

THE ESTUARY OF THE RIVER ORE, SUFFOLK: THREE DECADES OF CHANGE IN A LONGER-TERM CONTEXT

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ABSTRACT

This paper describes changes at the mouth of the River Ore, Suffolk, over the 30-year period up to 1985 and sets these in a longer-term context. Annual topographic and hydrographic surveys were carried out from 1956 until 1970, with further surveys in 1980 and 1985.

The period 1970–85 shares with the previous decade and a half both the recession of the Shingle Street shoreline opposite the distal part of Orford spit, and the continuing growth of the shingle banks which represent an inter- and sub-tidal extension of the latter. However, there have also been major differences. Firstly, over the period 1970–85 the orientation of the main channel at the estuary entrance changed from an alignment roughly at right angles to the overall coastline, to one broadly parallel with the Shingle Street shore. Secondly, between 1980 and 1985 the distal point of Orford spit underwent slight recession. These changes were accompanied by increasingly complex bathymetry at the estuary entrance.

The mechanism by which the spit ultimately breaks up is 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 district in relation to the overall 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”. He believed that the minor spit running northwards along the Shingle Street shore reflected local sediment circulation in that direction in spite of the general trend towards the south. A series of papers by Carr (1967; 1969; 1970) and Carr and Baker (1968) followed the development of the coastline from pre-Pliocene times. Specific aspects of present-day processes have been described 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 point of the major spit, and along the Shingle Street shoreline were reported in Cobb (1957), Carr (1965, 1972), and Randall (1973). It is the purpose of the present paper to describe the results from additional survey data obtained in 1980 and 1985, and to set the whole post-1956 period in the context of the longer-term evolution of the Orford spit and Ore estuary.

Orford spit is frequently quoted in geomorphological textbooks as a particularly good example of a shingle spit. Spits are more or less linear, sub-aerial, landforms produced by the net longshore deposition of sediment transported by waves and currents. They occur where, for some reason such as the presence of a river channel, the zone of deposition has been separated from the immediate coastline. The seaward side of a spit is invariably subject to higher energy levels than that facing the land.

North Weir Point is the termination of the shingle structure which extends from

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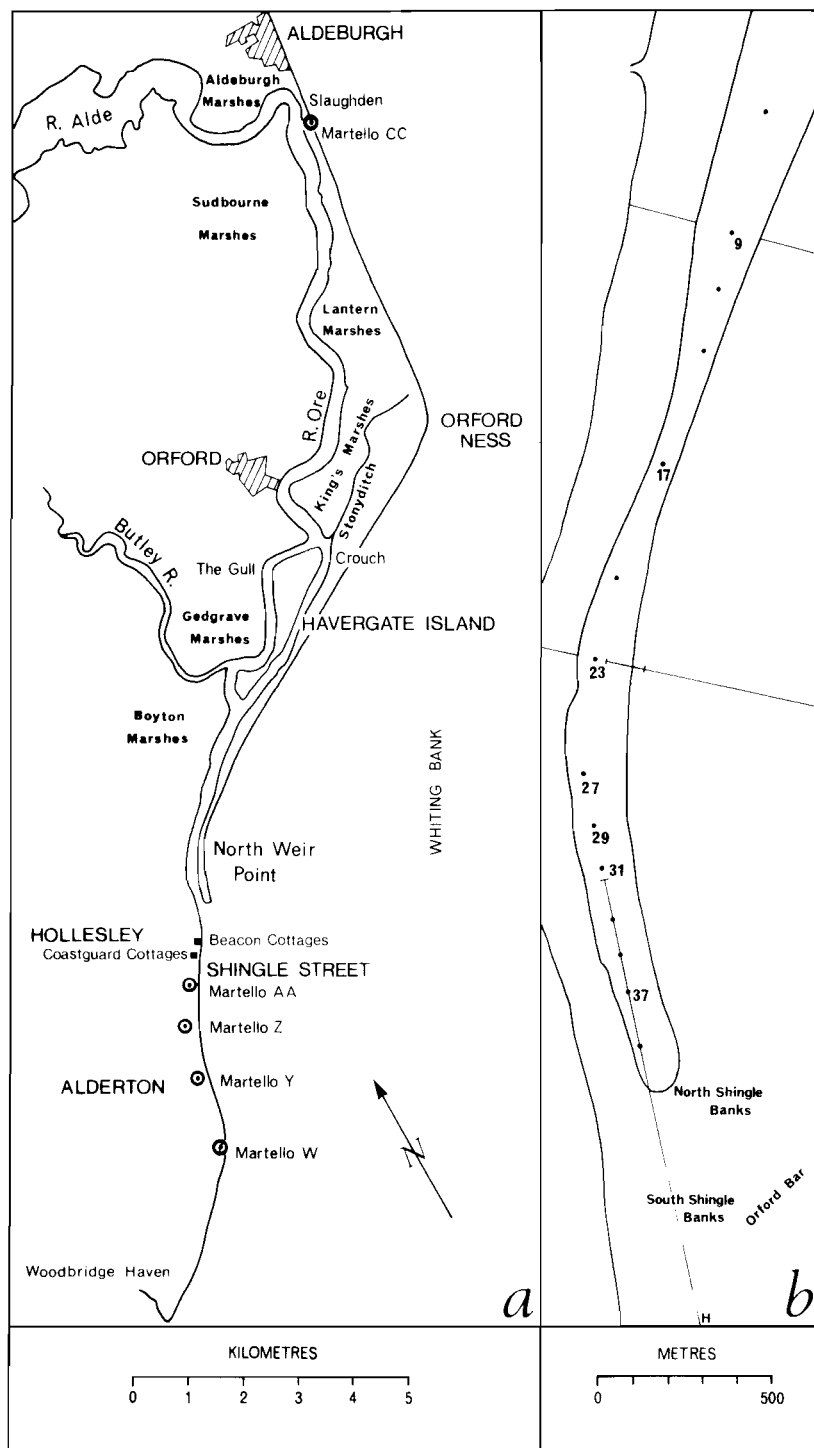


FIG. 1.

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

Aldeburgh in the north in a southerly and south-westerly direction for almost 15 km (Fig. 1, which shows all the places mentioned in the text). 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 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 cusped foreland of the Ness, but is scarcely evident on the seaward side of the river further south.

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 (S.P.) 17 in Fig. 1b). Over the whole of this stretch as far as the 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, for example by the incorporation of parts of the inter-tidal banks situated immediately to the south, or its breaching, may result in an extreme form of these with the recurves separated by tidal pools (e.g. immediately north of S.P.s 27 and 29). Figure 2 is a photograph of the mouth of the River Ore; Fig. 3 shows the ridge structure north of North Weir Point.

Although the width of the spit varies, its composition and height show a remarkable uniformity. The material is almost exclusively flint, probably derived from offshore at times when the 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 grade of material. That part of the spit below the 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 predominate. 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 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 opposite 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 of development but, because of their discontinuity, are hard to date accurately. Cobb (1957) and, later, Randall (1973) described lagoons which extended as far south as Martello Y. These were partly the legacy of the former course of the River Ore, partly the effect of the redistribution of beach material thereafter, and partly artificial. Since Cobb's paper most of these lagoons have been modified by coastal processes to a greater or lesser degree, with those south of Beacon Cottages having been totally destroyed.

The main channel of the River Ore at the entrance to the estuary has varied from an essentially shore-normal (e.g. 1958) to a shore-parallel (e.g. 1985) alignment over time, with consequent effects on the disposition of the shoals at the estuary mouth. This aspect is discussed in greater detail below. The shoals vary in height both over time and space with zero to +1 m O.D. (i.e. approximately high tide level) being a fairly typical maximum, although greater values have been recorded.





FIG. 2.

Orford spit, Shingle Street, and the River Ore: composite of vertical air photographs taken 4 February 1983. (Cambridge University Collection: copyright reserved.) Flight RC8-EZ; prints 64 and 66.

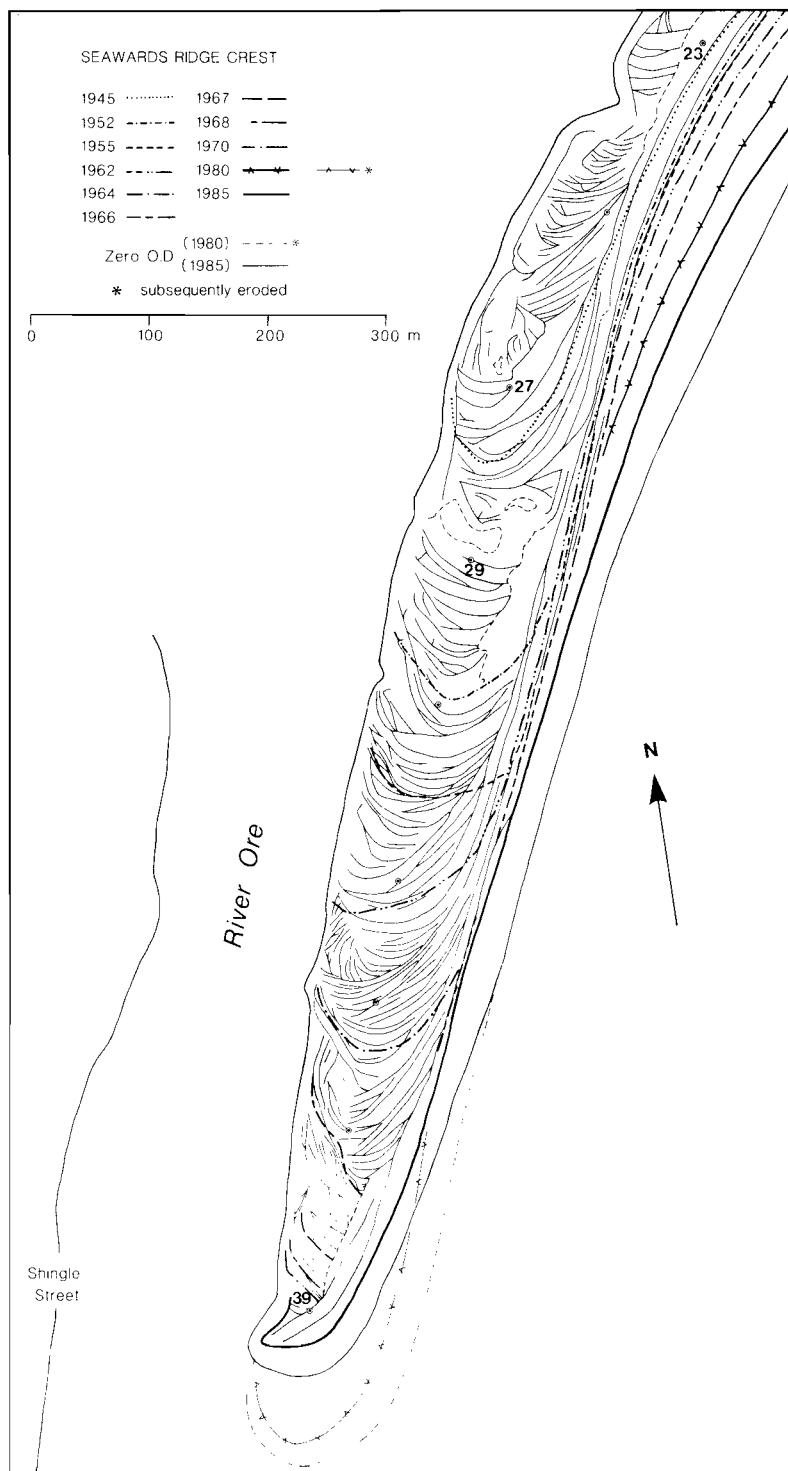


FIG. 3.
North Weir Point: shingle ridge structure and development to 1985.

SUMMARY OF RESEARCH 1956–70

As a result of the annual topographic and hydrographic surveys up to 1970, and the acquisition of experimental and process data during the period 1956–70, a number of conclusions were reached. These were discussed in Carr, 1965, 1972; and are summarised below.

1. Even in the short term, accretion of the distal point of the Orford spit was highly irregular, ranging from zero in 1956–57 to 80 m in 1962–63.

2. There was no direct inter-relationship between the rate of growth of the distal point of Orford spit and the distance between that distal point and the banks and shoals which formed an inter- or sub-tidal shore-parallel extension of the spit towards the south. (It had been tempting to believe that there might be a “leap-frogging” effect with the shoals providing the foundations for the subsequent rapid growth of the distal point. This may well happen at other stages in the evolution of the spit.)

3. Nor was there any obvious correlation between the annual onshore wind/wave frequency and the annual growth of North Weir Point, i.e. contemporary events and geometry were largely determined by previous events (hysteresis).

4. As North Weir Point progressed to the south the Shingle Street shoreline underwent recession, i.e. there was a minimum width of the River Ore (Fig. 4). Randall (1973) cited Myrick and Leopold (1963) as having observed this phenomenon elsewhere.

5. There appeared to be a rapid increase in the quantities of material remaining in the system after 1967 as compared with earlier years. There was also some suggestion that measured maximum tidal velocities (c. 2 ms^{-1}) had fallen over the period.

6. It was thought that as the spit and river channel increased in length without the compensation of further volumes of water from additional tributaries being incorporated into the system (i.e. there was no increase in the river “gorge” (Keulegan, 1951)), the hydraulic efficiency of the estuary would be reduced. One consequence of this would be that the hydraulic gradient between the river side of the spit and the seaward side would increase. Under tidal surge conditions this might be enough to provide a mechanism for breaching. More recently Carter *et al.* (1984) have invoked the same explanation for the breaching of barriers between lagoons and the sea in southern Ireland. Furthermore, because the shoals at Orford were progressively displaced southwards, an increasing proportion of the main spit would become more and more exposed to the full force of wave action.

7. Unlike in the case of Spurn Head (de Boer, 1969) successive distal points have not been produced landwards of each other. Cartographic evidence showed this to have been the case since about A.D. 1800. Furthermore, peat with a radiocarbon age of 5390 ± 110 years B.P. was found exposed *in situ* in the estuary south of, but in direct line with, Orford spit. This confirmed that from the time that North Weir Point had been as far south as at present it must always have been in the same spatial relationship, i.e. there could not have been any landward recession at that location otherwise the peat would have been eroded away by former river courses seawards of the present one. This spit does not “migrate monotonously landward” as do the barriers of Carter *et al.*

8. The final appearance of shingle ridge crests differed from their form when first deposited. That is, subsequent wave activity could push additional material onto the initial crest or seaward flank of a ridge, or weld further ridges onto those already in existence (Fig. 5b).

9. Tracer experiments (Kidson, Carr and Smith, 1958; Kidson and Carr, 1959) had indicated that longshore transport of pebbles could be rapid (especially in a southerly

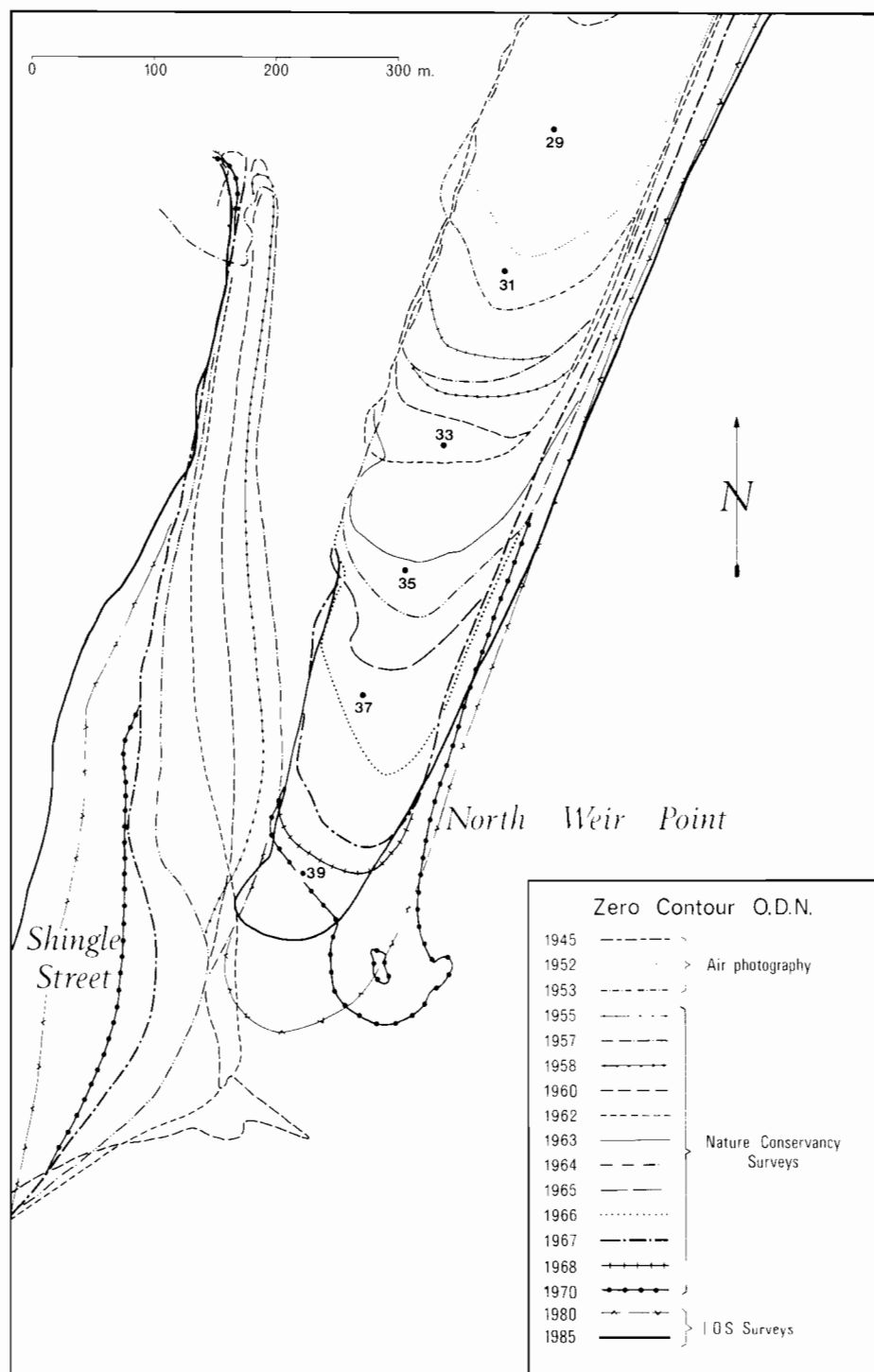


FIG. 4.

North Weir Point and Shingle Street: growth of the distal point and associated landward recession (1945-85).

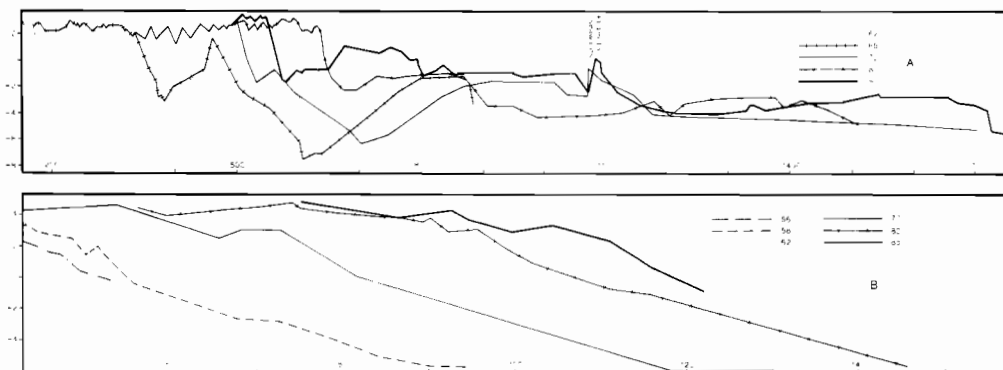


FIG. 5.

Orford spit, North Weir Point and the Ore estuary: lines of section (a) Section 31q (= 37H) 1962–85; (b) Section 23 seaward 1956–85. For location see Fig. 1b. Vertical exaggeration of (a) = $\times 20$; (b) = $\times 1.75$. Simplified from original data.

direction), therefore there was no need to seek sources of material immediately updrift to feed the growth of North Weir Point and the banks beyond.

10. Comparable alignment of the coastline did not necessarily result in similar erosion or accretion. Where alignment differed, waves reaching the shore could change from constructive to destructive in effect.

11. There was no onshore movement of ridges. This reflected the steeper shoreline compared with sand, and the absence of suitable material offshore.

PERIOD 1970–85

Although only 2 further surveys have been undertaken since 1970 (in 1980 and 1985) they effectively double the length of accurate observations available. Figs 3 and 4 show the ridge structure at North Weir Point in May 1985 and the continuing erosion of the Shingle Street shoreline, respectively. The latter is noteworthy in as much as between 1970 and 1985 North Weir Point actually retreated slightly, although the shoals in the estuary continued their growth towards the south. The distal point was pushed landwards both between 1970–80 and 1980–85 with the result that the Shingle Street shore responded similarly. The minimum width of the River Ore continued to be maintained even under different circumstances. Further north, opposite S.P. 31, the Shingle Street shoreline now appears to have become stable while relative stability also applies to the more exposed coast south of Beacon Cottages. This is in marked contrast to the 150 m plus erosion between 1924 and 1973 at Coastguard Cottages (Randall, 1973).

The 1970, 1980 and 1985 bathymetric surveys all show a lack of well-defined ebb and flood channels inside the river entrance (Figs 6a, b, c). This situation had been true of most, but not all, pre-1970 surveys. The most dramatic change in the bathymetry between 1970 and 1985 has been the realignment of the main channel of the River Ore between North Weir Point and Shingle Street. Figures 6a, b, c show the seabed contours in metres below Ordnance Datum, approximately mean sea level. Figure 6a indicates the essentially simple geometry prevailing in 1970. The main channel was clearly defined and ran between the distal point of Orford spit and the bank to the south which was linked to the shoreline at Shingle Street.

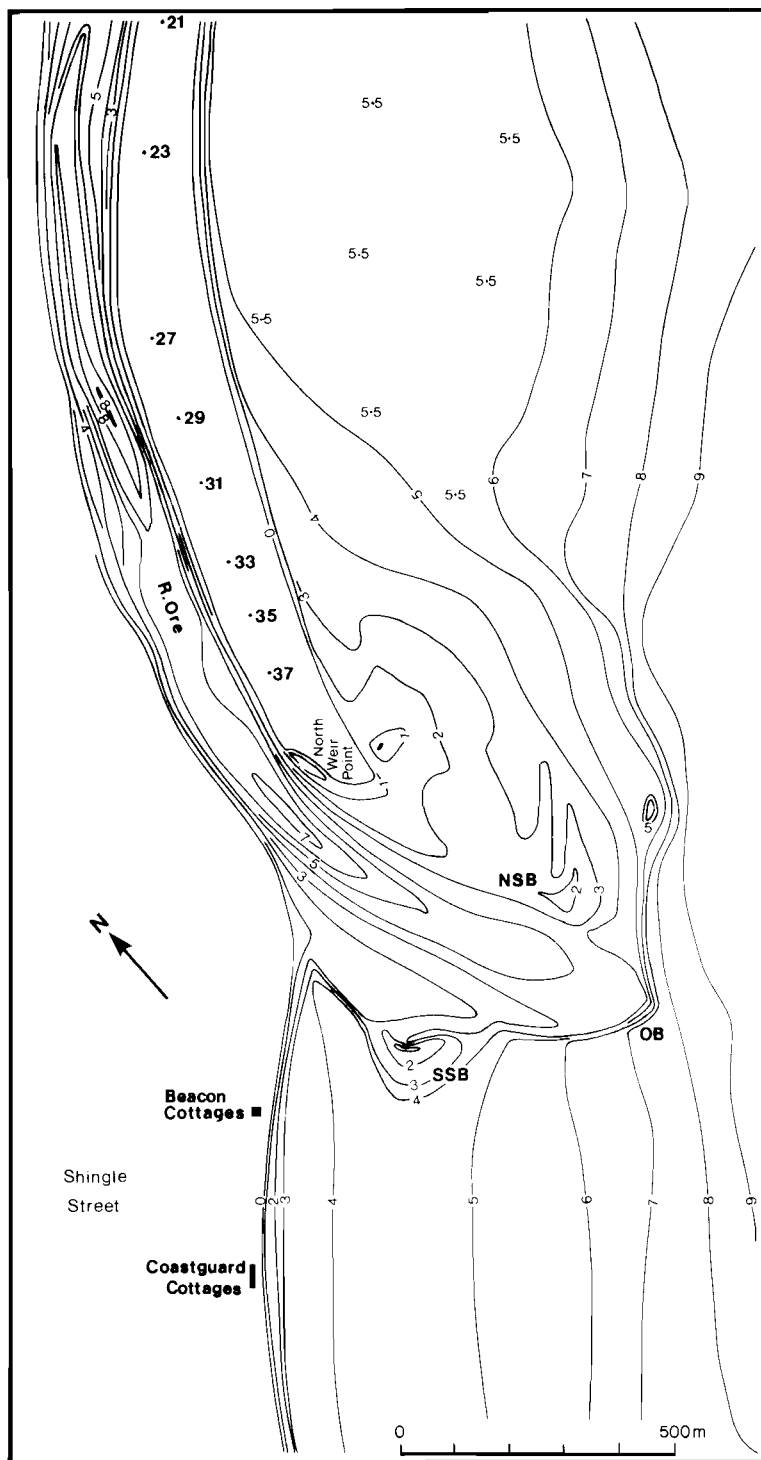


FIG. 6a.

Mouth of the River Ore: hydrographic charts. (a) July 1970; (b) July 1980; (c) May 1985. Contours drawn at 1 m intervals below O.D. (approximately mean sea level) except (b) where they are at 0.5 m. (Fig. 6a is a corrected version of that shown as Fig. 8 in Carr, 1972.)

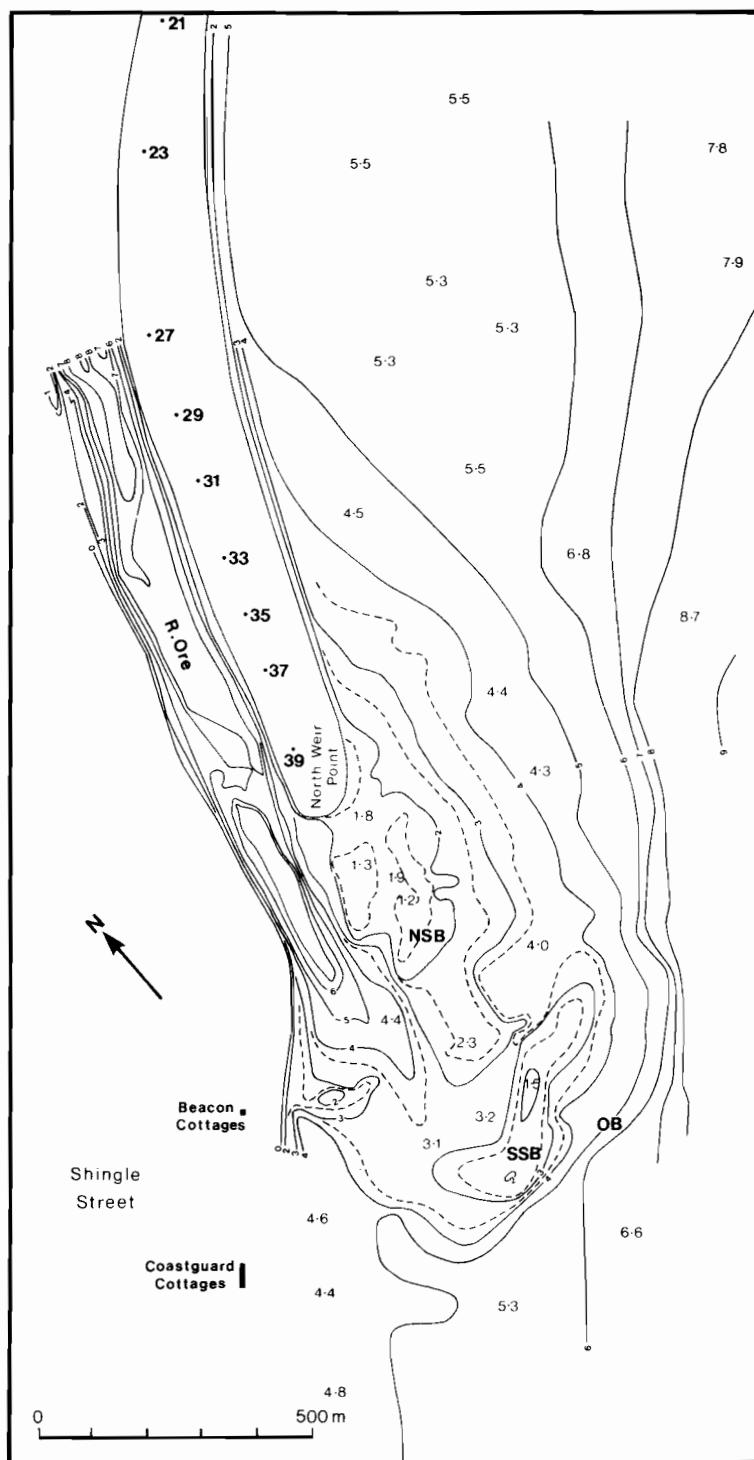


FIG 6b.
July 1980

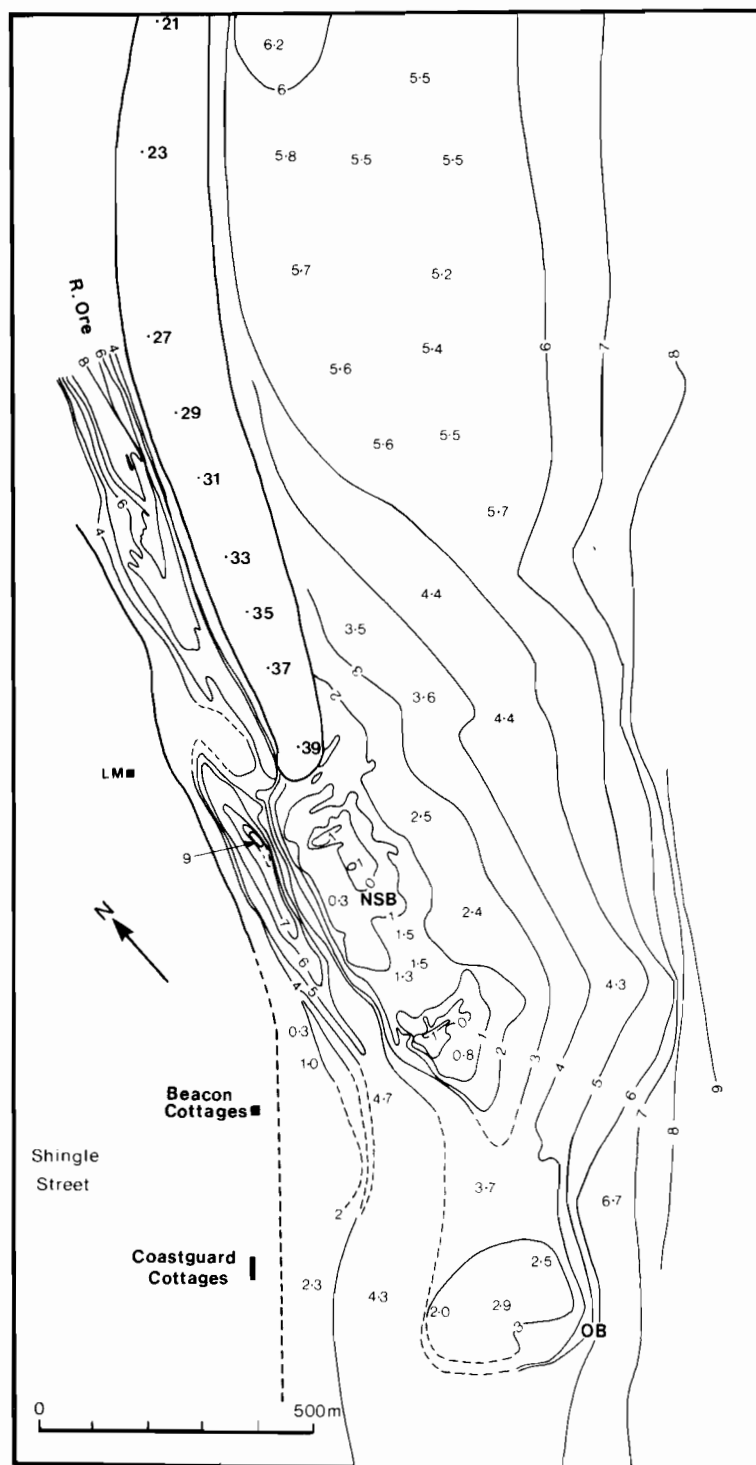


FIG. 6c.
May 1985

By 1980, the bathymetry had substantially altered (Fig. 6b). The tongue aligned normal to the shore at Shingle Street remained a prominent feature but had migrated further south so that it was now located opposite Beacon Cottages. There were effectively 2 main channels in the estuary with that running shore-parallel immediately seawards of the Shingle Street tongue being substantially wider than the one dividing the extension of North Weir point from the South Shingle banks shoal and Orford Bar. Overall, the estuary bathymetry had become irregular and confused, hence the contours are shown at half-metre intervals to define them better.

By 1985, the situation had become far clearer with the main channel now directed almost parallel to the Shingle Street coastline and with the shoals extending to the south of Coastguard Cottages (Fig. 6c). An interesting feature of the 1985 chart was the increase in relative relief. Not only were there 3 places on the banks where the crest exceeds +1 m O.D.—these crests could be short-lived—but there was one location in the main channel, between the leading mark (L.M.) and Beacon Cottages, where the depth exceeds -9 m O.D., i.e. some 2 m more than in both 1970 and 1980 and 3 m more than that shown in any of the 19th century charts. The minimum depth in the main channel of the estuary also appeared to be somewhat more in 1985 than in 1980 but this may merely reflect insufficient data offshore of Beacon and Coastguard Cottages in the latter survey.

Figures 7a, b give isopleths of accretion and erosion for 1970-80 and 1980-85, respectively. Both figures show the accretion south of North Weir Point in the line of the spit which has been typical of the period at least since the late 1950s (Fig. 5a). They also show the erosion of the channel of the River Ore which is reflected in the recession of the Shingle Street shoreline north of Beacon Cottages. Other features do vary, even allowing for the different time spans involved. Erosion on the northern face of the shingle banks was quite extensive between 1970 and 1980 (as it had been previously to that time) but accretion is the dominant feature almost everywhere apart from North Weir Point and the main channel to the west-southwest between 1980 and 1985. The original North and South Shingle banks had virtually merged by 1980 and a new southern bank, located just south of the latitude of the Coastguard Cottages, appears to have developed thereafter.

The change in the alignment of the channel and the development of the shoals in the line of the distal point had been anticipated in the earlier papers. So, too, had the continued widening of the spit further north in the line of S.P. 23 (Fig. 5b), where progressive accretion on the seaward side had increased the width at zero O.D. from 102 m to 167 m between 1956 and 1985. However, still further north, in the line of S.P. 9, slower, but steady erosion had occurred so that over the same period the spit had receded landward by 31 m. This section is typical of most of the northerly area which was routinely surveyed topographically. S.P. 17 falls approximately midway between S.P.s 9 and 23 and it is immediately north of there that there was a length of some 300 m from which gravel was extracted during the inter-war years. Although some infilling through overwash processes had occurred by about 1960 the excavation was still largely intact in 1980. By 1985 most of the southern portion of the site had been infilled by shingle pushed over the narrow beach crest by storm waves. The crest is lower (by some 0.6 m) than to either north or south and the immediate impression is that it is the site of a potential breach both on width and elevational grounds. However, survey data between 1956 and 1985 indicate that this may be more apparent than real. It is not this stretch of coastline that has diminished in height, but rather that the elevation of the seaward ridge both to north and south has increased. Furthermore, the width of the spit in the area of S.P. 17 has remained stable. Some weakness, nevertheless, must continue to exist.

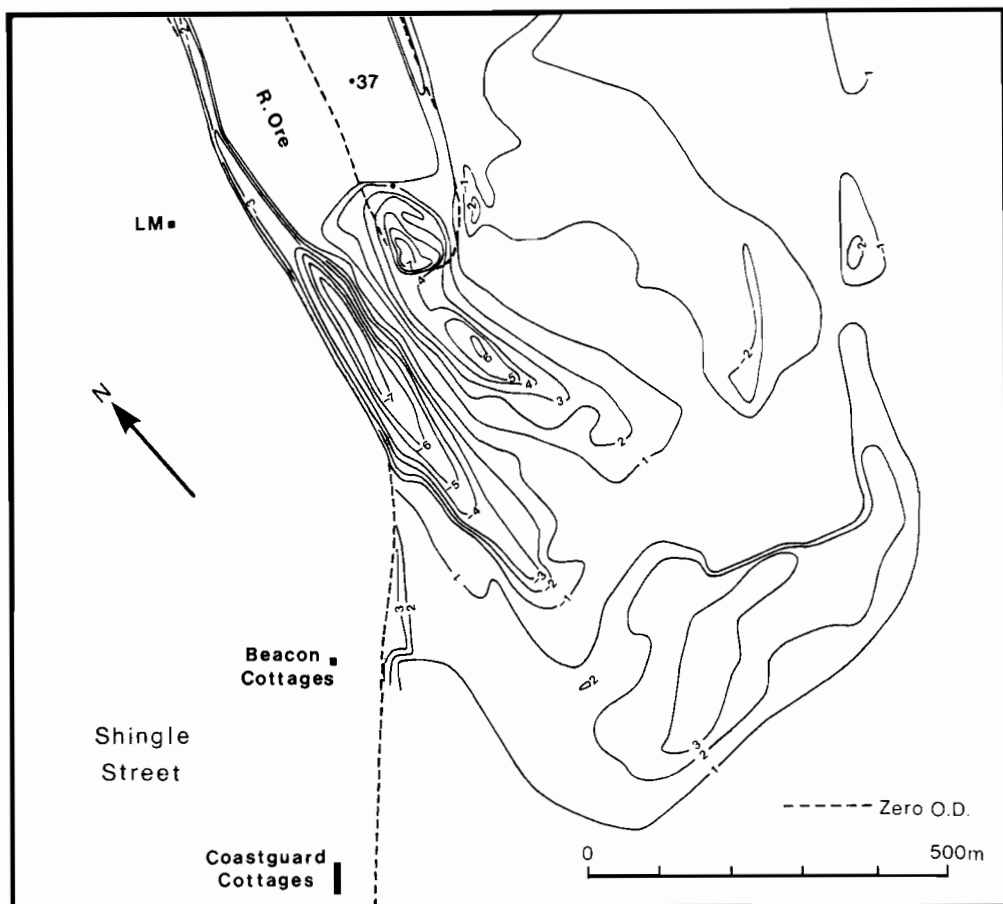


FIG. 7a.

Mouth of the River Ore: isopleths of erosion and accretion. (a) 1970–80, (b) 1980–85. Isopleths are drawn at 1 m intervals. The diagrams show the erosion of the Shingle Street coastline opposite North Weir Point; the extension of the inter- and sub-tidal shoal in line with Orford spit; and the displacement of Orford bar towards the south. In Fig. 7b (opposite) the recession of the main spit is at variance with the continuing growth of the banks. (See also Fig. 5a.)

LONGER TERM CONTEXT

Throughout the last 180 years, and perhaps longer, the position of the distal point of Orford spit has varied within a distance of some 2.7 km (Fig. 8). Figure 9 is a diagrammatic representation of the evolutionary sequence of the spit and its inter-relation with the Shingle Street coastline. (The lagoons have been stylised.) This idealised “cycle” may be interrupted, or truncated, by chance events such as the exploitation of points of weakness by storms and surges, and therefore only rarely fully develops. Because maps and charts are essentially snapshots in time certain phases of the spit’s development may be unrepresented over one particular sequence or, indeed, at all. Diagrams (a) to (d) are based on the experiments and surveys carried out between 1956 and 1985 and represent stages of development within that period. Diagrams (e) to (g) are all based on historical maps and charts but the actual dates are not sequential. Diagrams (h) to (j) are conjectural

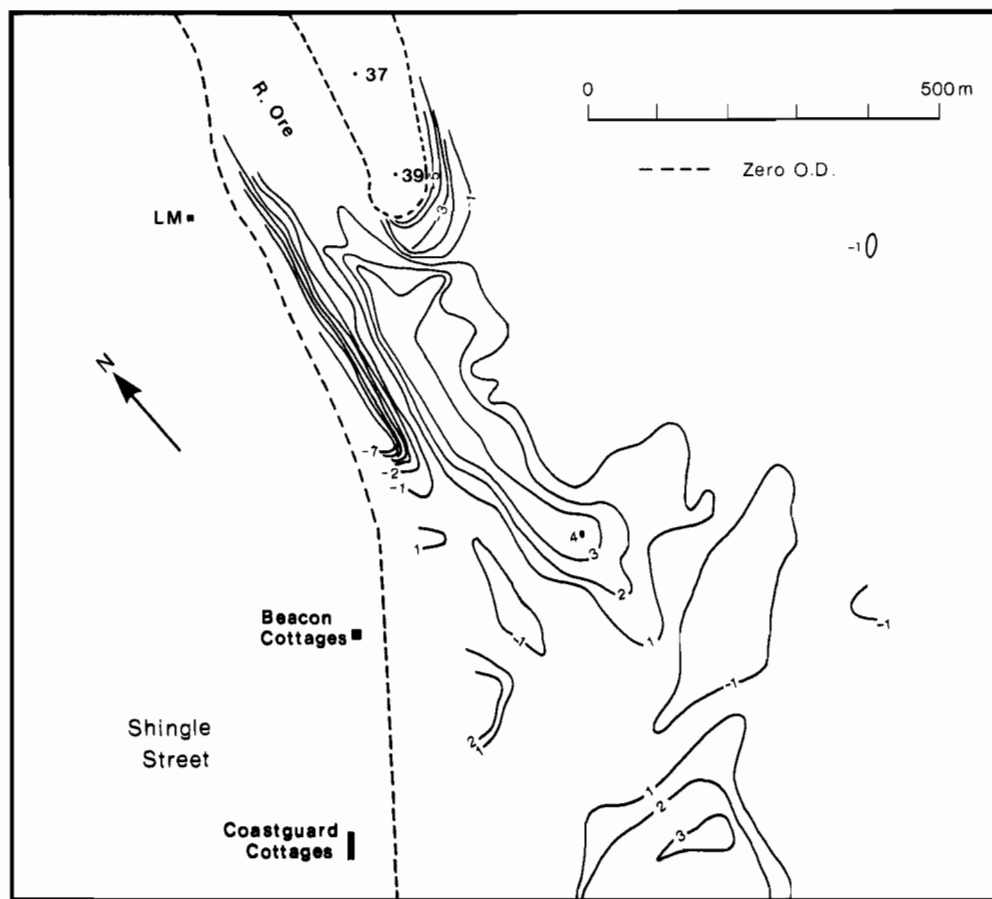


FIG. 7b.
1980-85

although with a factual basis. Thus, it is known that a series of lagoons developed along the Shingle Street shoreline after about 1895. These have been the subject of erosion for at least the last 60 years (Randall, 1973). It is also known that the spit receded to the maximum recorded distance north about, or some time prior to, 1921 (Fig. 8) (Steers, 1926; Carr, 1969), but it is not clear as to the nature of the final stages of the recession nor as to the fate of the shingle immediately south of the then distal point. Figures 9h, i assume minimum movement of sediment. The "1940" position shown in diagram (j) is based on air photographs taken in 1945. Randall (1973) made the observation that shingle extraction during the 1939-45 war resulted in an irregular and atypical coastline immediately thereafter.

The difference in timespan between any "cycle" reflects the varying amount of recession. Thus, in 1985, the distal point of the spit was still well north of the 1812 and 1885 positions. The present "cycle" has already lasted nearly a century as against the previous one's duration of 73 years. However, the maximum recession between 1812 and 1885 (in about 1838) was little more than half that recorded in the current sequence.

It is conceivable that once the hydraulic geometry is impeded and the northern part of the spit lacks the protection from nearshore banks, the spit could retreat in one major stage

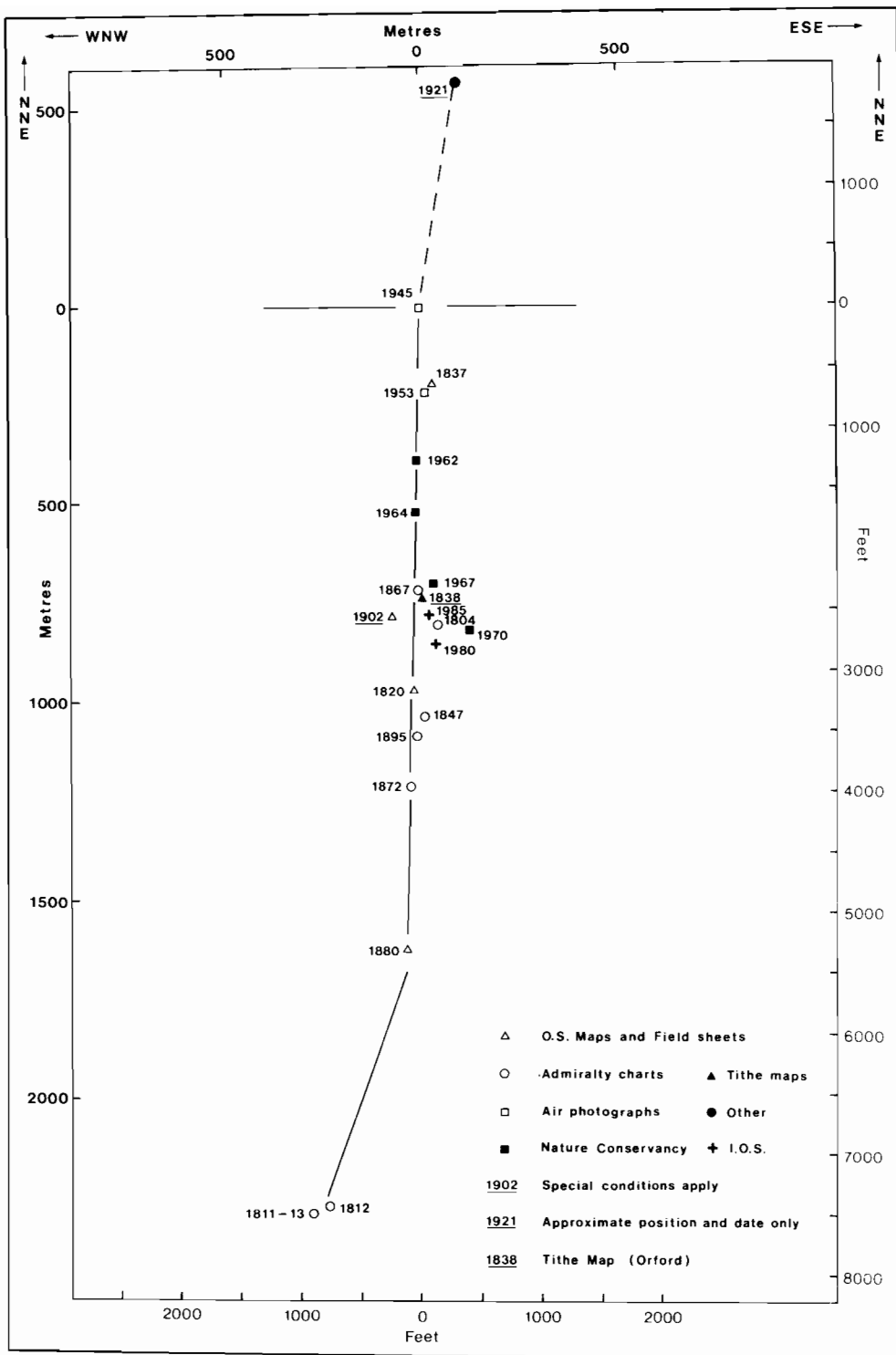


FIG. 8.

North Weir Point: distal point 1804-1885 showing variation in length but consistency in orientation. Note the clustering of dates close to the mean position and the apparent variability in growth rates from time to time. The latter are largely determined by the disposition of the contemporary banks and shoals.

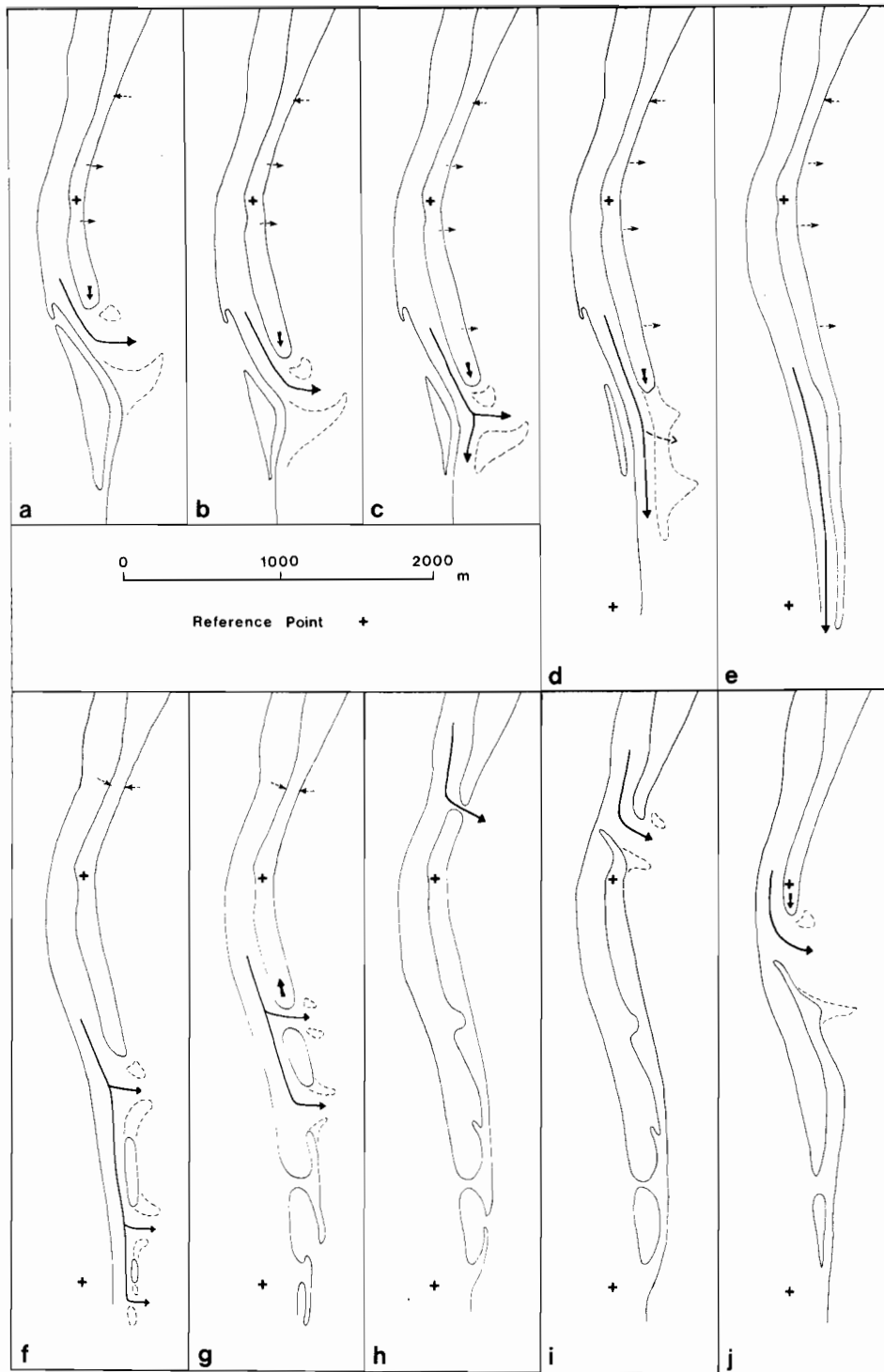


FIG. 9.

The "cycle" of development: Orford spit and Shingle Street. The dates are as follows with approximate years in brackets: (a) 1958; (b) 1966; (c) (1975); (d) 1985; (e) 1812 and (1885); (f) 1895; (g) 1902; (h) (1920); (i) (1930); (j) (1940). Heavy arrows represent main channel flow; small arrows indicate trends in erosion and accretion. For sources see References.

to a point where storm waves could breach it or where the bed might be readily fluidised (Nishimura and Lau (1979) cited in Carter *et al.*, 1984). Even under normal conditions local seepage occurs through the pebbles comprising Orford spit and Shingle Street. Alternatively, recession might be by stages as was the case post-1885. One possible weak point is the area north of S.P. 17 where, under surge conditions, a marked hydraulic gradient could develop. Were a breach to occur here it would represent the furthest recession of Orford spit to be recorded.

The data for the 4 decades from 1945 indicate that North Weir Point has grown by about 760 m (most of it between 1945 and 1970). This is slightly more than one-quarter of the fluctuations recorded over the well-documented period from 1804 (Fig. 8). Cartographic evidence prior to that time is not particularly accurate with one exception, a small estate map by Badulph Agas in 1589. This includes part of the coastline at Shingle Street and suggests that the outline there was essentially similar to that still prevailing. It is difficult to see on what basis Randall (1973) could claim that Shingle Street had a cliffed coast in the Middle Ages; the marshes to landward all predate that time. Figure 9 suggests that once the "bulge" on the Shingle Street shoreline is removed rapid growth of the major spit takes place. Although the sequence was interrupted between the 1847 and 1867 charts (Redman, 1865) the shingle banks remained largely 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 1812–13 (Carr, 1969) and about 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).

The sequence of development outlined in Fig. 9 has a number of implications. As noted above, Kidson (1963) used the inter-relationship between Orford spit and Shingle Street as an example of "counter-drift" in contradistinction to Robinson's (Robinson, 1960) belief in the mass transference of material from one shore of an estuary to the other following the breach of a spit. Kidson showed that the small Shingle Street spit aligned up-river had developed subsequent to the 1945 outline depicted on air photographs. Furthermore, tracer experiments (Kidson, Carr and Smith, 1958) demonstrated that labelled pebbles could travel across the estuary from Orford spit to reach the Shingle Street coastline and the area of the minor spit. However, as Carr (1972) noted, such a situation is likely to apply only during certain phases of the major spit's development: when the Shingle Street shoreline is exposed to wave action from the south or at least when onshore waves can be refracted in such a manner as to impose a northerly component to the transport of beach material there. At other stages mass transfer and bar by-passing (Bruun and Gerritsen, 1960), with, in this case, material from the north moving quickly out of the system is likely to dominate.

CONCLUSIONS

Between 1956 and 1970 annual surveys and experimental work enabled a detailed understanding of the mechanism by which the Ore estuary and the adjacent coastline evolved under the conditions then prevailing. Additional surveys in 1980 and 1985 provide further evidence and a broader perspective. In the light of nineteenth century experience it is tempting to suggest that over the next decade or so Orford spit will extend rapidly southwards while sowing the seeds of its own destruction. The slight recession of North Weir Point over the period 1980–85 has its parallel. Redman (1865, p. 203) wrote: "... for some years past, the outlet has been stationary, or rather it has receded north-

wards ...". As Fig. 8 shows such an event was to be followed by rapid growth to the south, culminating in the break-up of the spit from about 1893 (Cobb, 1957) onwards. It will be interesting to see the extent to which such a cyclic development will be repeated.

ACKNOWLEDGEMENTS

Research until 1970 was carried out by the (then) Physiographical Section of the Nature Conservancy, initially under the direction of Professor C. Kidson. The 1980 and 1985 surveys were undertaken by staff from the Institute of Oceanographic Sciences at Taunton, prior to the closure of the laboratory there. I.O.S. is a constituent body of the Natural Environment Research Council.

It gives particular pleasure to thank all those people who have helped in the acquisition and processing of data over a long period of time. Only the writer has provided continuity!

REFERENCES

- AGAS, B. (1589). Plan of Winston's Marsh in the Manor of Bawdsey. Public Record Office reference MPB 36.
- AUSTEN, F. W. (1812). Admiralty chart, original rough. Hydrographic Office reference 789(B).
- BRUUN, P. and GERRITSEN, F. (1960). *Stability of coastal inlets*. Volume 1. North-Holland Publishing Company, Amsterdam.
- BULLOCK, F. (1847). Admiralty chart, original rough. Hydrographic Office reference L 7288(B).
- CALVER, G. (1867). Admiralty chart, original rough. Hydrographic Office reference B 1446(B).
- CARR, A. P. (1965). Shingle spit and river mouth: short-term dynamics. *Transactions of the Institute of British Geographers*, **36**, 117–129.
- CARR, A. P. (1967). The London Clay surface in part of Suffolk. *Geological Magazine*, **104**, 574–584.
- CARR, A. P. (1969). The growth of Orford spit: cartographic and historical evidence from the sixteenth century. *Geographical Journal*, **135**, 28–39.
- CARR, A. P. (1970). The evolution of Orfordness, Suffolk, before 1600 AD: geomorphological evidence. *Zeitschrift für Geomorphologie*, New Series, **14**, 289–300.
- CARR, A. P. (1972). Aspects of spit development and decay: the estuary of the River Ore, Suffolk. *Field Studies*, **3**, 633–653.
- CARR, A. P. and BAKER, R. E. (1968). Orford, Suffolk: evidence for the evolution of the area during the Quaternary. *Transactions of the Institute of British Geographers*, **45**, 107–123.
- CARTER, R. W. G., JOHNSTON, T. W. and ORFORD, J. D. (1984). Stream outlets through mixed sand and gravel coastal barriers: examples from southeast Ireland. *Zeitschrift für Geomorphologie*, New Series, **28**, 427–442.
- COBB, R. T. (1957). Shingle Street: Suffolk. *Report of the Field Studies Council*, **3**, 31–42.
- DE BOER, G. (1969). The historical variations of Spurn Point: the evidence of early maps. *Geographical Journal*, **135**, 17–27.
- HODGKINSON, J. (1783). *The County of Suffolk*. Published Faden, 1783. British Museum reference (Maps) 5200(6).
- KEULEGAN, G. A. (1951). Third progress report on tidal flow in entrances. *United States National Bureau of Standards*, Report No. 1146.
- KIDSON, C. (1963). The growth of sand and shingle spits across estuaries. *Zeitschrift für Geomorphologie*, New Series, **7**, 1–22.
- KIDSON, C. and CARR, A. P. (1959). The movement of shingle over the sea bed close inshore. *Geographical Journal*, **125**, 380–389.
- KIDSON, C., CARR, A. P. and SMITH, D. B. (1958). Further experiments using radioactive methods to detect the movements of shingle over the sea bed and alongshore. *Geographical Journal*, **124**, 210–218.
- ORDNANCE SURVEY (1902) 6" sheets LXXVII, S.E. and LXXXIV, N.E. Second edition.
- PIRIE, G. (1895). Admiralty chart, original rough. Hydrographic Office reference B 5833(B).
- RANDALL, R. E. (1973). Shingle Street, Suffolk: an analysis of a geomorphic cycle. *Bulletin of the Geological Society of Norfolk*, **24**, 15–35.
- REDMAN, J. B. (1865). The East Coast between the Thames and the Wash estuaries. *Minutes of the Proceedings of the Institution of Civil Engineers*, **23**, 186–256.

- ROBINSON, A. H. W. (1960). Ebb-flood channel systems in sandy bays and estuaries. *Geography*, **45**, 183–199.
- SPENCE, G. (1804). Admiralty Chart, original rough. Hydrographic Office reference 664(B).
- STEERS, J. A. (1926). Orford Ness: a study in coastal physiography. *Proceedings of the Geological Association*, **37**, 306–325.

APPENDIX

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 makes any form of swimming very dangerous and causes 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 if a boat is available. Such studies can be related to the 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 the colonisation of vegetation and the 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.

During the main period of research (1956–70) a wide range of data was obtained in the Orford area, including tidal current velocities; sea wave incidence; and wind frequencies and direction. However, the present paper relies very largely on topographic and hydrographic surveys. These were undertaken annually until 1970; further surveys were carried out in 1980 and 1985. Once a triangulation framework had been established, topographic data were obtained by levelled profiles and planetabbling with a telescopic alidade. The sections were extended seawards, and supplemented by additional bathymetric data, in order to provide information both for an annual hydrographic chart, and for a plot showing the changes in erosion and accretion between one survey and another. A launch, equipped with an echo-sounder, was used for the marine work. Until 1970, the position of the vessel was fixed by measuring sextant angles between a series of beacons erected onshore; in 1980 and 1985 a Decca "Trisponder" microwave positioning system was used instead. As the configuration of the estuary changed over time the area surveyed and the location of control points also needed to vary.

Postscript

An hydrographic survey of the estuary entrance (by Cmdr J. Pryor, R.N.(Rtd)) in April 1986 indicated that the depths over the Orford Bar area were about 1 m less than those found during the May 1985 survey described above. A topographic re-survey of the end of North Weir Point spit in June 1986 by the writer showed that the distal point had developed a series of new recurves and hence a net growth of some 74 m beyond the May 1985 position, thus virtually regaining the whole length of the spit lost between 1980 and 1985. Because of continuing recession prior to this re-growth the total extent of new ridges was 124 m. This represents the highest annual recorded growth in any year since 1955. However, the extension was rather narrow with a typical width between zero O.D. on the seaward and landward sides of about 60 m, and a maximum crest height of 4.0 m or less. The June 1986 position for 0 m at the point falls almost exactly 79 m WNW of the equivalent position in 1980 as depicted in Fig. 8.

The net impression derived from the 1986 hydrographic and topographic surveys is of the failing hydraulic efficiency of the estuary as witnessed by the deposition of shingle on the banks and the rapid extension of the spit (coupled with the customary retreat of the Shingle Street shoreline). It will be fascinating to see to what extent the 1985–86 experience is representative of the longer-term picture over the next decade.