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ASPECTS OF SPIT DEVELOPMENT AND DECAY: THE ESTUARY OF THE RIVER ORE, SUFFOLK

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This paper reviews developments at the mouth of the River Ore, Suffolk, since the data of Cobb (1957) and Carr (1965). Cobb followed changes at Shingle Street to 1955 principally from air photographs; Carr considered the estuary generally, and especially the distal point, up to 1962–1963. Continuous wave and tide records were obtained for 1967–1968 and anemometer records at King's Marshes from 1966 onwards (Aldeburgh from 1964). Tidal current data were obtained in 1967, 1968 and 1969. Annual topographic and hydrographic surveys continued until 1970.

The data show:

(a) Onshore windrun and significant wave height and frequency do not correlate well with growth of the distal spit.

(b) Peat at the mouth of the estuary confirms the cartographic evidence. This suggested that rebuilding of the spit occurred in the same lateral position.

(c) Calculations over the past 12 years suggest that since about 1967 accretion in the estuary has become dominant over erosion; until that time, even with the sometimes rapid growth of the spit, they were finely balanced.

(d) Certain features of detail (e.g. the differential growth of distal point and offshore bar) are examined, particularly in relation to Carr (1965). Potential causes of break-up of the spit are discussed.

Introduction

Previous papers have described both the general evolution of the Orford area and that of the estuary of the River Ore in particular. Of the general papers Redman (1865) considered the area in relation to the coastline of East Anglia and Steers (1926) examined the evolution of the spit as a whole. Kidson (1963) used the configuration of the Ore estuary as an example of "counter-drift". More recently a series of papers by Carr (1967; 1969; 1970) and Carr and Baker (1968) followed the development of the district from pre-Pliocene times. Specific aspects of present-day processes have been reviewed elsewhere. For example, Kidson, Carr and Smith (1958) and Kidson and Carr (1959) studied the movement of beach material alongshore, immediately offshore and at the mouth of the river estuary. Changes at the mouth of the river, at the distal end of the major spit, and along the Shingle Street shoreline are described in Cobb (1957) and Carr (1965). It is the purpose of the present paper to extend the data of Cobb and Carr; to try and shed light on the causes of the growth and destruction of the spit, and to refer to the problems left outstanding in the 1965 paper.

North Weir Point is the termination of the shingle structure which extends from Aldeburgh in the north in a southerly and south-westerly direction for almost 15 km. (Fig. 1). The northern section between Aldeburgh and Orford Ness consists of an eroding beach which has receded landward for at least several centuries. This beach is backed by reclaimed salt marsh which separates the shingle coastline from

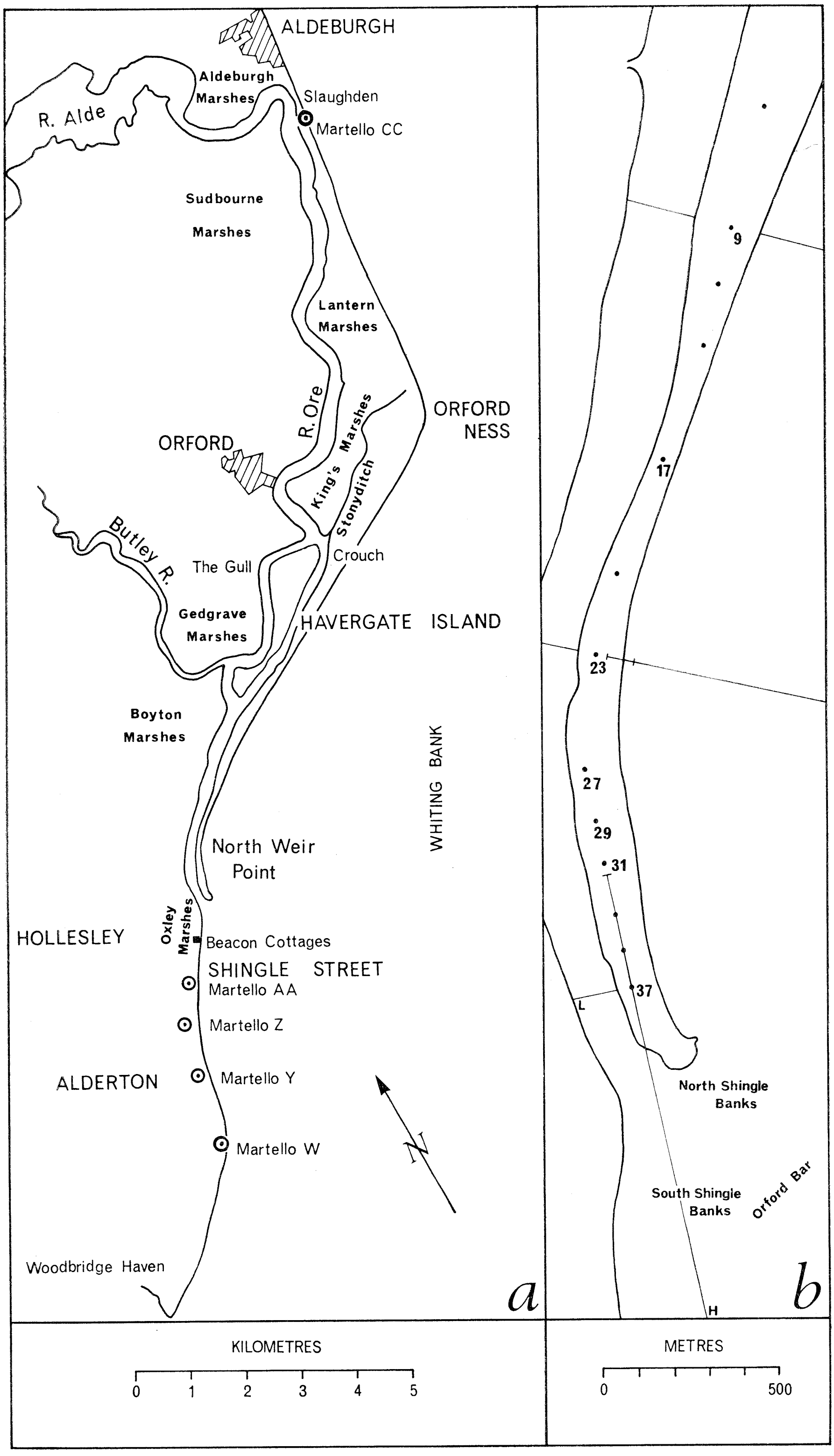

FIG. 1.

Orford, Suffolk: (a) site map of area. (b) North Weir Point and part of Shingle Street. Sections and survey points referred to in the text are shown.

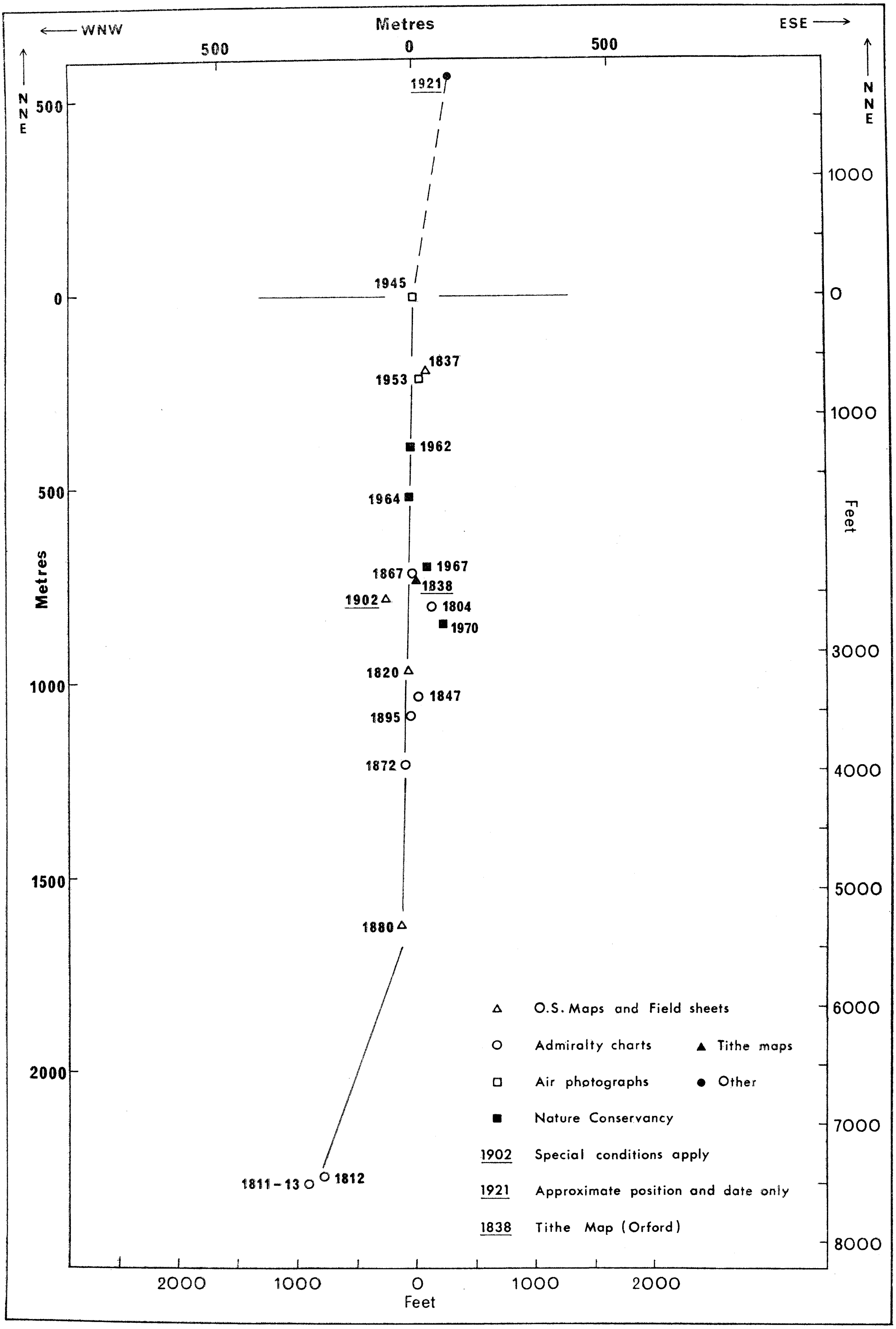

FIG. 2.

North Weir Point: distal point 1804–1970 showing variation in length but consistency in orientation. Peat data confirms the cartographic record (see text).

the River Ore. The river itself runs parallel to the shore and has the appearance of having been diverted from its original exit near Slaughden. Salt marsh is again present landward of the cuspate foreland of the Ness, but is scarcely evident on the seaward side of the river south of there.

South of Orford Ness, with its complex pattern of shingle ridges (Carr, 1970) the spit narrows to reach its minimum width of under 50 m. at high water mark about 1·5 km. north of the present river mouth (Survey Point 17 in Fig. 1b which shows the various survey points referred to in this paper). Over the whole of this stretch as far as the distal end of the spit the structure consists of a series of sub-parallel ridges on the riverward side of which recurves may be present. Very rapid growth of the distal point (Cobb, 1957) or its breaching may result in an extreme form of these with the recurves separated by tidal pools (e.g. immediately north of Survey Points 27 and 29). Fig. 3 indicates the ridge structure to the north of North Weir Point.

While the width of the spit varies both its composition and height show a remarkable uniformity. The material is almost exclusively flint, probably derived from offshore at times when sea level was lower than at present or from the glacial gravels of the cliffs to the north. Its size ranges throughout the whole of that included in the term "pebble" in the Wentworth scale. Individual ridges or constituent parts of a ridge may show a predominance of a particular grading of material. That part of the spit below low water mark shows a similar size grading with some additional finer sediment between the interstices of the pebbles, but further offshore mud and sand can also be found. The ridges on the river side reach a maximum height of just above 2 m. O.D. (Newlyn), while the beach crest varies between about 3·3 and 4·9 m. O.D., dependent upon the period during which it was constructed, the orientation of the spit, and the conditions under which the ridge was both built and later modified. Intervening swales may be as much as 1·5 m. lower than the ridges but are generally only about 0·3 m. lower.

The ridge structure at Shingle Street, on the other side of the estuary, opposite and to the south of North Weir Point is in many ways comparable although generally lower, far more ephemeral in character and with the majority, but not all (Cobb, 1957), of the recurves facing the reverse direction. The Shingle Street structures north of Beacon Cottages (Fig. 1) rarely exceed 3·4 m. in height and are frequently less. They show traces of several previous phases in development. Cobb describes the lagoons extending as far south as Martello Y. These were partly the legacy of the former course of the R. Ore, partly the effect of redistribution of beach material thereafter, and to some extent artificial. Since Cobb's paper most of these features have suffered further modification and reduction but lagoon 4, immediately north of Beacon Cottages remains largely unaltered.

Between North Weir Point and Shingle Street lies the River Ore. On each side of the river's main channel are the North and South Shingle Banks, areas of considerable size which are exposed for at least part of each tidal cycle. Since the description given in Carr (1965) considerable changes have taken place (Figs. 3, 4 and 6 to 10). While on some occasions parts of the South Bank have exceeded zero O.D. it has been the North Bank which has generally been higher. In addition, the narrow swash channel between North Weir Point and the North Bank has become eliminated while during 1970 the highest point of the Bank became joined to the spit. The effect of wave refraction associated with this development was to produce another, but smaller, tidal pool at the end.

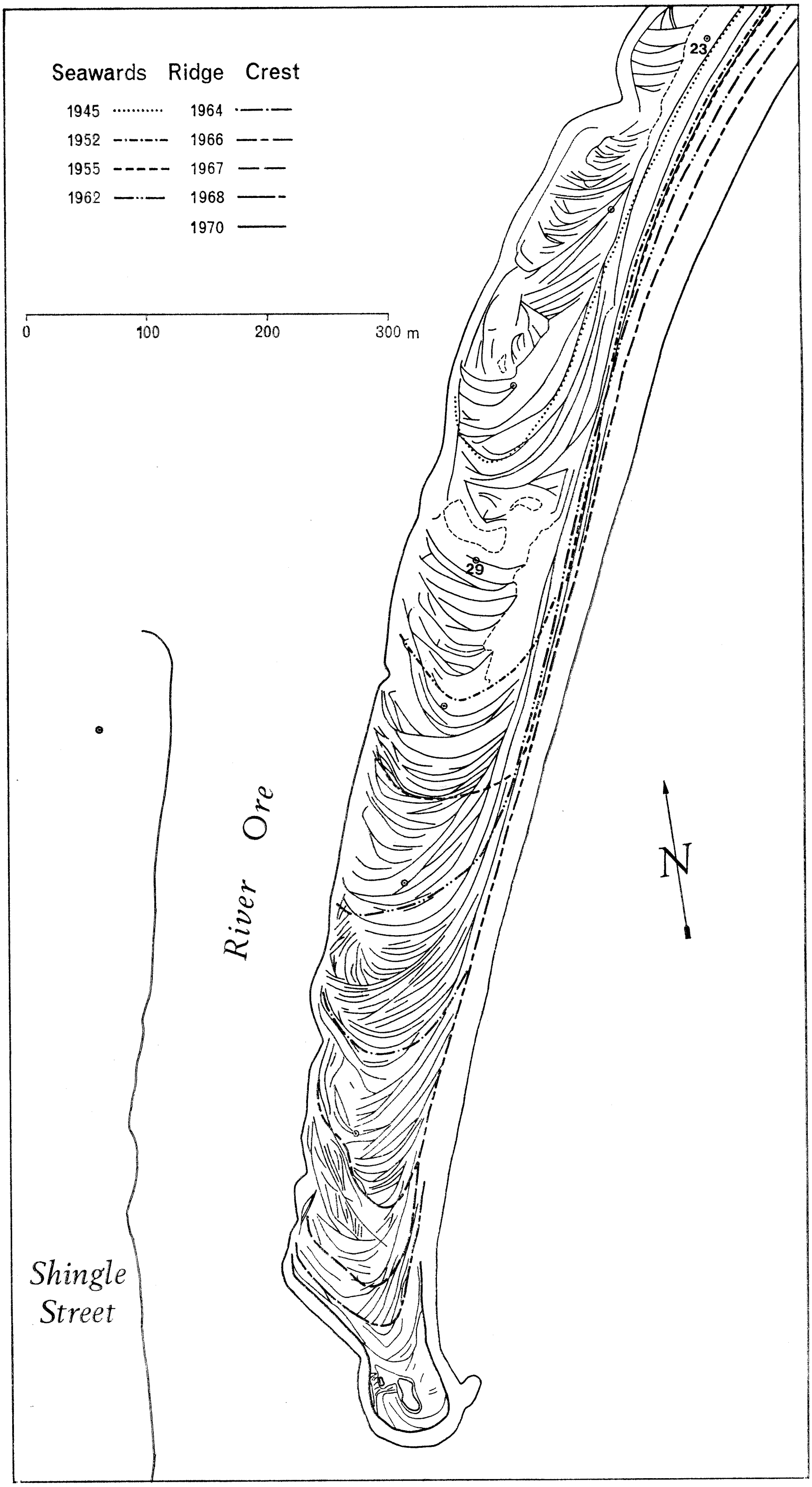

FIG. 3.
North Weir Point: shingle ridge structure and development to 1970.

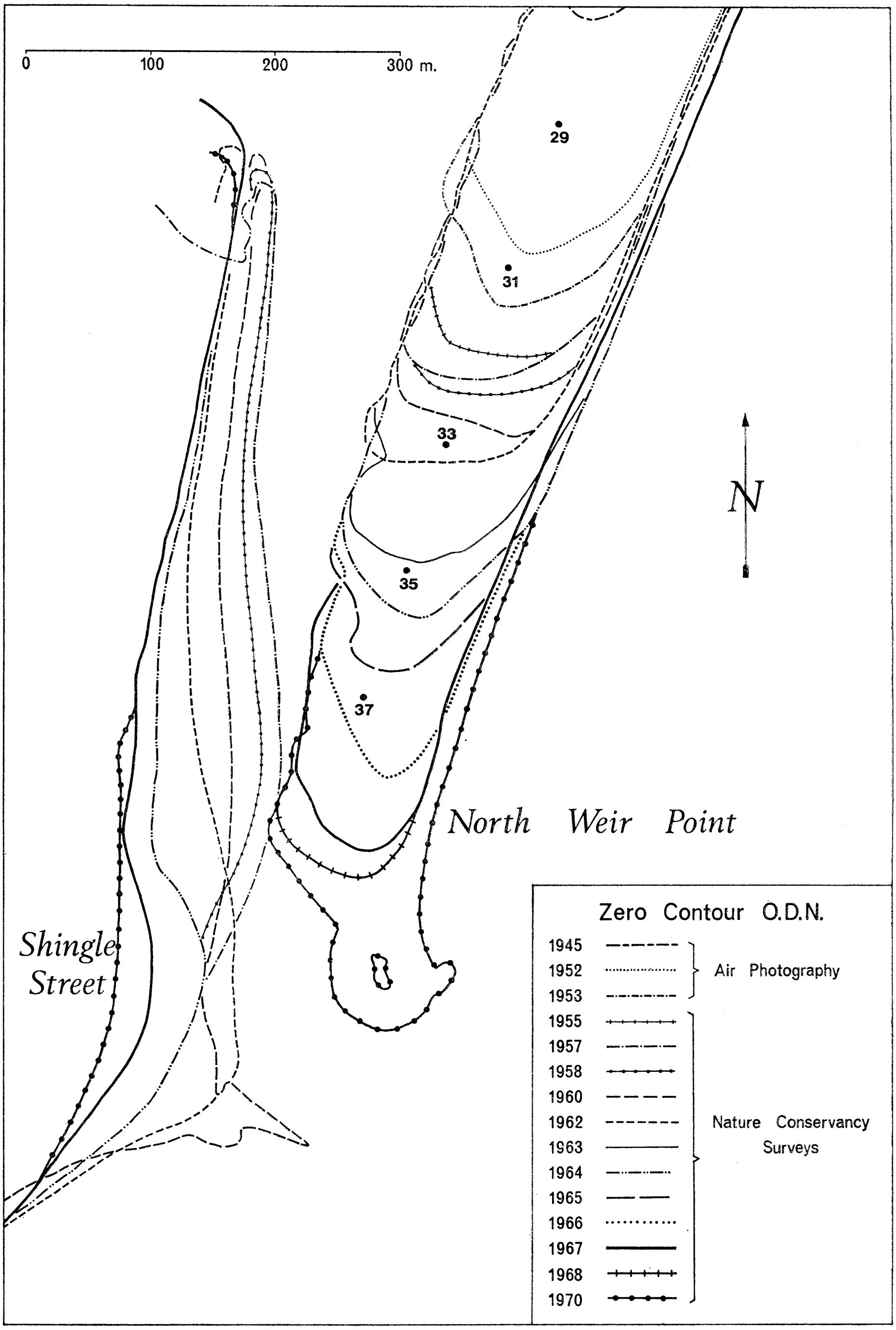

Fig. 4.

North Weir Point and Shingle Street: growth of the distal point and associated landward recession (1945–1970).

Fig. 2 relates the changes over the past decade and a half, during which detailed studies have taken place, to those since the beginning of the nineteenth century. Cartographic evidence prior to that time is not particularly accurate with one exception, a small estate map by Badulph Agas (1589). This includes part of the coastline at Shingle Street and suggests that the outline there was essentially similar to that still prevailing. Fig. 2 indicates that once the "bulge" on the Shingle Street shoreline is removed rapid growth of the major spit takes place. Although between the 1847 and 1867 charts the sequence was interrupted it was not restarted, the shingle banks remaining virtually intact. It is not unknown for small breaches in sand or shingle spits to heal themselves (Bruun and Gerritsen, 1960). Major stages of recession occurred in 1812–1813 (Carr, 1969) and 1893 (Cobb, 1957). Hodgkinson's map of 1783 and Spence's chart of 1804 both provide evidence to suggest still earlier growth to the south (Carr, 1969).

Data

Topographic and hydrographic surveys have been carried out yearly since 1956. The area covered hydrographically was extended in 1964. Charts and isohyets of erosion and accretion have been compiled from this information. Techniques used have been broadly similar to those outlined in Carr (1965) (see Appendix 1). In addition some other data have been obtained from time to time. During 1967, 1968 and 1969 tidal current velocities were obtained at representative sites, depths and states of the tidal cycle, mainly using a Toho Dentan CM-2 direct reading current meter. This instrument provides both velocity and direction. The readings which are summarized in Table I agree with limited records taken in 1959 and largely supersede the figures in Cobb (1957), Kidson, Carr and Smith (1958) and Carr (1965), all of which were based on values from earlier Admiralty charts.

Table I. *Orford, Suffolk: maximum tidal current velocities in ms.*$^{-1}$ *For location see figure 1. Depths are in metres below the water surface and are approximately related to zero O.D. Figures for the surface are omitted because of turbulence: they are similar to or slightly greater than those at −1·5 m. Near slack water the direction of flow is not necessarily the same at the surface and near the sea/river bed, e.g. on the flood the bottom tends to change first*

Section	Springs										Neaps										Depth (m.)
	Flood					Ebb					Flood					Ebb					
	1·5	3·0	4·5	6·0	7·5	1·5	3·0	4·5	6·0	7·5	1·5	3·0	4·5	6·0	7·5	1·5	3·0	4·5	6·0	7·5	
9 river	1·6	1·6	1·5	1·4	1·0	1·6	1·5	1·4	1·0	0·8	1·5	1·2	1·0	1·1	—	1·4	1·5	1·2	1·0	1·0	
9 sea	—	—	—	—	—	0·6	0·5	0·5	0·5	0·4	0·5	0·5	0·4	0·3	—	0·5	0·4	0·3	0·3	—	
23 river	1·7	1·4	1·5	1·3	1·0	—	—	—	—	—	1·3	1·2	1·2	0·9	0·8	1·2	1·2	1·0	—	—	
37_L (river)	1·8	1·7	1·7	1·3	1·0	2·1	2·0	1·9	1·5	—	1·6	1·6	1·2	1·4	—	1·9	1·6	1·5	1·3	—	
37_H (line of spit)	1·5	1·5	1·5	1·4	1·4	2·1	2·0	1·9	1·5	—	1·2	1·2	1·3	1·2	1·0	1·9	1·7	1·6	1·2	—	

Wave and tide records have been obtained for a period of ten minutes every six hours from a pressure type unit (Hardcastle, 1967) located immediately offshore of Survey Point 9 at a depth of 6·7 m. below O.D. Mean sea level is approximately 0·15 m. above O.D. High water ordinary spring tides reaches about 1·5 m. At spring tides there is an amplitude of the order of 2·8 m. but this is reduced at neap tides to 2·0 m. In common with most North Sea sites tide heights do not follow predicted levels very closely.

Tables IIa, b give data for wave period and significant wave height (Tucker, 1963) using 1,370 recordings taken between January 1967 and December 1968. The values for significant wave heights are clearly affected by the offshore banks and it is unlikely that the calculated maximum predicted wave heights could be attained at this location, although they may be further south as the spit grows in that direction. The figures for predicted heights are 3·9 m. in 1 year: 4·7 m. over 2 years: 6·3 m. over 10 years and 8·2 m. over 25 years. The maximum plotted wave height was 3·4 m. The dominance of short period waves indicates that they are virtually all wind-driven. They are also steep in profile.

Table II. *Orford, Suffolk: Wave data*

Tz secs.	% occurrence
3·0– 3·5	0·2
3·5– 4·0	0·0
4·0– 4·5	0·6
4·5– 5·0	11·4
5·0– 5·5	21·3
5·5– 6·0	22·4
6·0– 6·5	23·2
6·5– 7·0	10·0
7·0– 7·5	4·1
7·5– 8·0	3·0
8·0– 8·5	1·9
8·5– 9·0	0·6
9·0– 9·5	0·3
9·5–10·0	0·2
10·0–10·5	0·6

a: Distribution of zero crossing frequency.

Hs metres	% occurrence	% exceedance	H max. metres
0·0–0·1	56·4		
0·1–0·2	16·3	43·6	0·2
0·2–0·3	12·0	27·3	0·4
0·3–0·4	7·4	15·3	0·6
0·4–0·5	3·1	7·9	0·8
0·5–0·6	1·3	4·8	1·0
0·6–0·7	0·9	3·5	1·2
0·7–0·8	1·1	2·6	1·4
0·8–0·9	0·6	1·5	1·6
0·9–1·0	0·0	0·9	1·8
1·0–1·1	0·3	0·9	2·0
1·1–1·2	0·2	0·6	2·2
1·2–1·3	0·0	0·6	2·4
1·3–1·4	0·1	0·4	2·6
1·4–1·5	0·1	0·3	2·8
1·5–1·6	0·1	0·2	3·0
1·6–1·7	0·0	0·1	3·2
1·7–1·8	0·1	0·1	3·4

b: Significant wave height-metres.

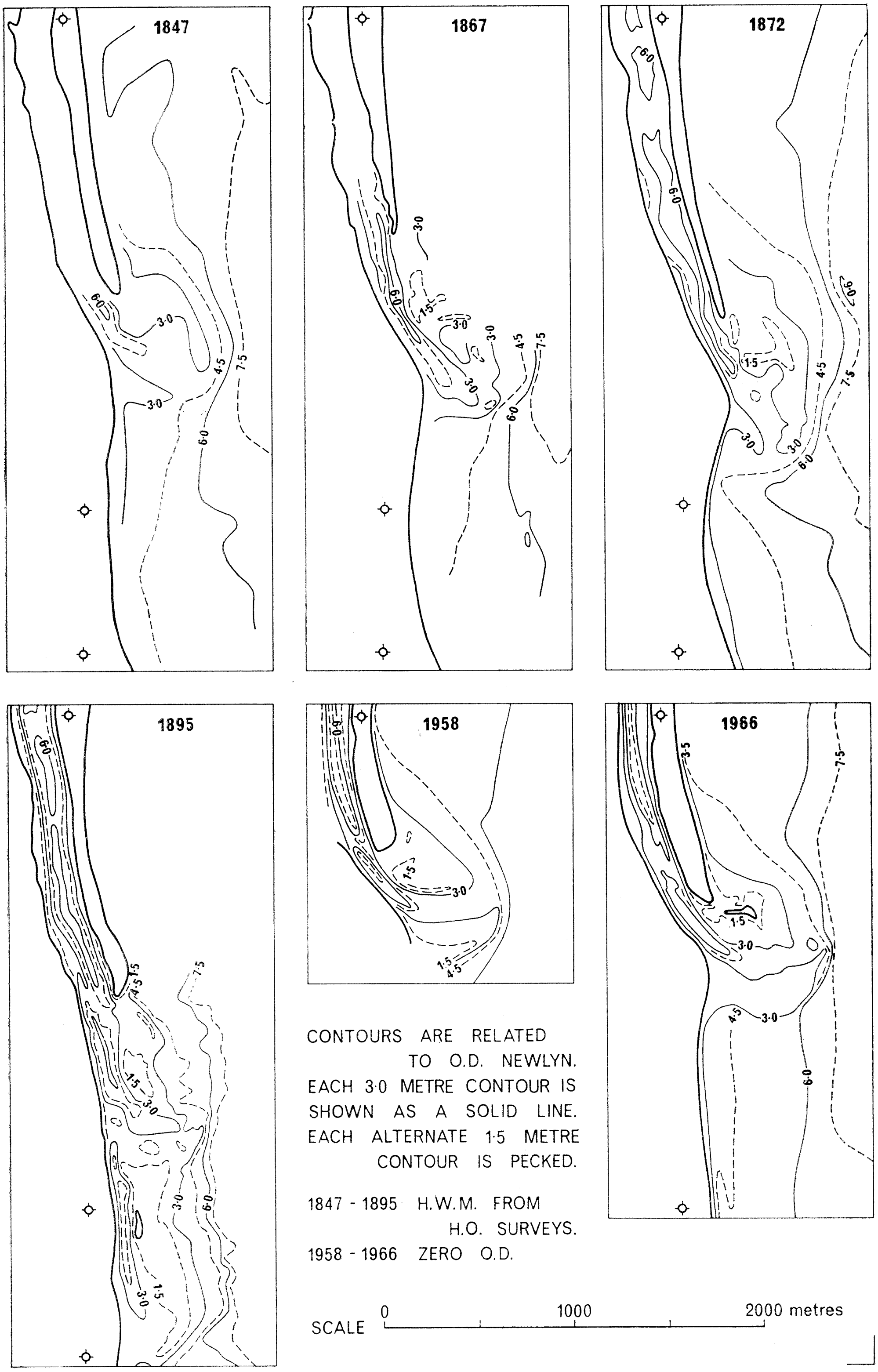

FIG. 5.

River Ore: estuary mouth (1847–1966). 1847–1895 redrawn from Admiralty (Hydrographic Office) surveys; 1958; 1966 from Nature Conservancy data. For details, see text. 1847 = Bullock (H.O: L 7288). 1867 = Calver (H.O: B 1446). 1872 = Parsons (H.O: A 3671). 1895 = Pirie (H.O: B 5833).

H_s metres \ T_z seconds	4·0–4·5	4·5–5·0	5·0–5·5	5·5–6·0	6·0–6·5	6·5–7·0	7·0–7·5	7·5–8·0	8·0–8·5	8·5–9·0
1·1–1·0	0	0	0	1	1	1	0	0	0	0
1·0–0·9	0	0	0	0	0	0	0	0	0	0
0·9–0·8	0	1	1	4	1	1	0	0	0	0
0·8–0·7	0	1	1	2	5	0	0	0	0	0
0·7–0·6	0	0	1	1	4	1	1	1	0	0
0·6–0·5	0	2	7	6	5	1	0	0	0	1
0·5–0·4	0	4	10	7	8	2	0	1	1	1
0·4–0·3	0	5	15	12	12	7	4	2	1	0
0·3–0·2	3	19	28	28	20	9	3	4	2	1
0·2–0·1	0	21	33	42	47	21	10	4	4	1

c: Wave distribution per 1,000 occurrences. 557 occurrences are below 0·1 m H_s for which T_z cannot be obtained.

Table IIc shows the relationship of wave period (T_z) against significant wave height where H_s is greater than 0·1 m.

Since 1964 climatological records have been provided by the Meteorological Office station at Aldeburgh. From 1966 similar records, but for wind velocity and direction only, have been obtained from an anemometer installed at King's Marshes opposite the town of Orford. These records have been somewhat fragmentary. Correlations between the two sites based on a total of 1,323 pairs of data between April 1967 and March 1968 give values which fall within the monthly ranges:

$y = 0{\cdot}65x+2{\cdot}9$ and $y = 0{\cdot}90x+4{\cdot}4$ ($r = 0{\cdot}58$ and $0{\cdot}81$ respectively) for wind speed in knots and

$y = 0{\cdot}75x+17{\cdot}3$ and $y = 0{\cdot}96x+21{\cdot}4$ ($r = 0{\cdot}60$ and $0{\cdot}99$ respectively) for direction in degrees from true north

where y = Orford and x = Aldeburgh.

In the light of these figures the Aldeburgh records are used for subsequent analysis.

During 1969 peat beds became exposed on the floor of the channel of the River Ore north of Beacon Cottages and directly in line with the distal end of North Weir Point. These beds which appear to be *in situ*, varied between 6·4 and 7·9 m. below O.D. A radiocarbon date for a sample at 6·4 m. gave a figure of 5,390±110 BP. The peat, in which the proportion of *Pinus* and *Quercus* pollen was high, probably formed in a lagoon or creek on the Shingle Street shore.

Discussion

A number of features are apparent as a result of the data obtained since the 1965 paper:

(i) A major ridge was produced in the winter of 1966–1967 at North Weir Point. The alignment of this is atypical of the normal series of recurves. In fact, it was caused by refraction resulting from the North Shingle Bank at that time. Similarly, the new tidal pond formed at the distal end of the spit in 1970 was

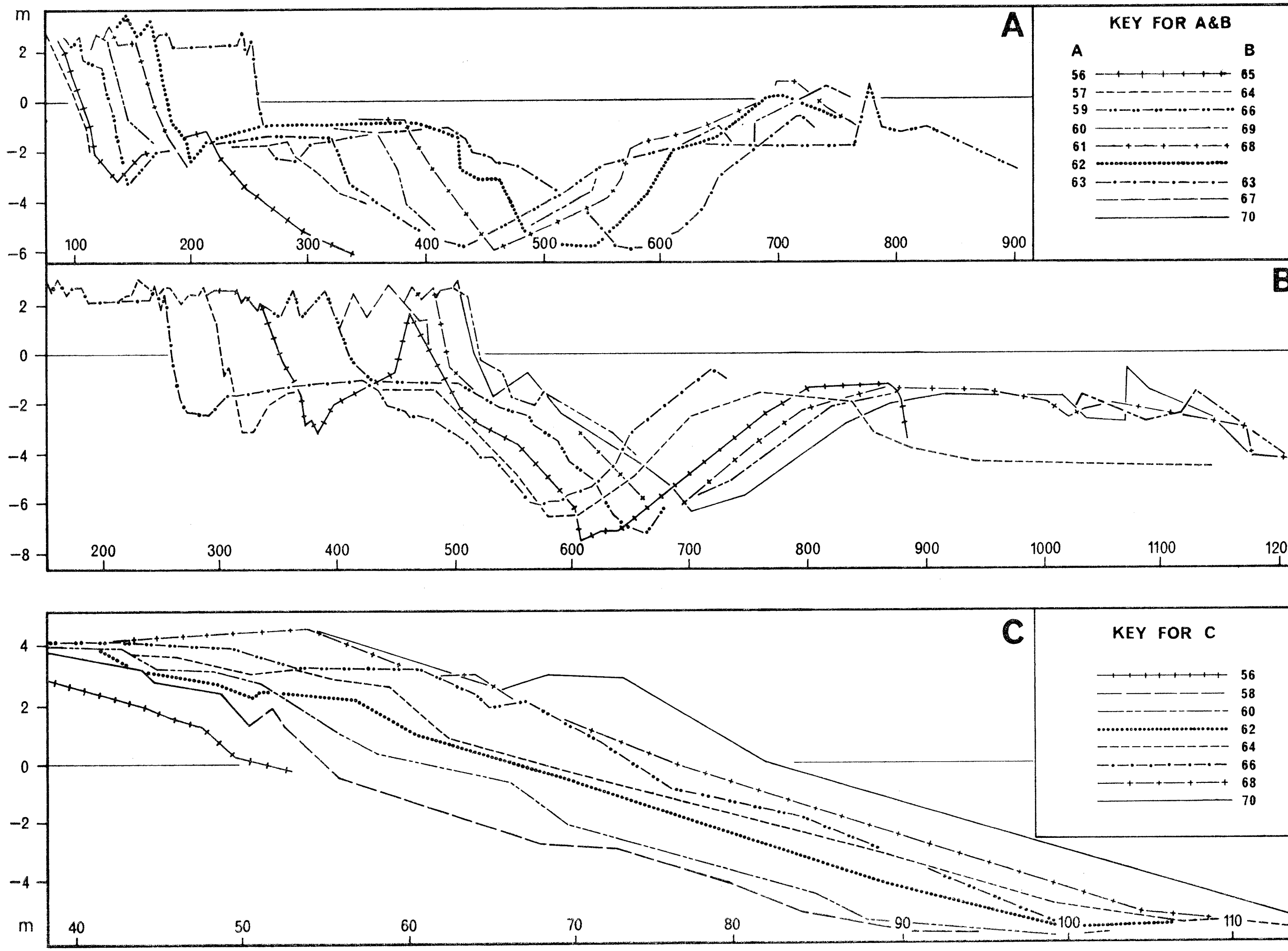

Fig. 6.

Orford spit, North Weir Point and the Ore estuary: lines of section. (a) Section 31q (= 37H) 1956–1963. (b) Section 31q (= 37H) 1963–1970. (c) Section 23 seawards 1956–1970. For location see Fig. 1b. Vertical exaggeration of *a*, *b* = x 20; *c* = x 1·75. Note the variability of accretion between the spit and the bar (*a* and *b*) and consistency of widening of the spit near Section 23 (*c*). Simplified from original data.

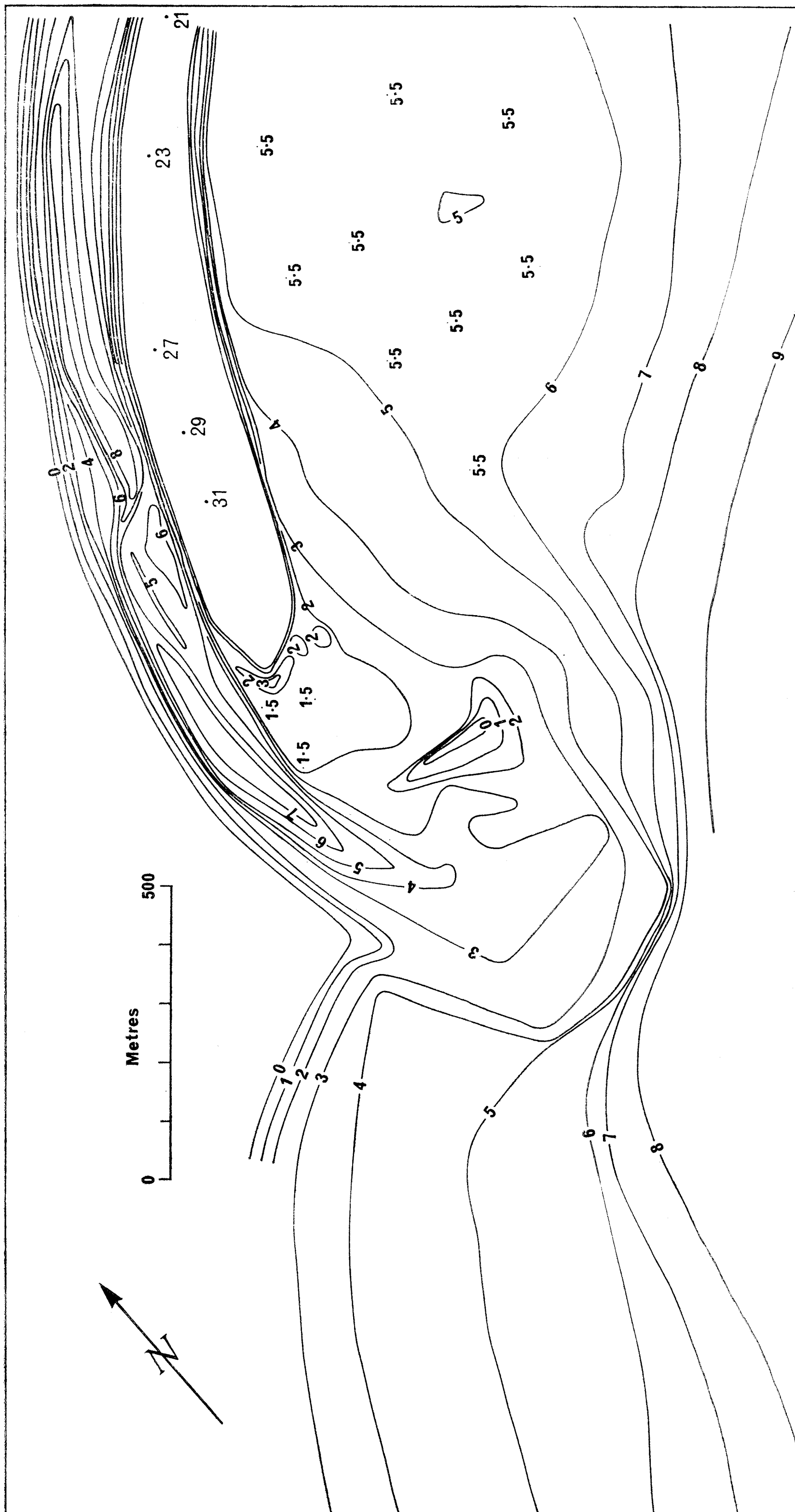

Fig. 7.
Hollesley Bay and the mouth of the River Ore: hydrographic chart, September 1964. (Hydrographic data for 1958 is given in Fig. 5). Contours are drawn at 1 m. intervals below O.D.

also a product of wave refraction, thus adding a third possible way in which such features can be formed.

Thickening has continued opposite Survey Point 23 (Fig. 6c). It was noted in Carr (1965) that the width had doubled there between 1945 and 1962 contributing to a strengthening of the end of the spit. This produces an apparent continuity of the ridge structure which observations show is not warranted. Isohyets of erosion and accretion (Figs. 9 and 10) demonstrate the continued erosion of the north face of the North Shingle Bank. The variability in the height of that Bank has already been noted. There appears to be a periodicity in the development of ebb and flood channels (van Veen, 1936) within the river mouth (Figs. 7 and 8). It is not known whether more frequent surveys would show this related to particular physical conditions (Robinson, 1960) but over the last 7 years all full surveys have been kept to spring tides during the summer months. For a short period the river Ore had two channels, one typical in the present stage of development at right angles to the main spit, and another parallel to the Shingle Street shore. The latter failed to develop. A feature of some interest is that the deepest part of the river is still near Survey Point 29 in spite of the prolongation of the spit.

(ii) The wind and wave data (Tables II and IIIb and Fig. 11) show that the growth of the spit (Table IIIa) for the years 1962/1963 and 1968/1969 was essentially similar to the intervening period in spite of the marked increase of easterly winds for those years. This may indicate that the disposition of the offshore banks and bar is more significant in the accretion of the spit than other factors.

(iii) Current readings between 1967 and 1969 suggest that there may be a slight drop towards the end of the period in question. However, although the data for 1959 is very restricted, it does not tend to confirm this view. An indication of tidal current velocities is given in Table I.

(iv) In the 1965 paper it was suggested that the greater rate of growth of the offshore bar towards the south relative to the growth of the spit (Fig. 6a, b) might possibly cause the break up of the latter. This has not been the case and it now appears that, at least with this length of the spit, the changing relationship between bar and spit is merely a part of the mechanism of build-up. As the two become further apart tidal current velocities fall, friction of the bed increases and deposition, at least of finer material subject to tidal currents, becomes more feasible between them.

(v) The peat in the mouth of the estuary is important since it confirms the cartographic evidence. The latter suggested that, contrary to data elsewhere (e.g. de Boer, 1969), rebuilding following phases of recession, was carried out in the same lateral position. The only way in which the peat could have remained *in situ* during more than the 5,000 years since its development is by the deep river channel to landward (Figs. 7 and 8) being either always in its present place or, alternatively, so far to seaward that the peat deposit was unaffected. No gradual progression of the spit landward is conceivable. A lower relative sea level in the past would merely aggravate the position.

(vi) Attempts have been made to estimate the quantities of material which have been eroded and deposited in and around the estuary where measureable change can be recorded. Such calculations cannot differentiate between shingle and silt; they have to assume that the echo-sounder is adjusted correctly and

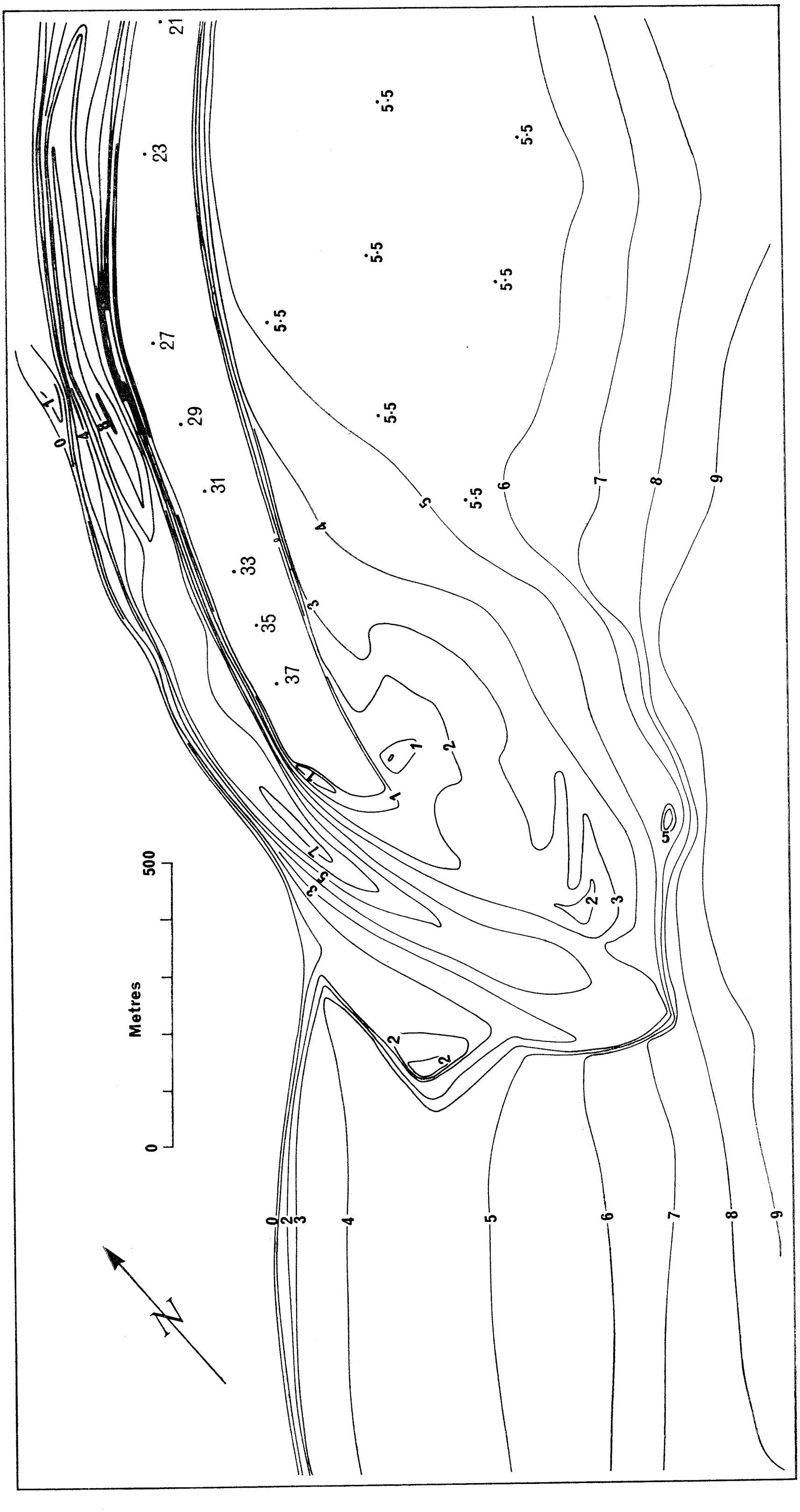

FIG. 8.
Hollesley Bay and the mouth of the River Ore: hydrographic chart, July 1970. Contours are drawn at 1 m. intervals below O.D.

PLATE I.

Orfordness, Shingle Street and the River Ore from the air. Cobb's lagoons 4 and 6 are prominent in the foreground as is the Shingle Street "counter-spit". Note Havergate Island, the change in orientation of the shingle ridges opposite and to the south of Havergate, and the cuspate foreland of the Ness. 1964.
Picture by J. K. St. Joseph from Cambridge University Collection (AHB 85). Copyright.

Table 3. *Relation between growth of the distal part of Orford spit and prevalence of onshore winds over 17 knots (8·7 ms⁻¹)*

Period	Accretion (m.) (zero O.D. contour)		Average (line 31q.)
	line $37_H/31_q$	Maximum (where different)	
1945–1955	—	—	28·3
1955–1956	27·4	—	
1956–1957	0·0	—	
1957–1958	10·7	—	
1958–1959	7·9	—	19·3
1959–1960	12·8	—	
1960–1961	28·4	—	
1961–1962	18·3	—	
1962–1963	80·5	—	
1963–1964	40·8	—	
1964–1965	50·9	—	58·5 Prolonged period of easterly (onshore)
1965–1966	54·3	87·2	winds December 1962-March 1963
1966–1967	70·7	61·9	
1967–1968	19·2	25·6	
1968–1969	26·2	33·8	13·7 Incorporates North Shingle Bank
1969–1970	−3·7	88·4	

a: North Weir Point—accretion of the distal point 1945–70. Maximum values are given only when significantly different from line $37_H/31_q$).

Period	Direction		Resultant wind direction
	020–100	020–190	
1964–1965	2,157	3,212	082
1965–1966	2,574	4,956	102
1966–1967	2,487	4,971	104
1967–1968	2,451	3,402	079
1968–1969	5,616	7,602	079
1969–1970	3,015	4,533	075

b: Aldeburgh: onshore winds equal to or greater than Beaufort force 5 (8·7 ms⁻¹). Figures are for windrun in nautical miles. Direction from true north. Data for Aldeburgh is only available from 1964. Periods refer to the interval between annual topographic and hydrographic surveys at Orford and thus generally run July-June.

provides no problems of interpretation, and also that the tide record is both accurate and consistent.

The problem of coarse or fine particles is the most serious. Fine material such as silt is clearly affected by the tidal currents of the estuary. Bruun and Gerritsen (1960) have pointed out the tendency for fine material to be deposited riverwards, and coarse material seawards, of a bar. The greater effect of waves on the seaward face is demonstrated by the shoal there being of a simple geometric form.

It is not realistic to believe that all the other conditions are invariably met but it should be possible to obtain a long-term trend. For example, calculations suggest that during the period up to about 1966–1967 the accretion within the area of the estuary subject to change was largely matched by erosion of equivalent volumes of material from sites nearby. This does not appear to have been the case between 1967 and 1970 where the amount of material added is far greater

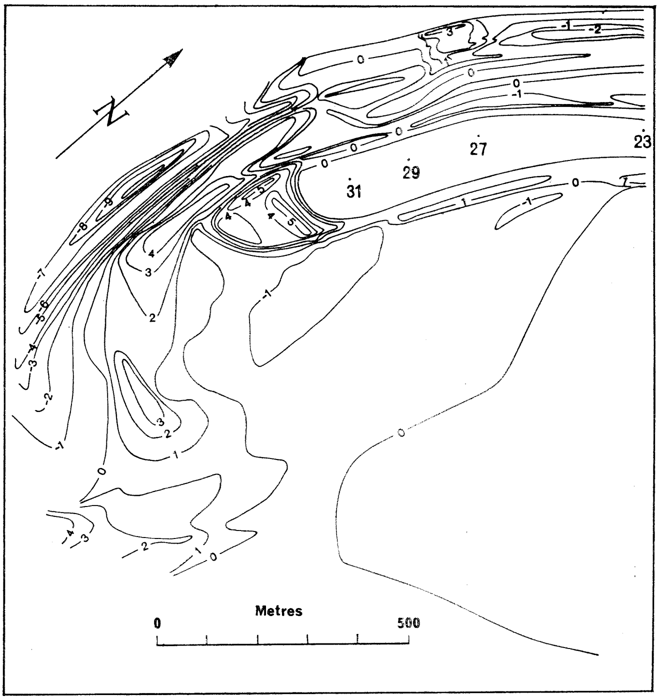

Fig. 9.

Hollesley Bay and the mouth of the River Ore: isopleths of erosion and accretion 1958–1964. Isopleths are drawn at 1 m. intervals. Data for the Shingle Street shore are not available for the whole of this period.

(perhaps 6–7 times) than that removed. This is what would be expected if the hydraulic efficiency of the estuary diminished as the river course became extended but the magnitude of the change was not anticipated.

The chief problem regarding this spit, and indeed others, is the cause of its eventual breakup. There are a number of possibilities which probably work in concert one with another;

(i) As the spit grows further towards the south both its and Shingle Street's shoreline become straighter. This, coupled with the elimination of the offshore banks would mean that material would tend to get out of the system faster. There would be less likelihood of counter-drift (Kidson, 1963). Therefore, as growth progresses, there would be a tendency for the structure to become thinner and more tenuous.

(ii) Fig. 5 gives an indication of the outline of the coast and the contours within the estuary area. The nineteenth century data is derived from Admiralty charts and that for 1958 and 1966 from Nature Conservancy surveys. As the spit builds further south the protection of the offshore Whiting Bank is lost and the offshore contours become steeper (especially that of —4·5 m. for 1872 and 1895). Both these factors may be relevant in that waves become more effective and influence the shoreline from a greater number of directions.

(iii) As the river becomes straighter, the spit more tenuous (i) and wave action more effective (ii) it is easier for the narrow gap at the mouth of the river to be blocked under storm conditions and the water ponded up within.

(iv) Keulegan (1951) suggested that there could be stability only if either a spit remains in the same place or its "gorge" increases in proportion to the river's length and flow. Keulegan was really considering sand and silt but his concept would help to explain the instability of a shingle structure such as the Orford spit in its final stages. In Keulegan's concept the river becomes less efficient with

Fig. 10.
Hollesley Bay and the mouth of the River Ore: isopleths of erosion and accretion 1964–1970. Isopleths are drawn at 1 m. intervals.

time and thus choked up so that rapid accretion would occur. This is, in part, the effect of friction on the bed.

(v) Surges, both positive and negative, are not infrequent on the North Sea coast. That in 1953 was not relevant in the breakup of the spit because of the situation at the time but in more critical conditions it could well have been so. The lengthening of the spit has three effects: there is insufficient time for the increased outflow of the river to be discharged; there is an increasing hydraulic gradient between the two sides of the spit; and there becomes a greater time lag between high or low water in the river and on the seaward side. All these would be most effective during surge conditions and could result in greater seepage and susceptibility to overtopping. There is evidence of seepage at the tidal pond at Survey Point 29 in calm conditions as early as February 1957. Although on a small scale this had the effect of modifying the outflow channel into the river. Greater seepage has occurred since that time at selective points, for example, near Survey Points 23 and 31 as well as continuing near Survey Point 29.

Major recession of the spit took place at about the turn of the century. The fact that such recession continued by stages thereafter suggests an initial break-through, possibly caused by seepage, in association with an inefficient estuary. Such a breakthrough could take place in storm conditions but might equally well be the result of ponding back of water within the river, as be the effect of physical destruction through wave attack. In any event the initial breach of 1893 was inadequate to restore the hydraulic efficiency of the estuary, and

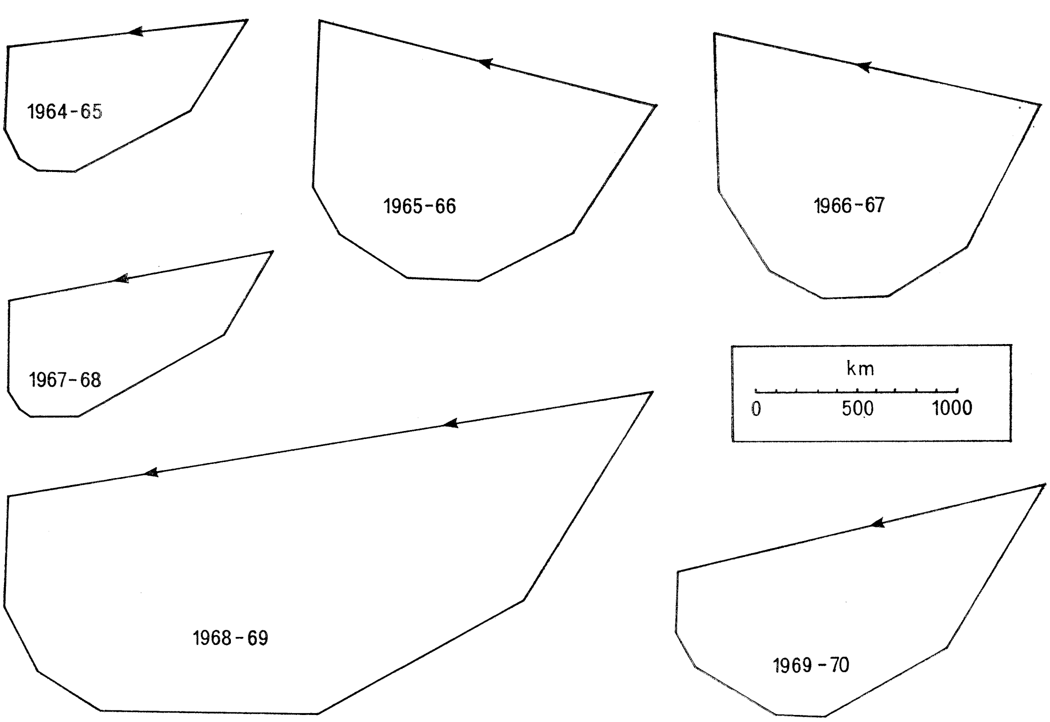

FIG. 11.
Aldeburgh: onshore wind run and resultants for strengths equal to or greater than Beaufort force 5 ($8 \cdot 7$ ms^{-1}). Periods between annual topographic and hydrographic surveys and thus, generally, July-June.

could well have aggravated the situation. This is suggested by the Admiralty chart of 1895 where there are several minor channels. Even where two channels initially have the same tidal prism (= flow capacity) as did one previously the effect of the river bed is to reduce their efficiency and for increased silting to take place. If this were the case it could help to explain subsequent retreat of the spit. Seepage is probably more significant with a pebble beach than with a sandspit in part because of the steeper offshore gradient but largely because of the greater porosity of the material.

Migration of a shingle spit, such as at Orford, depends primarily on the magnitude of littoral drift. For this estuary it has been calculated as in the order of 10^5 m.^{3} per year. The velocity and phase difference of tidal currents are liable to play only a fairly minor and indirect role here. Bar by-passing (Bruun and Gerritson, 1960) is therefore likely to be dominant.

The role of Shingle Street is essentially a negative one. With the growth of the major spit towards the south, the earlier features are largely destroyed whether they are lagoons derived from the River Ore, or counter-spits formed when the estuary was more open and more material was available for re-sorting.

Conclusions

Although the past 15 years has been a period of almost continuous growth of North Weir Point, and recession of Shingle Street, evidence has been produced which helps to shed light both as to the factors which influence accretion and those which may cause the spit's destruction. The latter can only be verified with time and even then their relevant importance may vary between one occasion and another. Perhaps more important is the lack of correlation between onshore windrun (and associated waves) and growth of the North Weir Point spit. The data demonstrate that not only must other processes be of importance but that a relationship should be sought between the dynamics of the estuary as a whole rather than one, albeit important part of it: a part which can be likened in some ways to the tip of an iceberg.

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APPENDIX I

Projects and Techniques

Short term geomorphological projects in the Ore estuary are restricted in their scope. This stems partly from the difficulty of access to the National Nature Reserve of Orfordness-Havergate; the limited topographic changes likely to occur during the short-term, and the problems posed by the high tidal velocities. For instance, the latter make any form of swimming very dangerous and cause other problems for sub-aqua divers, such as visibility. Nevertheless there are opportunities for geomorphological field studies. Detailed mapping of the ridge and lagoon structure is possible at Shingle Street, while suspended sediment studies can be undertaken in the estuary especially if a boat is available. Such studies can be related to size of particles, depth of samples and state of the tide. Similarly an analysis of particle size and packing density could be carried out on, and through, the shingle ridges. This could be correlated with colonization of vegetation and susceptibility to erosion of particular ridges.

Those wishing to carry out research projects on the National Nature Reserve should first contact the Nature Conservancy's Regional Officer at Norwich. Similar approaches need to be made to the appropriate landowners at Shingle Street.

The techniques used in the paper include:

(a) *Survey:*

Both topographic and hydrographic survey methods have been widely used in the research programme described. Initially a trigonometric framework was established using metal pipes installed in the shingle. These pipes were subsequently replaced by flush concrete blocks which tapered towards the top and had provision for ranging poles to be placed in the centre. Subsidiary blocks were added to mark the various section lines to be surveyed. Levelling was carried out between the concrete blocks to provide height control. Thereafter additional blocks were added as the spit grew southward and as replacements became necessary. Other blocks were sited at Shingle Street. Both the triangulation and levelling were incorporated into the Ordnance Survey network.

Two distinct operations were undertaken for the routine land survey. Firstly, profiles were levelled across the ridge structure as far as low-water mark. Secondly, the position of the ridge crests were planetabled on a scale of 1:1,000 using a telescopic alidade. Selected contours were added to the spot heights obtained by this method. Revisions of the Orford spit and the Shingle Street coastline (only) were undertaken generally at annual intervals.

A 5.5 m. survey launch, equipped with a Kelvin Hughes MS 26A echo-sounder, was employed for the hydrographic work. Sections surveyed on land were extended either to Shingle Street or for a distance of about 1 km. offshore, as applicable. Pairs of sextant readings were obtained as the boat travelled along the line of the section and their position was scribed on the echo-sounding trace. The angles were generally taken onto Dexion tripods erected over the concrete survey points. To facilitate observations the tripods had fluorescent boards with ranging poles running vertically through the centre of them.

Echo-sounding was carried out for a period of about 2 hours on each side of high water on suitable spring tides. Initially tide height was recorded on ranging poles placed in the water and levelled in.

These methods were initiated in 1955–1956 under the aegis of the then head of the Physiographic Section of the Nature Conservancy, C. Kidson. From 1964 onward, a number of changes were instituted. These included the replacement and extension of certain survey lines to obtain better coverage of the bar area; the planetabling of the North Shingle Bank which had formerly been echo-sounded, and the use of electronic means to record tide height.

(b) *Other data sources:*

(i) *The wave and tide recorder* was situated offshore of survey line 9 (Fig. 1b). This position was selected because of the relative stability of the coastline; the abrupt drop offshore; and the facilities available there, but is not ideal. The underwater pressure unit was designed by the National Institute of Oceanography but was provided with different electronic circuitry to enable car batteries, instead of mains, to be used as a power source. The data were recorded onto two separate chart recorders housed in a hut on shore. The tide recorder, which operated continuously, was a Rustrak bar-type instrument; the wave recorder was of pen type and designed to work for four periods of ten minutes per day. A digital recorder was also installed. The recorders and pressure units were connected by armoured cable.

A simpler pressure unit was tried in the river to record tide heights there but deposition of silt prevented satisfactory results from being obtained. Other problems encountered were the susceptibility of the offshore unit to be affected by trawling, and the abrasion of the armoured cable through shingle movement both down and along the beach.

(ii) *Tidal current readings* were taken using two different direct-reading instruments. The Hilger and Watts Mark III current meter, modified for use under brackish and salt water conditions, provided velocity only. The second unit, a Toho-Dentan CM-2 direct-reading current meter, provided both data on velocity and direction. A 50 kg. weight was generally necessary to ensure that the unit was suspended vertically.

Readings were taken at various depths; at different states of the tide; and at both Springs and Neaps. A number of sites were chosen along existing echo-sounding section lines. The most serious problem encountered was the difficulty of regaining the precise position of the boat for comparable readings under different tidal conditions. Data obtained are very limited for the amount of time and effort required.

Direct reading instruments were chosen because floats merely give information on surface currents and may be influenced by wind; other methods tend to give only indirect evidence of current velocities or have very high capital cost.

(iii) The Munro self-generating anemometer installed at King's Marshes comprised a Mark II cup generator and Mark IIb wind vane. This instrument provided both velocity and direction. It was erected on a 12.5 m. lattice tower.

Although the anemometer's duplex recorder was sheltered in an exterior box as well as its own case, records were often fragmentary. This was largely due to the humidity which caused failures in the clock mechanism and the chart paper, especially during the winter months. Problems in the ink feed also occurred from time to time. Sufficient data were obtained, however, to enable correlations between the Orford site and the Meteorological Station at Aldeburgh.