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THE STORM SURGE OF 11 JANUARY 1978 ON THE EAST COAST OF ENGLAND

J. A. STEERS, D. R. STODDART, T. P. BAYLISS-SMITH, T. SPENCER AND P. M. DURBIDGE

The storm surge of 11 January 1978 caused considerable damage on the coasts of Lincolnshire, the Wash, and East Anglia. Along the north Norfolk coast surge levels varied between 4·6 and 5·9 m OD, similar to those of the 1953 surge (salt-marsh surface levels lie between 2·2 and 2·5 m). At Scolt Head Island dunes were cut back 20 m, and fresh sediment aprons were formed behind the seaward beach crest. These are 40–70 m wide, up to 50 cm thick, and extend for over 600 m. Their approximate volume is 3×10^4 m^3. In contrast there was little change on the salt marshes. Analysis of Wells tide-gauge records shows 46 tides higher than 3·6 m during 1954–78, 5 higher than 4·0 m, and 2 higher than 4·4 m; there is some indication from historical records of increasing height and increasing frequency of storm surges on this coast.

I. THE GENERAL EFFECTS

THE STORM OF 11 January 1978 caused considerable damage on parts of the east coast of England between north Lincolnshire and the North Foreland but, except in some places, was less severe than that of 31 January–1 February 1953 (Steers, 1953). The four synoptic charts (Fig. 1), based on the daily weather reports of the Meteorological Office, show clearly that a low of considerable intensity developed in the area to the west of the Wash shortly before 0600 hours on 11 January. By noon, the centre had moved some 65 km to the northeast of the mouth of the Wash, and by 1800 hours it had reached, in less intense form, the Low Countries. By midnight it reached the Hamburg area and then passed eastwards and had virtually disappeared by midday on 12 January. Pressure in the depression fell to 976 mb, and north and, later, north-north-east winds reached force 9 (75 km h^{-1}) with gusts up to 130 km h^{-1}.

The weather report at noon on Wednesday, 11 January noted that a 'low developed over the British Isles and moved steadily southeastwards into the southern North Sea, bringing a very cold northerly airstream into most districts. During the next 24 hours the low will move into Germany and, with a ridge persisting west of the British Isles, a very strong, very cold northerly airstream will persist over all parts.' On Thursday at midday, the depression had moved to south Denmark and 'an associated cold front . . . moved rapidly east . . . [and] was followed by northerly gales across all parts of the British Isles.'

The strong northerly winds persisted for some time, but the maximum amount of storm damage occurred during the evening and night of 11 January. If we now turn to tidal and surge conditions, the impact of the storm will be clear. Table I shows the predicted tide at 16 stations and also the height of the actual water level (tide plus surge). For comparison, the heights of the storm tides of 31 January

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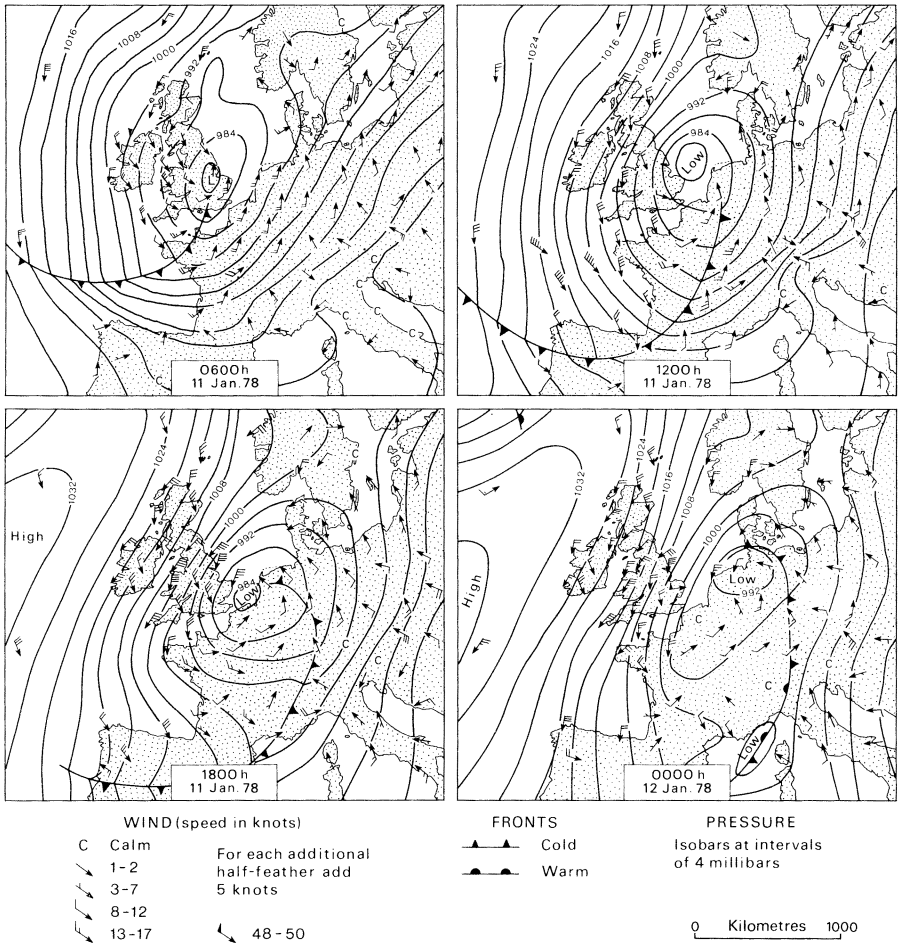

Fig. 1. Synoptic situation from 0600 hours on 11 January to 0000 hours on 12 January 1978. Based on daily weather reports issued by the Meteorological Office

1953 and 3 January 1976 are added. The figures demonstrate the effect of the 1978 tide in the Wash: the wind was blowing almost directly into the Wash and for a time the waters of the Nene and Ouse were dammed back. Fortunately the much quicker disappearance of the low, and also the absence of a surge building up as it did in 1953, prevented a recurrence of the 1953 conditions in 1978.

In the Humber and along the Lincolnshire coast, tidal levels were higher than in 1953 and 1976: the height above predicted tidal level in 1953 was 0·72 m more than in 1976 and 1978 but was on a lower tide. The warning system worked reasonably well except on the northeast coast (Richards, 1978), so that flood warnings were issued some two to three hours before the maximum in the coastal towns of Lincolnshire. Flooding, however, was locally serious. In Cleethorpes about 1000 houses were seriously affected over an area of five km² behind defences. The railway line between Grimsby and Cleethorpes was put completely out of action because hundreds of tons of ballast were washed from under the track, which runs close to the coast for over a kilometre before it reaches Cleethorpes station. Over a short distance the track itself was seriously displaced

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TABLE I

Water levels during the storm surges of 1953, 1976 and 1978 (metres O.D.)

	31 Jan 1953	*3 Jan 1976*	*11 Jan 1978*	
	evening tide	*evening tide*	*predicted evening tide*	*actual evening tide*
Wick	–	–	3·86	3·92
North Shields	3·32	3·43	2·81	3·52
Barton on Humber	–	–	–	5·15
South Ferriby	4·79	5·3	4·4	5·3
Immingham	4·50	4·50	3·71	4·67
Grimsby	–	4·35	3·4	4·5
Boygrift	–	4·3	3·2	4·5
Boston Dock	5·25	5·24	4·3	5·5
Boston Grand Sluice	5·40	5·22	–	5·63
Fosdyke	*ca* 5·4	5·18	4·3	5·9
Wisbech	*ca* 5·1	4·99	4·3	5·6
King's Lynn	5·65	4·99	4·37	5·92
Wells	5·13	4·46	3·1	4·91
Great Yarmouth	3·28	2·69	1·1	2·19
Southwold	3·50	2·50	1·4	2·00
Aldeburgh	3·78	2·83	1·4	2·45

and twisted. At Sandilands and Mablethorpe, 28 houses and 8 business premises were flooded, and chalets and caravan sites suffered at Trusthorpe, Ingoldmells and one or two other places. At Boston, the church and 180 houses were flooded owing to the collapse of a brick wall. No warning was given at Boston since the predicted surge was 0·84 m, but unfortunately it reached 1·2 m. At Skegness, the sea bank to the north of the pier was unbroken, but there was much loss of sand from the beach in front of it. The pier, about 900 m long, suffered severe damage. It was built in 1881 and, as at Hunstanton, the far end on which the theatre stands was left isolated by a gap more than 100 m wide. Table 1 shows that in 1978 conditions in the Wash were worse than in 1953: the Wash acted as a wide funnel into which the wind and surge mounted to a maximum. Similarly, in the dyked prolongations of the rivers Nene and Great Ouse, the water level was forced upwards and serious flooding resulted. The relatively slight damage on the Lincolnshire coast was the result of the much stronger masonry sea walls built after the 1953 flood and also partly because the wind was more or less parallel to the coast. It would probably be wrong to argue, as was done by one MP, that the great damage at Wisbech and King's Lynn was induced by this and by sea walls on the coast of north Norfolk. In fact, apart from the promenade at Hunstanton, there is no sea wall but only earth embankments protecting marsh lands in front of Holme, Thornham, Brancaster, Brancaster Staithe, Burnham Overy and Wells. The great shingle ridge extending from Blakeney to Weybourne, where the cliffs begin, fronts the marshes at Cley and Salthouse. Many of these embankments were broken and considerable areas of marsh were flooded.

The greatest apparent damage in the Wash was that done to the numerous caravans and similar structures, and also to the pier at Hunstanton. Along much of the Wash between south Hunstanton and Wolferton, many caravans stood on shingle ridges, often with a low area behind them, which, as in 1953, became a more or less continuous lagoon. The caravans were swept southwards and

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crushed one against the other. Some of the iron legs of Hunstanton pier were found more than 8 km to the south. If caravans or comparable structures are placed on shingle banks which are wave-built and artificially maintained, it follows inevitably that they will suffer when such a storm occurs. Sea walls along the Wash were also breached and extensive damage was done to holiday caravan sites on low, reclaimed land.

On the north Norfolk coast, although many earth walls were breached, relatively little damage resulted. Apart from Wells and one or two other places, most of the coast consists of nature reserves faced by shingle banks, wide beaches and dunes. The dunes were locally cut back 3–7 m; the great shingle bank off Salthouse was overtopped and its level reduced about 1 m. It was soon bulldozed up from the land side, but before this was done the great piles driven in after the 1953 storm stood out prominently. Now the inner side looks, and is, unnaturally steep, but although Salthouse marshes and part of the coast road were flooded, there was no loss of life as in 1953.

The dunes and sea wall at Holme were not breached; at Thornham, shingle ridges were flattened and spread landwards; at Titchwell, the west and east banks of the reserves were broken and the Royal Society for the Protection of Birds (RSPB) was presented with a problem; the water just flooded the Warden's House at Brancaster Staithe; the effects of the storm on Scolt Head Island are treated fully in Part II of this paper. The Overy wall was overtopped in two places but did not give way. Two major breaches were made in the long wall that runs from the quay to the lifeboat house at Wells, and extensive flooding of the marshes ensued, but the inner (i.e. western) limit of the flood was held by the wall built in 1720. Moreover, although there was some subsequent minor flooding, the salt water ran off quickly. The beach huts at Wells were much damaged and readers of the local and national press were made aware that a 300-ton coaster had been quietly left in the car park on Wells quay. A 25-ton fishing vessel in the Channel – the skipper was on board and below – dragged its anchors when the breach nearer the quay was made in the sea wall and was swept through to make, without serious damage, a 3 km circuit before it came to rest close to where the pavilion had been on the playing field. The rapid plugging of the seaward breach by a flight of helicopters each carrying and dumping half a ton or more of material from a quarry behind Wells was an operation worth watching. Stiffkey and marshes further west, like those to the east, were flooded and cleaned in the sense that most of the rubbish and loose material was swept landward and left as a drift ridge. Before the Salthouse shingle bank was bulldozed, one could stand on the main coast road and see the breakers on the beach.

No serious damage, apart from local erosion, was done to the cliffs between Weybourne and Happisburgh, but there was locally bad flooding at Walcott – which also suffered in 1953 and to a lesser extent in 1976. In 1953, a sea wall was built to replace what was in fact a low cliff, but this was not sufficient to prevent the flooding of the coast road and some nearby houses. The defences east of Cromer prevented serious erosion to the cliffs; for some distance they are wooden structures which would break the force of the waves and prevent to some extent material from the cliffs being washed seawards. The major defences at Walcott were undamaged.

Farther east, at Winterton, there was severe scouring. The concrete wall built in 1953 was covered by dunes but in the storm of 1978 it was exposed in several places. A strip of dune 10–12 m wide was the estimated loss on the seaward side of the Winterton National Nature Reserve (NNR); the sea also broke through in

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three places. Beyond Winterton the coast turns more and more to the south and so the winds were less directly onshore. Yarmouth and Lowestoft escaped without serious flooding or damage, but farther south, the soft cliffs between Pakefield and Minsmere all suffered some loss. Erosion at Benacre and Covehithe has been severe for some years, and is particularly evident after storms. Opposite point 528 823 (OS 1 : 50 000 sheet 156), 8·8 m of cliff were eroded between 19 March 1977 and 11 March 1978; at 529 820, 7·9 m – the cottage and garden wall have now been removed to prevent vandalism; at 523 816, 14·0 m of cliff disappeared in the same period. At 530 823, severe erosion on 2 January 1976 led to the exposure of a timber-lined well, which for a short time stood on the beach 3·4 m in front of the cliff. On 23 September 1976 at this same point, further erosion led to the exposure of another well. The Long Covert south of Benacre Broad has been considerably eroded for some years and several large trees have been washed away. The cliffs between Benacre Broad and the sea walls and promenade at Southwold have also suffered, but the greatest loss in recent storms has been at Benacre and Covehithe. The progress of recent erosion at Covehithe, indicated by the distance to the edge of the cliff top from fixed points (A: 528823; B: 528820; C: 527816), has been as follows:

Point A	1977	230·9 m	Point C	1977	121·1 m
	1978	222·0 m		1978	107·1 m
	1979	200·1 m		1979	86·3 m

At point B the loss in 1978 was 7·9 m and in 1979 15·6 m. The height of the cliff is about 3 m at point A and rises gradually to about 9–10·5 m at C. Two wells and a medieval rubbish pit were exposed by this retreat near point 530824 during the first three months of 1979. At Southwold, the pier was damaged, as were also the pavilion and beach huts on the esplanade. Although the harbour was flooded, the sea walls were not overtopped. On the other hand the river walls along the Blyth were, and flooding was at its worst to the south of the channel. At Walberswick, the outer beach was flattened and a breach was made into Corporation marshes. Westwood, Reedland and Dingle marshes were all flooded, and some river walls at Westwood and Dingle were overtopped but scarcely damaged.

Farther south, the cliffs at Dunwich were attacked and eroded more severely than in 1953. This was the result of a northerly wind, whereas in 1953 at this point it was slightly northwest. At Minsmere, the beach and sea bank did not suffer. The beach between Thorpeness and Aldeburgh held and prevented flooding. At Aldeburgh, there was no damage to the concrete wall between the Coastguard Station and the Martello Tower, but overtopping caused considerable damage to the road and shingle bank behind it. The beach between the Martello Tower and the Lighthouse was breached in three places.* Borrow pits made during and after the war may have weakened this part of the ridge. South of the Lighthouse, the area of the NNR was unaffected. Some flooding occurred at Havergate Island and

*It is not improbable that this stretch of coast will suffer severely in future gales. The promenade which ends just south of the Brudenell Hotel is in process of becoming a small 'headland'. The groynes to the south hold up a narrow beach, and the Martello Tower is also becoming a headland on a small scale. Although the movement of shingle oscillates between the Martello Tower and the promenade, the major movement is to the south. But both factors mean that less shingle passes south of the Martello Tower. Since some shingle has been removed from the landward side of Sudbourne Beach and from Lanterne Marshes, it follows that this part of the coast is likely to become progressively weaker, and it would not be surprising if considerable, and even serious, changes took place along it – and if so, the remainder of Orford Ness may suffer.

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Shingle Street, and there was a little damage to the concrete wall at Bawdsey. Flooding caused damage to houses, caravans and boats at Felixstowe Ferry and Felixstowe.

Essex was sheltered from the main force of the wind. Breaches were made in several walls – Colne Point, Dengie, the Blackwater – and some, e.g. at Leigh NNR, were overtopped. But compared with 1953 the damage was very light.

In Kent, the parts of the coast which suffered most were the Isle of Sheppey and Shell Ness Hamlet where the damage was extensive. About 400 ha were flooded to a depth of 1·5 m; this land was sown with winter wheat and seed rape; some of it was grazing marsh. Unfortunately, the afternoon tide on 12 January also came through the breach which was about 80 m long. There was flooding in the Isle of Harty, and at Deal fishing boats were carried into the streets.

In other places the waves overtopped the walls but did not breach them. This led to considerable scouring of the insides of walls which, fortunately, had been recently strengthened. There was serious trouble at Sheerness, and at Margate most of the pier was swept away. It is curious that three piers were so badly damaged; they had survived earlier storms. Whether the age of the piers was the main factor or whether the waves passing under them disrupted them is a matter of guesswork. It is questionable whether they will ever be replaced.

II. THE STORM SURGE AND ITS EFFECTS AT SCOLT HEAD ISLAND

The storm surge of 11 January 1978 was the most extreme event to affect the north Norfolk coast since that of 31 January–1 February 1953 (Steers, 1953; Steers and Grove, 1954). The predicted evening tide at Wells on both 10 and 11 January was 3·1 m above Ordnance Datum (OD), high enough to inundate the marshes by 0·7–0·9 m. Because of the unusual meteorological conditions, the predicted level was considerably exceeded (reaching 4·91 m at Wells), and the flood levels reached were marked by prominent drift lines along the entire coast. In the two weeks following the surge, flood levels were surveyed at a number of localities, and special attention was given to changes at Scolt Head Island.

Maximum drift levels, as related to local benchmarks, varied from about 4·5 to 5·5 m OD. The following heights were established:

Holme Marsh	5701 3444	4·61 m
Burnham Deepdale	5803 3444	4·62 m
Burnham Overy Staithe	5846 3444	5·51 m
Holkham Gap	5888 3451	5·51 m
Wells Quay	5918 3437	4·91 m
Warham Marsh	5949 3438	4·99 m
Stiffkey Marsh	5964 3439	5·55 m
Morston	6006 3443	5·26 m
Blakeney	6028 3442	4·90 m
Cley	6046 3443	5·14 m

These elevations probably approached, or even locally exceeded, those of the 1953 surge. Grove (1953) quotes heights of 4·27–4·88 m at Blakeney, and Robinson (1953) gives maximum observed heights in that year on the English coast of 4·97 m at Dover and 5·03 m at Immingham. Jensen (1953), however, quotes general levels of 5·18–5·49 m west of Thornham, 5·49 m at Burnham Overy, and 4·57 m at Wells and Stiffkey. The 1953 flood level marked on the

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grain warehouse at Wells Quay stands at 5·13 m, though a similar mark at Blakeney, at 6·07 m, undoubtedly refers to the greatest height of wave action rather than a still-water level, since it stands some 1·5 m above the surge level quoted by Grove. A marker post on the site of the former railway station on the enclosed Holkham marsh (5892 3442) gives a 1953 flood level of 4·02 m. Some of this variability probably results from differences in exposure, but a major difference between the surge events of 1953 and 1978 was the importance of wave action at the top of the tide in the former year and the comparatively calm conditions at the same stage in 1978 (R. Chestney, pers. comm.). For comparison, it is perhaps worth noting the heights of other recent historic floods, as marked on public buildings on the Norfolk coast: these include 4·66 m on 26–27 August 1912 at Stiffkey, and 4·96 m in 1897 at Blakeney.

At Scolt itself, the surge, at least on marshes in the lee of the main seaward ridge, was rather lower than in the more exposed locations of Stiffkey and Cley. The following heights were determined:

West end	58025 34670	4·71 m
Wire Hills	58025 34660	4·95 m
Hut	58080 34655	5·00 m
House Hills	58165 34649	5·22 m

The heights on the adjacent mainland (Burnham Deepdale, Overy Staithe) were 4·62 and 5·51 m. There is some indication that the Scolt levels may have been slightly lower than in 1953: the only firm elevation we have on the island for that surge is of 5·37 m at the east end.

A surge level of 4·5 m would flood Missel, Hut, Plover and Plantago Marsh surfaces to depths of 2·2–2·5 m. The sea-wall enclosing Deepdale and Norton marshes has elevations of 4·5–5·3 m, and in places came very close to being overtopped. The main seaward ridge of Scolt is variable in height: the high dunes near the Hut reach 20 m and at Norton Hills 10·5 m, but long intervening stretches (Smuggler's Gap, Low Hills) reach only 4·0–5·0 m. In these areas, surge waters overtopped the ridge and spilled across the marsh surface (Fig. 2).

Physiographic effects were studied by ground surveying and sampling during late January and early February 1978, with further observations continuing to September. Comparison was also possible between pre-surge (7 August 1967) and immediately post-surge (20 January 1978) aerial photographs at scales of 1 : 5 300 and 1 : 6 000 taken by the Cambridge University Department of Aerial Photography (Plates IV and V).

Beach and dune erosion

The line of seaward dunes was cut back along most of its length during the surge. In very broad terms, the amount of retreat was inversely related to the height of the dunes, being least at Hut Hills and reaching a maximum at the 1953 breakthrough. This doubtless resulted from the lesser amount of sediment needing to be removed from low dunes, and also the ease with which they were overtopped by the surge. There was, however, considerable erosion at the east point, and also at the southern end of the Long Hills lateral. Between Smuggler's Gap and Norton Hills retreat averaged 20 m, and was clearly evidenced by exposed rootmats on the upper foreshore. This retreat itself had the effect of drastically lowering the crestline of asymmetric but narrow dune ridges, and in places (e.g. west of Wire Hills and along Low Hills) only a narrow fragment of the

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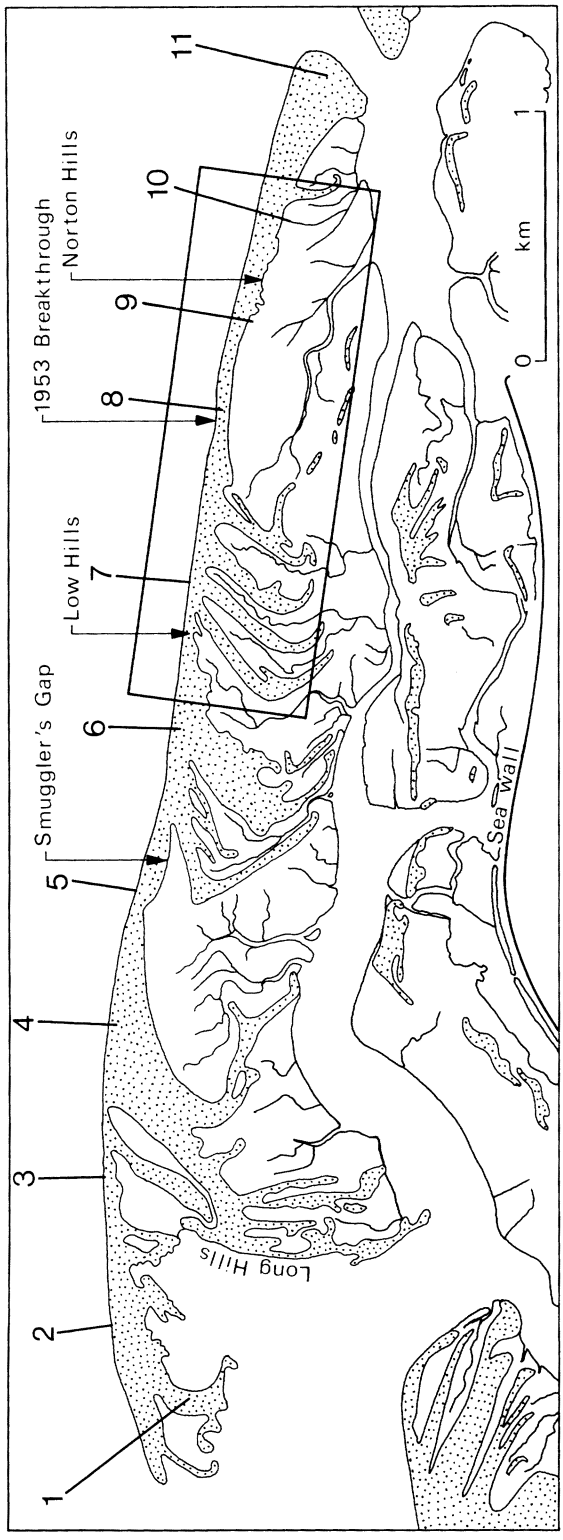

Fig. 2. Scolt Head Island, showing the location of Plates IV and V and of beach profiles 1—11

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original backslope now remains. The retreat compares with maximum figures of 10–20 m in 1953 (Grove, 1953), but is less than the spectacular erosion of up to 26 m recorded in that year near Benacre (W. W. Williams, *in* Steers, 1953).

As a result of this beach retreat, a substantial area of marsh mud was exposed on the foreshore east of the 1953 breakthrough. A mud outcrop 150 m long and 100 m wide was also exposed here in 1953, but within two years it had been reduced to less than half its width (A. T. Grove, pers. comm.). Since then its dimensions have fluctuated considerably, depending largely on the movement of beach sand. After the 1978 surge, the outcrop was 290 m long and up to 40 m wide; it stands between 0 and 1·0 m OD. Erosion has since been rapid, largely by peripheral collapse, with the formation of 'armoured mudballs', some of which were found several hundred metres to the west and even on the marsh side of the seaward ridge within two weeks of the surge. The area of outcropping marsh mud on the west side of the Long Hills lateral near Beach Point was also greatly extended, as Beach Point itself was pushed eastwards over the marsh surface.

Depositional aprons

Where the dunes were high, eroded material collapsed down the seaward face during the surge, and continued to do so for several weeks until the over-steepened cliffs regained a stable profile. Where the dunes were low, however, eroded material from the foreshore and ridge crest was deposited as a series of arcuate aprons of sand and shingle on the landward side of the ridge, partly overtopping marsh deposits. Small aprons were formed at Smuggler's Gap, but the main expanse extends for 0·6 km from the House Hills ridge to the 1953 breakthrough. The aprons here are 40–70 m wide. At the breakthrough itself, there is an extensive area measuring 0·4 km east–west and up to 150 m north–south, consisting partly of scoured channels and partly of fresh sediment deposits. These lobes and aprons have flat and rather featureless surfaces, sloping from sea towards the marsh, with steep foreslopes. In many places they block pre-existing creek channels. Profiles were surveyed across the aprons and pits were dug to determine both thickness of sediments and also their composition and internal structure.

Two such profiles are shown in Figure 3. Profile 6 is located at House Hills, near the western end of the area of storm overwash. It shows a small lobe of sandy material with maximum depth of 30 cm, extending 60 m inland of the new beach crest; the zone of erosion is some 20 m wide at this point. Profile 8, on the other hand, is located in the area of the 1953 breakthrough, and it was here that the 1978 storm had its greatest effect. The zone of deposition in this profile extends 180 m inland of the new beach crest, with up to 50 cm of new deposits. For the first 80 m inland from the crest these new deposits are poorly stratified sands, gravels and shingle, and they overlie a newly scoured surface cut in the 1953 apron. Thereafter the new deposits are mainly sands overlying a buried salt marsh surface. The depth of new deposits markedly decreases after a distance of 140 m, from a depth of 40 cm to less than 5 cm.

In total, sediment depths were determined at 5 m intervals along eight profiles. The mean depth of new deposits was calculated for each profile, and the planimetric area of new storm deposits in the zone represented by each profile was determined using aerial photographs. These data enable us to calculate the approximate volume of sediment deposited by this single storm along the seaward coast of Scolt Head Island, which amounts to 3×10^4 m^3. This figure relates only to the transport of sediment inland from the offshore zone, from the seaward

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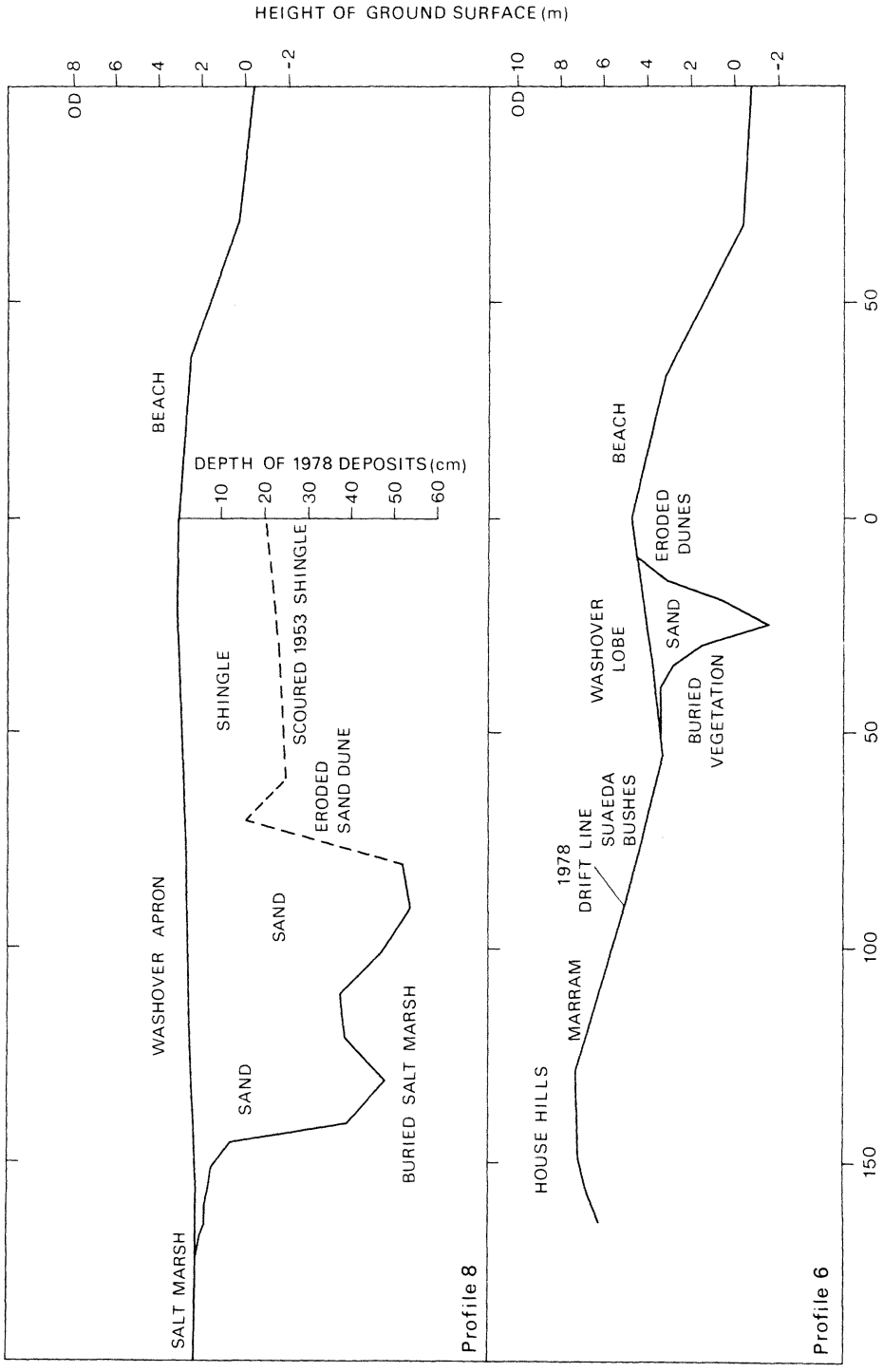

Fig. 3. Profiles of washover deposits on profiles 6 and 8 at Scolt Head Island

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beach and from the coastal dunes, to form new lobes and aprons well above high tide level. It takes no account of changes within the beach profiles themselves, nor of any longshore movement initiated during the surge, nor of offshore movement of sediment.

Sediment characteristics of the washover aprons

One hundred and thirty-five sediment samples were collected from a depth of 10 cm on four of the profiles. The sand fraction was separated and sieved at 0·25ø intervals. The sands of the washover deposits were found to have a median grain size of 1·59ø; they are very well to moderately well sorted, negatively skewed, and mesokurtic to leptokurtic (Table II). When compared with the sediments of the beaches and dunes at Scolt (Roy, 1967) they most closely resemble in mean characteristics those of the beach environment. However, when the scatter of values for all samples is considered (Fig. 4), it can be seen that the washover

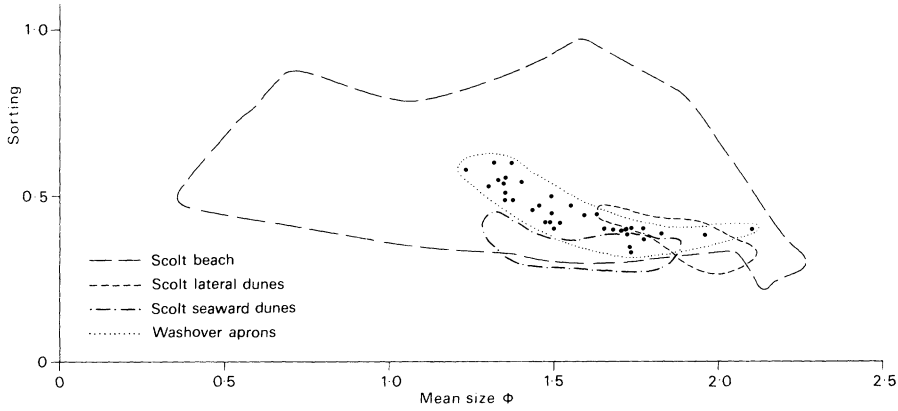

Fig. 4. Size and sorting characteristics of sands from the 1978 washover aprons (this paper) *and from the beach, seaward dune and lateral dune environments* (Roy, 1967) *at Scolt Head Island*

deposits are considerably less variable than those of the beach, and that they are in general both coarser and better sorted. In mean size the washover sediments resemble dune sands, but both at Scolt and at Blakeney the dune sands show a higher degree of sorting. These data suggest that both beach and dune sands are incorporated in the washover deposits, but that in this process both grain-size selection and a high degree of sorting of the material have taken place.

There is little variation in median grain size along the individual sediment profiles, apart from a fining in the landward 5–10 m. Mean grain size (which utilizes more of the distribution) shows a decrease towards the salt marshes. There is an increase in sorting to landward, the toes of the aprons being well sorted. This results primarily from the progressive shedding of coarser sediments as one moves landward across the aprons. In addition to sediment, great amounts of dead vegetation and drift timber were lodged at drift lines, most extensively along the western side of the House Hills laterals.

Marshes

The marsh surfaces appeared remarkably unaffected by the surge, both at Scolt and elsewhere on the Norfolk coast, though a great deal of dead vegetation was clearly removed from them to form the drift lines. The creeks in higher marshes also showed no obvious erosional effects, other than sporadic bank collapse which

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TABLE II

Mean size and sorting of sands from different depositional environments at Scolt Head Island and Blakeney Point

	Number of samples	*Mean size* ϕ	*Sorting* σI	*Source*
Scolt Head Island				
Beach	52	1·59	0·49	Roy 1967
Seaward dunes	33	1·60	0·34	–
Lateral dunes	19	1·94	0·35	–
Cockle Bight marsh	15	2·06	0·42	–
Ternery marsh	5	1·88	0·36	–
1978 storm aprons	135	1·56	0·45	This paper
Blakeney Point				
Beach	18	1·85	0·64	Bhattacharyya 1967
Dunes	11	2·15	0·29	–

may have resulted from the surge. Some creeks on lower marshes, however, showed massive and continuous blocky collapse along their banks, particularly well seen east of Beach Point (58010 34560). What physical processes triggered this collapse, and why such effects were limited in their distribution, is not apparent.

Subsequent change

No continuous seaward ridge at the 1953 breakthrough now exists, and the surface of the depositional apron here (about 3·0 m OD) is low enough to be regularly overtopped by spring tides. For example, the actual tides on 17–19 September 1978 reached 3·93 m at Wells. The breakthrough area was inundated, leaving a well-marked drift line at 3·7 m; the apron surface was strongly ripple-marked and in places scoured, and sediment was carried by well-defined drainage channels down into marsh creeks. In addition, in the lower areas adjacent to the marsh, a thin layer of mud was deposited over the sand.

Elsewhere, where the seaward ridge is higher and not overtopped during ordinary springs, the aprons have persisted with no topographic change. Sandy patches have been rapidly colonized by *Ammophila arenaria*, and *Suaeda fruticosa* has survived even where partly buried by shingle carpets. Along most of the Low Hills sector, the sediment aprons are thus likely to be persistent features, whereas the deposits at the 1953 breakthrough will undoubtedly continue to be modified during spring tides, and especially surges, in the future.

The eroded upper foreshore in front of the dune ridge had clearly been colonized by vegetation by September 1978. In the Low Hills sector especially, there was a zone 10–15 m wide of *Ammophila* (together with *Eryngium*, *Cakile* and *Honkenya*) approximately coincident with the scoured area, but all this vegetation was again removed by storms in the winter of 1978–79.

Frequency of surges

Although the 1978 surge is immediately compared with that of 1953, inundations of almost comparable height are not infrequent; Suthons (1963) lists

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15 since 1883. Though there is information on sea floods in eastern Norfolk back to at least 1287, there are fewer data on the north Norfolk coast (Jensen, 1953). There were major floods in the Wells marshes in July 1817, and along the coast, especially at Cley, in 1897. Nothing is known of the absolute heights of earlier surges, but the four highest recorded levels at King's Lynn are as follows:

Date	*Maximum height, m OD*	*Height above predicted tide, m*
11 March 1883	5·43	2·16
1 March 1949	5·24	1·92
31 January 1953	5·65	2·40
11 January 1978	5·92	1·60

Mean high water at this station is 2·74 m and HWOST*, 3·66 m.

The first surge for which there is any record at Scolt was that of 12 February 1938 (Steers, 1938; 1960: 64). This caused erosion of the Ternery dunes and along most of the seaward face, with overtopping of the seaward ridge opposite Spiral Marsh, at Smuggler's Gap, and near House Hills. In January 1953, the high dunes near the Hut were cut back an average of 7–11 m and a maximum of 18 m (Steers and Grove, 1954; Steers, 1960: 64; 1964: 656), damage being greatest to west- and northwest-facing dunes; Jensen (1953) gives a photograph of this erosion. All the lower dunes between Hut Hills and Norton Hills were submerged. The breakthrough occurred at the site of an earlier small breach in 1938 and had been predicted the previous year (Steers, 1952); iron posts and wire fencing to inhibit further erosion were erected in 1953 and 1956, and now stand 30–40 m seaward of the beach crest. The salt marshes were virtually unaffected (Steers, 1953).

Other major North Sea surges over the last thirty years include those of 8 January 1949 (Corkan, 1950); 20–21 March 1961, 15–17 February 1962 (Banks, 1974); 19 February 1969, 29 September 1969, 2–4 January 1976, and 11–12 January 1978 (Richards, 1978; Spink, 1978). The September 1969 surge reached 4·43 m at Burnham Deepdale, and that of January 1976 4·35 m, as shown by levelled watermarks (cf. the 1978 level of 4·62 m): corresponding water levels recorded by the Wells tide gauge for these two surges were 4·27 and 4·55 m respectively. Analysis of the Wells tidal records for 258 months between July 1954 and September 1978 (the period January 1973 to September 1975 is missing) shows 46 tides which exceeded 3·6 m (the level of the edge of Wells Quay), five which exceeded 4·0 m, and two which exceeded 4·4 m (on 3 January 1976 and 11 January 1978).

There is some indication both that maximum levels of inundation in southeast England have increased (by over 1 m in the case of the lower Thames) over the last 190 years as a result of regional subsidence (Horner, 1972: 180), and that the frequency of surges is also increasing. Thus at King's Lynn, R. Jenkins (pers. comm.) has shown from an analysis of annual maxima in tidal heights since 1860 that there were five years in which tides exceeded 4·98 m OD during the period 1860–1948 (89 years), and six during 1949–1978 (30 years), the latter including the two highest recorded tides. To a large extent, of course, the severity of a surge results from its coincidence with peak astronomical tides: that of 1949 occurred during neaps, and of 1953 on low springs. Nevertheless it does seem that we can

*High Water Ordinary Spring Tides.

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expect surges to play an increasing role in modifying the physiography of low dune and shingle coasts such as those of north Norfolk in the future.

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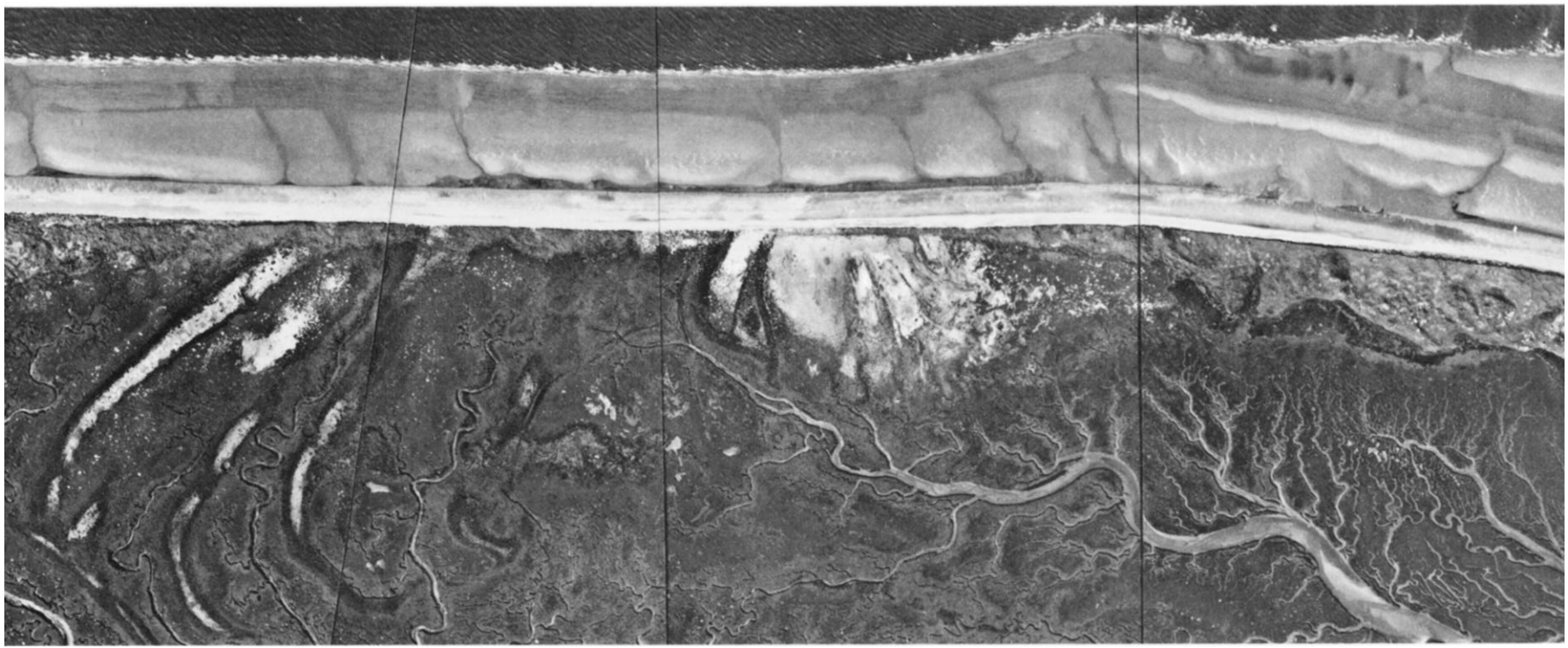
PLATE IV



Site of the 1953 breakthrough on Scolt Head Island, photographed on 7 August 1967

See pp. 192–205

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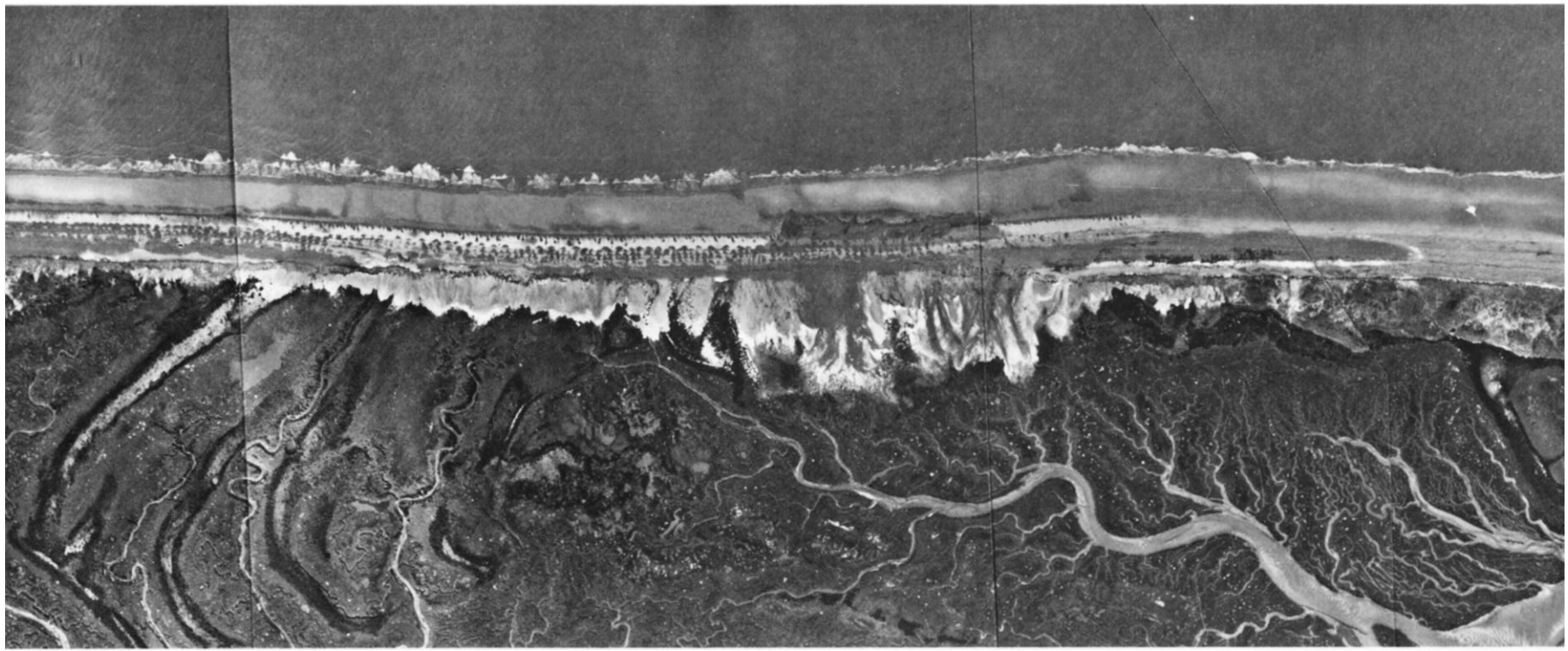
PLATE V



Photograph of the same area taken on 20 January 1978, after the storm surge

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