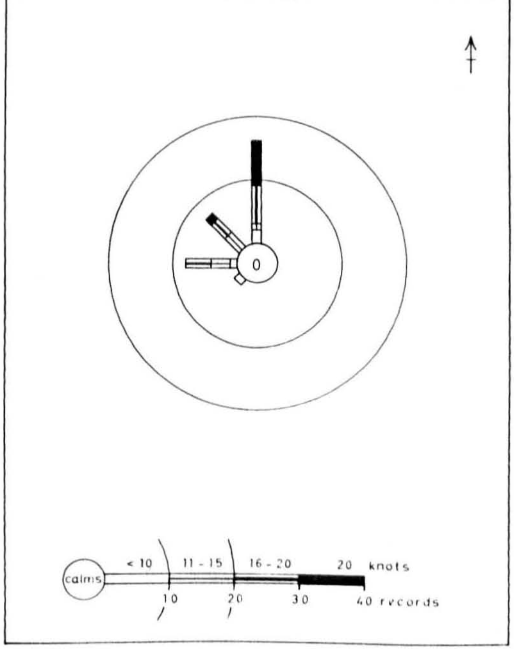


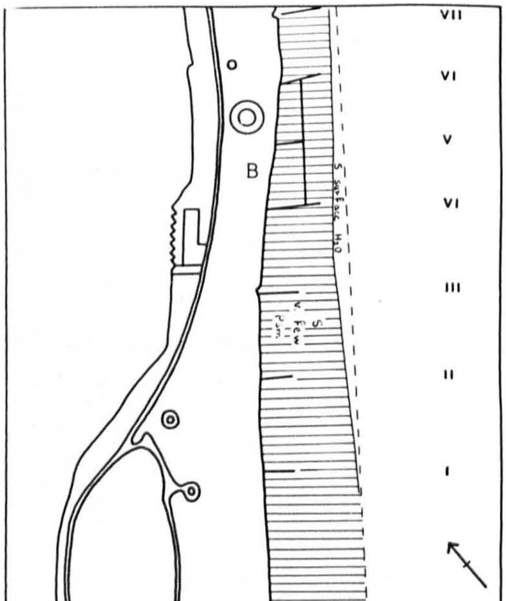
A PLAN OF BEACH FEATURES 22·3·61

SCALE 300 200 100 0 300 600 FEET



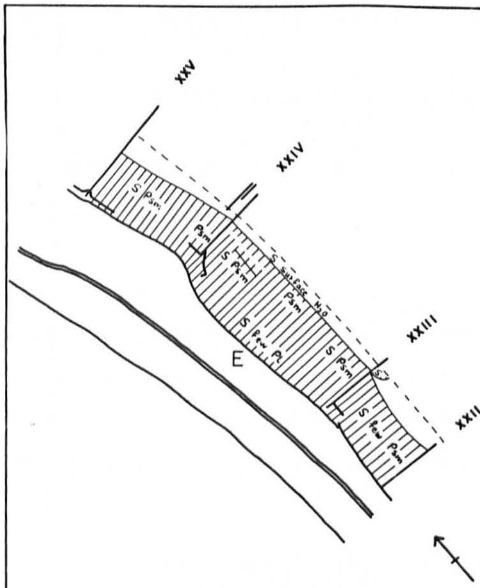
A PLAN OF BEACH FEATURES 22·3·61

WIND ROSE FOR SPURN HEAD 19·3·61 — 22·3·61




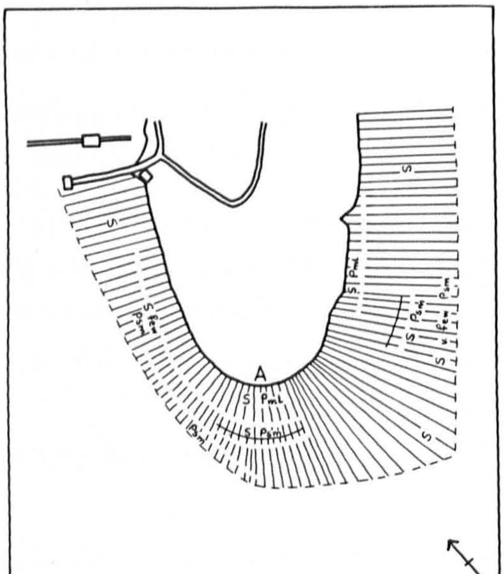
A PLAN OF BEACH FEATURES 29 · 3 · 61

SCALE 300 200 100 0 300 600 FEET



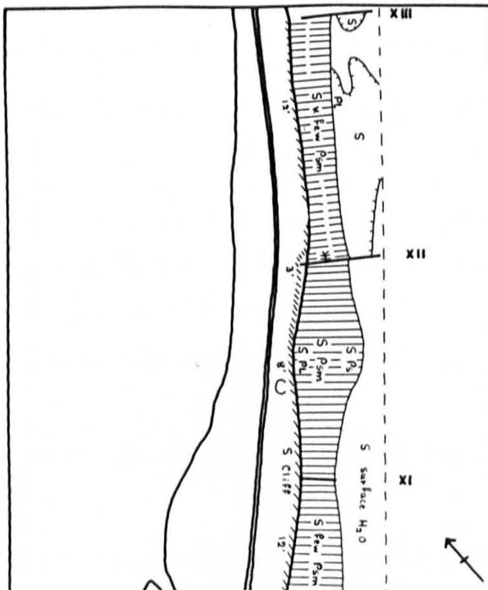
A PLAN OF BEACH FEATURES 29 · 3 · 61

SCALE 300 200 100 0 300 600 FEET



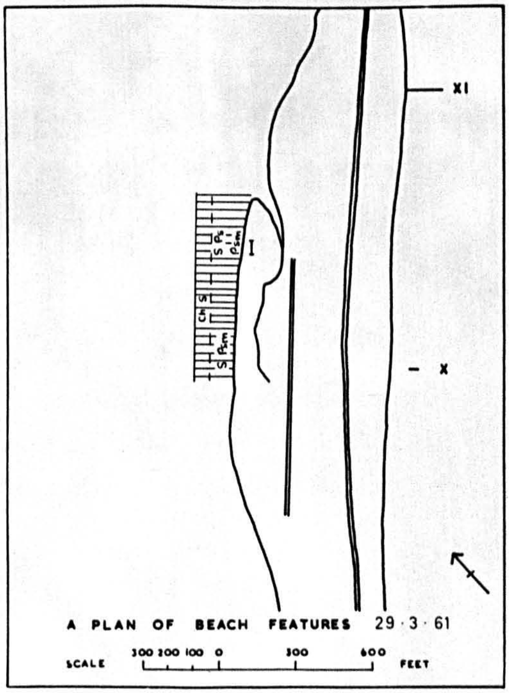
A PLAN OF BEACH FEATURES 29 · 3 · 61

SCALE 300 200 100 0 300 600 FEET

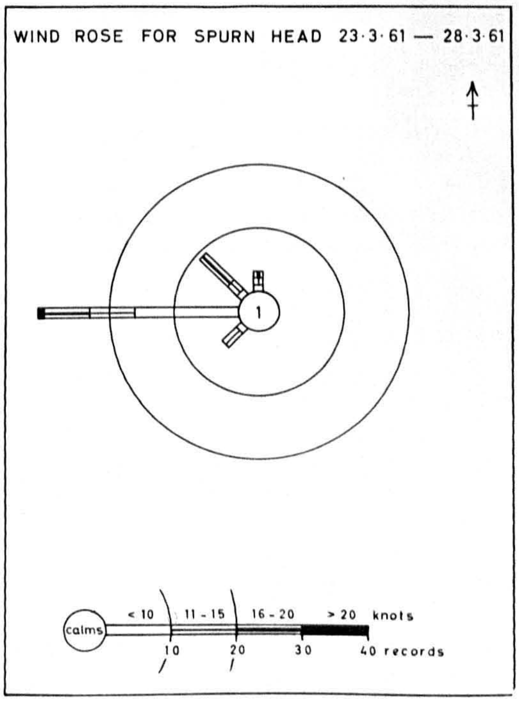


A PLAN OF BEACH FEATURES 29 · 3 · 61

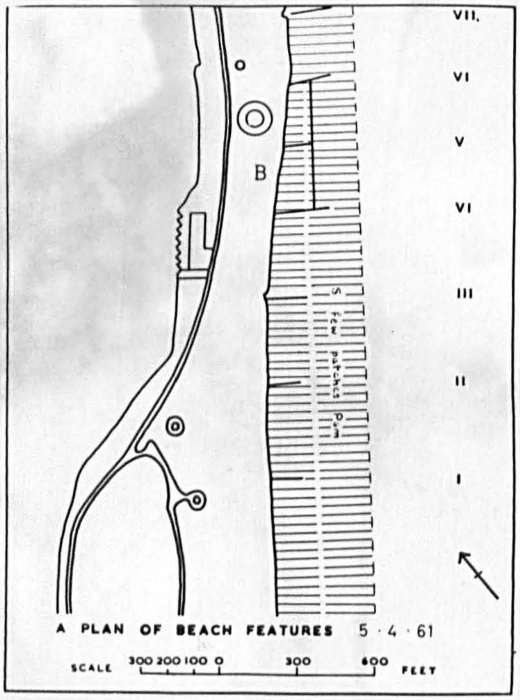
SCALE 300 200 100 0 300 600 FEET

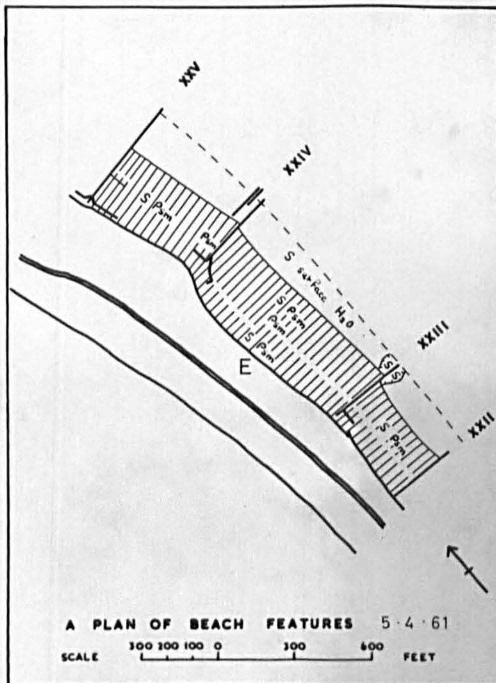


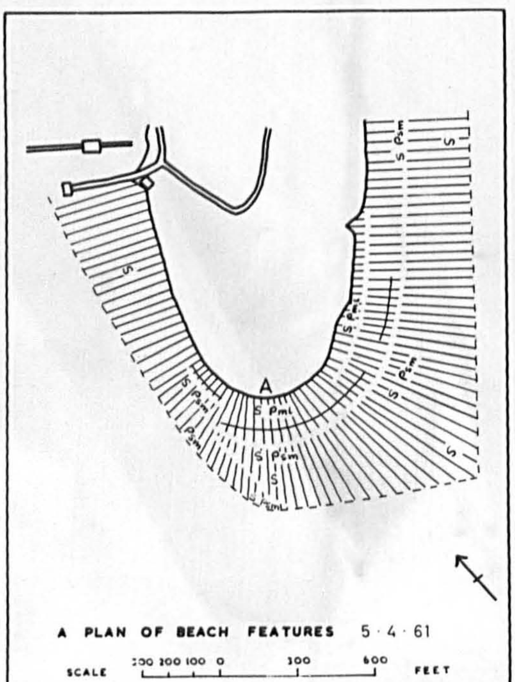
XI
X
I
A PLAN OF BEACH FEATURES 29·3·61
SCALE
300 200 100 0 300 600
FEET

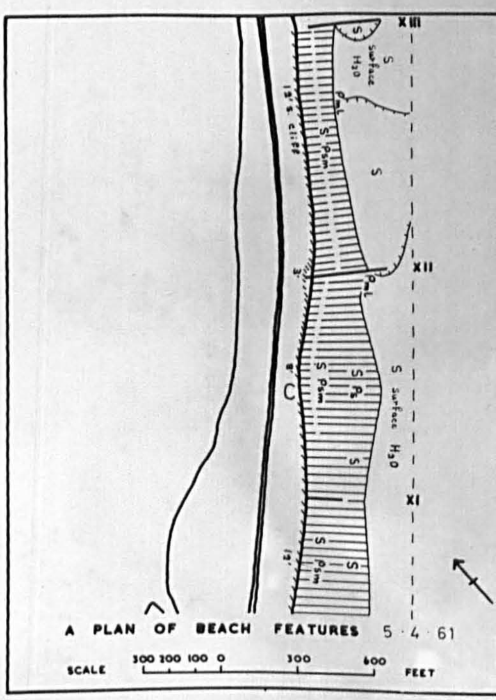


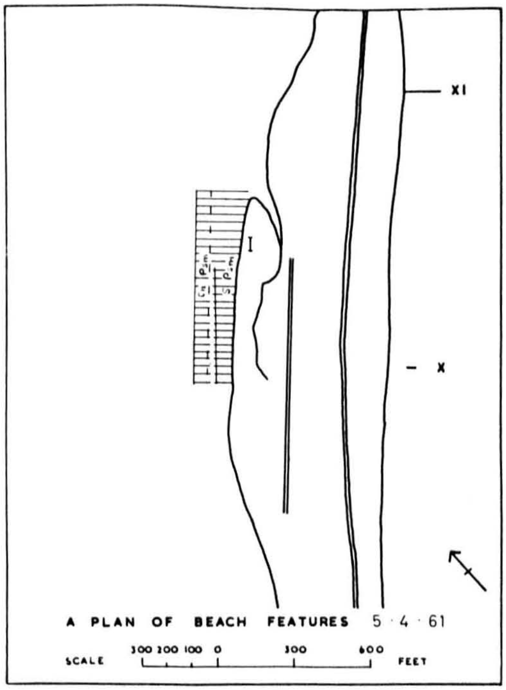
WIND ROSE FOR SPURN HEAD 23·3·61 — 28·3·61
1
calms
< 10
11 - 15
16 - 20
> 20 knots
10
20
30
40 records


VII.
VI
V
VI
III
II
I
B
S few patches P_sm
A PLAN OF BEACH FEATURES 5 · 4 · 61
SCALE 300 200 100 0 300 600 FEET

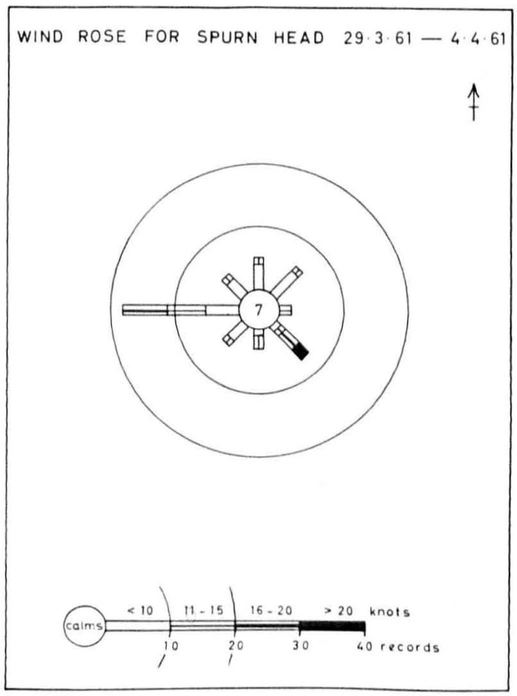

XXV
XXIV
XXIII
XXII
E
S surface H_2O
S P_sm
A PLAN OF BEACH FEATURES 5 · 4 · 61
SCALE 300 200 100 0 300 600 FEET


A
S
S P_sm
S P_ml
A PLAN OF BEACH FEATURES 5 · 4 · 61
SCALE 300 200 100 0 300 600 FEET


XIII
XII
XI
C
S surface H_2O
S P_sm
P_ml
A PLAN OF BEACH FEATURES 5 · 4 · 61
SCALE 300 200 100 0 300 600 FEET



XI
X
I
A PLAN OF BEACH FEATURES 5·4·61
SCALE
300 200 100 0 300 600
FEET



WIND ROSE FOR SPURN HEAD 29·3·61 — 4·4·61
7
calms
< 10
11 - 15
16 - 20
> 20 knots
10
20
30
40 records

BEACH FEATURES AT SPURN HEAD

AT INTERVALS OF 6 WEEKS FROM APRIL 1960 TO APRIL 1961

Direction of slope of upper beach

Convex break of slope on upper beach

Concave break of slope on upper beach

Cliff

Upper / lower beach division

Rises on lower beach

S Sand

Sh Fine shingle

Ps Pebbles < 2 ins. long diameter

Pm Pebbles 2 - 4 ins. long diameter

Pl Pebbles > 4 ins. long diameter

BC Boulder clay

M Mud

--- Low water mark

0 2000

feet

Fig. 2.3

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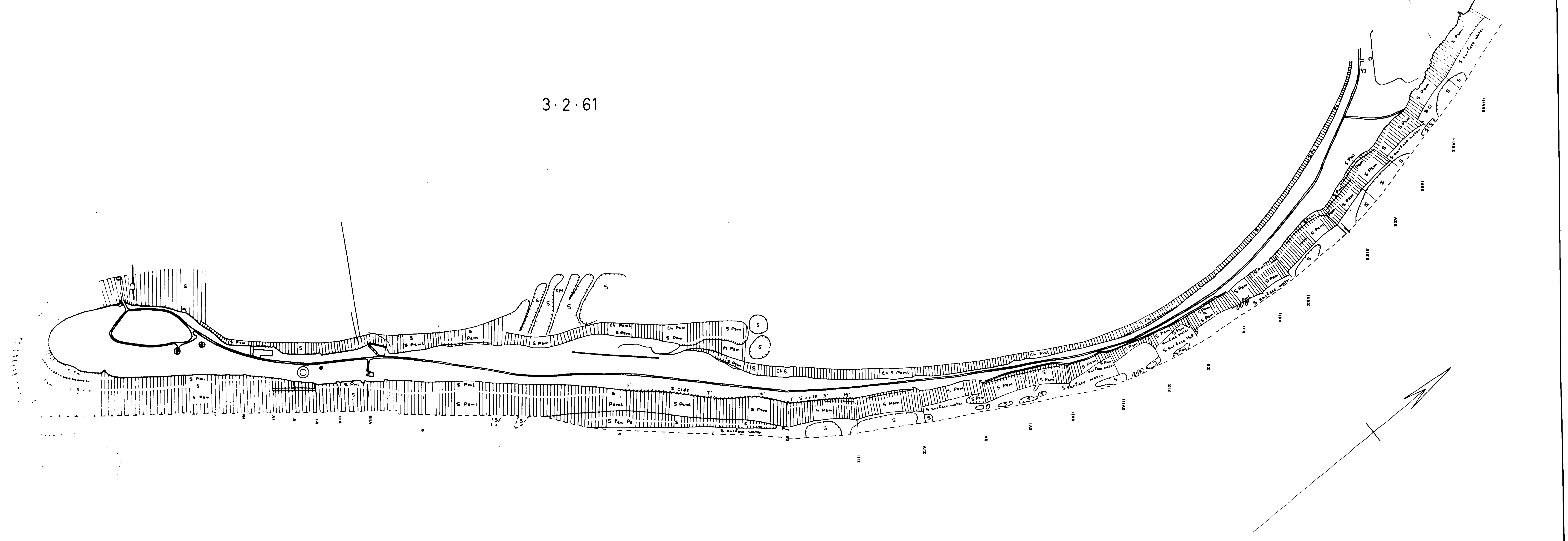
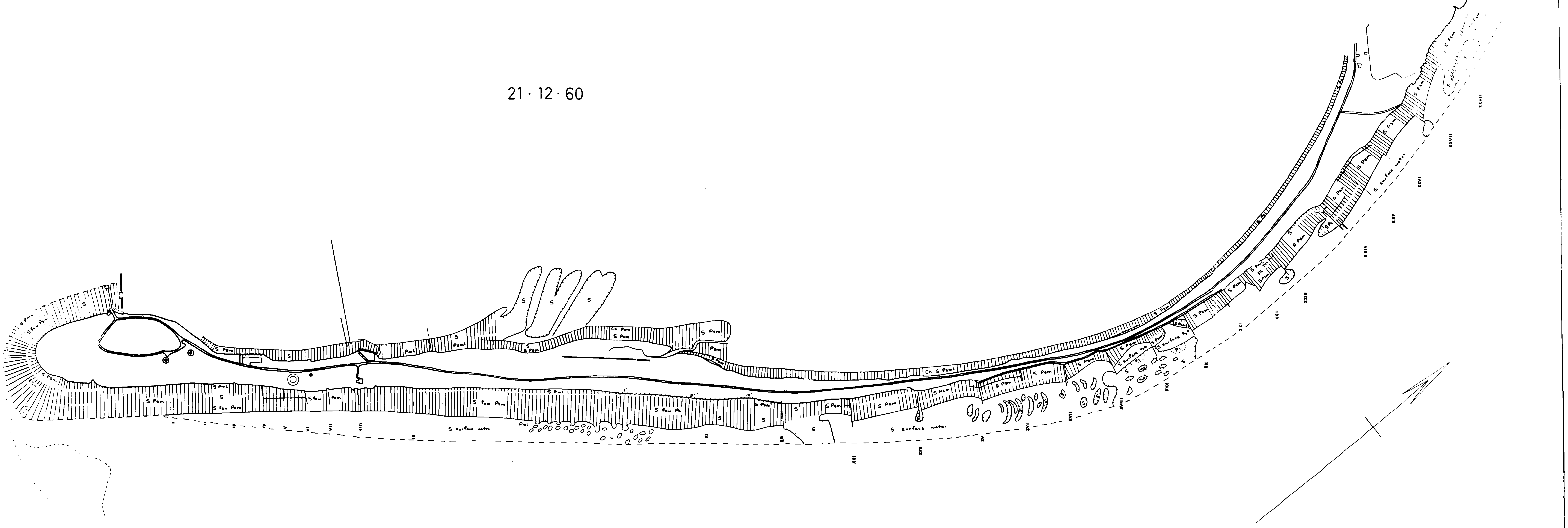
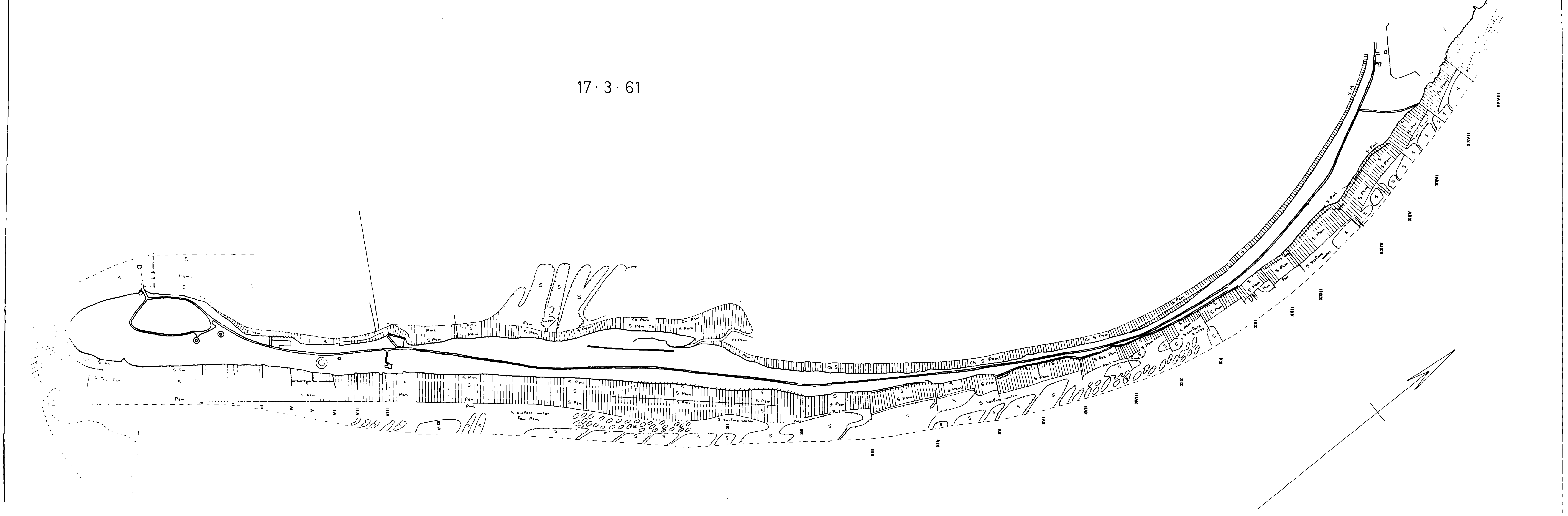
PULLOUTS

3·2·61

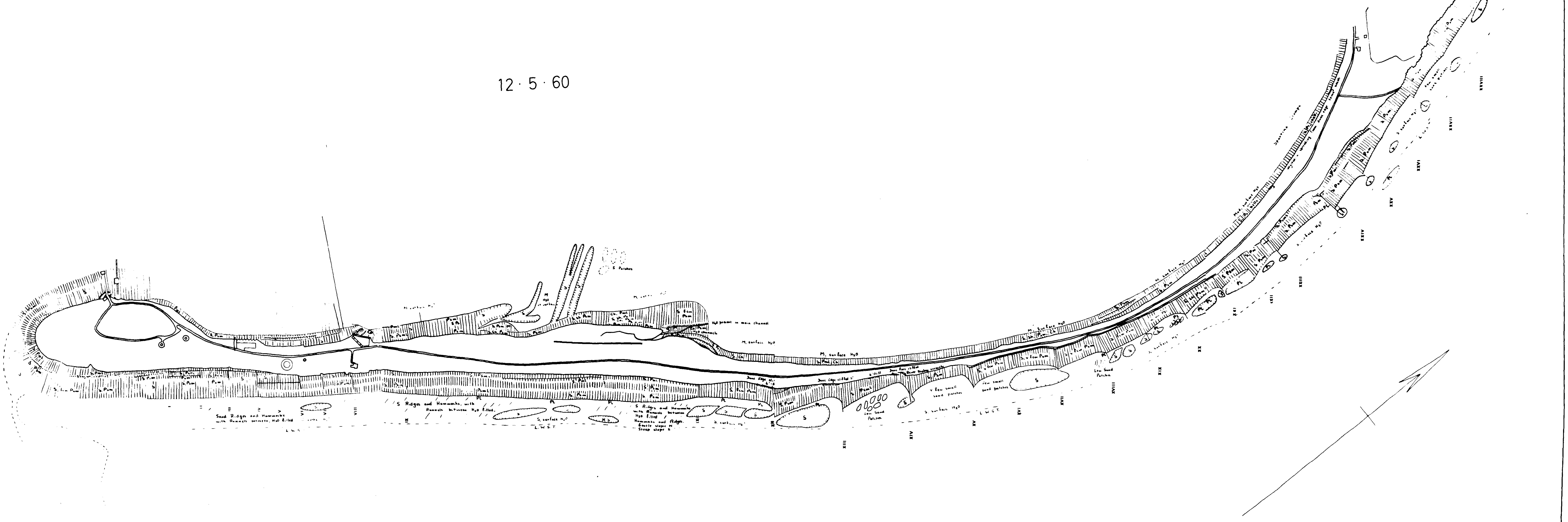


21 · 12 · 60



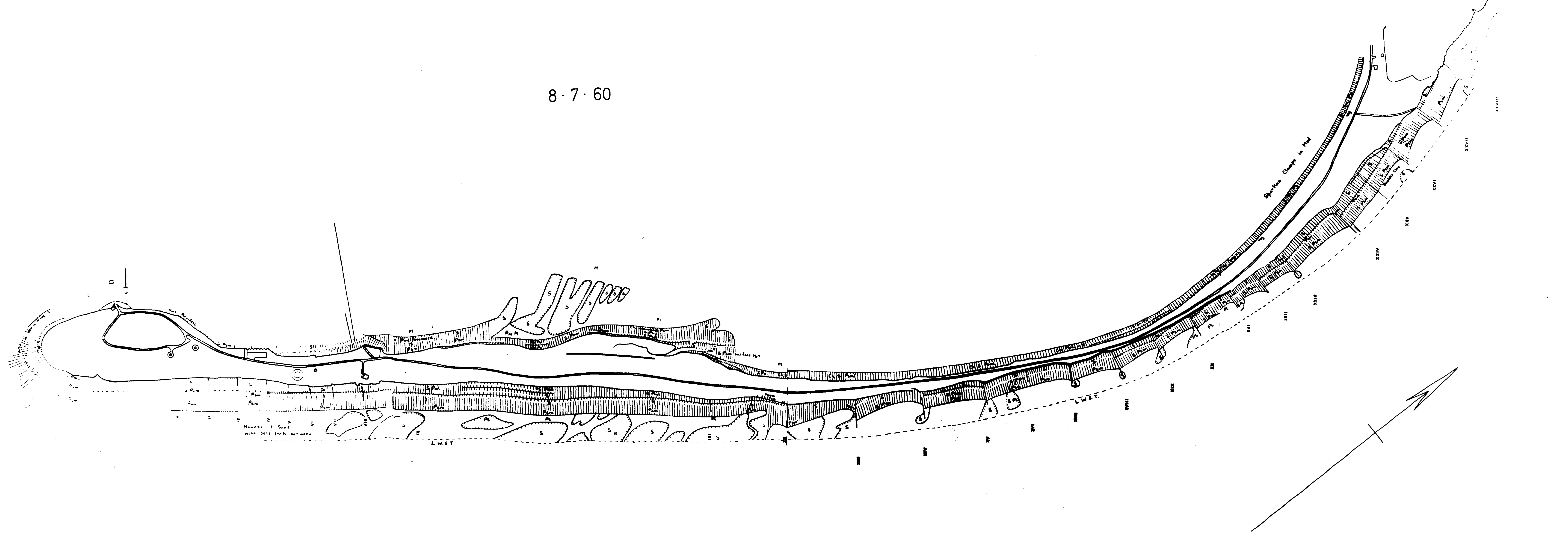

17 · 3 · 61

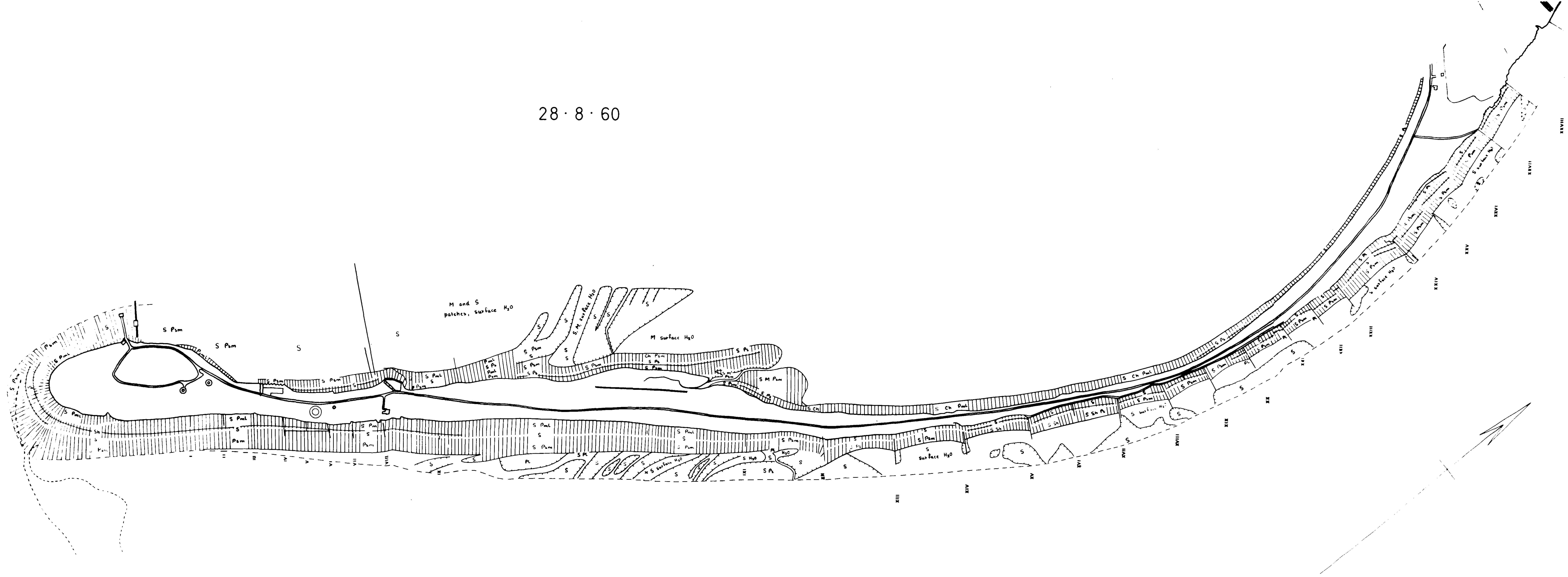
12 · 5 · 60



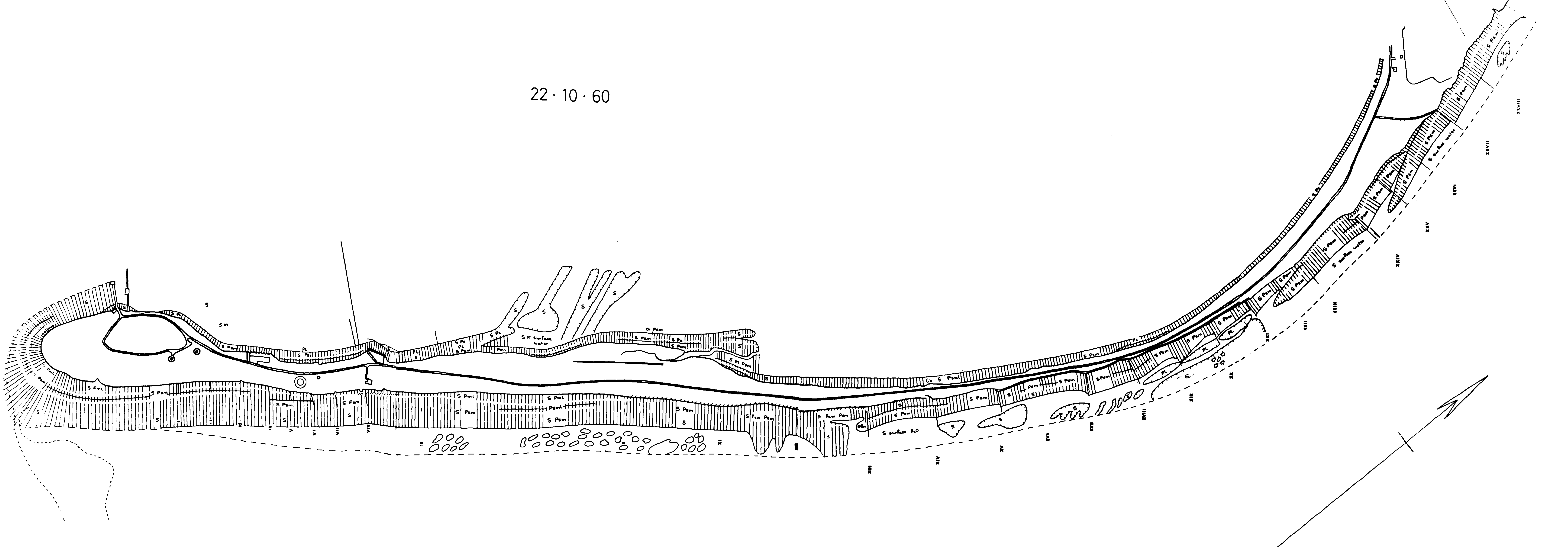
Sand Ridges and Hummocks with Runnels between, H2O filled
S Ridges and Hummocks, with Runnels between H2O filled.
S, surface H2O
L. W. S. T.
S Ridges and Hummocks with Runnels between H2O filled
Hummocks and Ridges. Gentle slope N Steep slope S
Dune Edge cliffed 5'
Low Sand Patches
V few small sand patches
Few small sand patches
S. surface H2O
M. surface H2O
S. Patches

8 · 7 · 60


Spartina Clumps in Mud
Mounds of Sand with Salt pools between
L.W.S.T.
L.W.S.T.


28 · 8 · 60
M and S
patches, surface H2O
M surface H2O
S Psm
S Ch Pml
surface H2O

22 · 10 · 60



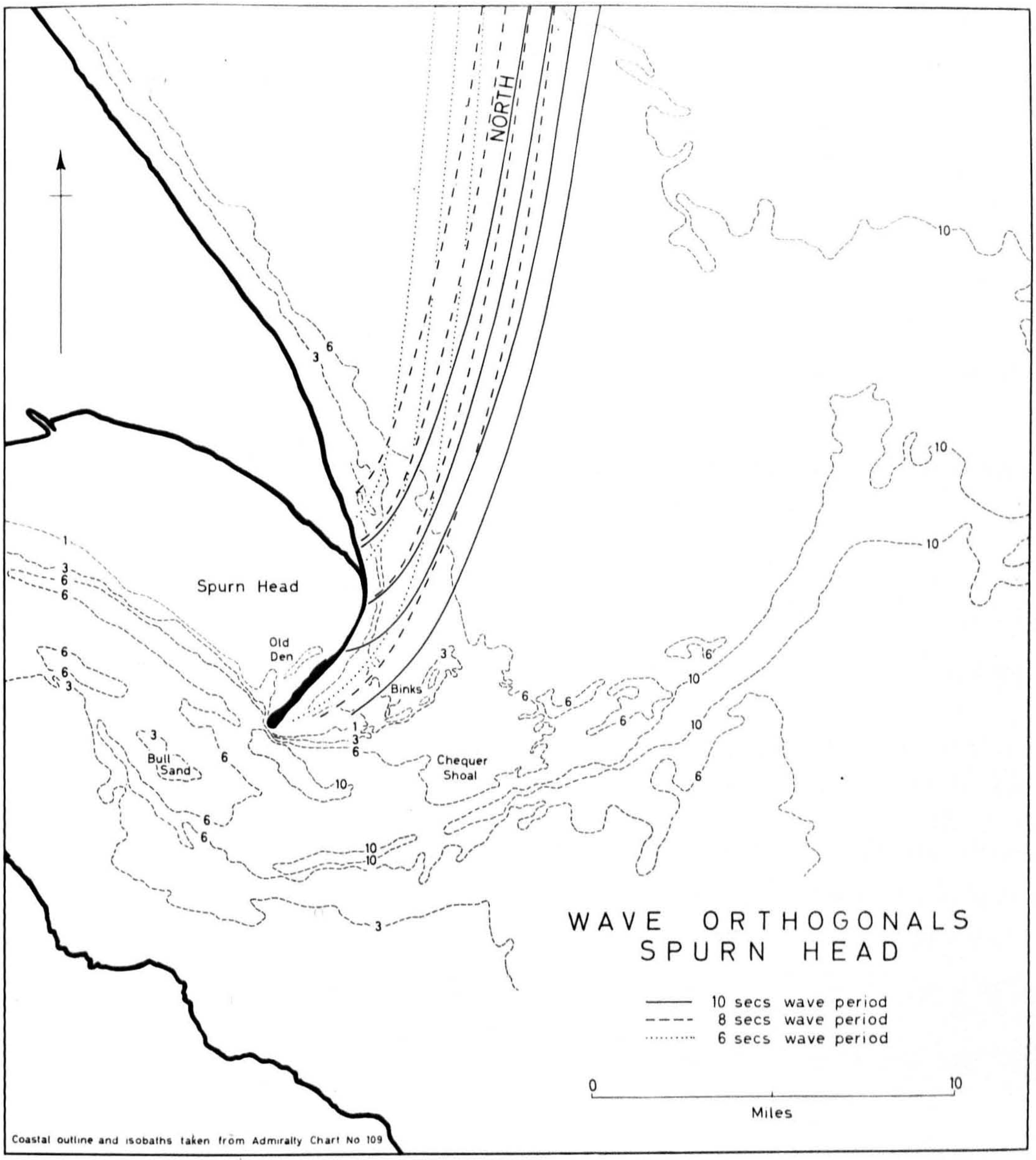

WAVE ORTHOGONALS
SPURN HEAD
10 secs wave period
8 secs wave period
6 secs wave period
0
10
Miles
NORTH
Spurn Head
Old Den
Binks
Bull Sand
Chequer Shoal
Coastal outline and isobaths taken from Admiralty Chart No 109

Fig.3.1

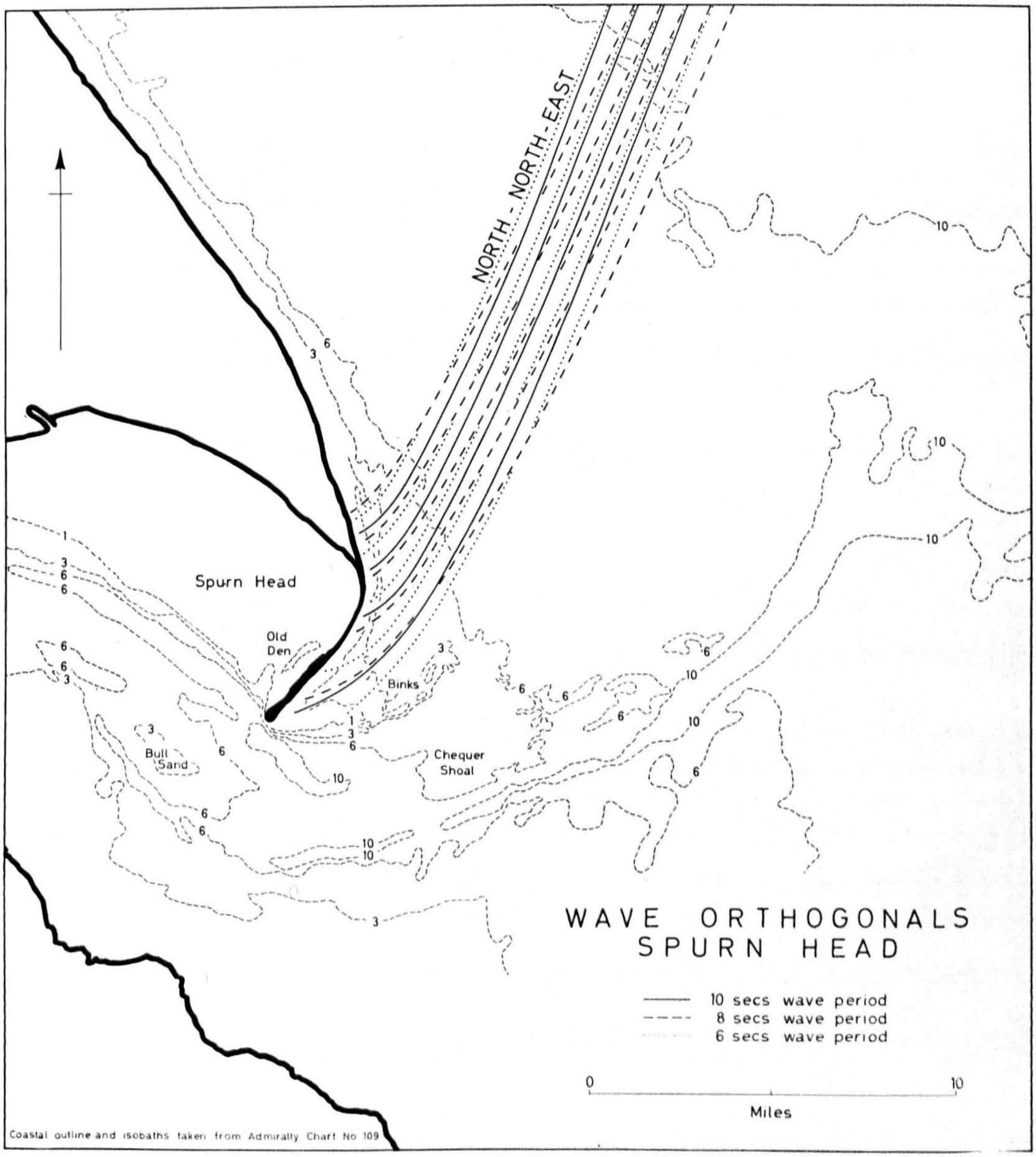

NORTH - NORTH - EAST
Spurn Head
Old Den
Binks
Bull Sand
Chequer Shoal
WAVE ORTHOGONALS
SPURN HEAD
10 secs wave period
8 secs wave period
6 secs wave period
0
10
Miles
Coastal outline and isobaths taken from Admiralty Chart No 109

Fig.3.2

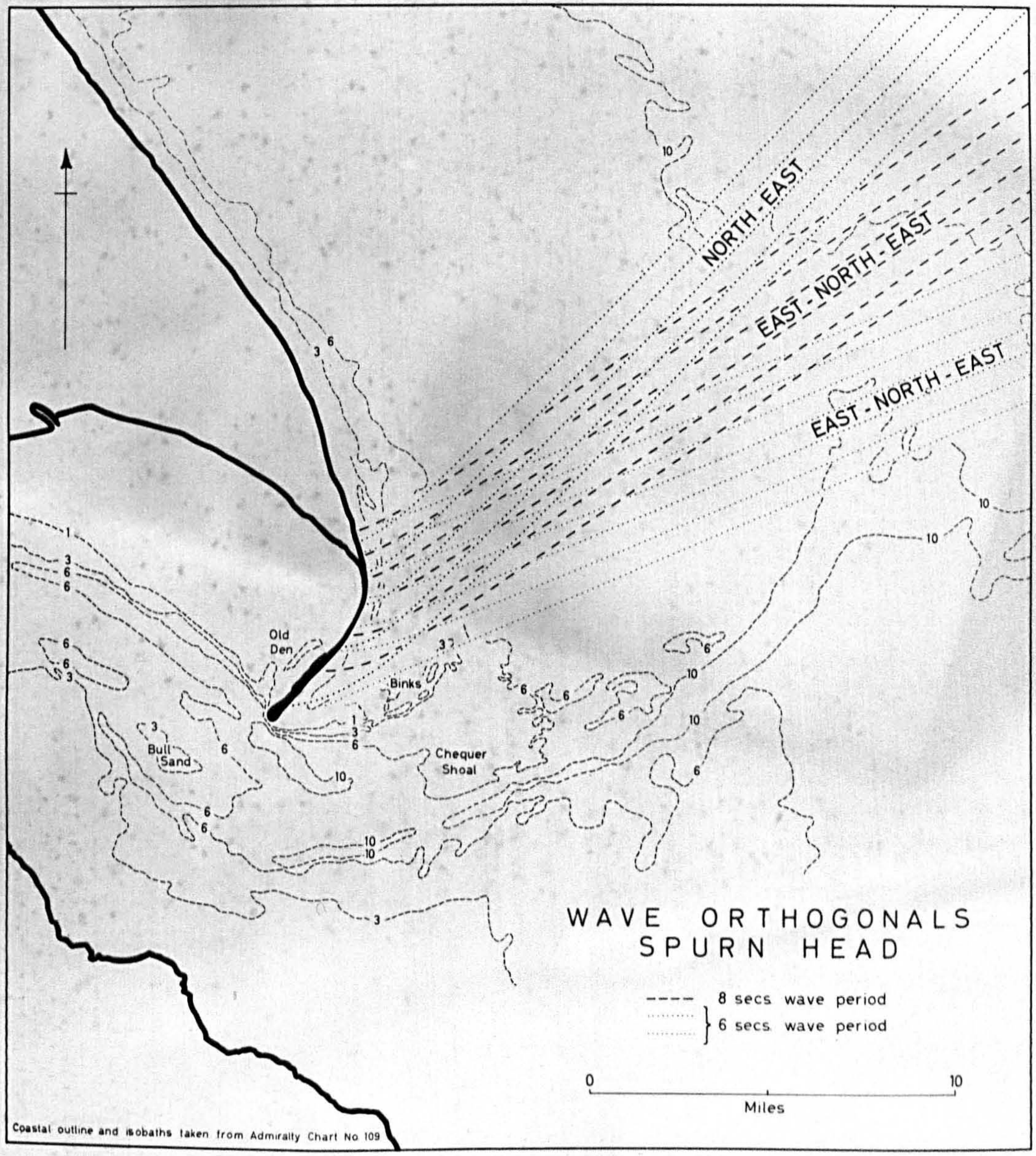
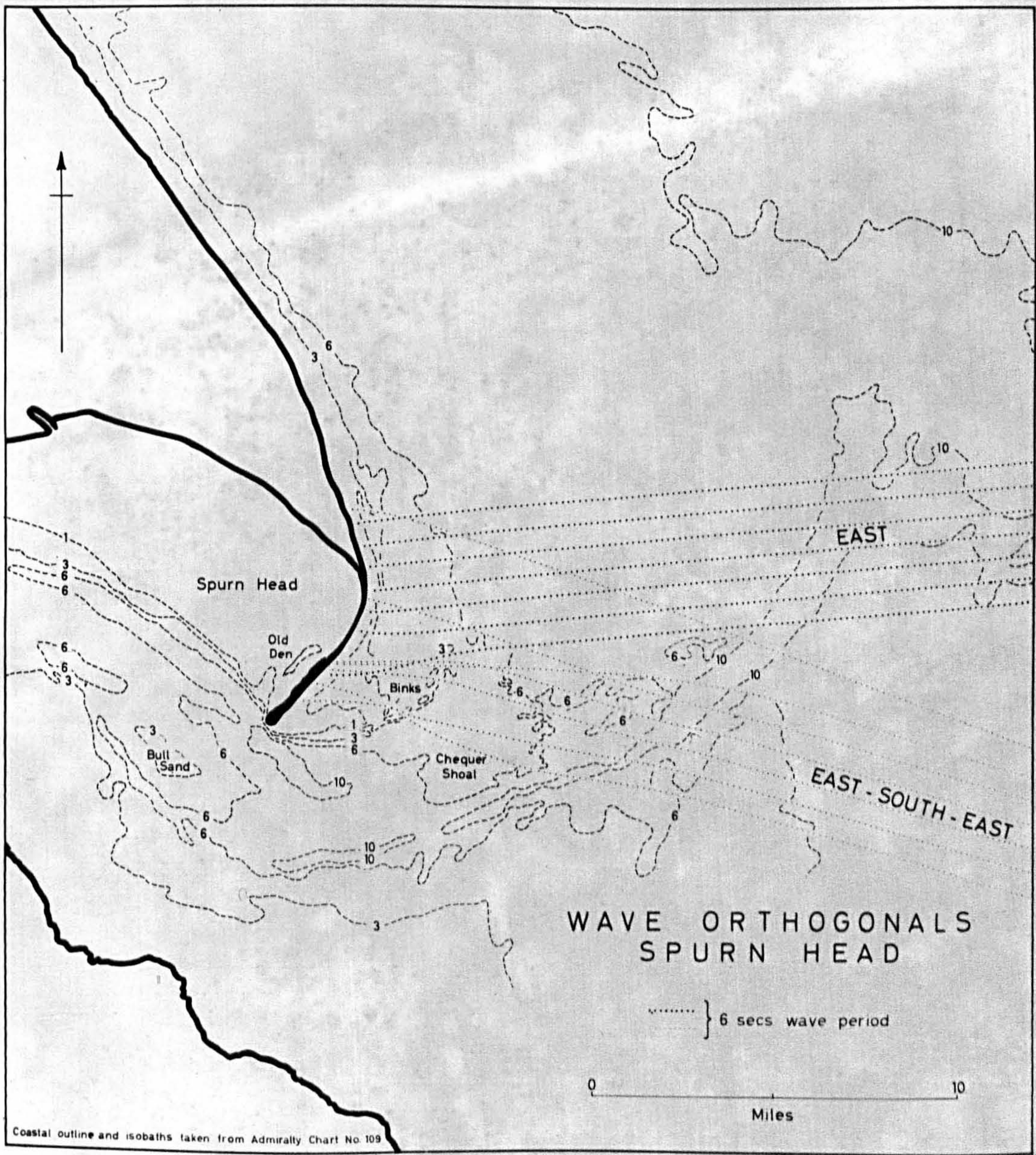

WAVE ORTHOGONALS
SPURN HEAD
8 secs wave period
6 secs wave period
0
10
Miles
NORTH - EAST
EAST - NORTH - EAST
EAST - NORTH - EAST
Old
Den
Binks
Bull
Sand
Chequer
Shoal
Coastal outline and isobaths taken from Admiralty Chart No 109

Fig.3.3



WAVE ORTHOGONALS
SPURN HEAD
6 secs wave period
Spurn Head
Old Den
Binks
Bull Sand
Chequer Shoal
EAST
EAST - SOUTH - EAST
0
10
Miles
Coastal outline and isobaths taken from Admiralty Chart No. 109

Fig.3.4

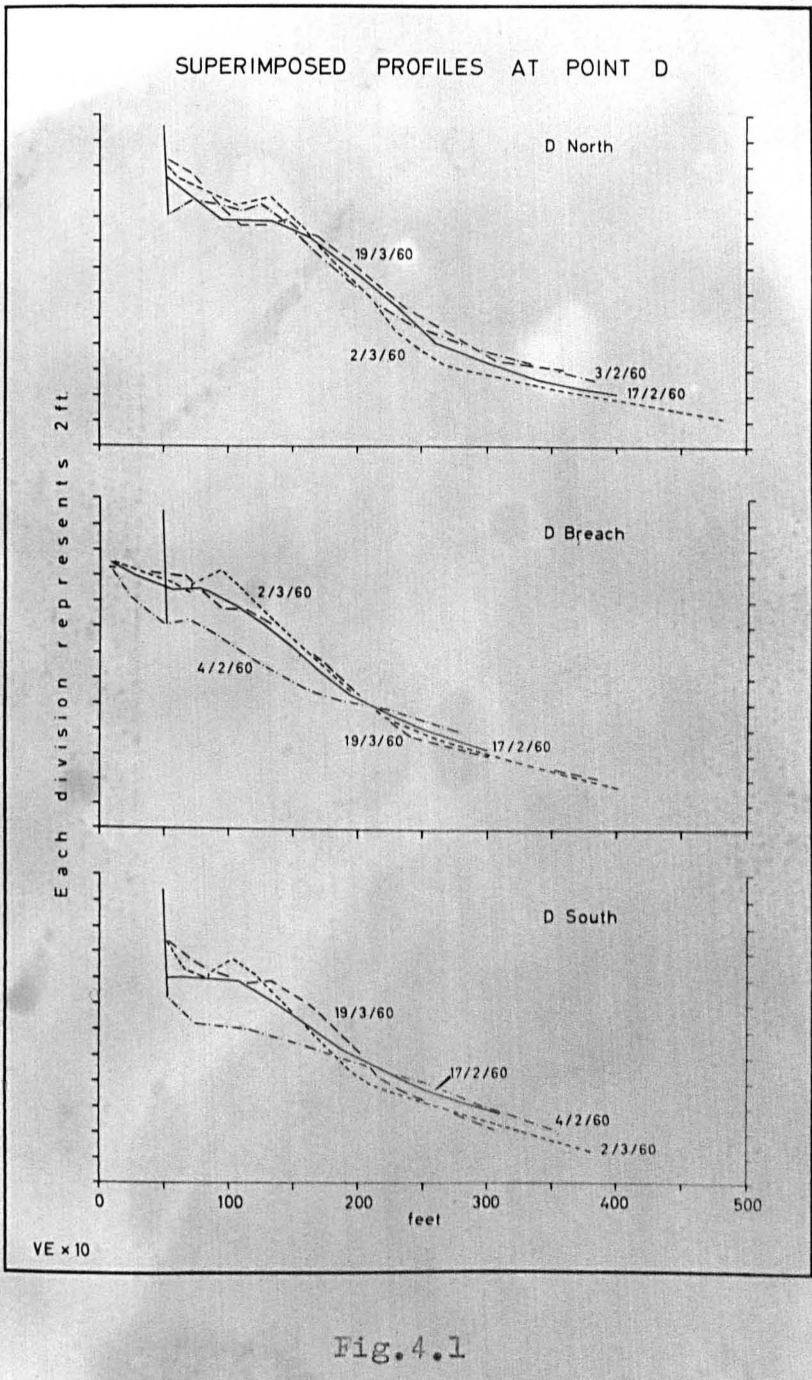

SUPERIMPOSED PROFILES AT POINT D
D North
19/3/60
2/3/60
3/2/60
17/2/60
D Breach
2/3/60
4/2/60
19/3/60
17/2/60
D South
19/3/60
17/2/60
4/2/60
2/3/60
Each division represents 2 ft.
0
100
200
300
400
500
feet
VE × 10

Fig.4.1

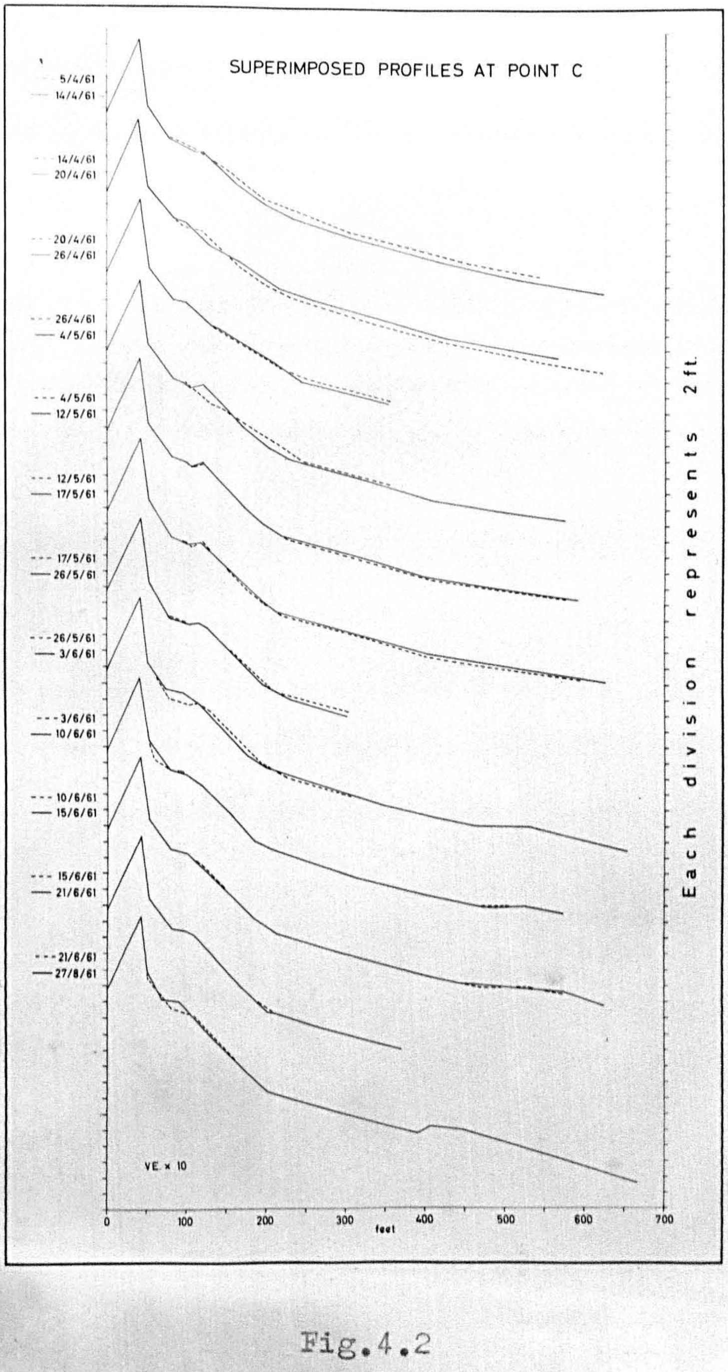

SUPERIMPOSED PROFILES AT POINT C
5/4/61
14/4/61
14/4/61
20/4/61
20/4/61
26/4/61
26/4/61
4/5/61
4/5/61
12/5/61
12/5/61
17/5/61
17/5/61
26/5/61
26/5/61
3/6/61
3/6/61
10/6/61
10/6/61
15/6/61
15/6/61
21/6/61
21/6/61
27/8/61
VE. × 10
0
100
200
300
400
500
600
700
feet
Each division represents 2ft.

Fig.4.2

BEACH FEATURES AT POINT C

APRIL TO JUNE 1961

Direction of slope of upper beach

Convex break of slope on upper beach

Concave break of slope on upper beach

Cliff

Upper / lower beach division

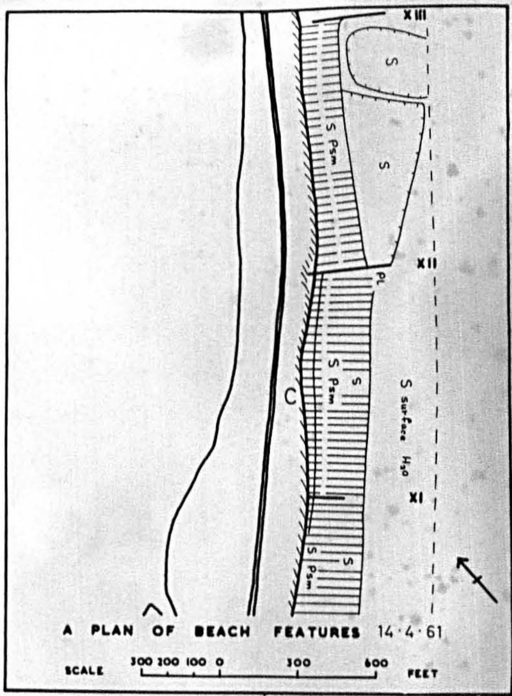
Rises on lower beach

S	Sand
Sh	Fine shingle
Ps	Pebbles <2 ins. long diameter
Pm	Pebbles 2 - 4 ins. long diameter
Pl	Pebbles >4 ins. long diameter
BC	Boulder clay
M	Mud

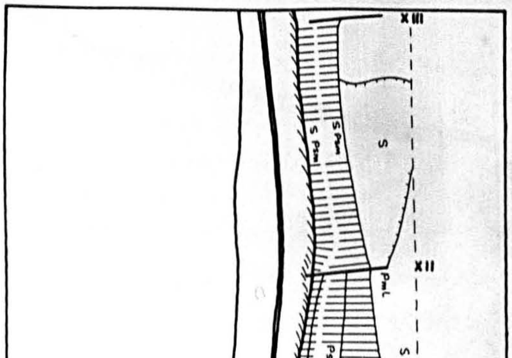
--- Low water mark

0 2000
feet

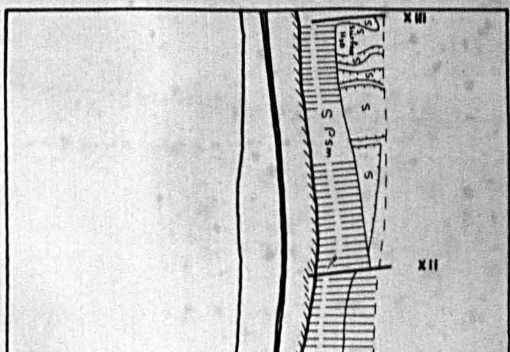
Fig. 4.3



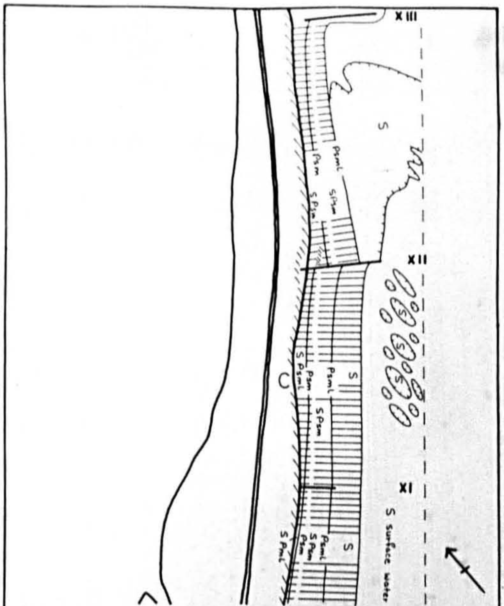
A PLAN OF BEACH FEATURES 14·4·61



A PLAN OF BEACH FEATURES 20·4·61

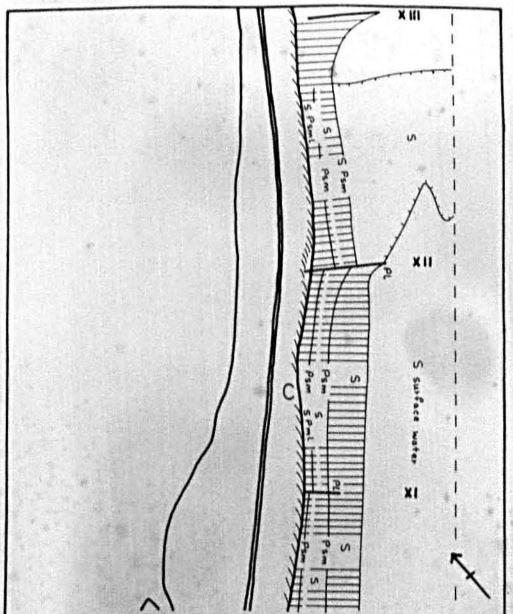


A PLAN OF BEACH FEATURES 26·4·61



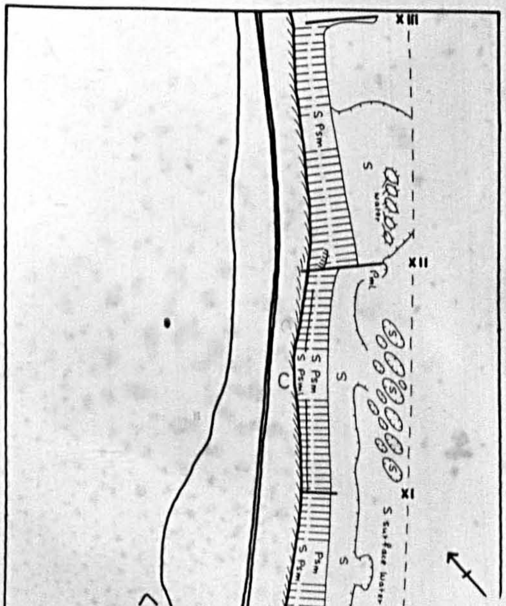
A PLAN OF BEACH FEATURES 4·5·61

SCALE 300 200 100 0 300 600 FEET



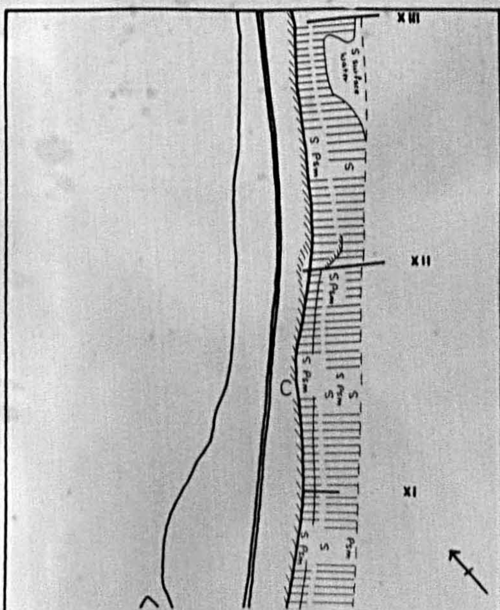
A PLAN OF BEACH FEATURES 12·5·61

SCALE 300 200 100 0 300 600 FEET



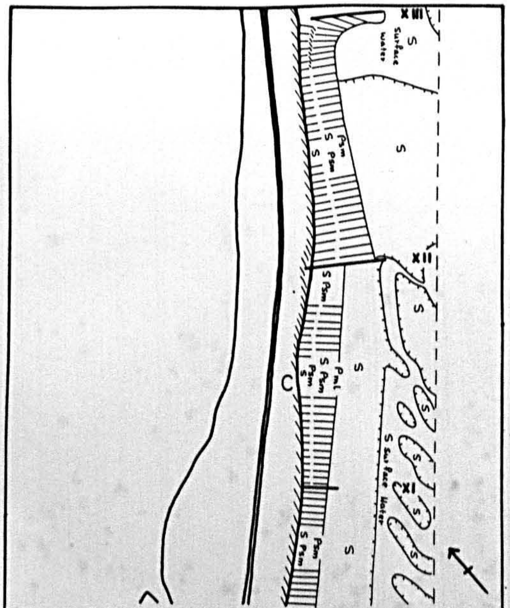
A PLAN OF BEACH FEATURES 17·5·61

SCALE 300 200 100 0 300 600 FEET



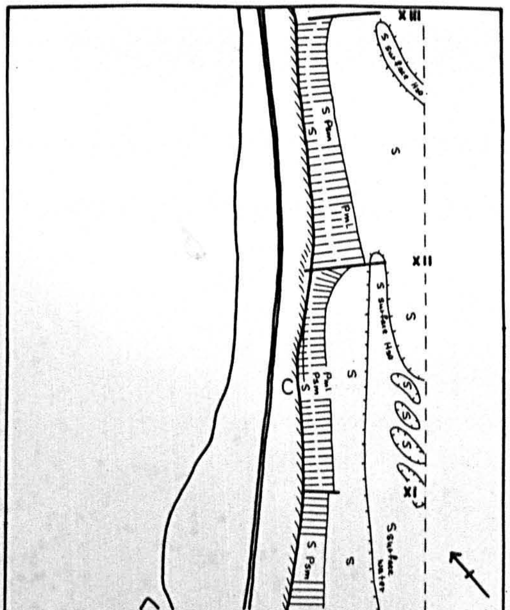
A PLAN OF BEACH FEATURES 26·5·61

SCALE 300 200 100 0 300 600 FEET



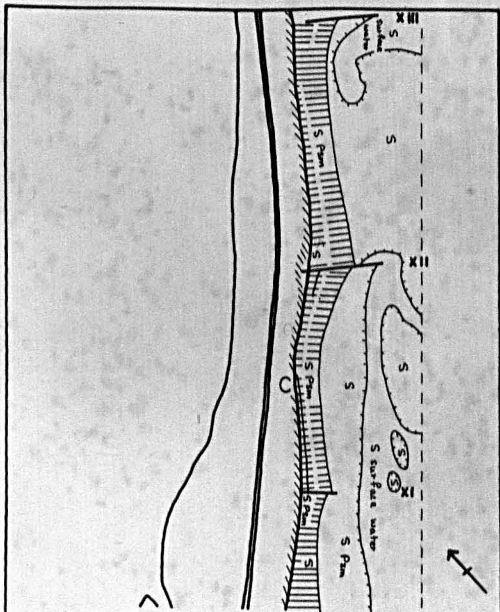
A PLAN OF BEACH FEATURES 3·6·61

SCALE 300 200 100 0 300 600 FEET



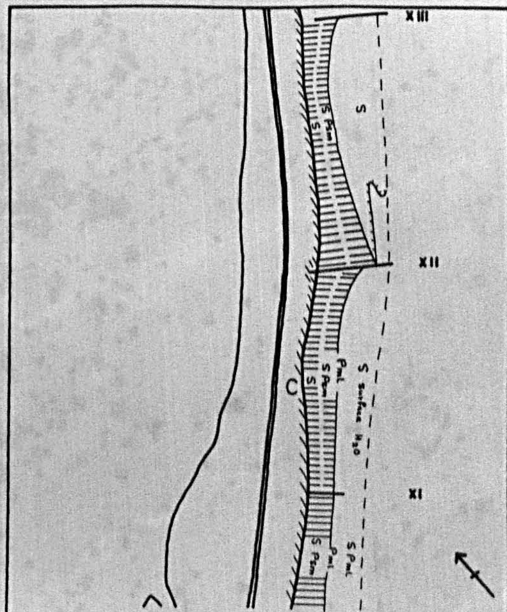
A PLAN OF BEACH FEATURES 10·6·61

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 15·6·61

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 21·6·61

SCALE 300 200 100 0 300 600 FEET

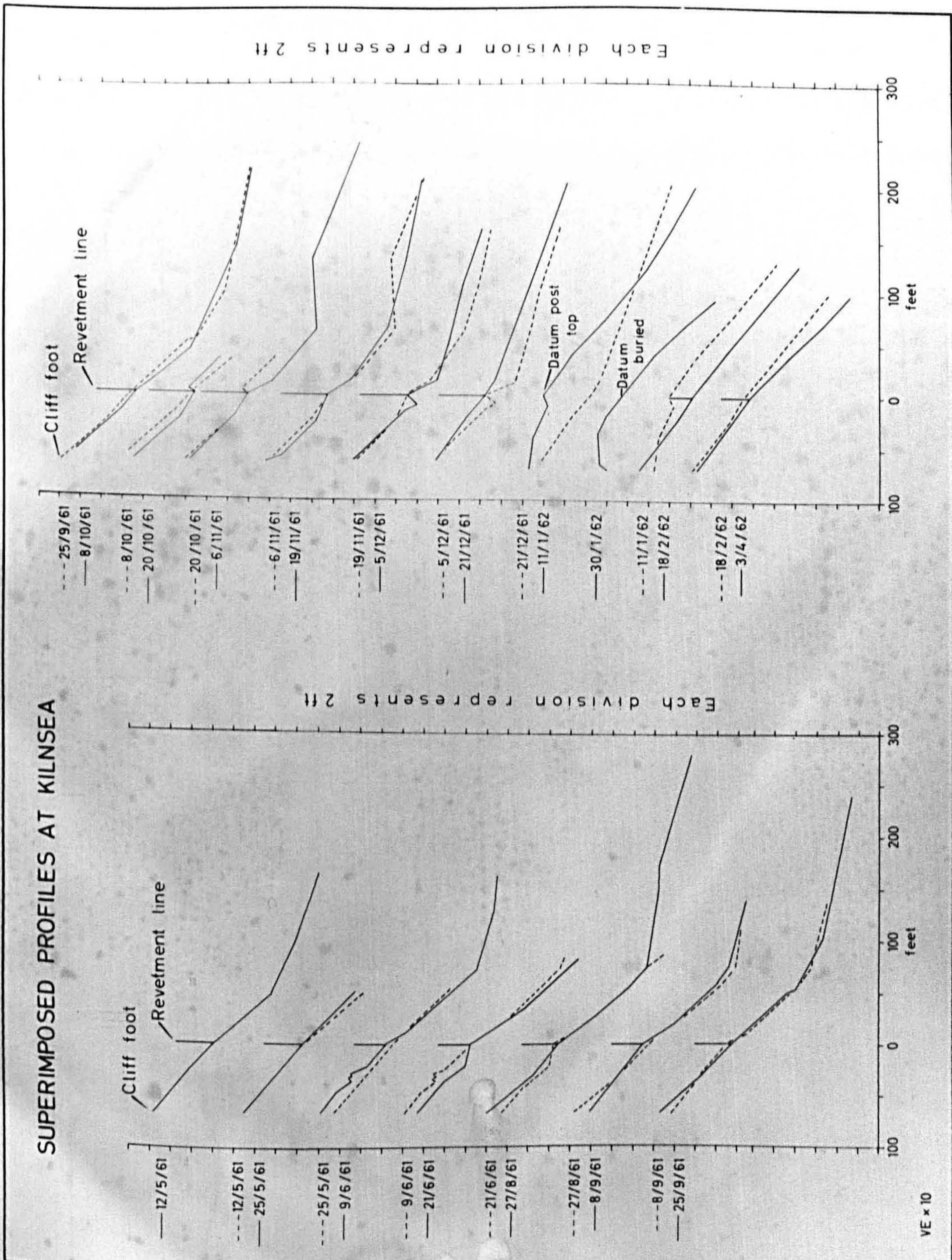

SUPERIMPOSED PROFILES AT KILNSEA
Cliff foot
Revetment line
Each division represents 2ft
100
0
100
200
300
feet
12/5/61
12/5/61
25/5/61
25/5/61
9/6/61
9/6/61
21/6/61
21/6/61
27/8/61
27/8/61
8/9/61
8/9/61
25/9/61
VE × 10
Cliff foot
Revetment line
Datum post top
Datum buried
Each division represents 2ft
25/9/61
8/10/61
8/10/61
20/10/61
20/10/61
6/11/61
6/11/61
19/11/61
19/11/61
5/12/61
5/12/61
21/12/61
21/12/61
11/1/62
30/1/62
11/1/62
18/2/62
18/2/62
3/4/62

Fig.4.4

BEACH FEATURES AT KILNSEA

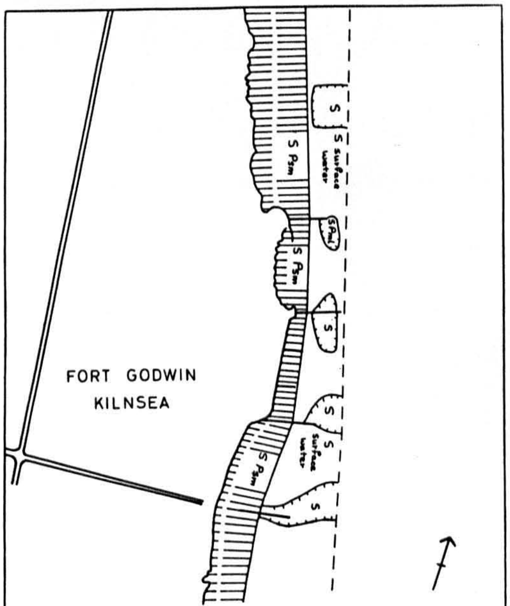
APRIL 1961 TO APRIL 1962

	Direction of slope of upper beach
	Convex break of slope on upper beach
	Concave break of slope on upper beach
	Cliff
	Upper / lower beach division
	Rises on lower beach
S	Sand
Sh	Fine shingle
Ps	Pebbles $<$2ins. long diameter
Pm	Pebbles 2 - 4ins. long diameter
Pl	Pebbles $>$4ins. long diameter
BC	Boulder clay
M	Mud
---	Low water mark

0 2000

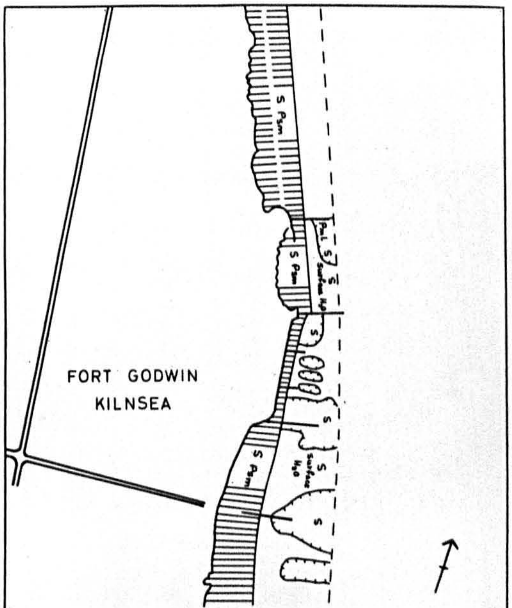
feet

Fig. 4.5



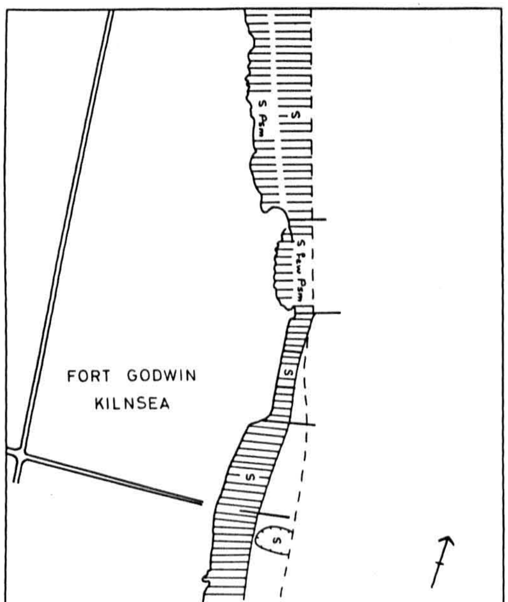
A PLAN OF BEACH FEATURES 29·4·61

SCALE 300 200 100 0 300 600 FEET



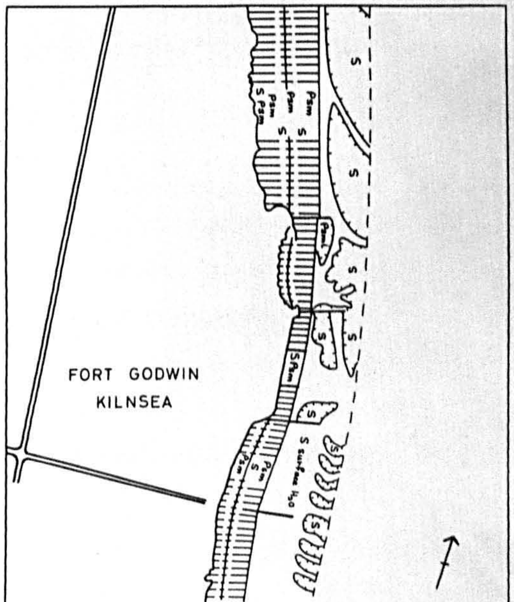
A PLAN OF BEACH FEATURES 12·5·61

SCALE 300 200 100 0 300 600 FEET



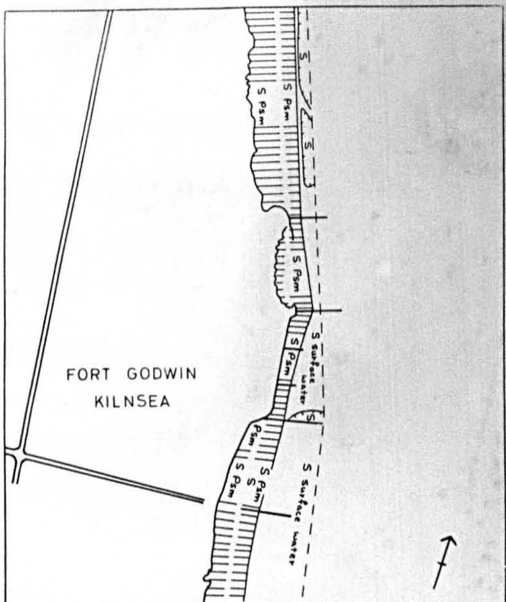
A PLAN OF BEACH FEATURES 26·5·61

SCALE 300 200 100 0 300 600 FEET

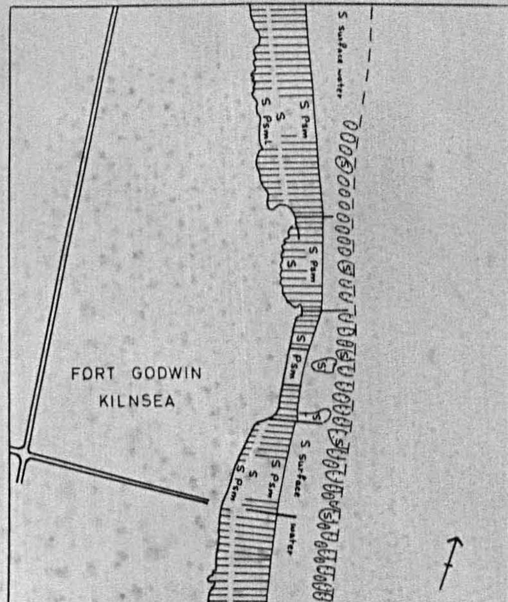


A PLAN OF BEACH FEATURES 9·6·61

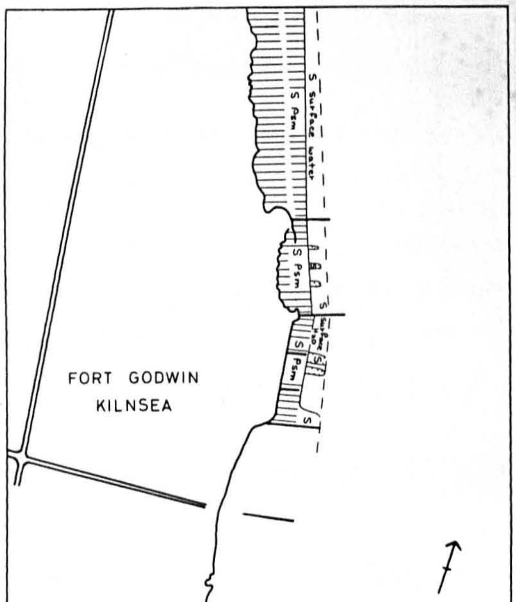
SCALE 300 200 100 0 300 600 FEET



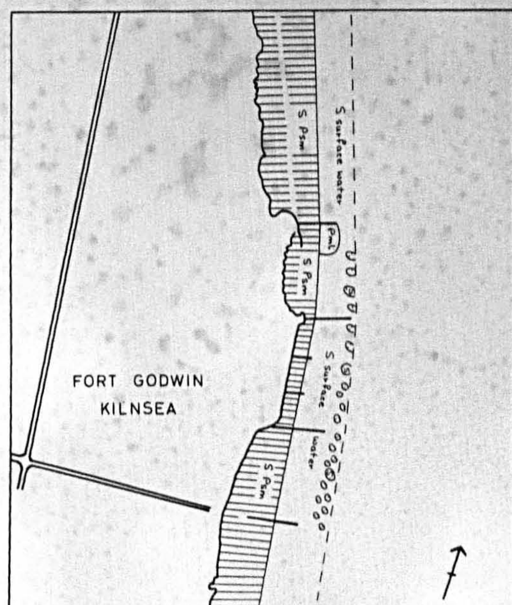
A PLAN OF BEACH FEATURES 21·6·61



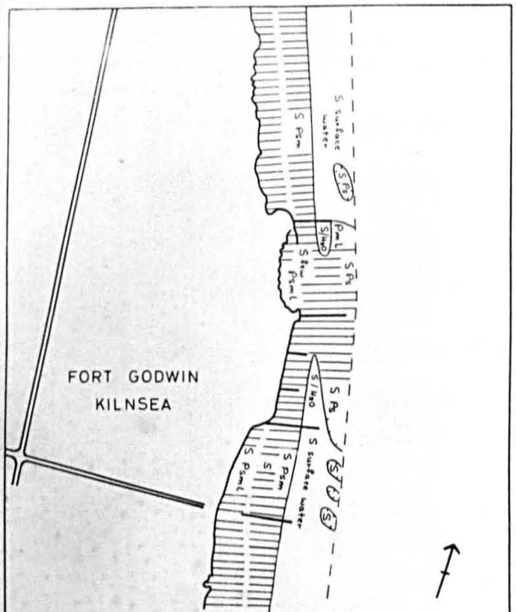
A PLAN OF BEACH FEATURES 27·8·61



A PLAN OF BEACH FEATURES 8·9·61

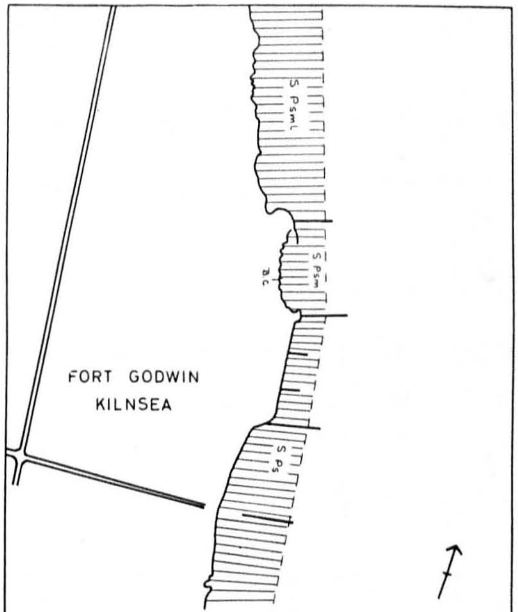


A PLAN OF BEACH FEATURES 25·9·61



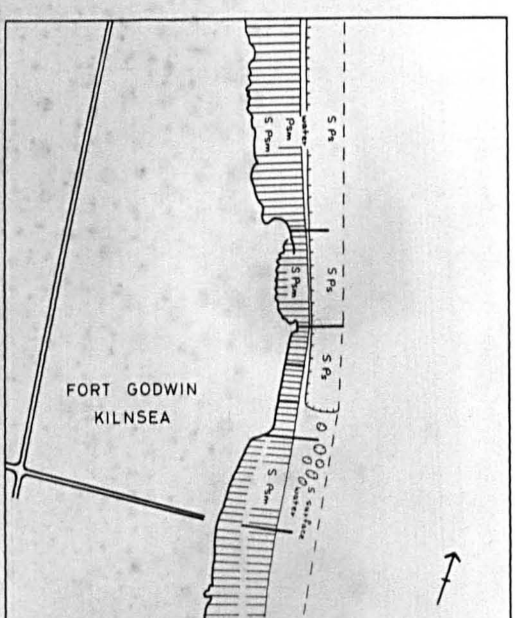
A PLAN OF BEACH FEATURES 8·10·61

SCALE 300 200 100 0 300 600 FEET



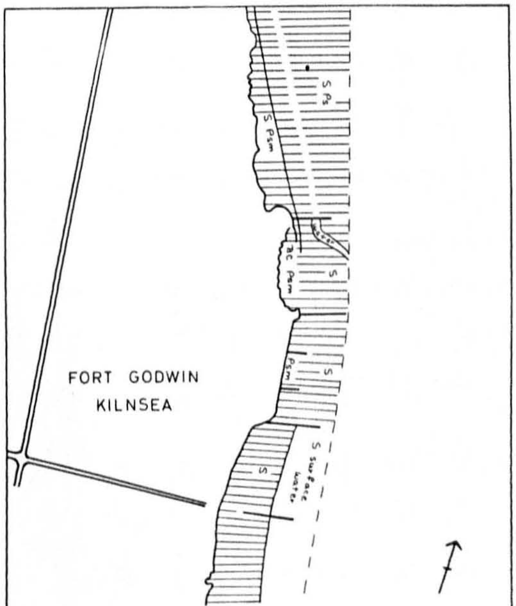
A PLAN OF BEACH FEATURES 20·10·61

SCALE 300 200 100 0 300 600 FEET



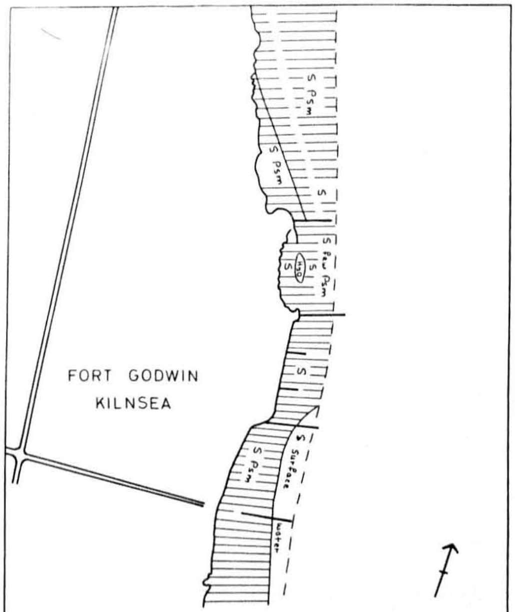
A PLAN OF BEACH FEATURES 6·11·61

SCALE 300 200 100 0 300 600 FEET



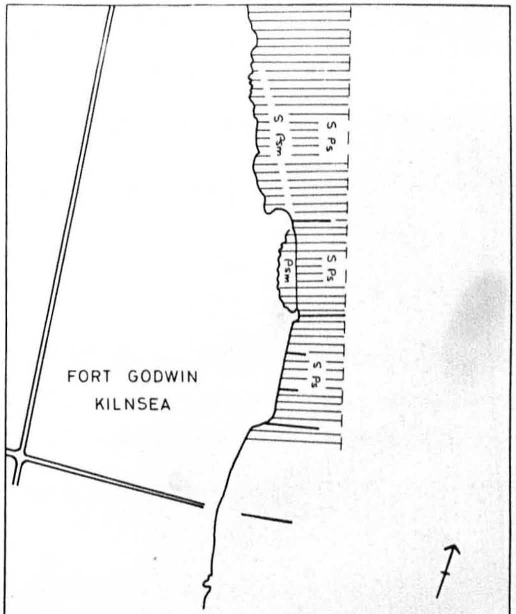
A PLAN OF BEACH FEATURES 19·11·61

SCALE 300 200 100 0 300 600 FEET



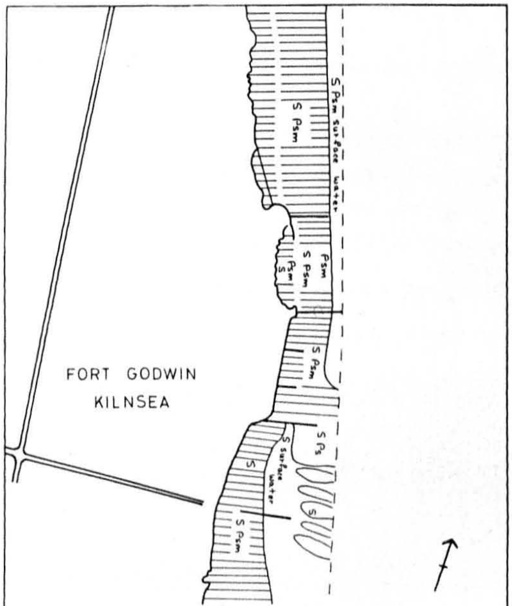
A PLAN OF BEACH FEATURES 5·12·61

SCALE 300 200 100 0 300 600 FEET



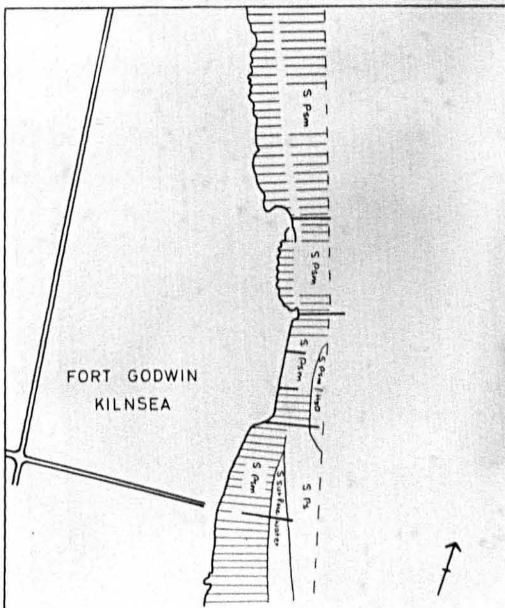
A PLAN OF BEACH FEATURES 21·12·61

SCALE 300 200 100 0 300 600 FEET



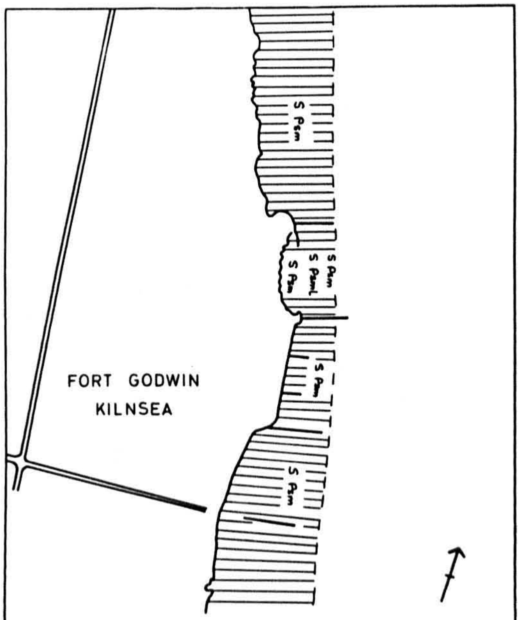
A PLAN OF BEACH FEATURES 11·1·62

SCALE 300 200 100 0 300 600 FEET



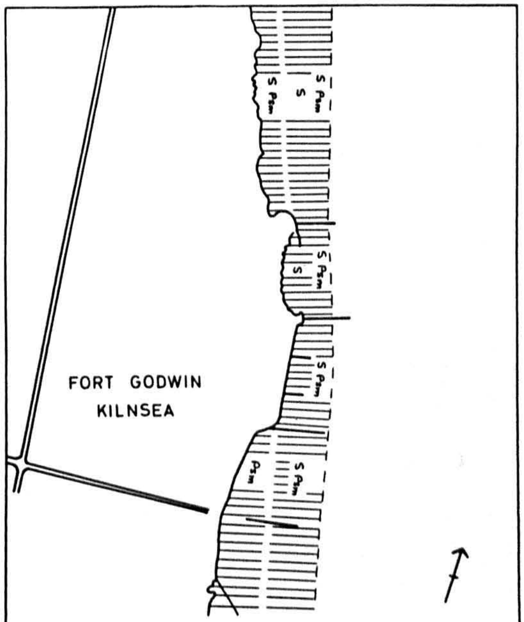
A PLAN OF BEACH FEATURES 30·1·62

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 18·2·62

SCALE 300 200 100 0 300 600 FEET



A PLAN OF BEACH FEATURES 3·4·62

SCALE 300 200 100 0 300 600 FEET

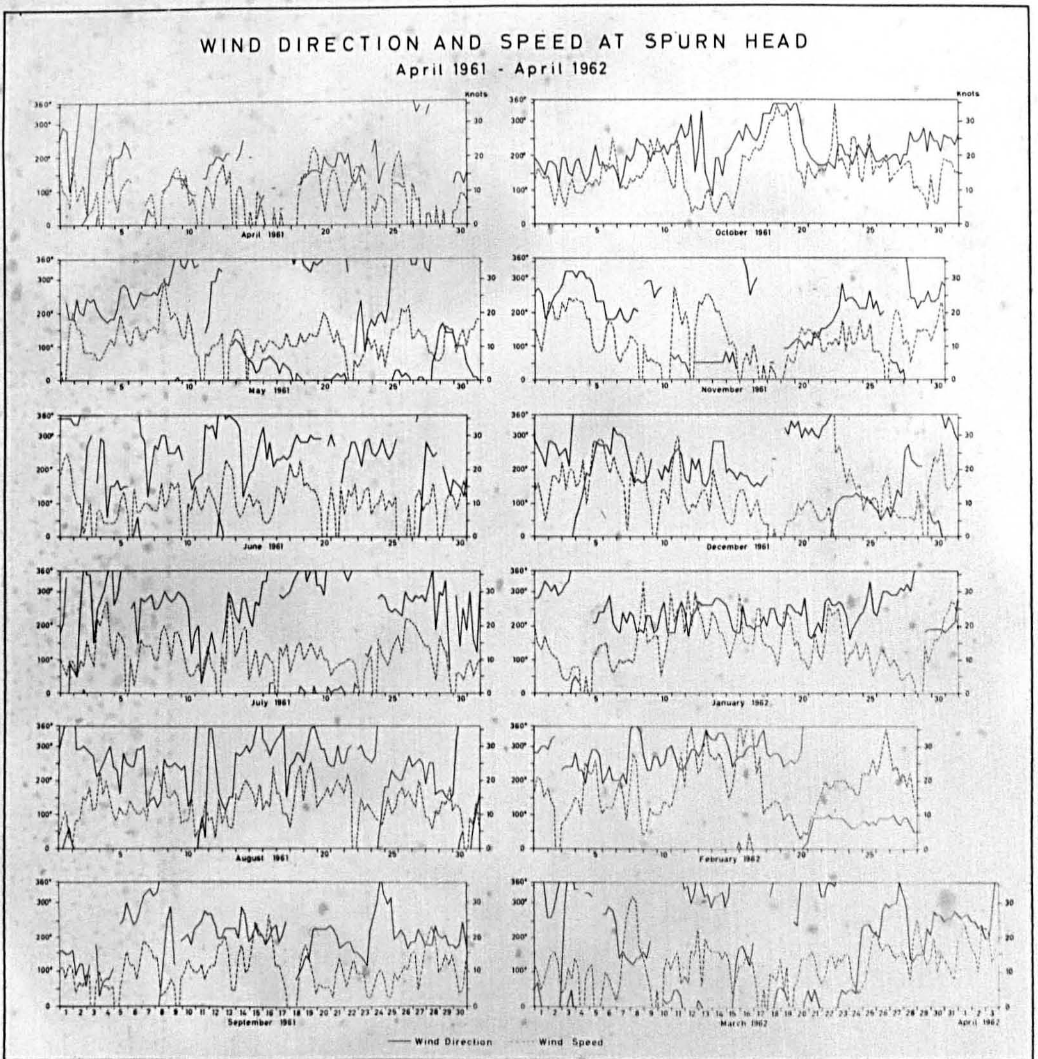
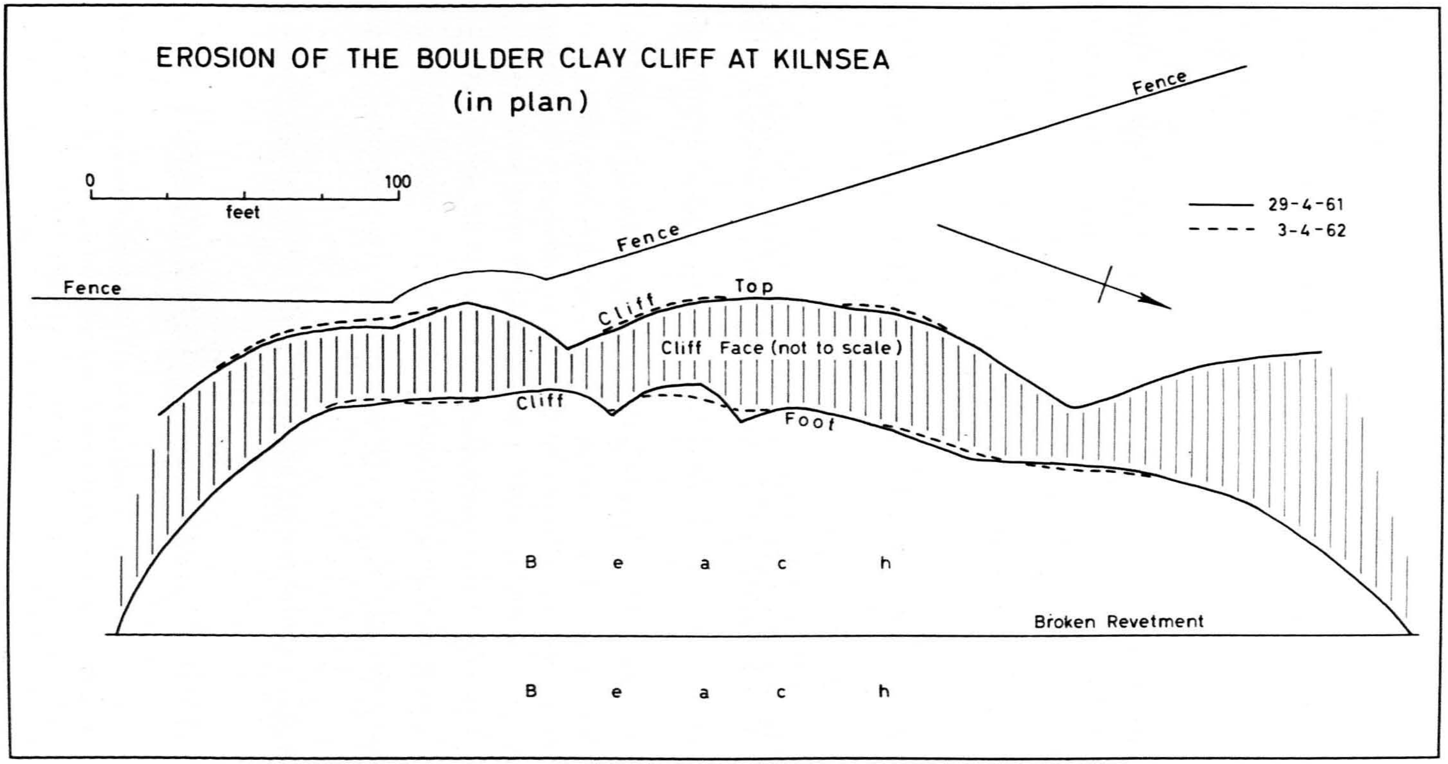
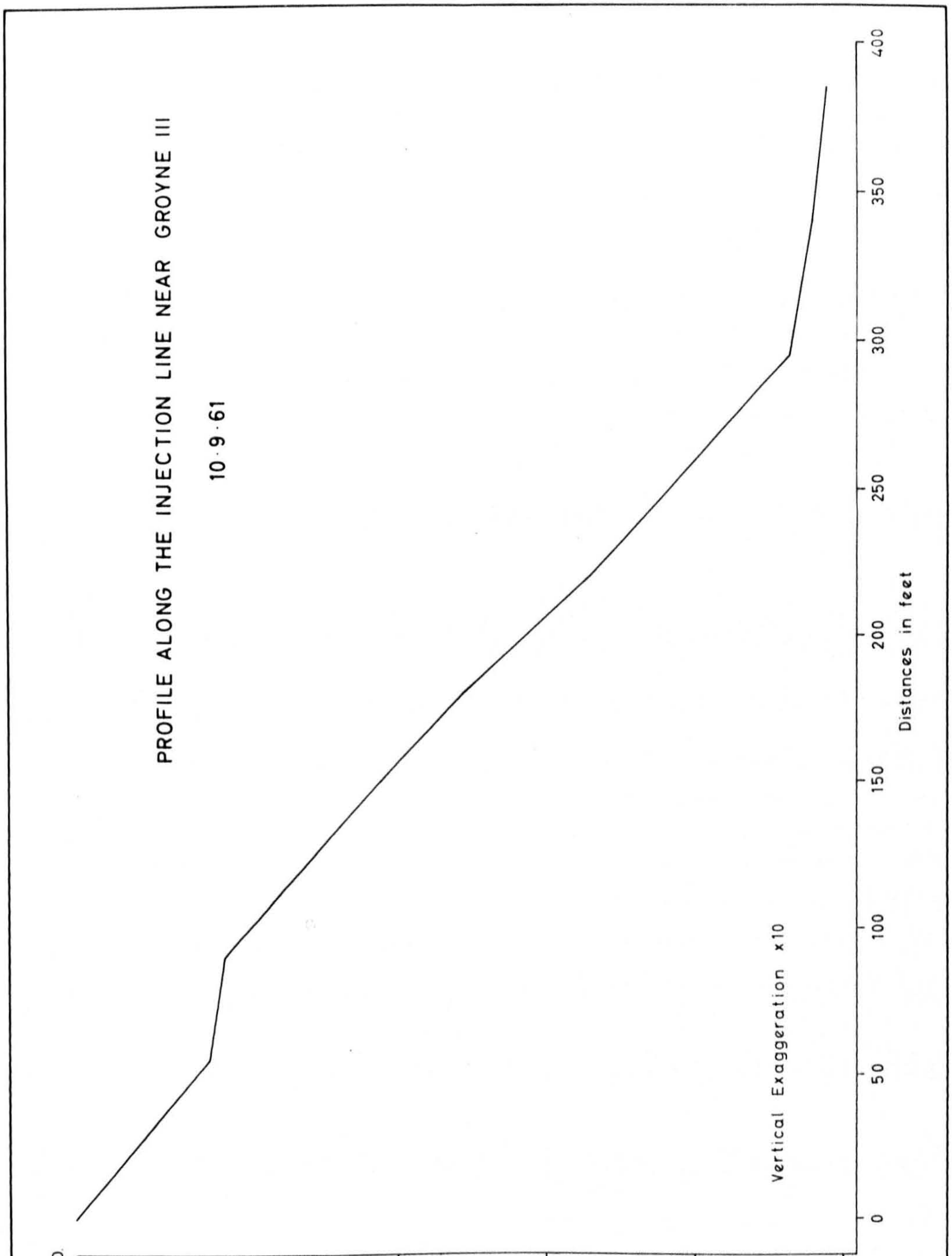

WIND DIRECTION AND SPEED AT SPURN HEAD
April 1961 - April 1962
April 1961
May 1961
June 1961
July 1961
August 1961
September 1961
October 1961
November 1961
December 1961
January 1962
February 1962
March 1962
April 1962
Wind Direction
Wind Speed
Knots

Fig.4.6

Fig.4.7

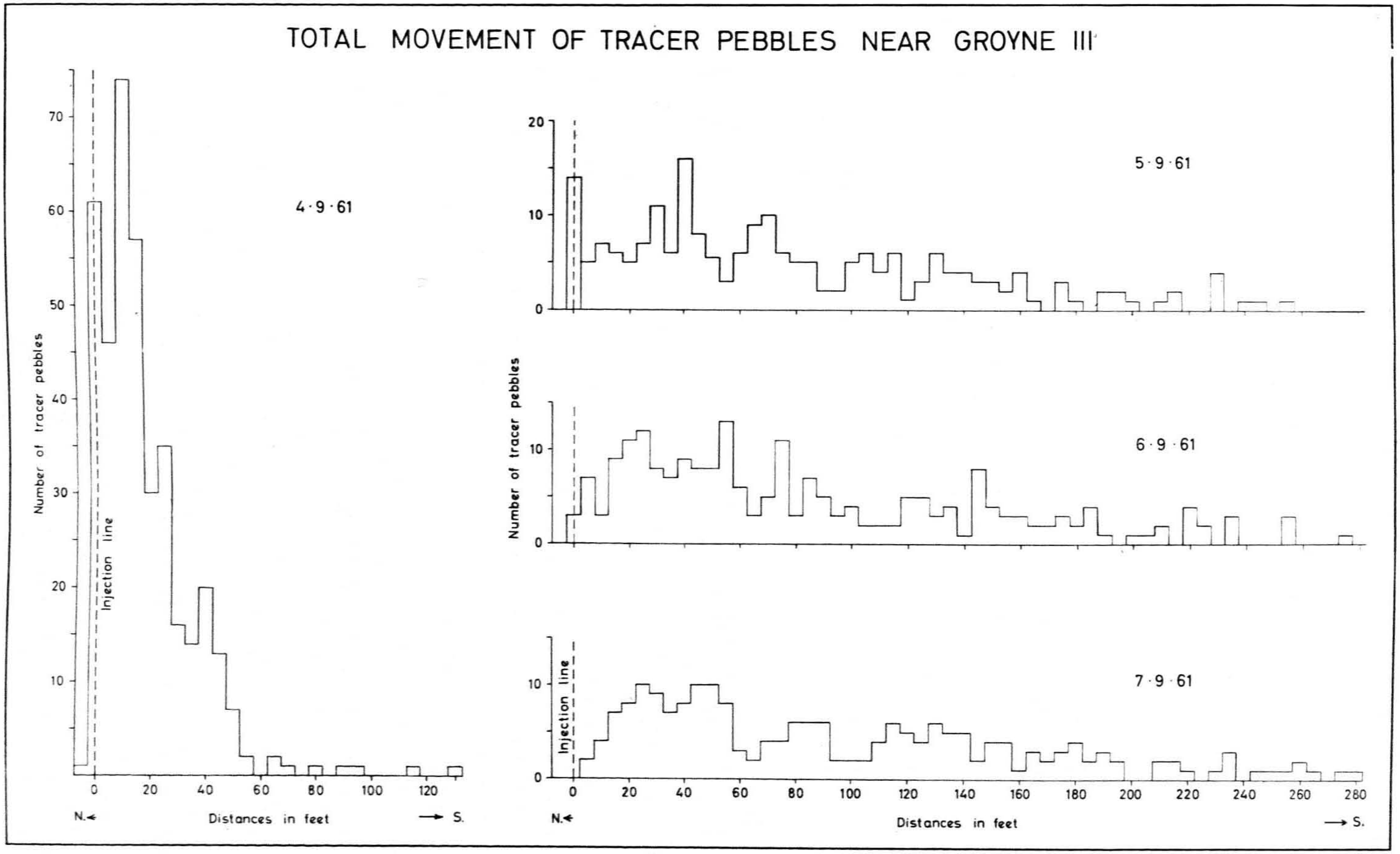

EROSION OF THE BOULDER CLAY CLIFF AT KILNSEA
(in plan)
0
100
feet
Fence
Fence
Fence
29-4-61
3-4-62
Cliff Top
Cliff Face (not to scale)
Cliff Foot
B e a c h
Broken Revetment
B e a c h



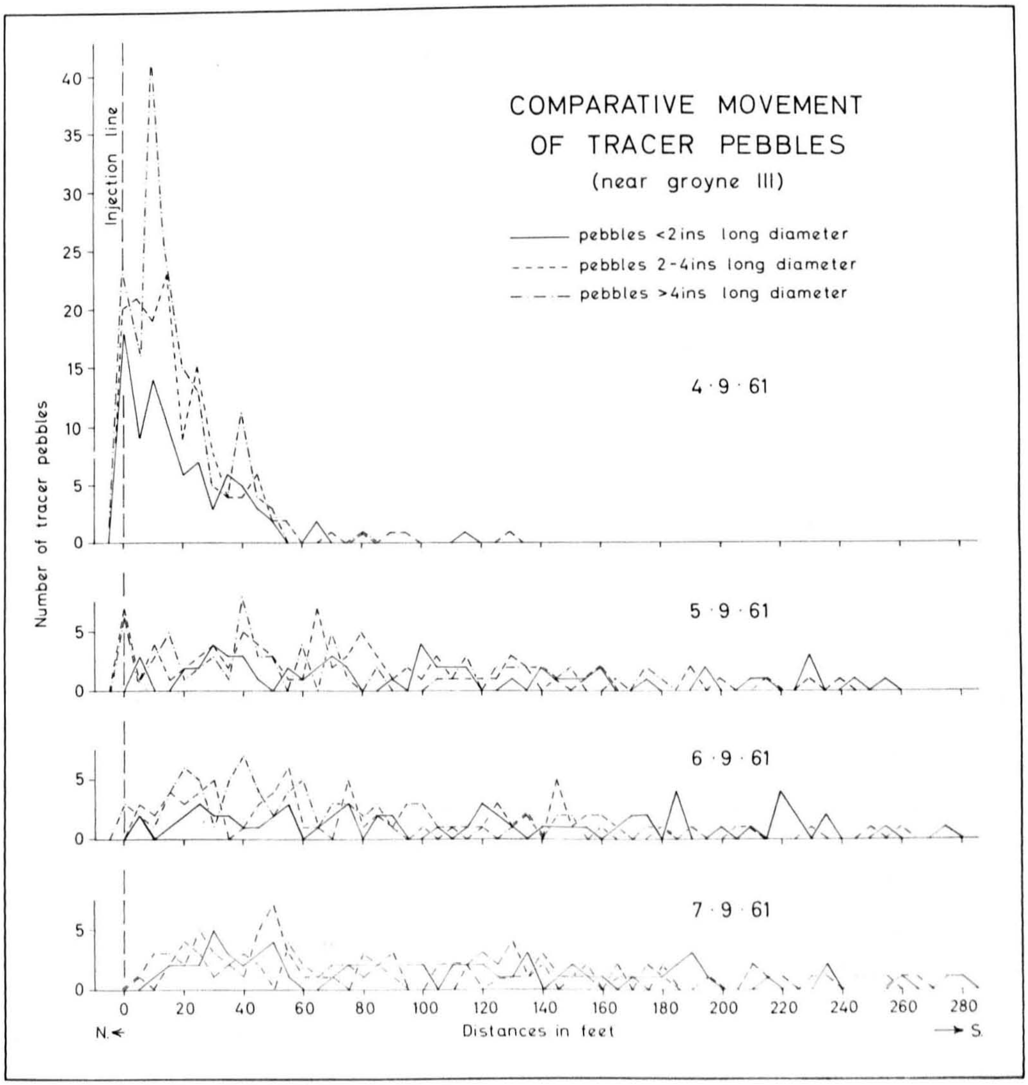
PROFILE ALONG THE INJECTION LINE NEAR GROYNE III
10·9·61
Vertical Exaggeration x10
Distances in feet
feet O.D.
15·79
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400

Fig.4.8

Fig. 4.9



TOTAL MOVEMENT OF TRACER PEBBLES NEAR GROYNE III
4·9·61
5·9·61
6·9·61
7·9·61
Number of tracer pebbles
Injection line
Distances in feet
N.
S.
0
10
20
30
40
50
60
70
80
100
120
140
160
180
200
220
240
260
280



COMPARATIVE MOVEMENT
OF TRACER PEBBLES
(near groyne III)
pebbles <2ins long diameter
pebbles 2-4ins long diameter
pebbles >4ins long diameter
Injection line
4 · 9 · 61
5 · 9 · 61
6 · 9 · 61
7 · 9 · 61
Number of tracer pebbles
Distances in feet
N.
S.

Fig.4.10

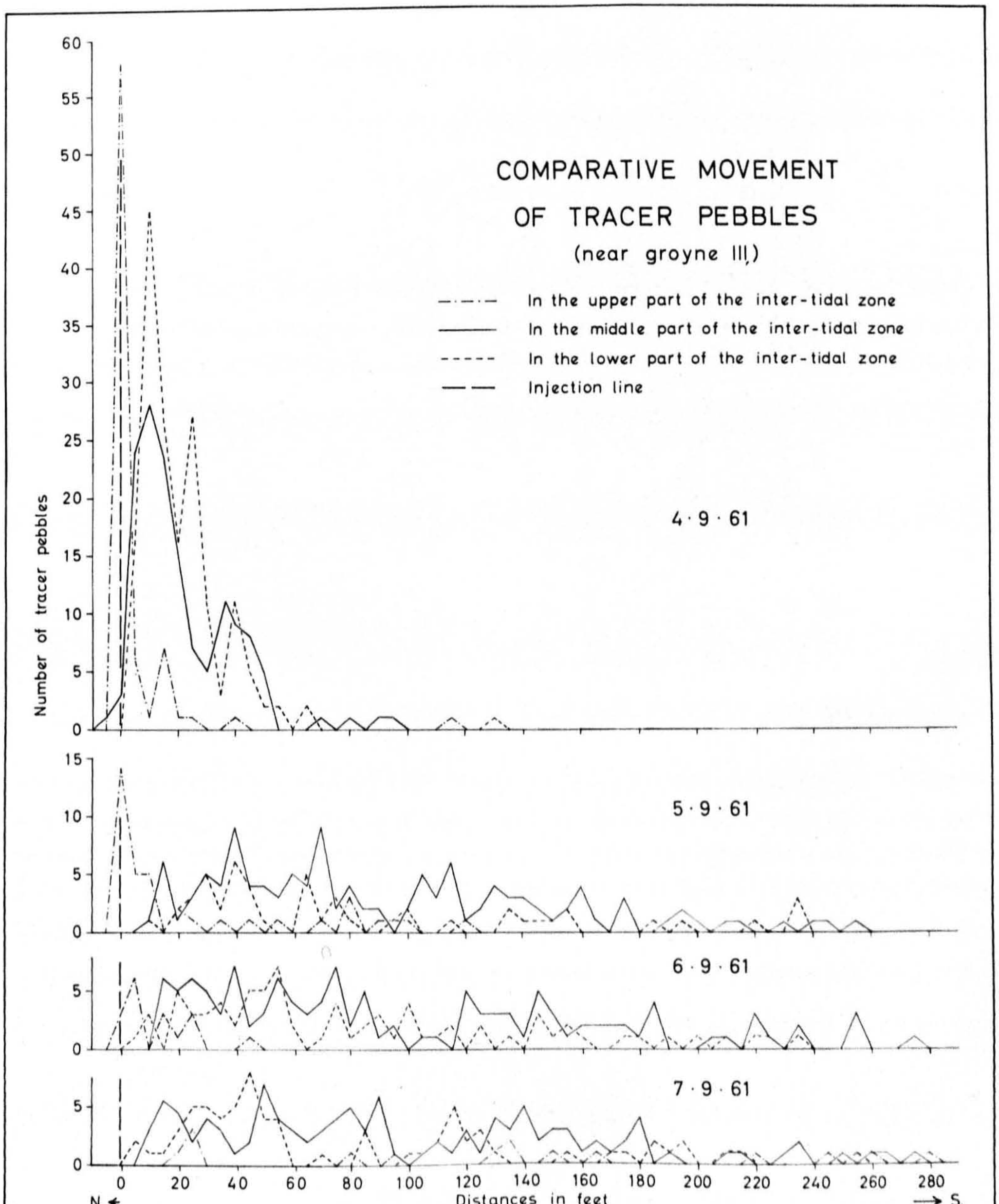

COMPARATIVE MOVEMENT
OF TRACER PEBBLES
(near groyne III)
In the upper part of the inter-tidal zone
In the middle part of the inter-tidal zone
In the lower part of the inter-tidal zone
Injection line
4 · 9 · 61
5 · 9 · 61
6 · 9 · 61
7 · 9 · 61
Number of tracer pebbles
Distances in feet
N.
S.
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
60
55
50
45
40
35
30
25
20
15
10
5

Fig.4.11

Fig. 5.1

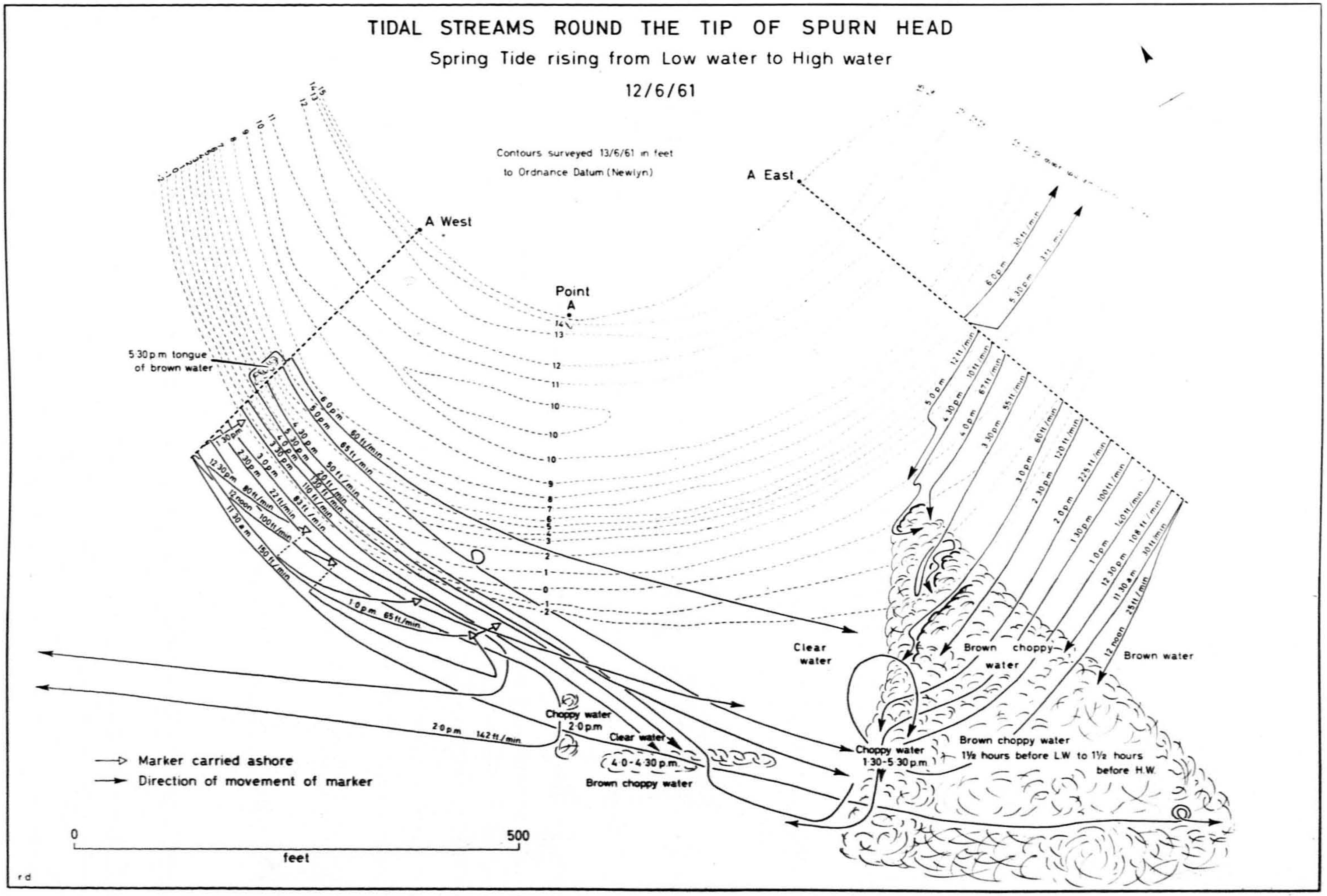
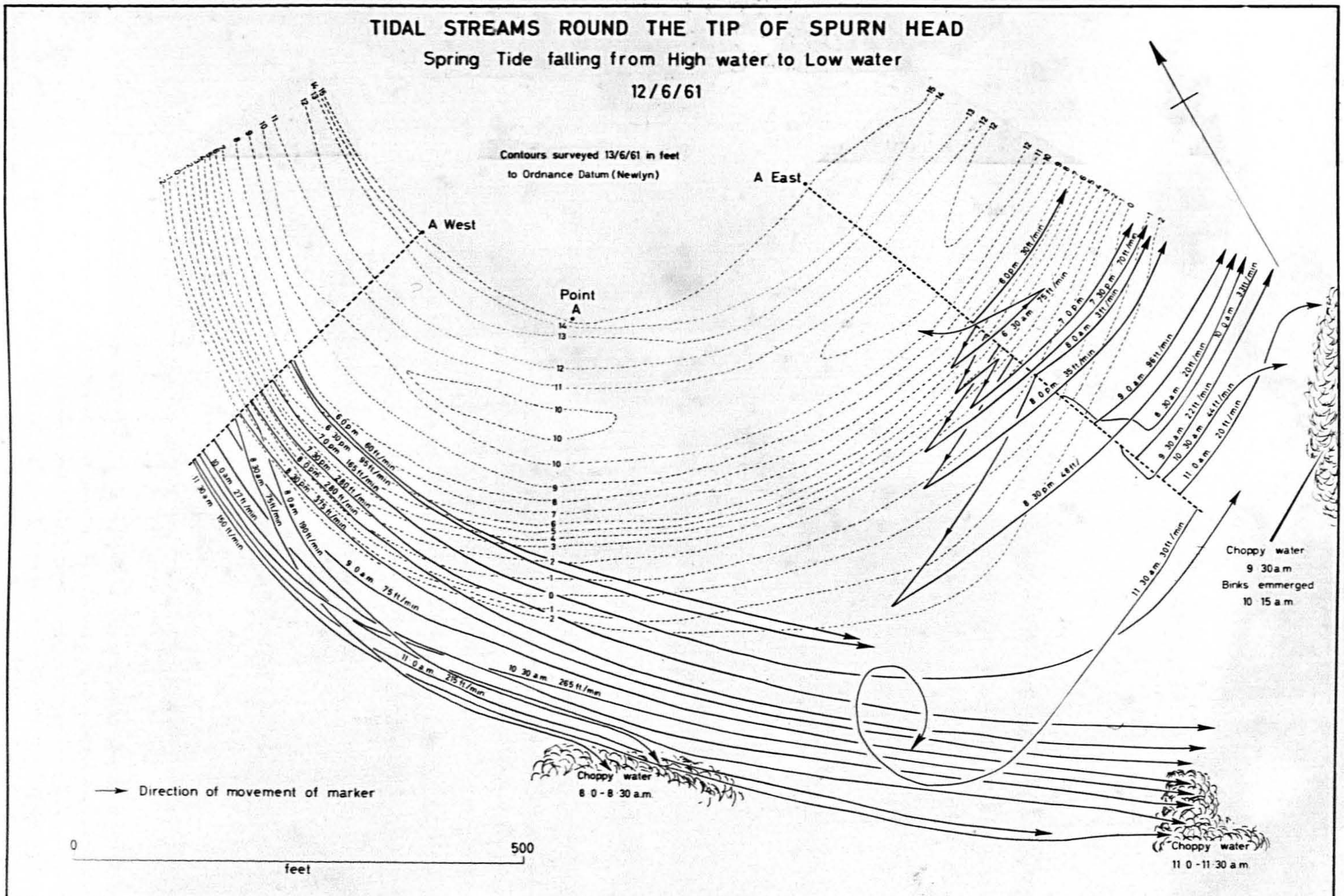
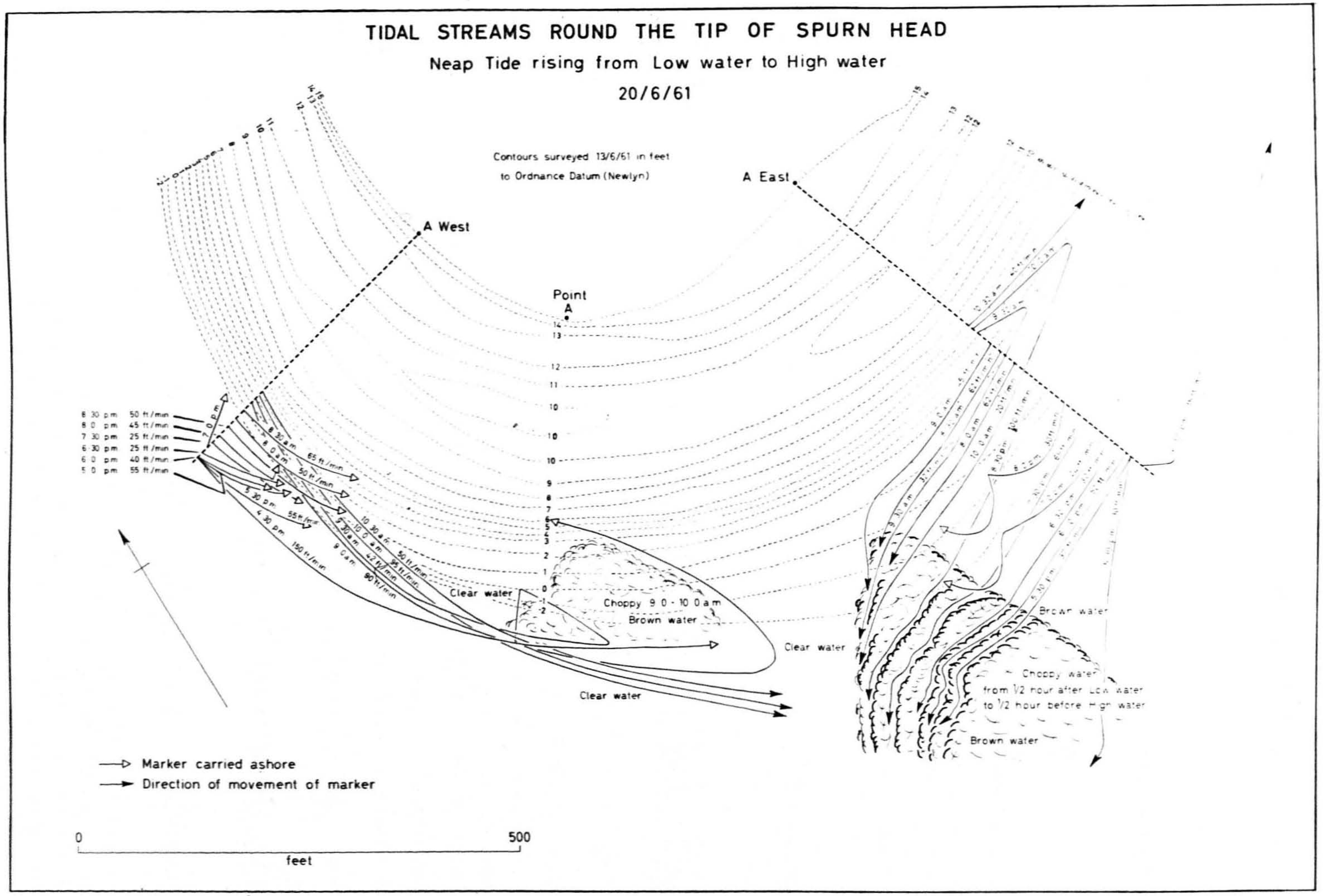

TIDAL STREAMS ROUND THE TIP OF SPURN HEAD
Spring Tide rising from Low water to High water
12/6/61
Contours surveyed 13/6/61 in feet
to Ordnance Datum (Newlyn)
A West
A East
Point
A
5.30 p.m. tongue
of brown water
6.0 p.m. 60 ft/min
5.0 p.m. 65 ft/min
4.30 p.m. 50 ft/min
1.0 p.m. 65 ft/min
12 noon 100 ft/min
11.30 a.m. 150 ft/min
2.0 p.m. 142 ft/min
Clear
water
Choppy water
2.0 p.m.
Clear water
4.0-4.30 p.m.
Brown choppy water
Choppy water
1.30-5.30 p.m.
Brown choppy water
1½ hours before L.W. to 1½ hours
before H.W.
Brown choppy
water
Brown water
6.0 p.m. 30 ft/min
5.30 p.m. 3 ft/min
5.0 p.m. 12 ft/min
4.30 p.m. 10 ft/min
4.0 p.m. 67 ft/min
3.30 p.m. 55 ft/min
3.0 p.m. 60 ft/min
2.30 p.m. 120 ft/min
2.0 p.m. 225 ft/min
1.30 p.m. 100 ft/min
1.0 p.m. 140 ft/min
12.30 p.m. 108 ft/min
11.30 a.m. 30 ft/min
12 noon 25 ft/min
Marker carried ashore
Direction of movement of marker
0
500
feet
r d

Fig. 5.2



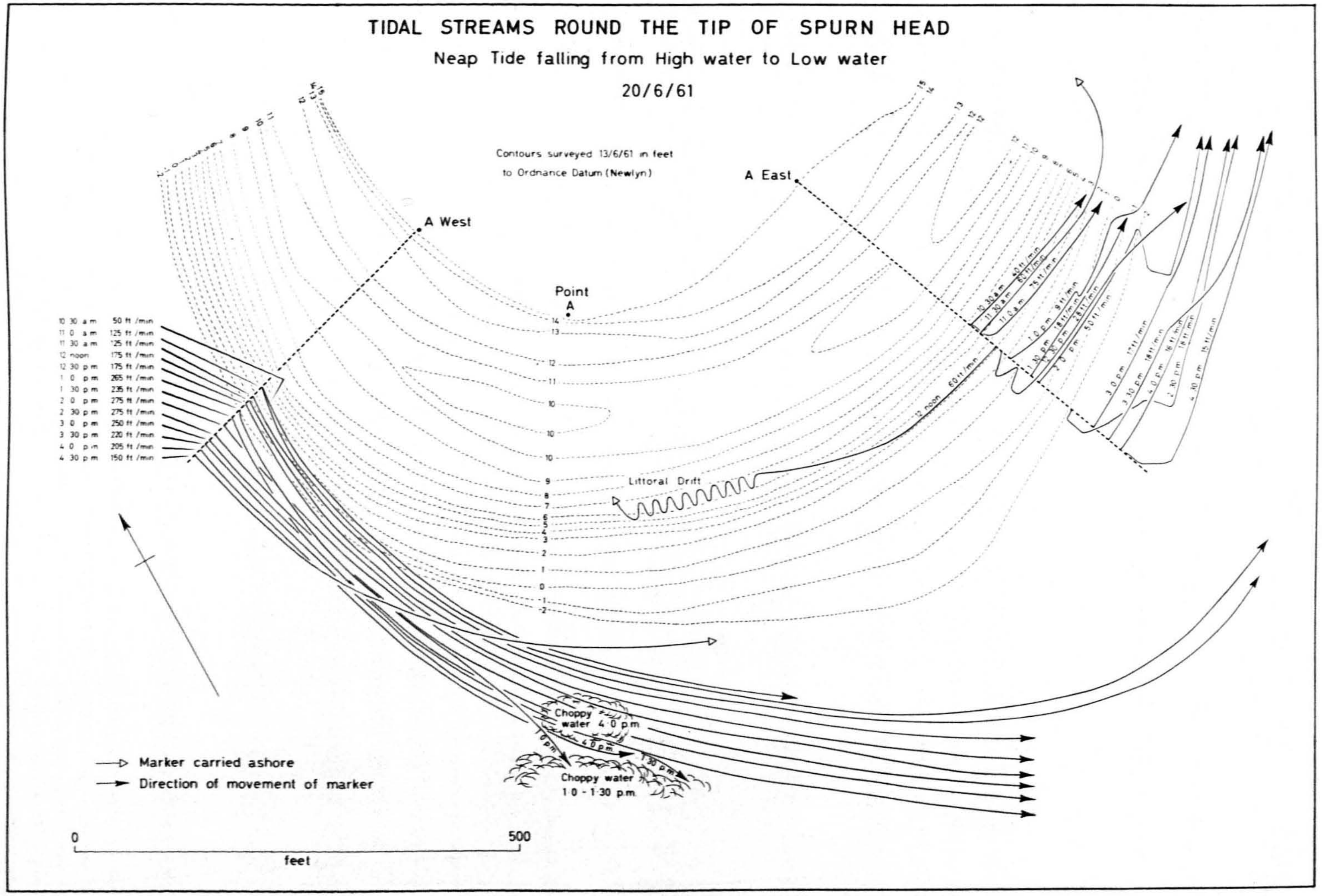
TIDAL STREAMS ROUND THE TIP OF SPURN HEAD
Spring Tide falling from High water to Low water
12/6/61
Contours surveyed 13/6/61 in feet
to Ordnance Datum (Newlyn)
A West
A East
Point
A
Choppy water
9 30 a.m
Binks emmerged
10 15 a.m
Choppy water
8 0 - 8 30 a.m.
Choppy water
11 0 - 11 30 a.m
Direction of movement of marker
0
500
feet



TIDAL STREAMS ROUND THE TIP OF SPURN HEAD
Neap Tide rising from Low water to High water
20/6/61
Contours surveyed 13/6/61 in feet to Ordnance Datum (Newlyn)
A West
A East
Point A
Clear water
Choppy 9.0 - 10.0 a.m. Brown water
Clear water
Clear water
Brown water
Choppy water from 1/2 hour after Low water to 1/2 hour before High water
Brown water
8.30 pm 50 ft/min
8.0 pm 45 ft/min
7.30 pm 25 ft/min
6.30 pm 25 ft/min
6.0 pm 40 ft/min
5.0 pm 55 ft/min
Marker carried ashore
Direction of movement of marker
0
500
feet

Fig. 5.3

Fig. 5.4



TIDAL STREAMS ROUND THE TIP OF SPURN HEAD
Neap Tide falling from High water to Low water
20/6/61
Contours surveyed 13/6/61 in feet
to Ordnance Datum (Newlyn)
A West
A East
Point
A
10 30 a m 50 ft /min
11 0 a m 125 ft /min
11 30 a m 125 ft /min
12 noon 175 ft /min
12 30 p m 175 ft /min
1 0 p m 265 ft /min
1 30 p m 235 ft /min
2 0 p m 275 ft /min
2 30 p m 275 ft /min
3 0 p m 250 ft /min
3 30 p m 220 ft /min
4 0 p m 205 ft /min
4 30 p m 150 ft /min
Littoral Drift
12 noon 60 ft/min
Choppy water 4·0 p.m
4·0 p.m
1·30 p.m
Choppy water 1·0 - 1·30 p.m
Marker carried ashore
Direction of movement of marker
0
500
feet

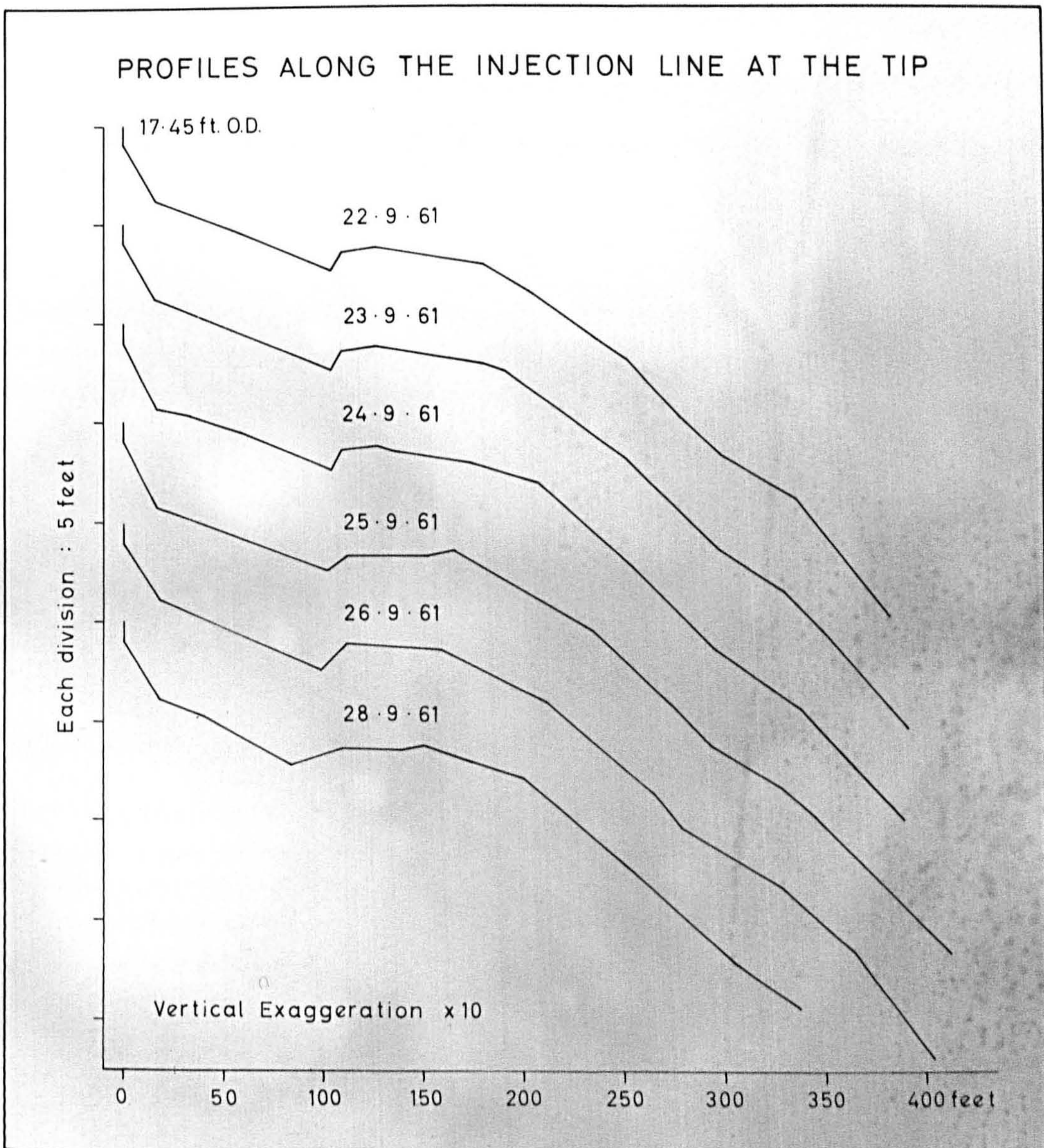
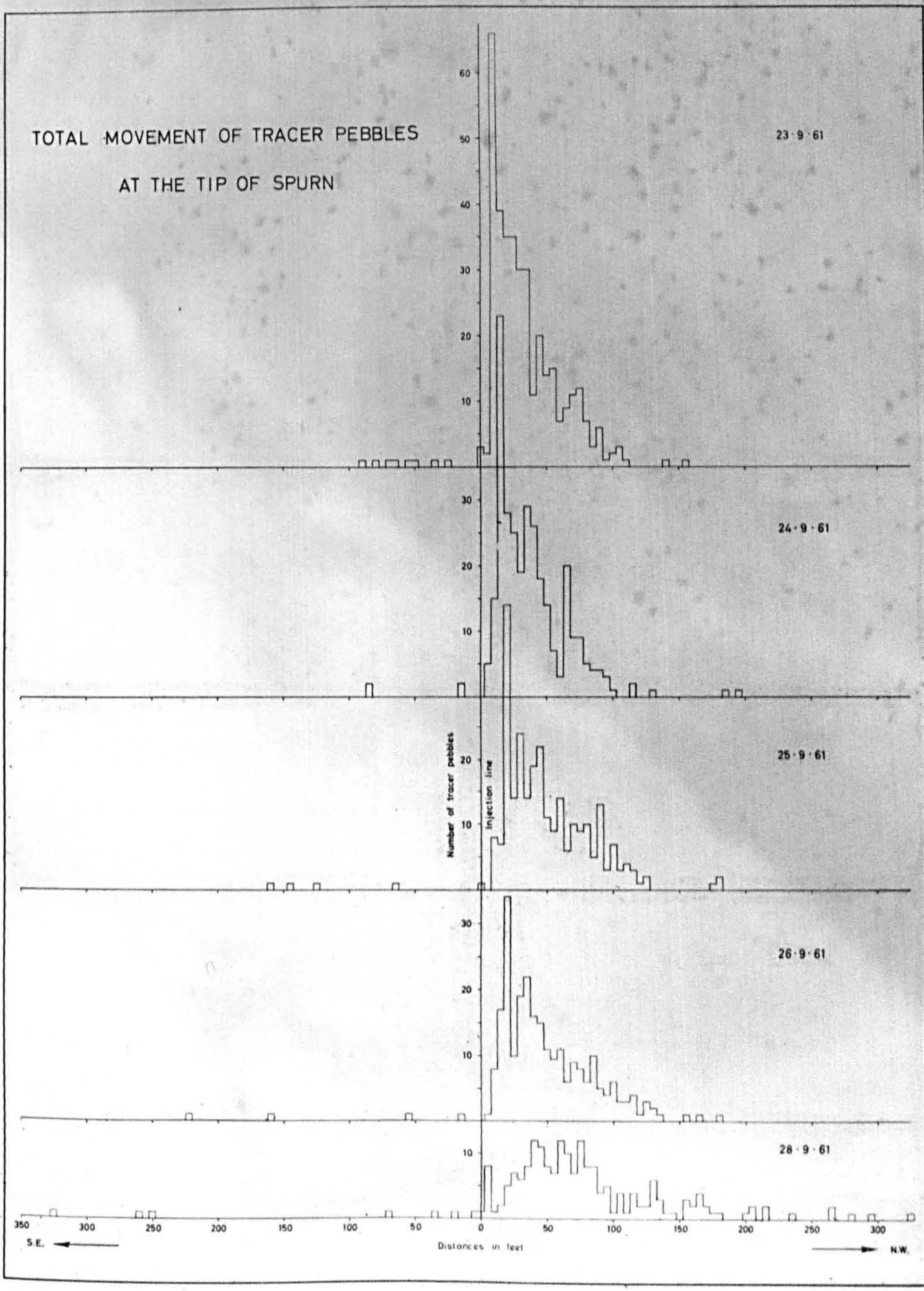
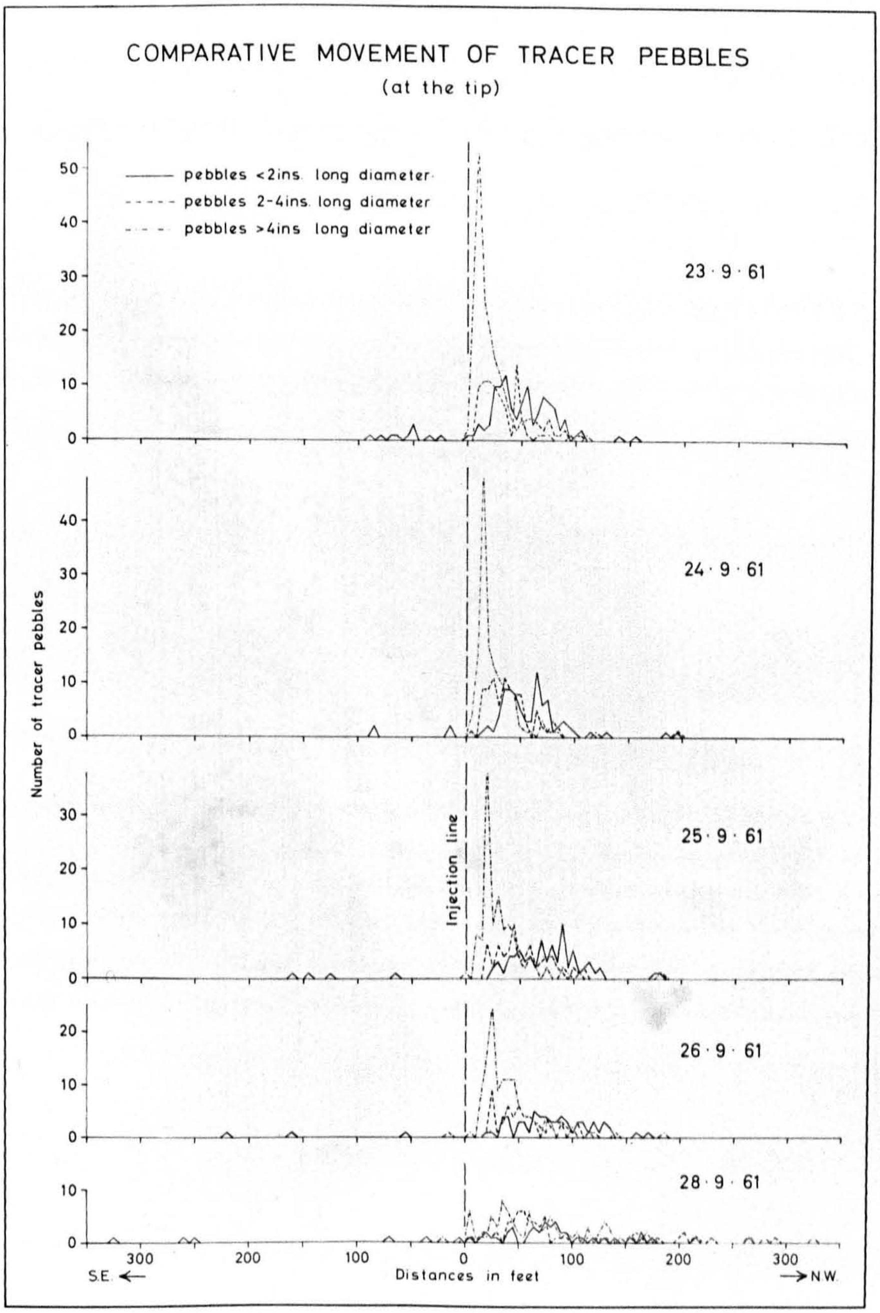

PROFILES ALONG THE INJECTION LINE AT THE TIP
17·45 ft. O.D.
22 · 9 · 61
23 · 9 · 61
24 · 9 · 61
25 · 9 · 61
26 · 9 · 61
28 · 9 · 61
Each division : 5 feet
Vertical Exaggeration x 10
0
50
100
150
200
250
300
350
400 feet

Fig.5.5



TOTAL MOVEMENT OF TRACER PEBBLES
AT THE TIP OF SPURN
23·9·61
24·9·61
25·9·61
26·9·61
28·9·61
Number of tracer pebbles
Injection line
S.E.
N.W.
Distances in feet

Fig.5.6



COMPARATIVE MOVEMENT OF TRACER PEBBLES
(at the tip)
pebbles <2ins. long diameter
pebbles 2-4ins. long diameter
pebbles >4ins long diameter
23 · 9 · 61
24 · 9 · 61
25 · 9 · 61
26 · 9 · 61
28 · 9 · 61
Number of tracer pebbles
Injection line
Distances in feet
S.E.
N.W.

Fig.5.7

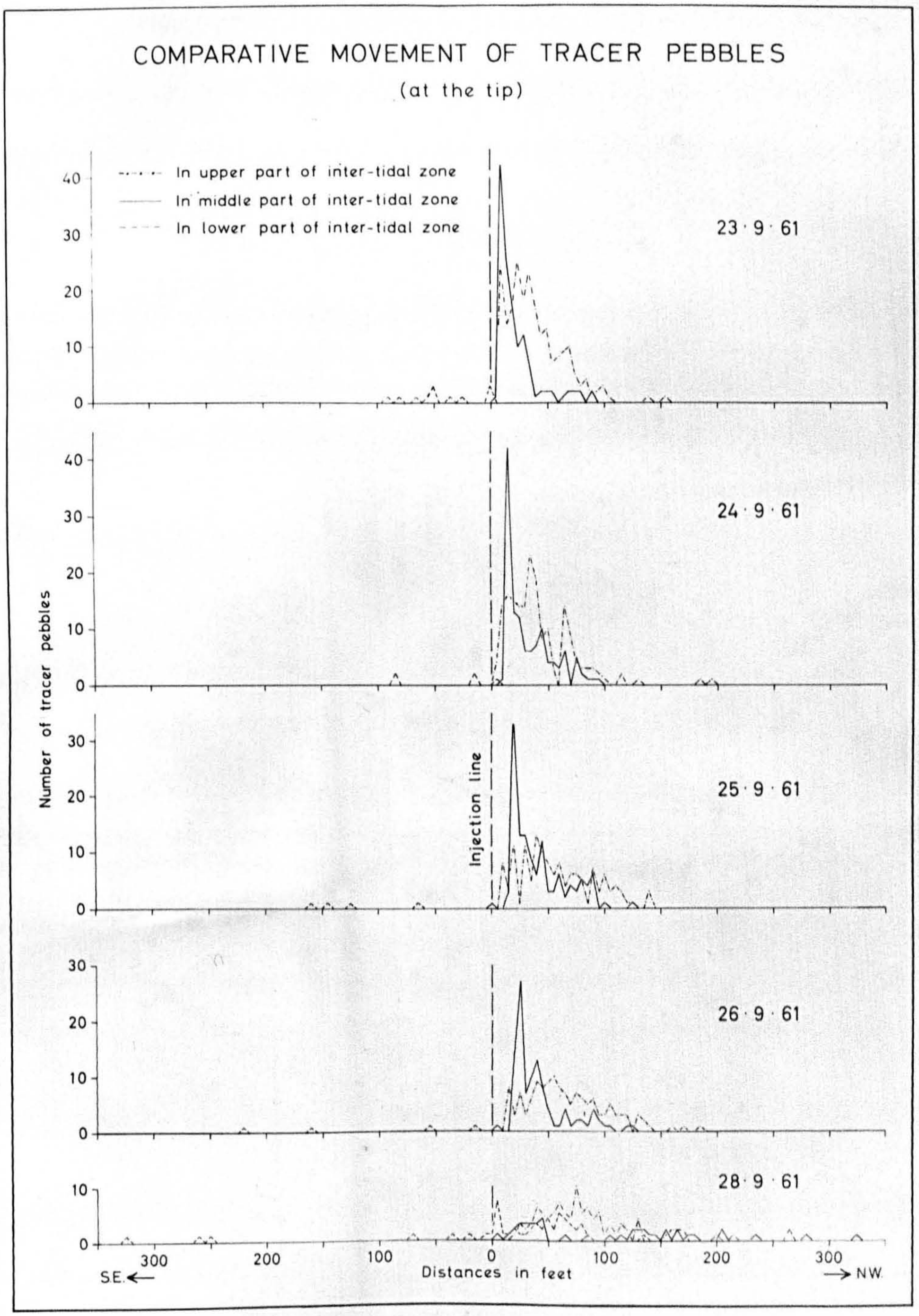
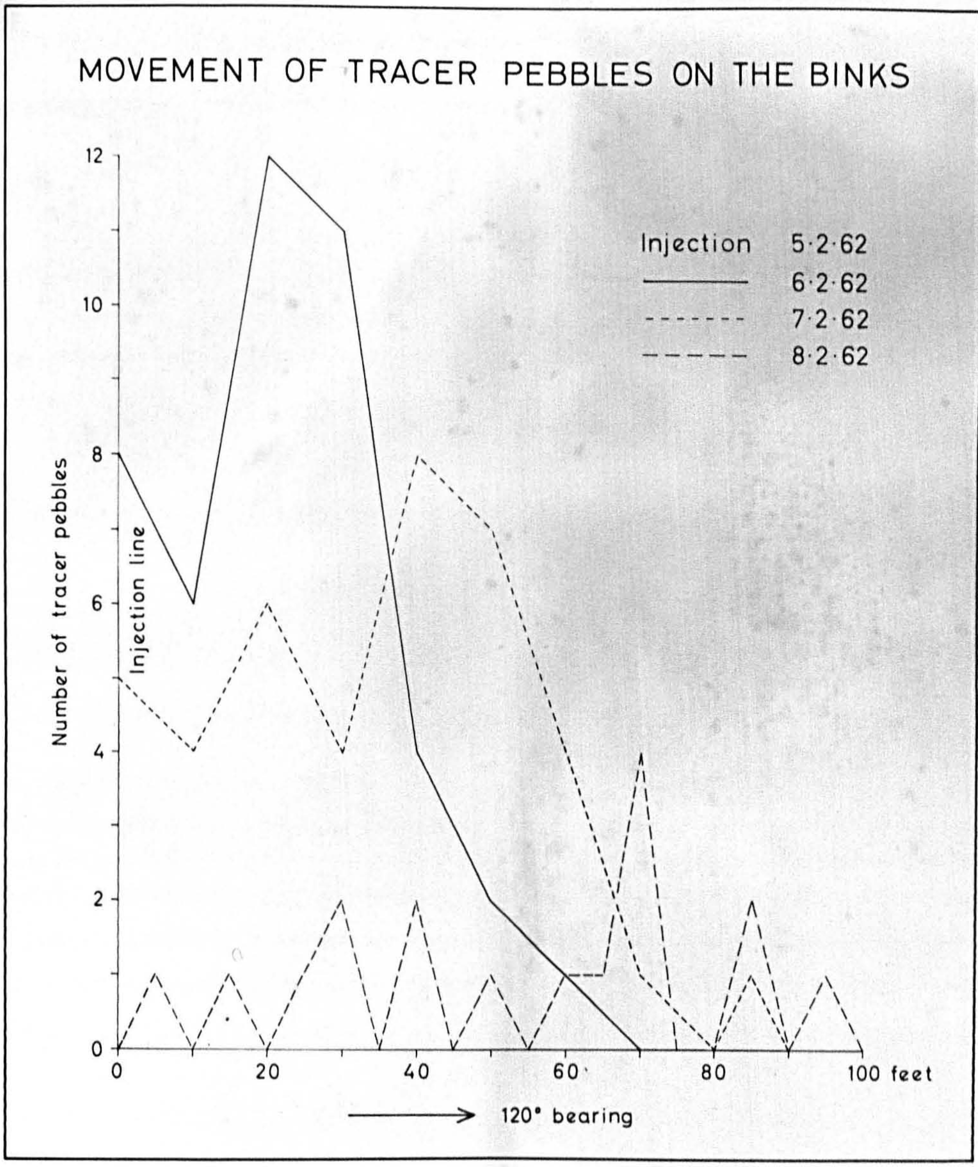

COMPARATIVE MOVEMENT OF TRACER PEBBLES
(at the tip)
In upper part of inter-tidal zone
In middle part of inter-tidal zone
In lower part of inter-tidal zone
23·9·61
24·9·61
25·9·61
26·9·61
28·9·61
Number of tracer pebbles
Injection line
Distances in feet
S.E.
N.W.
0
10
20
30
40
100
200
300

Fig.5.8



MOVEMENT OF TRACER PEBBLES ON THE BINKS
Injection 5·2·62
6·2·62
7·2·62
8·2·62
Number of tracer pebbles
Injection line
0
2
4
6
8
10
12
0
20
40
60
80
100 feet
120° bearing

Fig.5.9

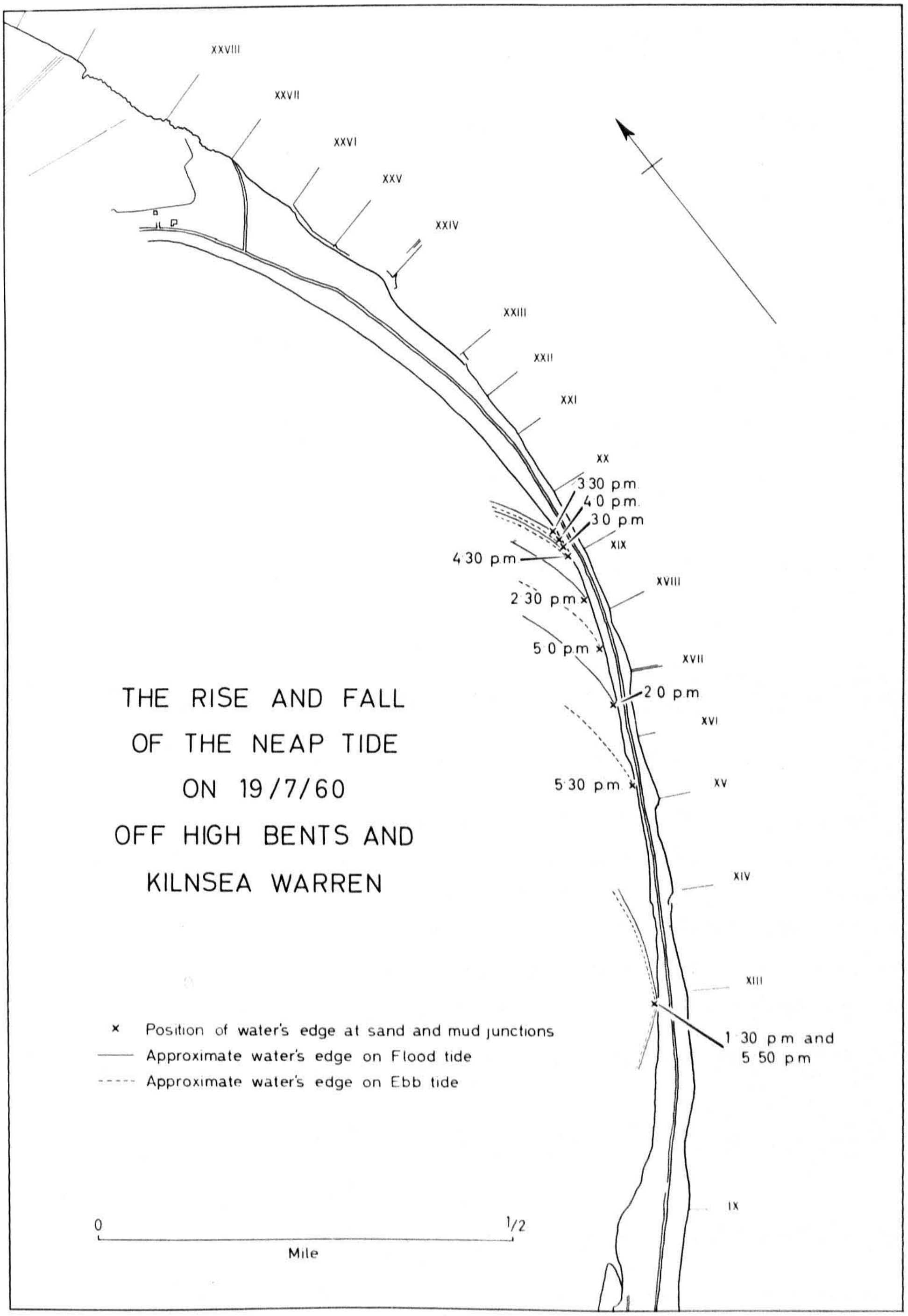
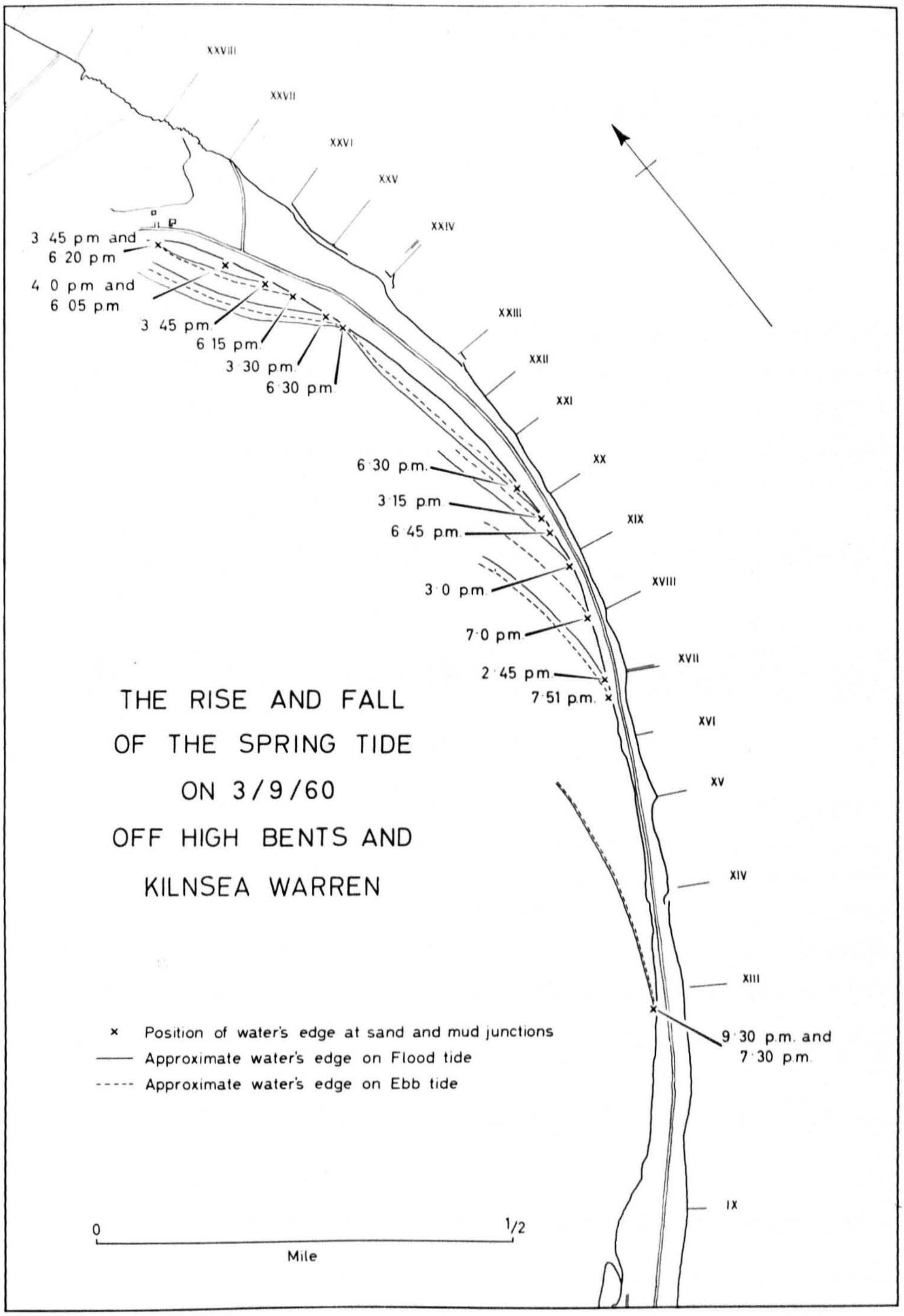

THE RISE AND FALL
OF THE NEAP TIDE
ON 19/7/60
OFF HIGH BENTS AND
KILNSEA WARREN
XXVIII
XXVII
XXVI
XXV
XXIV
XXIII
XXII
XXI
XX
3 30 p.m.
4 0 p.m.
3 0 p.m.
XIX
4 30 p.m.
XVIII
2 30 p.m.
5 0 p.m.
XVII
2 0 p.m.
XVI
5 30 p.m.
XV
XIV
XIII
1 30 p.m. and
5 50 p.m.
IX
× Position of water's edge at sand and mud junctions
Approximate water's edge on Flood tide
Approximate water's edge on Ebb tide
0
1/2
Mile

Fig.6.I



XXVIII
XXVII
XXVI
XXV
XXIV
XXIII
XXII
XXI
XX
XIX
XVIII
XVII
XVI
XV
XIV
XIII
IX
3 45 p.m. and
6 20 p.m.
4 0 p.m. and
6 05 p.m.
3 45 p.m.
6 15 p.m.
3 30 p.m.
6 30 p.m.
6 30 p.m.
3 15 p.m.
6 45 p.m.
3 0 p.m.
7 0 p.m.
2 45 p.m.
7 51 p.m.
9 30 p.m. and
7 30 p.m.
THE RISE AND FALL
OF THE SPRING TIDE
ON 3/9/60
OFF HIGH BENTS AND
KILNSEA WARREN
× Position of water's edge at sand and mud junctions
—— Approximate water's edge on Flood tide
----- Approximate water's edge on Ebb tide
0
1/2
Mile

Fig.6.2

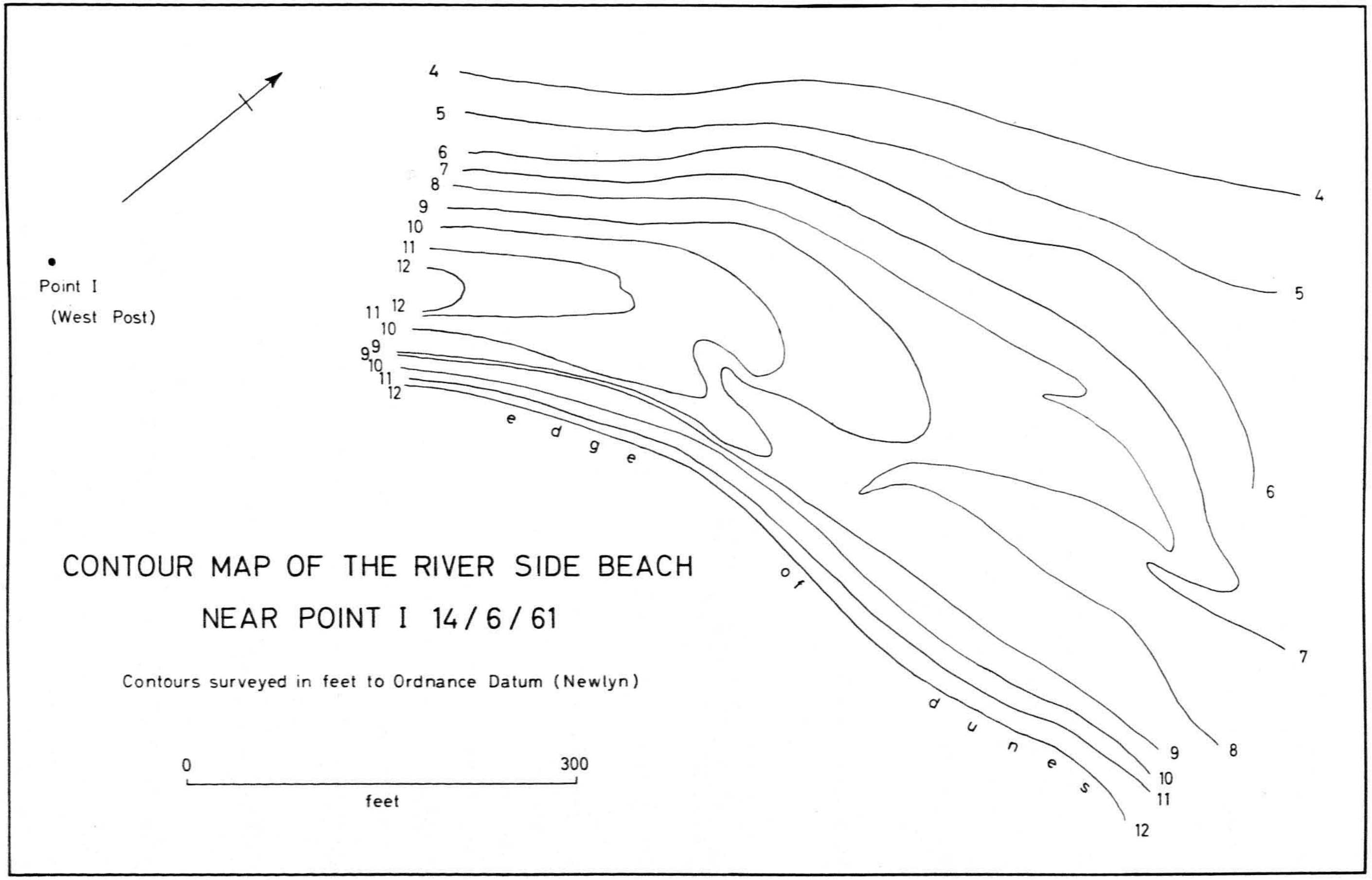
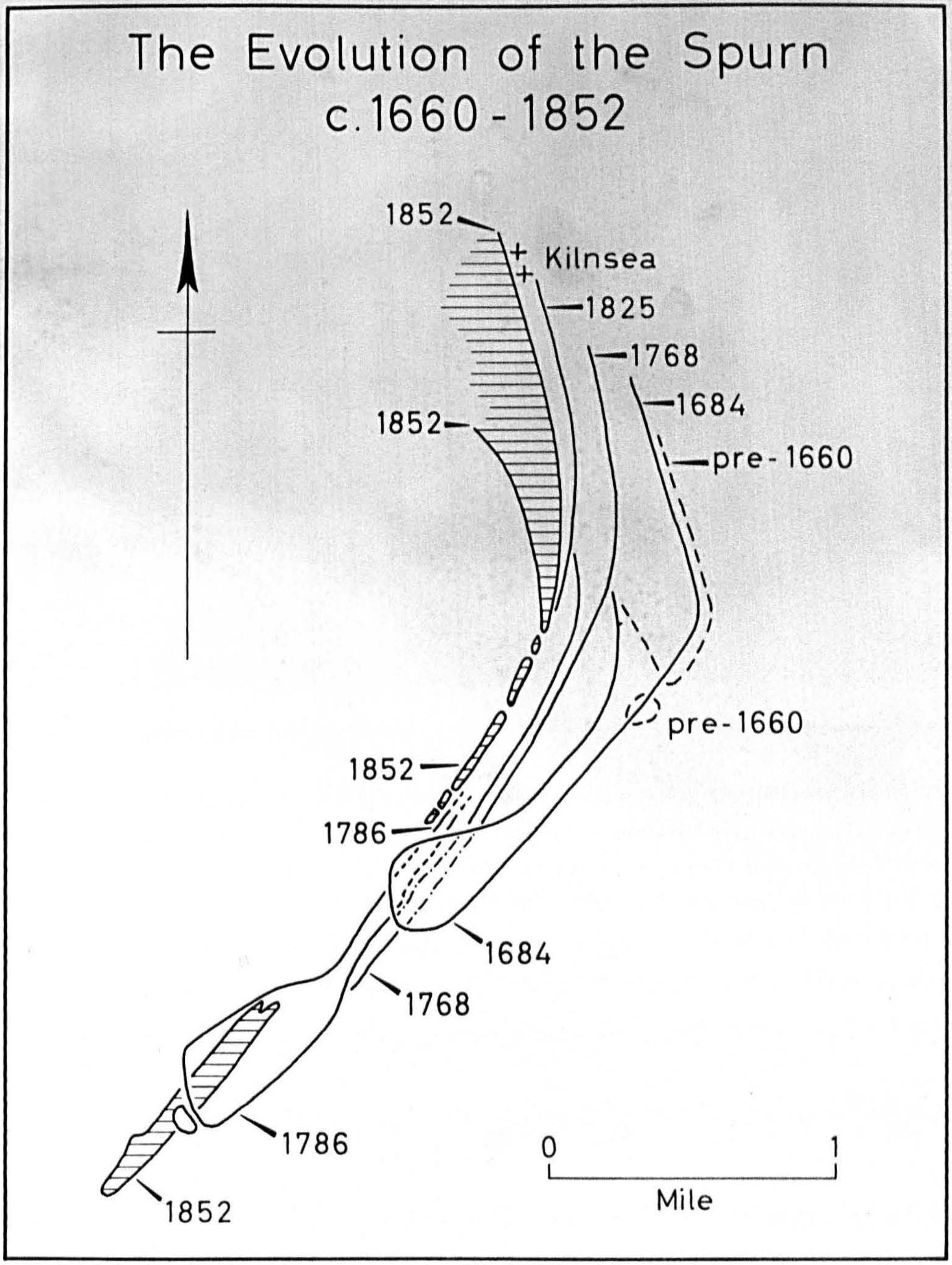

CONTOUR MAP OF THE RIVER SIDE BEACH
NEAR POINT I 14/6/61
Contours surveyed in feet to Ordnance Datum (Newlyn)
Point I
(West Post)
0
300
feet
edge of dunes
4
5
6
7
8
9
10
11
12

Fig.6.3



G. de Boer

ig.8.I

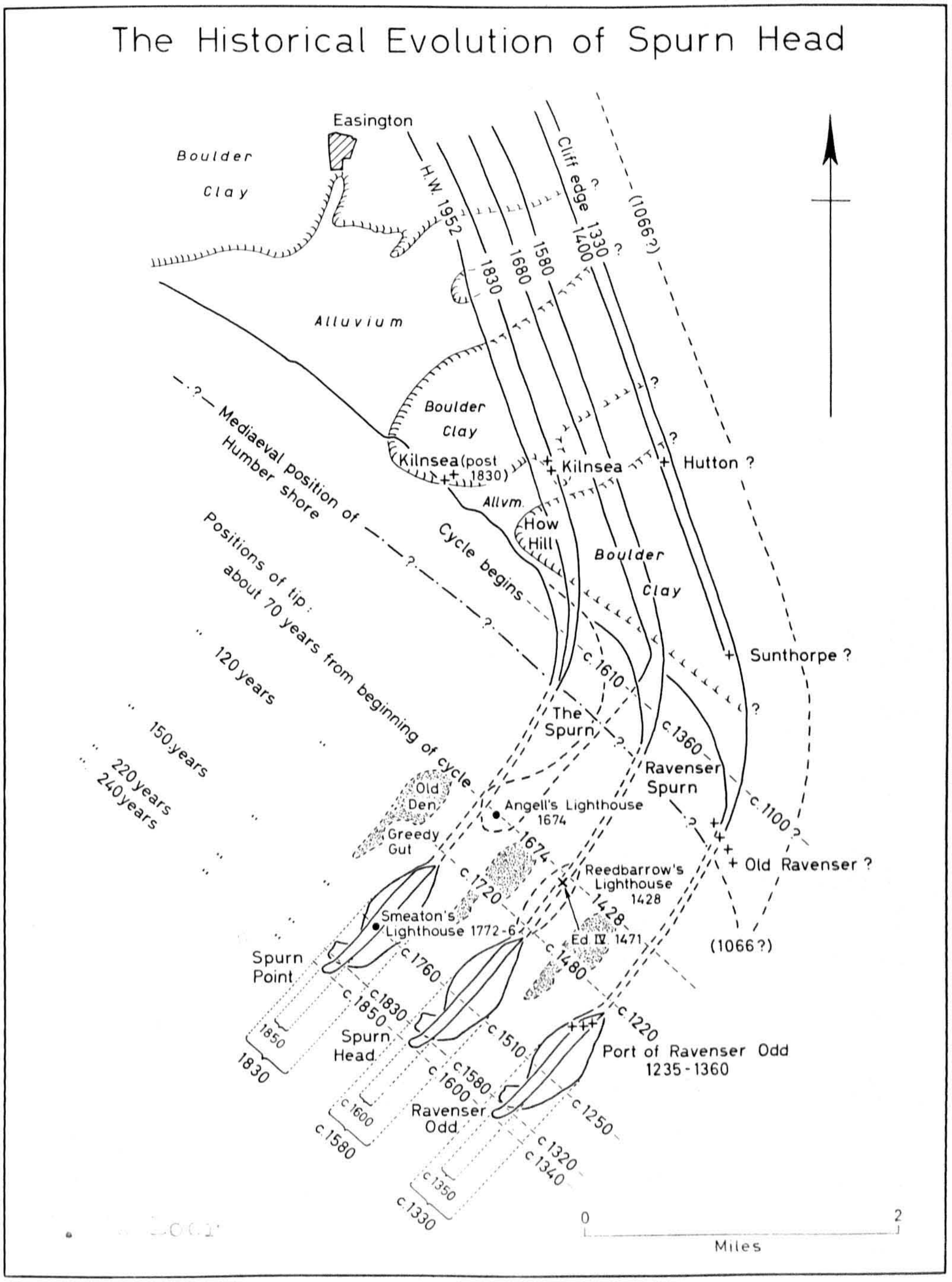

The Historical Evolution of Spurn Head
Easington
Boulder Clay
H.W. 1952
1830
1680
1580
1400
1330
Cliff edge
(1066?)
Alluvium
Boulder Clay
Kilnsea (post 1830)
Kilnsea
Hutton ?
Allvm.
How Hill
Boulder Clay
Mediaeval position of Humber shore
Cycle begins
Positions of tip: about 70 years from beginning of cycle
" 120 years
" 150 years
" 220 years
" 240 years
Sunthorpe ?
c.1610
The Spurn
c.1360
Ravenser Spurn
c.1100
Old Den
Greedy Gut
Angell's Lighthouse 1674
1674
+ Old Ravenser ?
c.1720
Reedbarrow's Lighthouse 1428
1428
Smeaton's Lighthouse 1772-6
Ed.IV. 1471
(1066?)
Spurn Point
c.1760
c.1480
c.1830
c.1850
1850
1830
Spurn Head
c.1510
c.1220
Port of Ravenser Odd 1235-1360
c.1580
c.1600
c.1600
c.1580
Ravenser Odd
c.1250
c.1320
c.1340
c.1350
c.1330
0
2
Miles

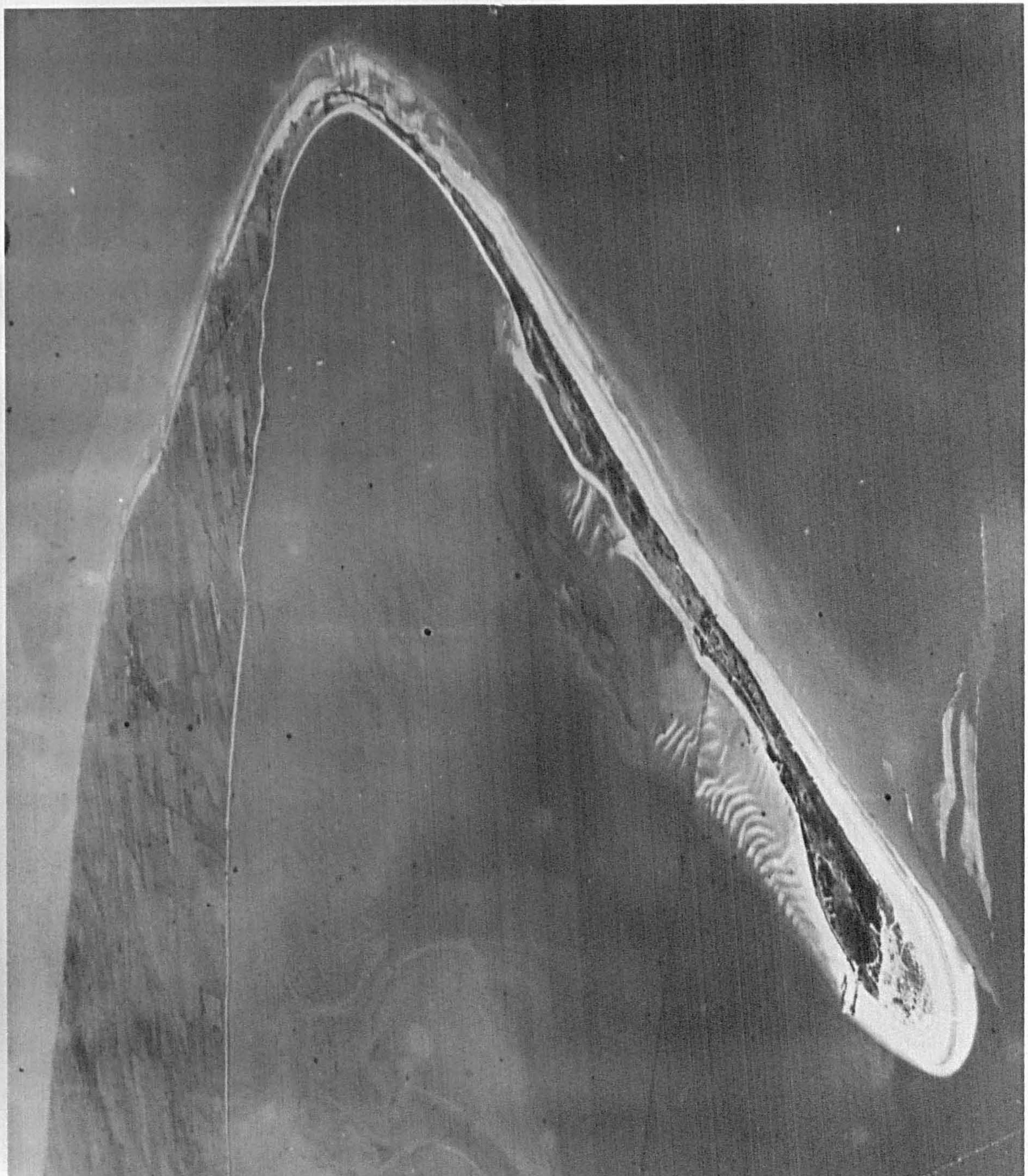
Fig.8.2

P L A T E S

CHAPTER 1

Plate 1.A An Aerial View of Spurn Head Looking North

13.5.59



CHAPTER 3

Plate 3.A A Swash Bar around the south-east part of the Tip
7.10.60

Plate 3.B Storm Waves at Kilnsea produced by strong north to
north-west winds. 18.2.62

Plates 3.C Storm Waves at Point D produced by strong north to north-west winds. 19.3.61

Plate 3.D Storm Waves at Point C produced by strong north to north-west winds. 19.3.61

Plate 3.E <u>Storm Waves Near Groyne III</u> produced by strong north to north-west winds. 19.3.61

Plate 3.F <u>Contrasting Wave Conditions along the Riverside of High Bents</u> 19.3.61

THE RESULTS OF STORM CONDITIONS

WITH STRONG NORTH TO NORTH-WEST WINDS

Plate 3.G Looking South from Point B after a period of build up

16.3.61

Plate 3.H Looking South from Point B during storm conditions

19.3.61

Plate 3.I   Looking South from Point D after a period of build up.

16.3.61

Plate 3.J   Looking South from Point D during storm conditions.

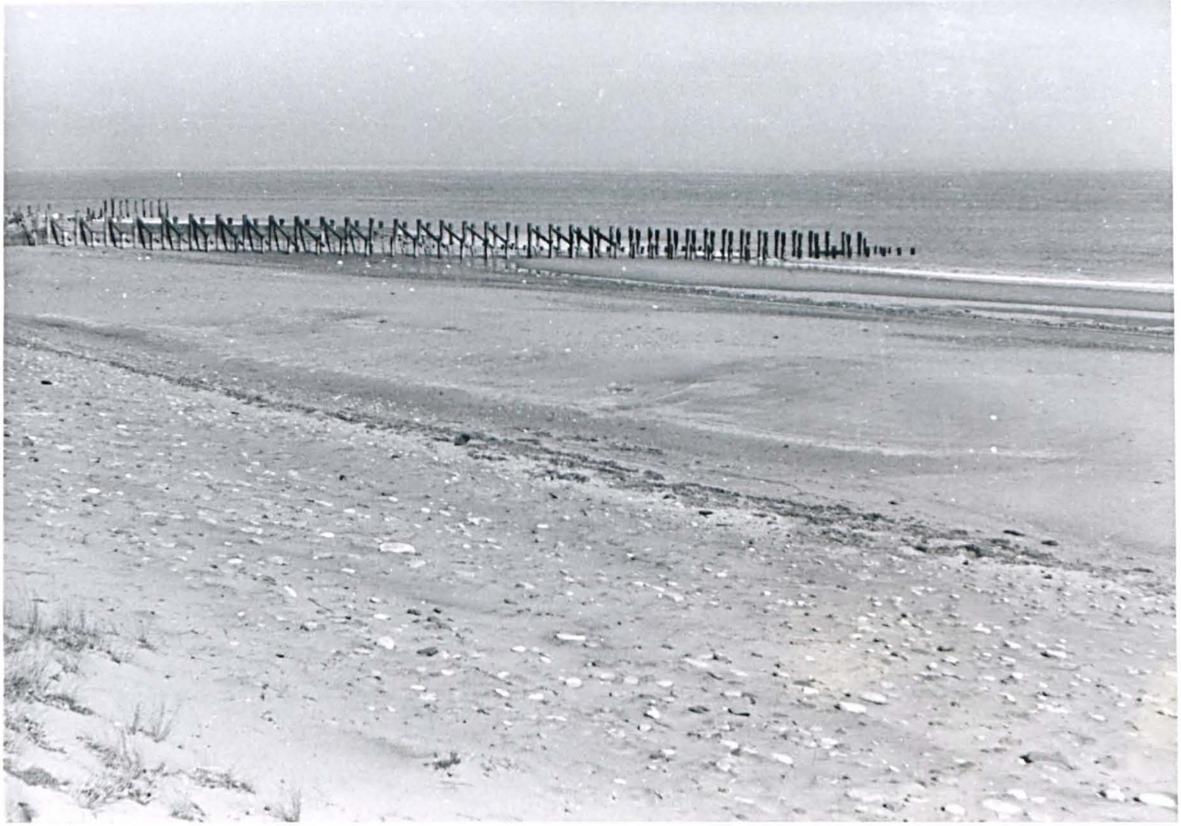
19.3.61

Plate 3.K <u>Looking North from Point E</u> after a period of build up

16.3.61

Plate 3.L <u>Looking North from Point E</u> during storm conditions.

19.3.61



The Low Section of Beach at Point D

Plate 4.A The Broken Groyne XVII 29.1.60

Plate 4.B The Collapsed Revetment at Groyne XVII 29.1.60

Plate 4.C <u>Erosion of the Dunes behind the Collapsed Revetment near Groyne XVII</u> 30.1.60

Plate 4.D <u>The Gap Torn in the Revetment Wall near Groyne XVII</u> with the eroded dunes behind. 30.1.60

The Low Section of Beach at Point C

Plate 4.E The Cliffed Dune Edge at Point C Looking North

14.1.61

Plate 4.F A Closer View of the Cliffed Dune Edge 14.1.61

Plate 4.G The Low Section of Beach looking north from groyne XI

19.3.61

Plate 4.H The Low Section of Beach looking south from groyne XI

19.3.61

Plate 4.I The Lower Beach Looking North from Groyne V

8.2.62 A continuous sand and shingle rise has been built south of the low section of beach.

Plate 4.J The Boulder Clay Cliff Behind the Breached Revetment at Fort Godwin, Kilnsea 10.9.61

Plate 4.K Erosion of a Projecting Section of the Boulder Clay Cliff at Fort Godwin, Kilnsea. 11.1.62

Plate 4.L The Erosion Viewed from the Cliff Top. 11.1.62

Plate 4.M The Site of the Experiment on the Longshore Movement of Material, near Groyne III. 10.9.61 Both upper and low beaches are exposed.

CHAPTER 5

Plate 5.A — The High Upper Beach at Point A During Storm Conditions

19.3.61 The wave action on the foredunes has left only the cores. A mound of drift wood, seaweed and torn vegetation is shown in the bottom right-hand corner, and could form the core to a new fore-dune.

Plate 5.B — Pebbles Alone Forming the Bottom Part of the Beach at the Tip at its narrowest Section 14.4.61

Plate 5.C Pebbles on the Bottom Part of the Beach at the Narrowest Section of the Tip 15.2.61

Plate 5.D The Triangular Area of Sand at the Tip with its Apex Towards the Neck of the Binks. 12.6.61

Slight hollows are seen in the surface.

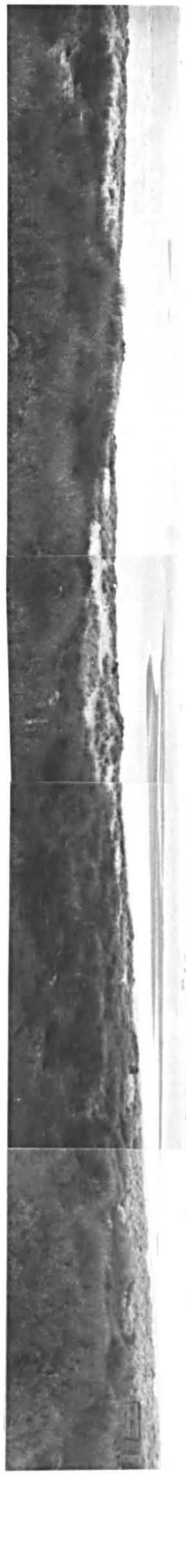
Plate 5.E Hollows in the Beach Adjacent to the Neck of the Binks, forming part of an irregular pattern of ebb ripples. 15.2.61

Plate 5.F One of the Many Large Hollows between Hummocks of Loosely Compacted Sand in the Tri~~na~~angular Area of Sand at the Tip. 15.2.61

5.G

<u>The Binks from the High Lookout Tower</u> 16.1.61

The narrow neck is seen joining the beach to the Inner Binks. The Middle Binks are exposed seawards of the Inner Binks and whilst isolated from them, the line of breakers shows that they are part of the same formation. Ebb ripples can be seen on the Inner Binks.



5.H Ebb Ripples on the Northern Part of the Inner Binks Looking West. 31.12.59

The alignment is approximately north-west to south-east. The beach at the Tip is seen in the background.

5.I Ebb Ripples on the Inner Binks near the Neck, looking West

15.2.61 The junction between the two sets of ripples is seen, although those on the south side are only slightly developed. The beach at the Tip lies in the background.

5.J The Central Area of the Inner Binks Looking South-East

25.9.61 Large ebb ripples are shown in the background

5.K The Inner Binks Close to the Neck, looking West

8.2.62. The ebb ripples are more rounded and less well defined than in the previous plates.

5.L The Northern Margin of the Inner Binks looking South-East

8.2.62 Well defined ebb ripples are shown.

5.M The Inner Binks looking South-West

25.9.61. Irregular mounds of sand on top of the shingle.

5.N <u>The Embayment between the Inner Binks and the East Shore of the Tip.</u> 19.1.61 Firm, finely ripple-marked sand is exposed.

Plate 5.O The Ebb Stream Washing the Shore at A West

12.6.61

Plate 5.P Conditions at A West at the Turn of the Tide about Low Water 12.6.61

Plate 5.Q <u>Drainage Channels Dissecting the Middle Part of the Beach at the Narrow Section of the Tip as the Tide Falls</u> 22.3.61

. Plate 5.R A Cliff Left in the Middle Part of the Narrow Section of the Beach at the Tip after the rapid removal of Material 13.2.61

. Plate 5.S A Close-Up View of the Cliff Shown Above 13.2.61

Plate 5.T A Cliff Being Cut in the Bottom Part of the Beach at the Narrow Section of the Tip. 23.3.61

CHAPTER 6

Plate 6.A The Cliffed Dune Edge on the Riverside of High Bents

22.3.61. The result of two storm surges

Plate 6.B Shingle Partly Burying Vegetation at the Edge of the Dunes at Point I. 22.3.61 The result of two storm surges.

Plate 6.C   <u>The Surface of Old Den Looking North</u>   20.1.62

Plate 6.D   <u>The Surface of Old Den Looking South</u>   20.1.62

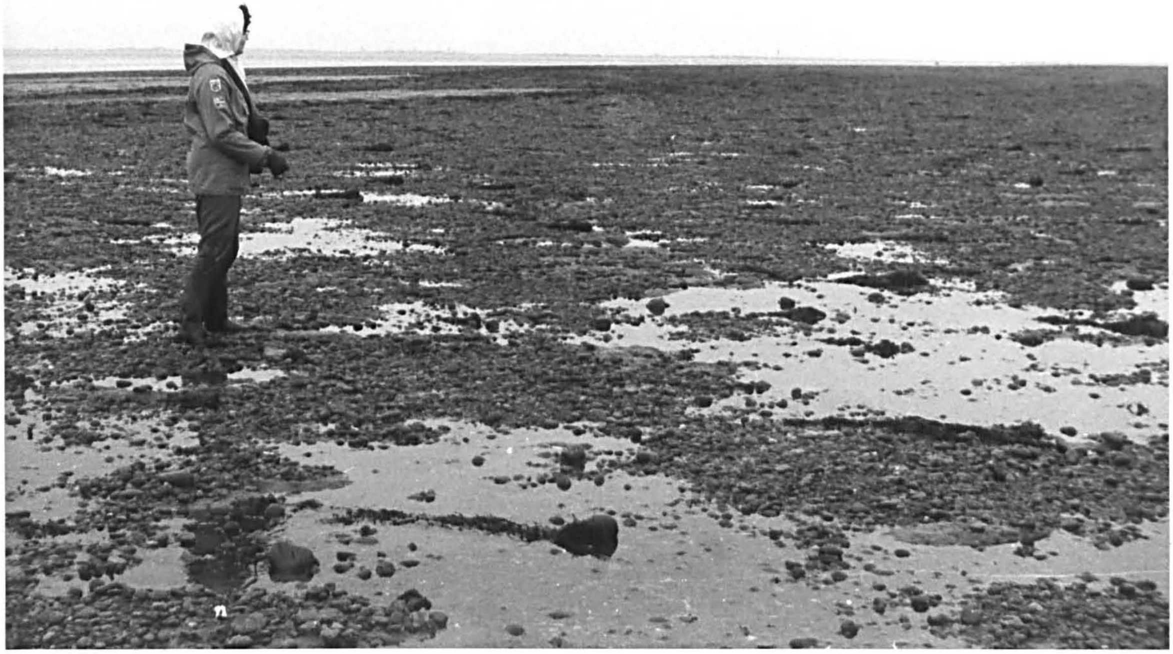


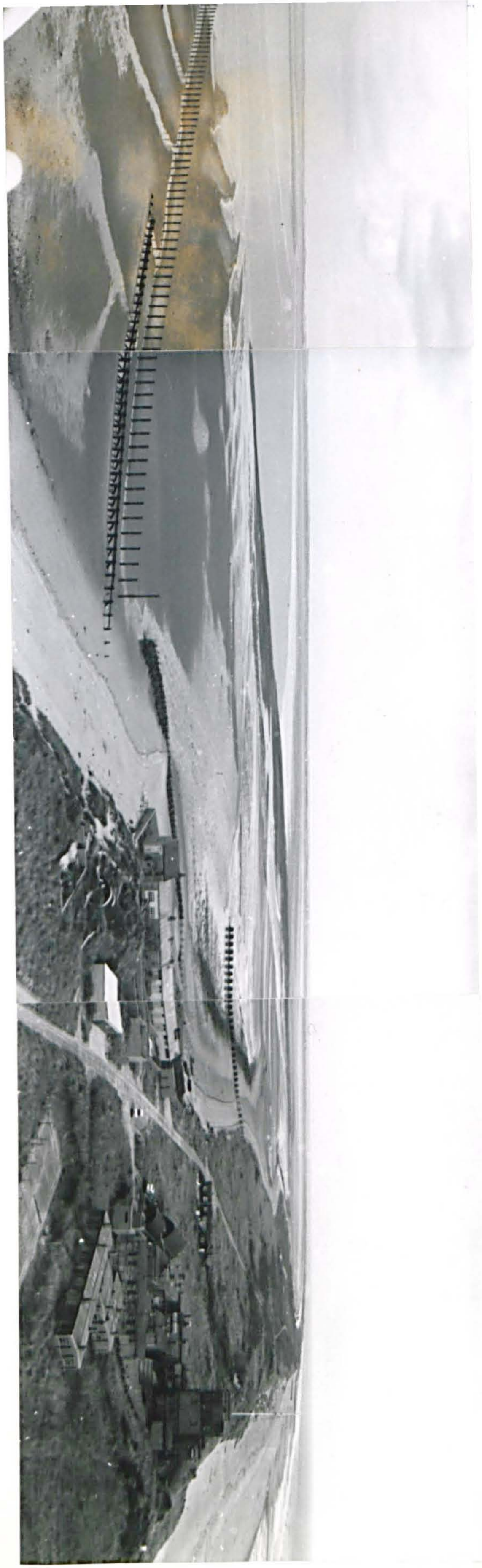
Plate 6.E   <u>Part of the Delta Formation on Old Den Looking East</u>

20.1.62

CHAPTER 8

Plate 8.A Spurn Head from the Top of the Lighthouse.

8.9.61 Above, looking south-west; below, looking north-east.

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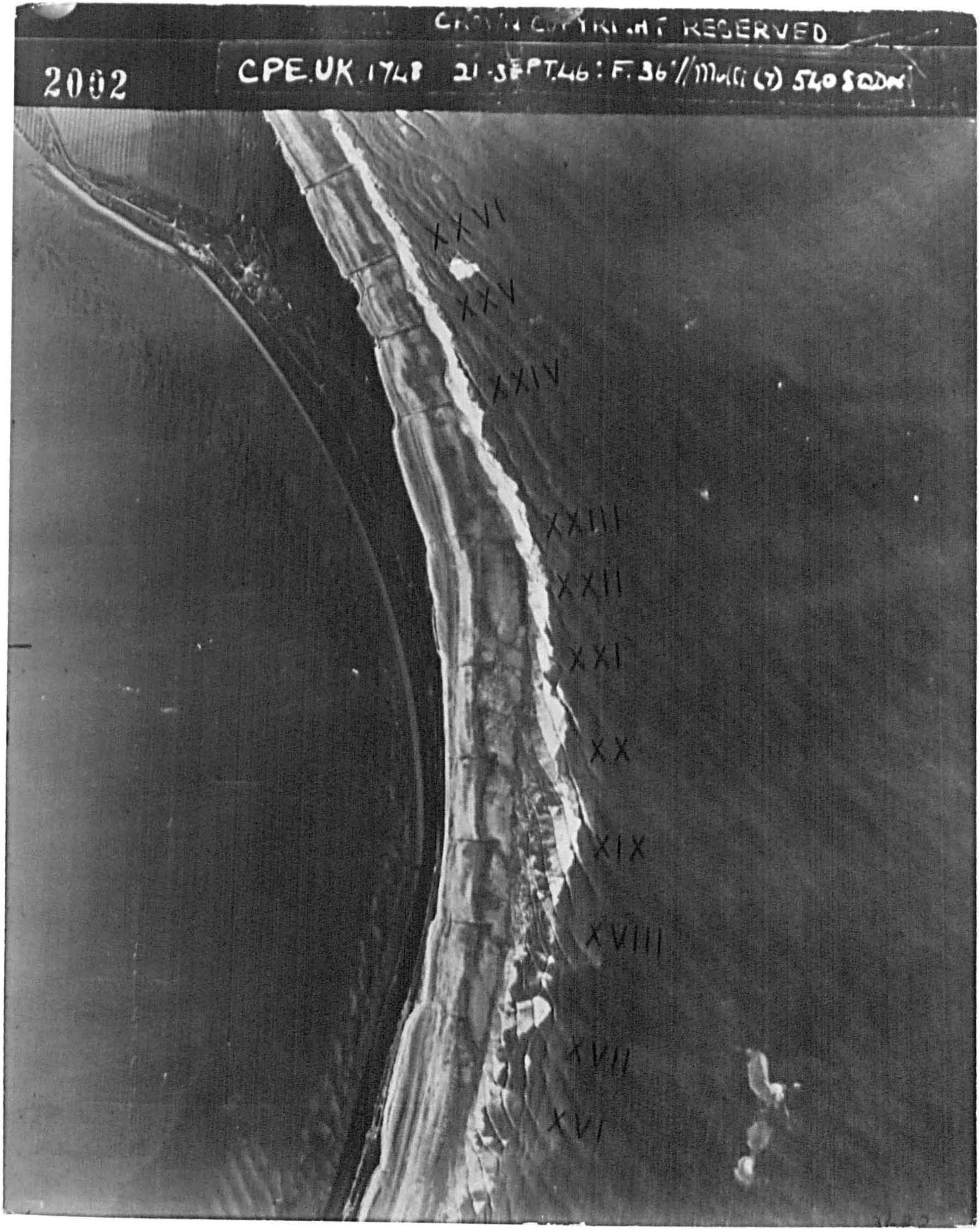
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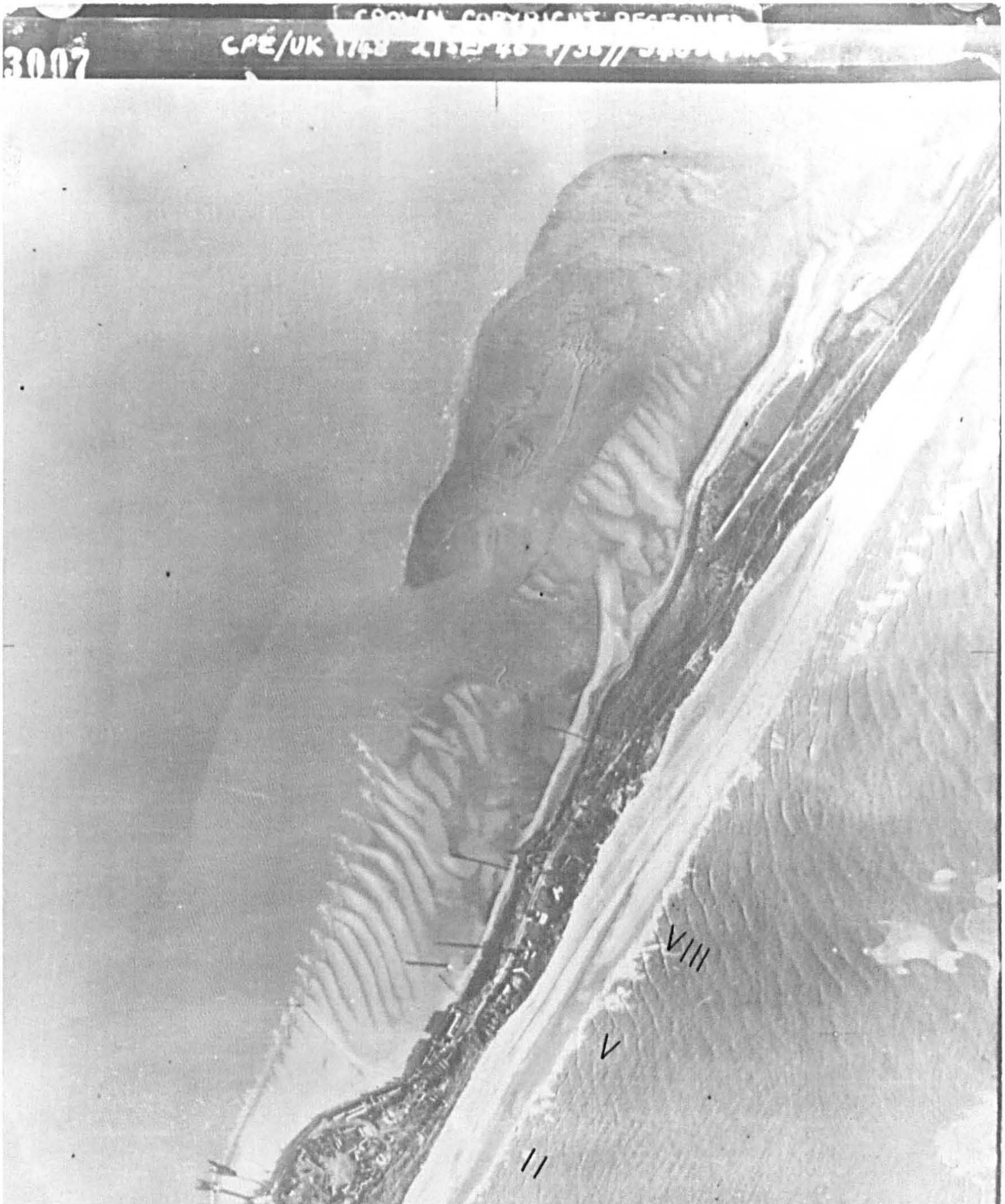
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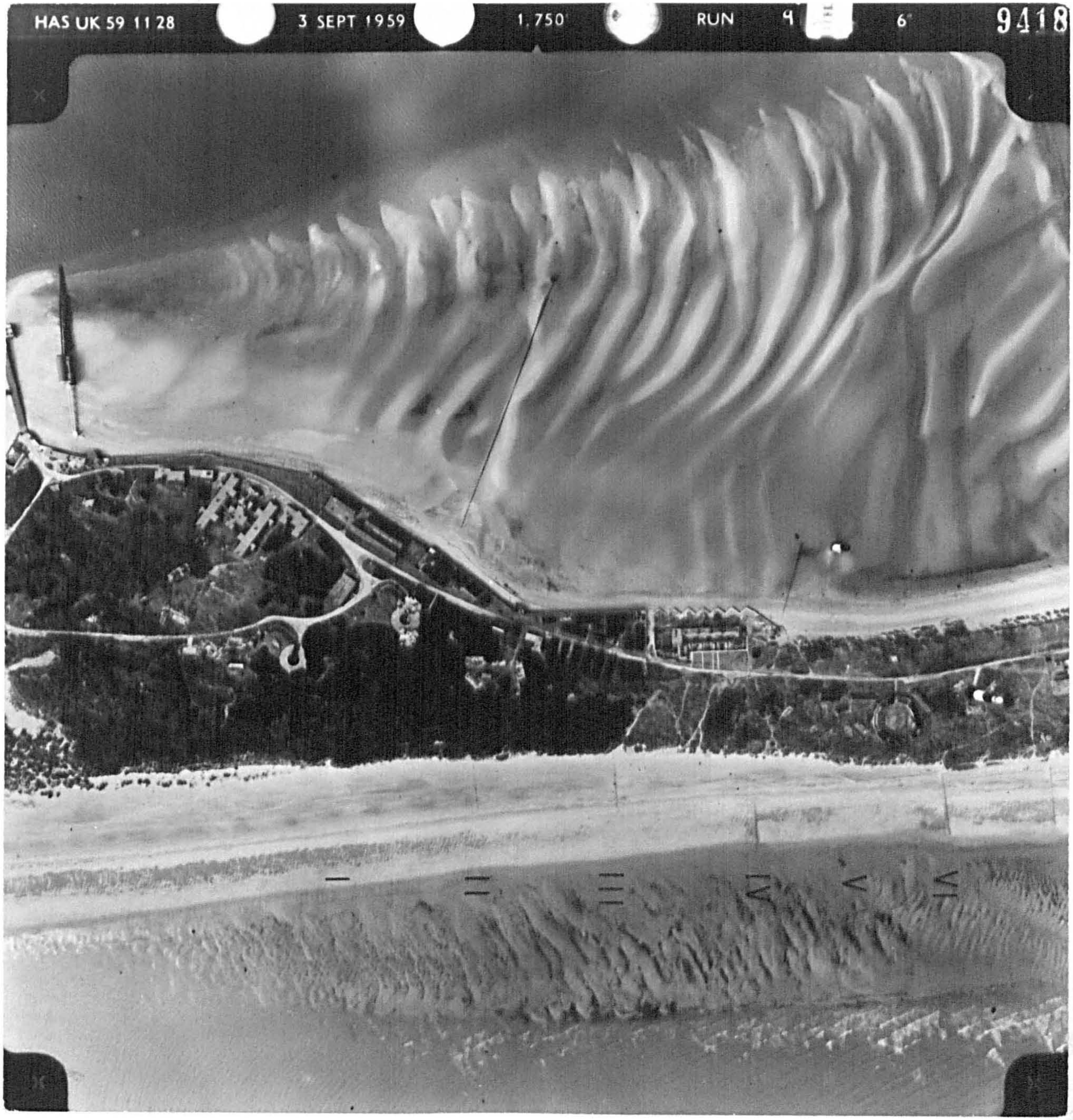
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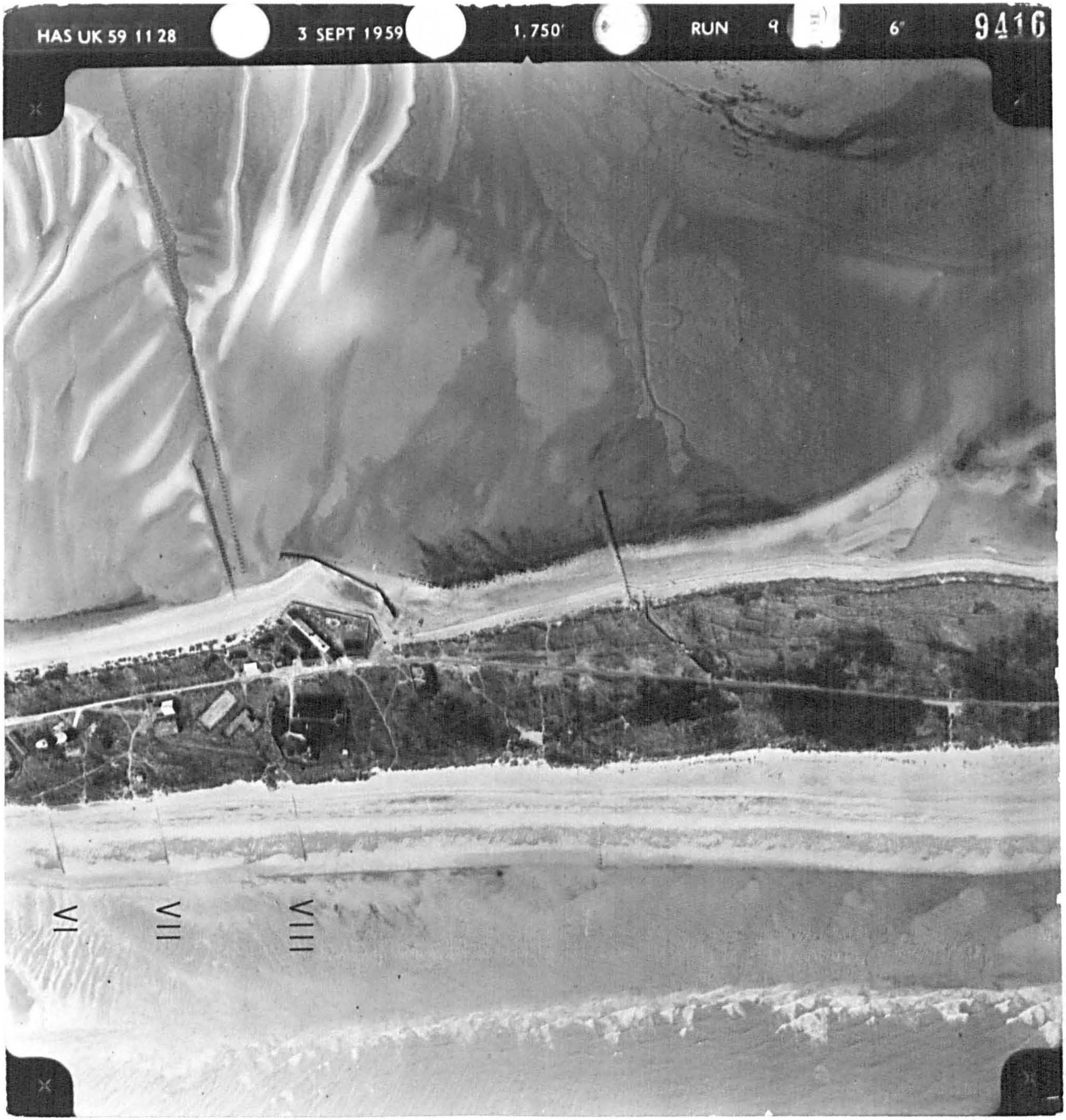
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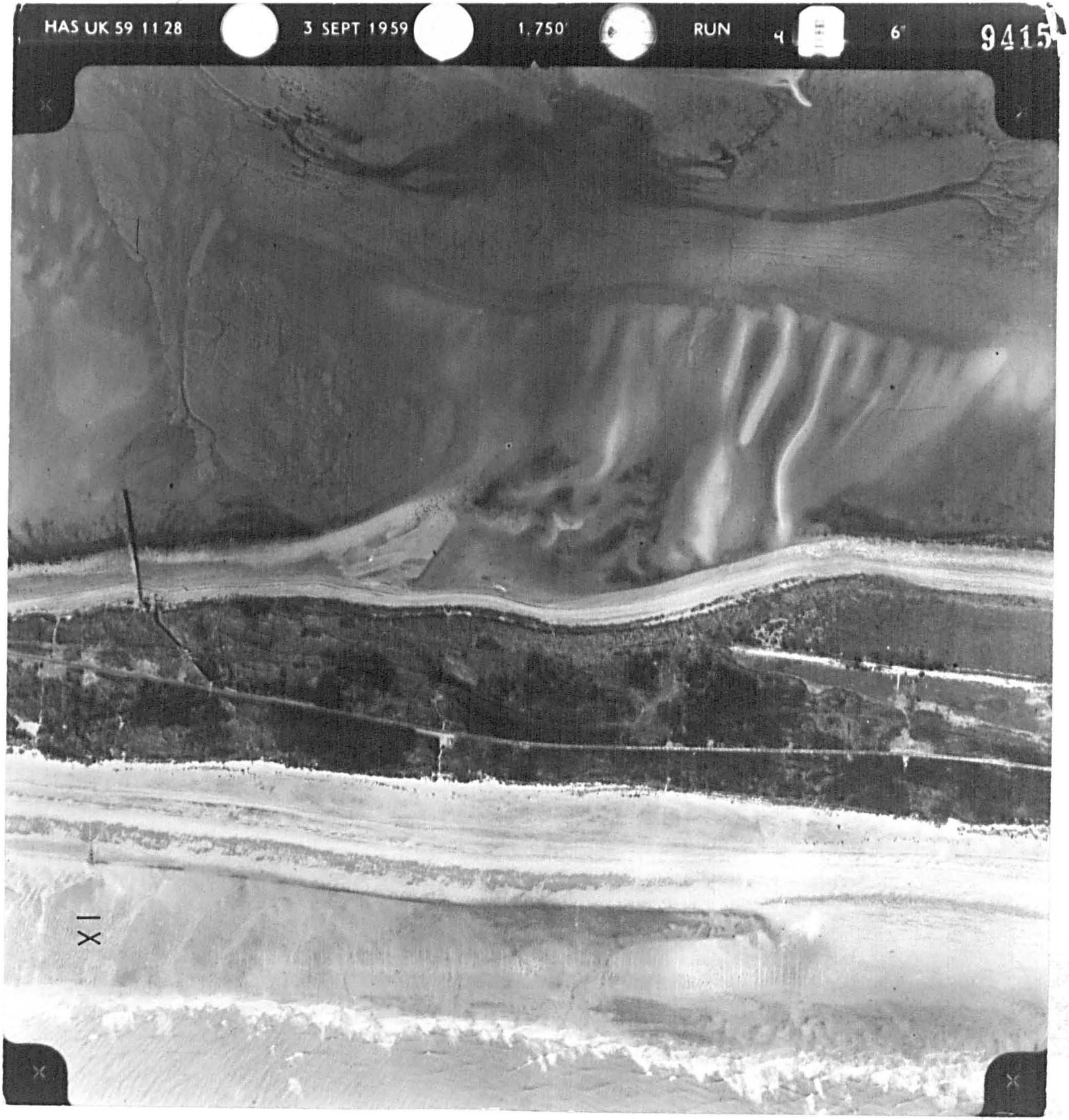
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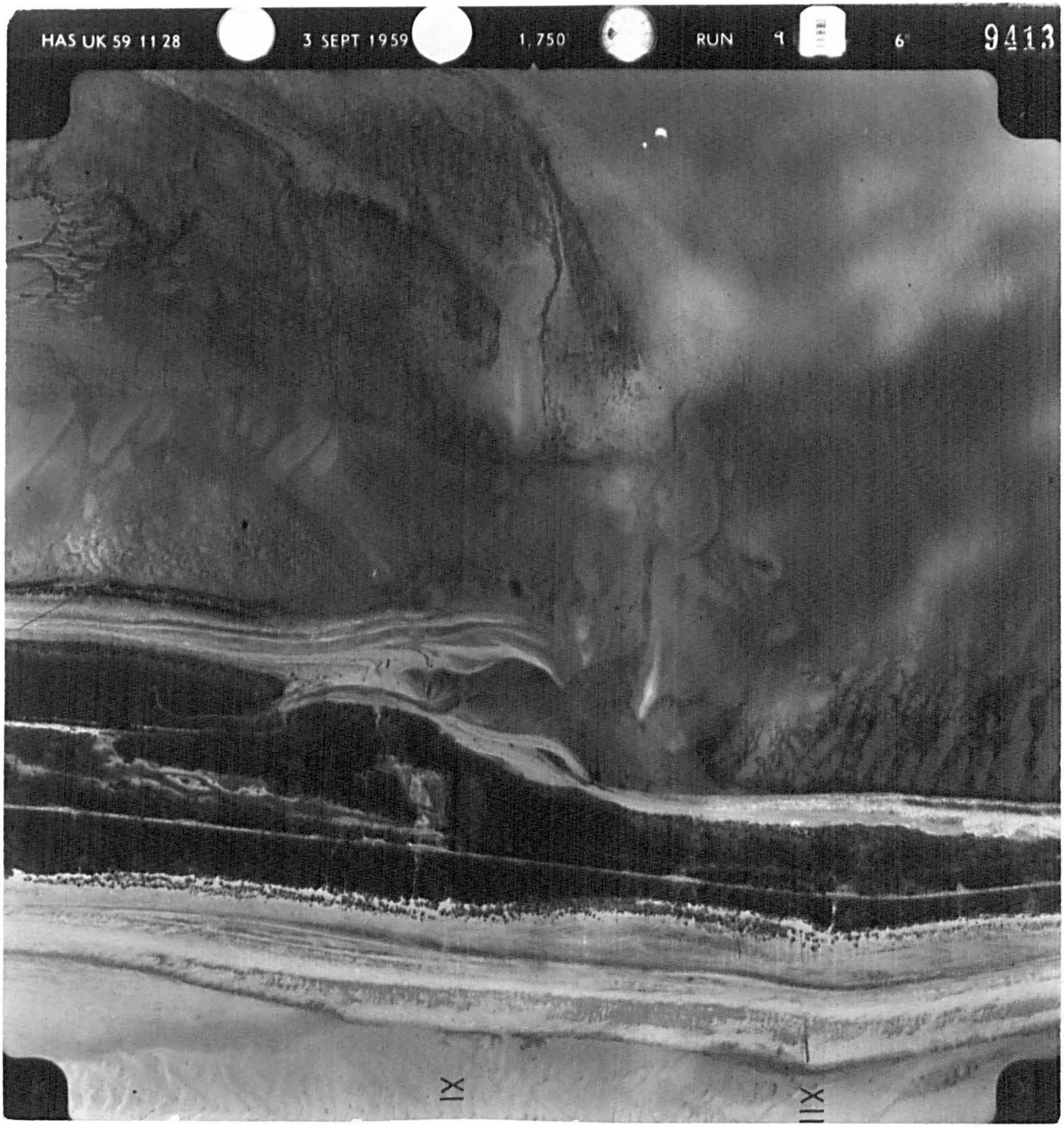
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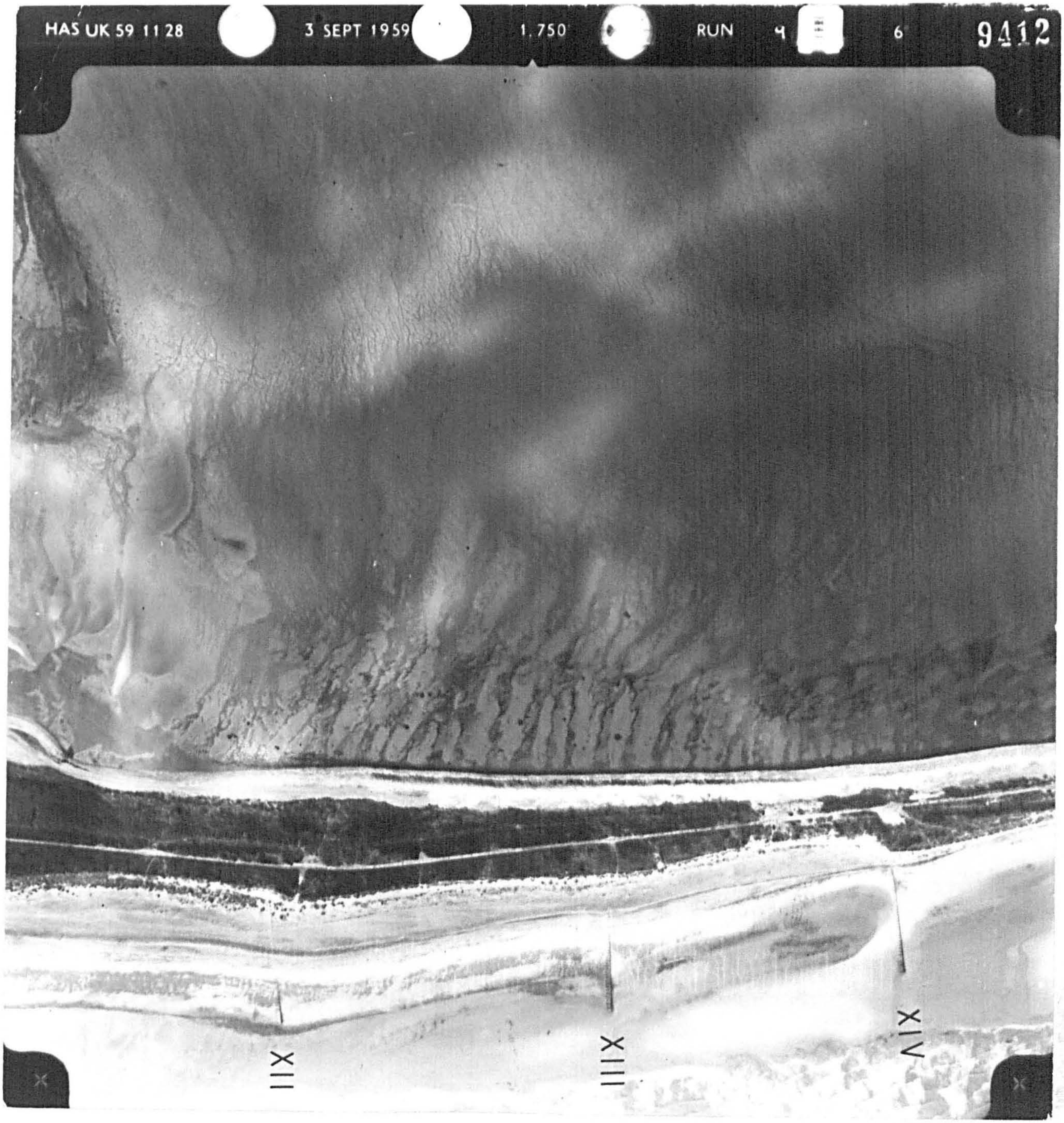
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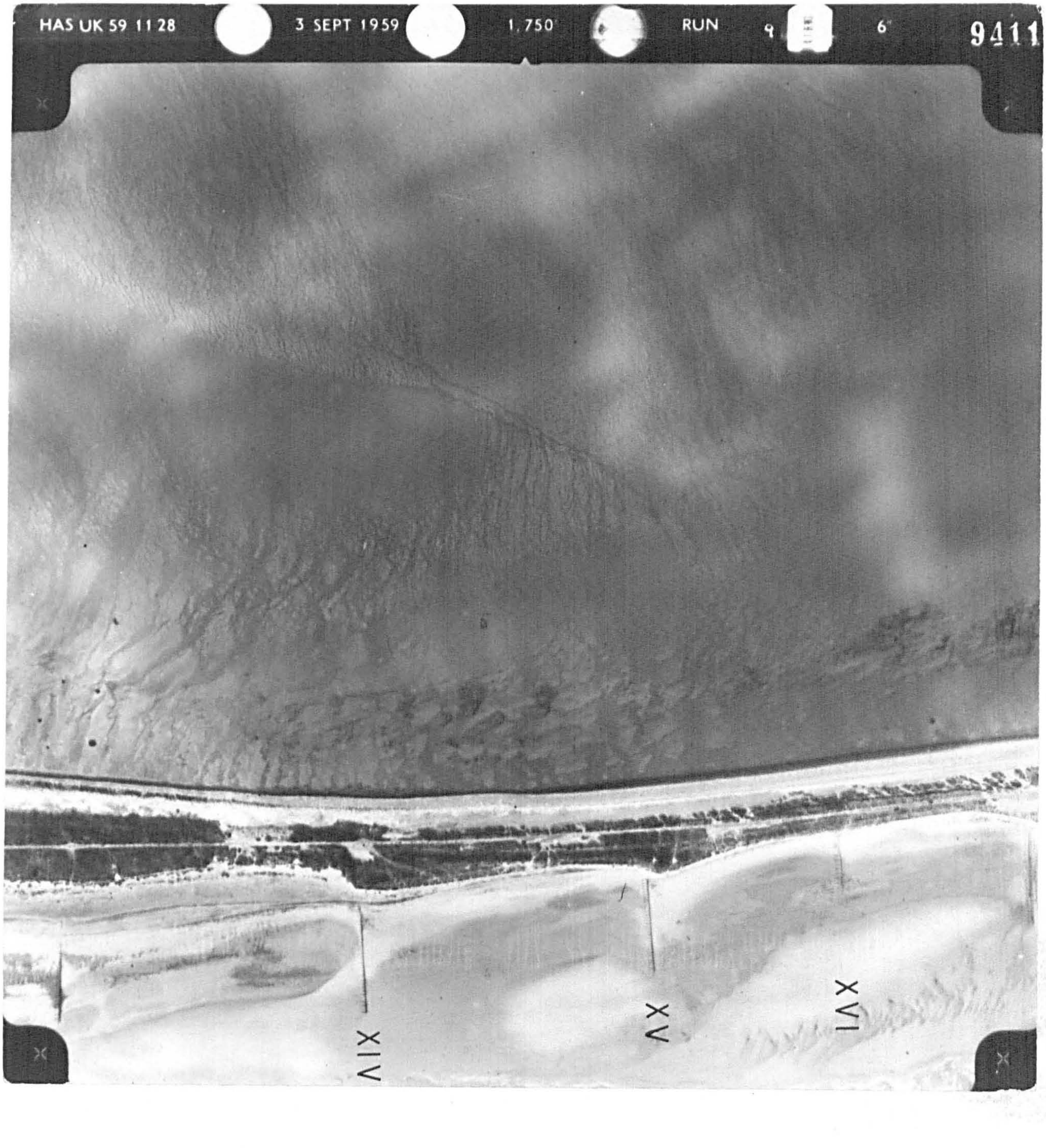
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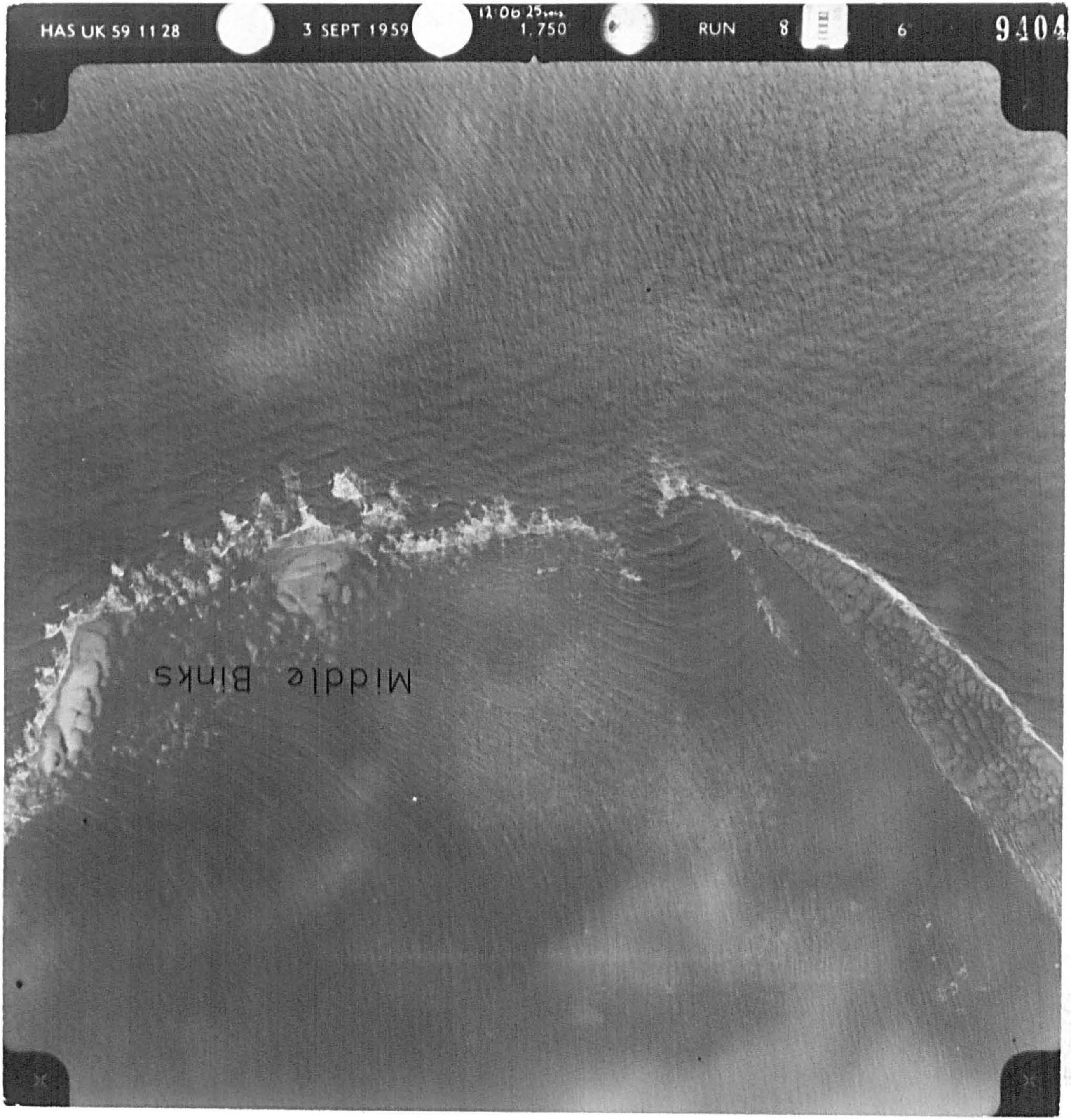
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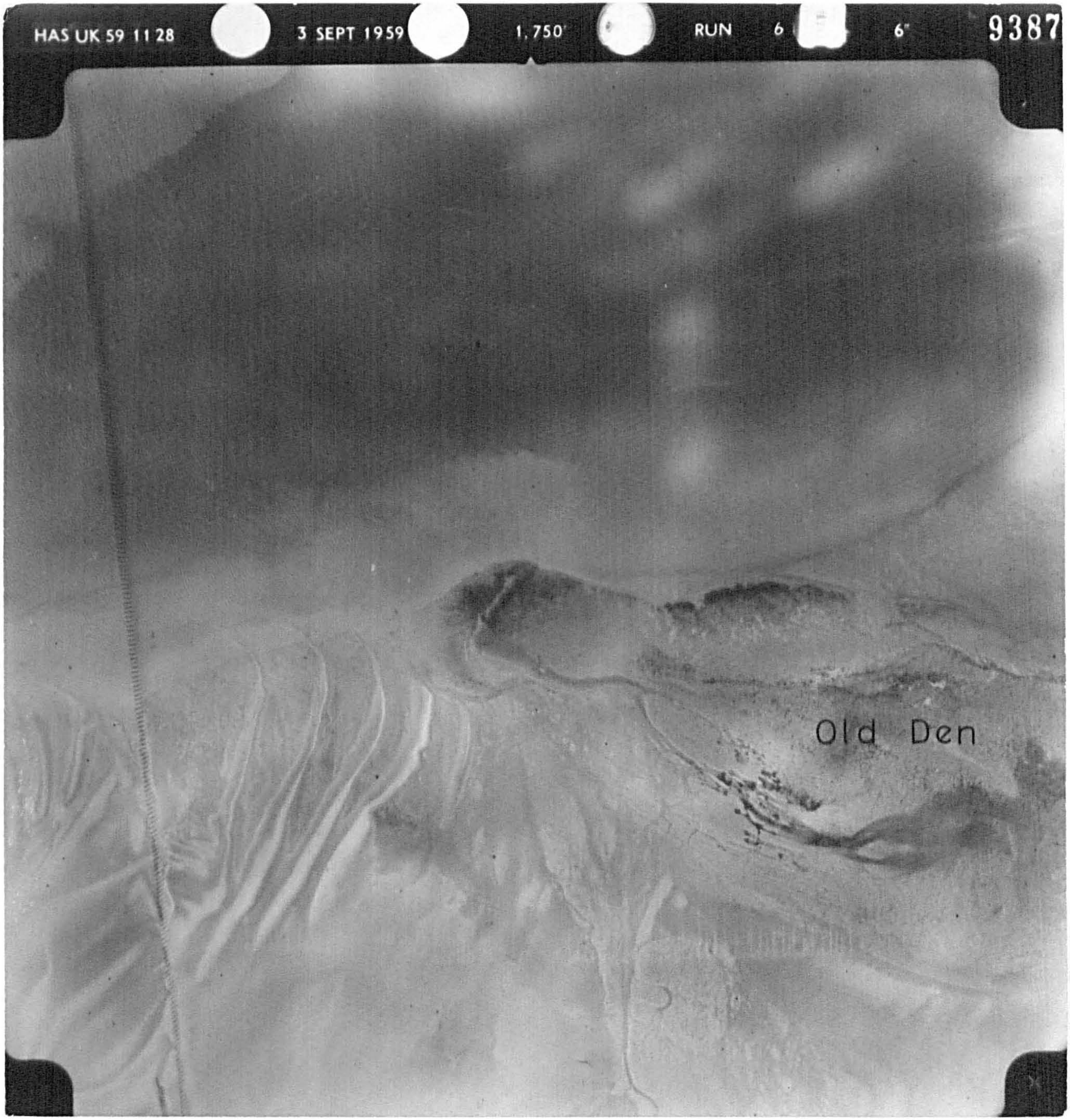
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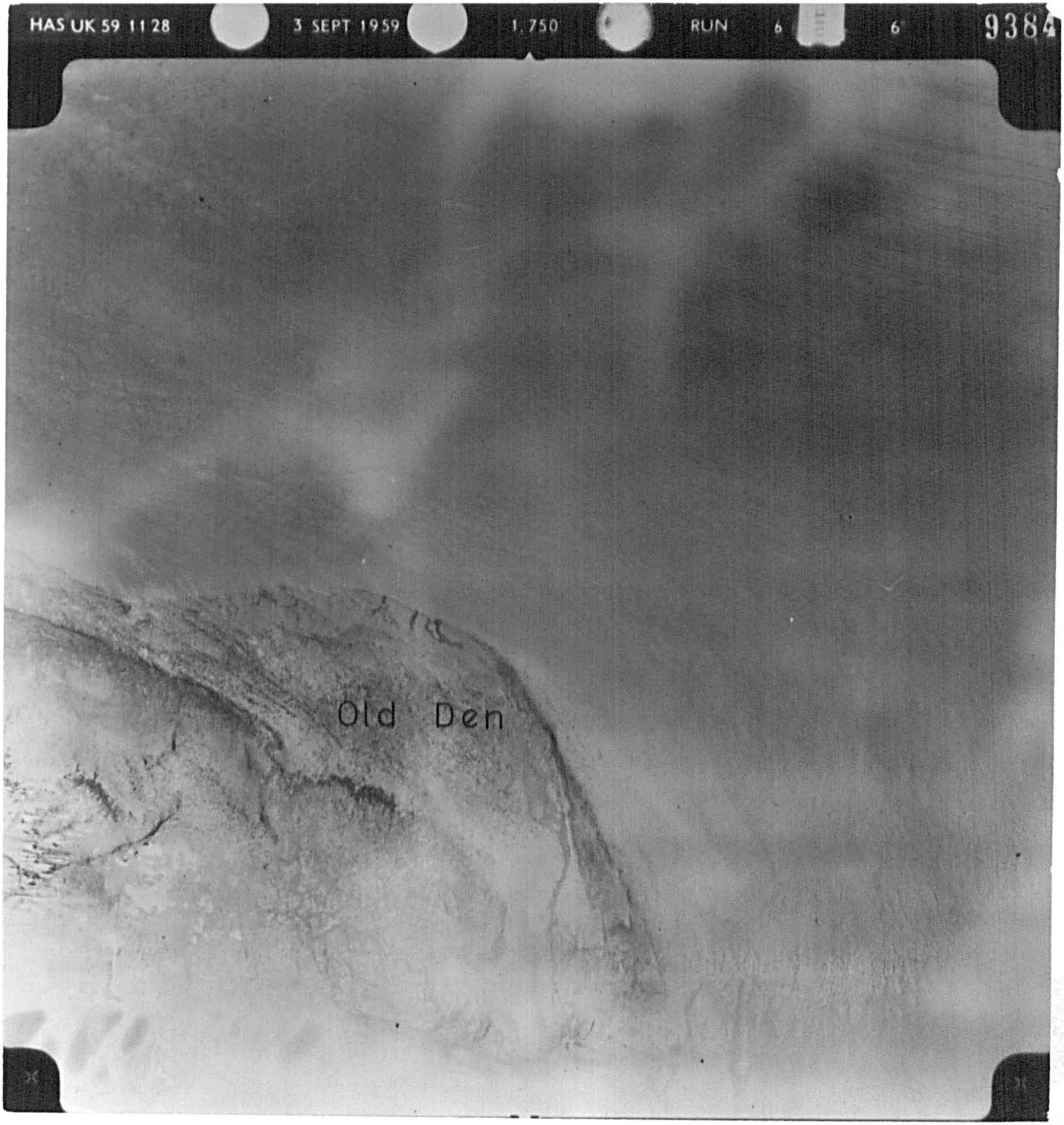
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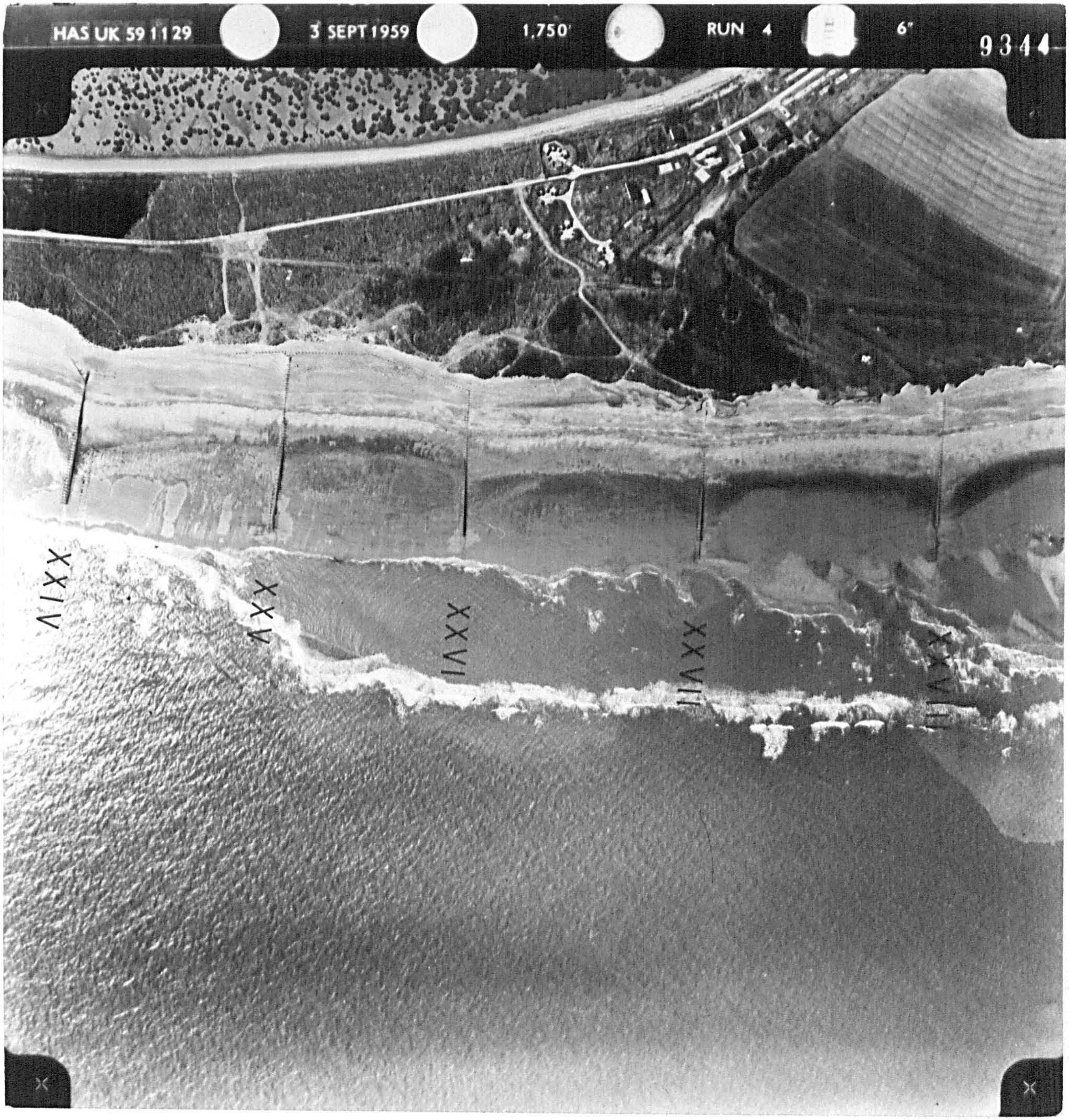
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9342
Kilnsea


HAS UK 59 1129
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HAS UK 59 1129
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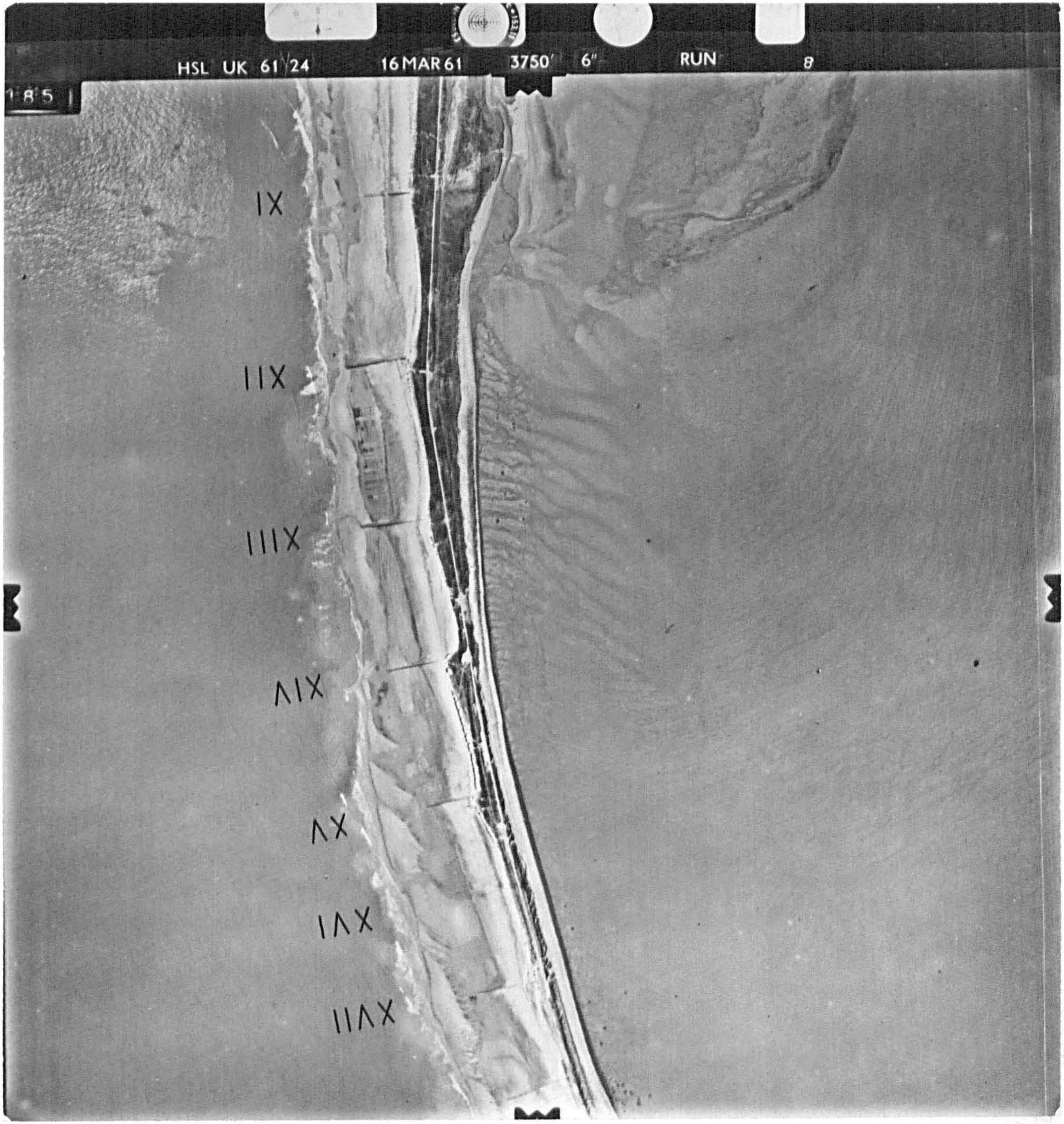
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6"
RUN
8
183
IX
IIX


HSL UK 61/24 16 MAR 61 3750' 6" RUN
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XX
XIX
XVIII


HSL UK 61/24
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RUN
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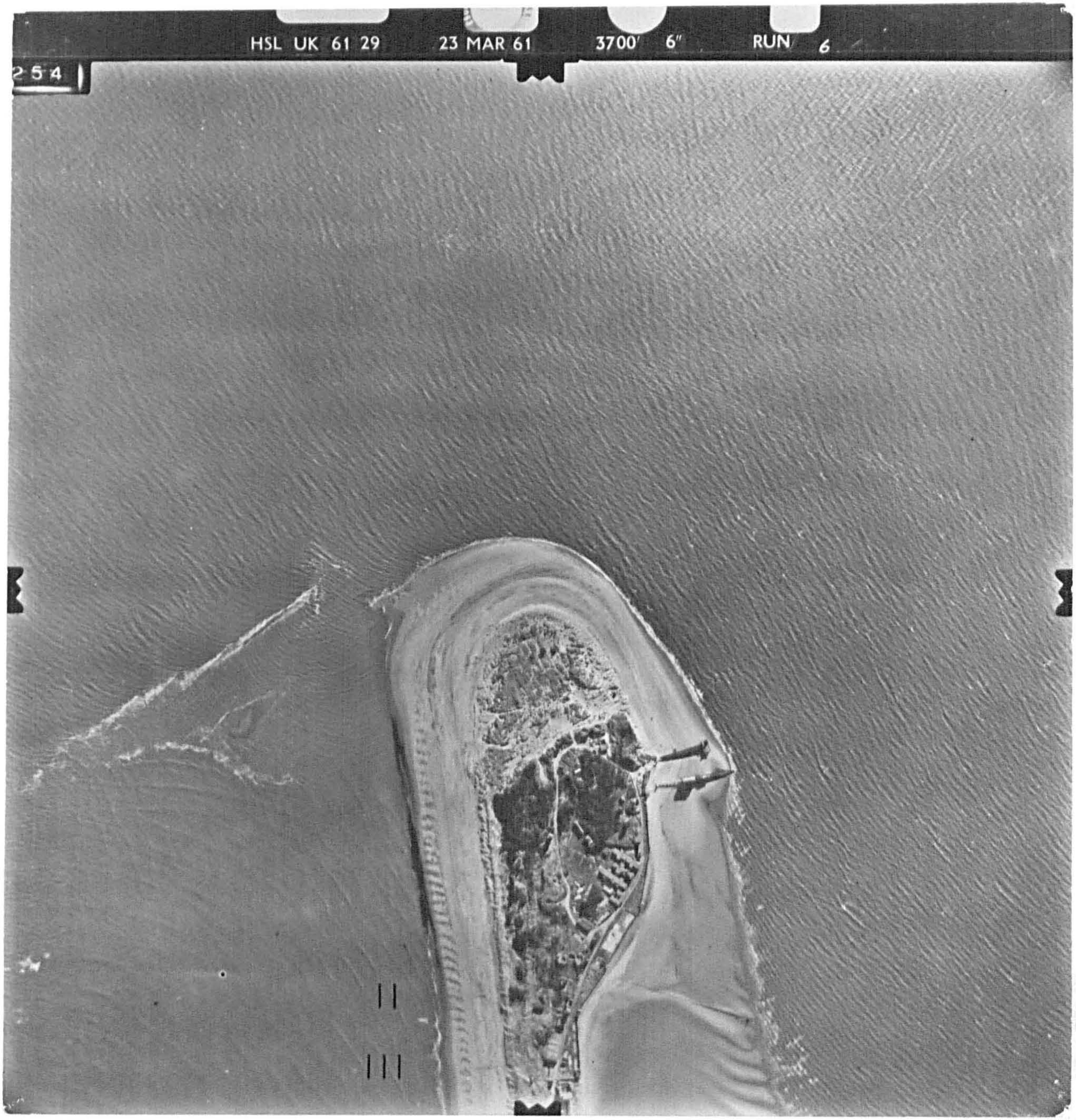

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