ENGLISH COASTAL EVOLUTION

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BY

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WITH ILLUSTRATIONS AND MAPS AND PLANS

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PREFACE

THIS book makes no pretentions to be a treatise on the evolution of coastlines. It is rather an attempt to consider the coast of England and Wales in the light of the theories on coastal development already so ably expounded by Prof. W. M. Davis, Prof. D. W. Johnson and M. Emm. de Martonne.

It has been impossible to give an equal degree of attention to all parts of the English coast and to keep in touch in all cases with the most recent coastal changes. Libraries have not always been accessible nor visits to the coast feasible, and I am conscious that errors may well occur in the account of regions with which I am not personally very familiar. For such errors, more easily explained than excused, I should like to apologize here to those local workers who may detect them.

For reading portions of the book in manuscript and giving me valuable advice and criticism I am greatly indebted to Prof. P. G. H. Boswell, Prof. W. M. Davis, Dr. Edward Greenly and Dr. John S. Owens. Amongst others—too numerous to mention—from whom I have received all kinds of assistance I should like to thank in particular my mother ; Mr. Anthony Belt for a quantity of information about Hastings and for permission to reproduce old prints of the coast in the possession of the Museum

Committee there; the Rev. G. G. Knox for an account of the re-entry of the sea into Pagham Harbour; my brother Mr. H. B. Ward for much general assistance, and Mr. H. J. Osborne White for the latest views on the separation of the Isle of Wight from the mainland. My acknowledgments are also due to Mr. A. R. Hinks for permission to reproduce material that appeared in the *Geographical Journal*, to Mr. P. M. F. Cole for kindly allowing me to reproduce a map from his late father's book on the Antiquities of Hastings, to Messrs. Dent & Co., and Messrs. MacMillan & Co. for similar permission to reproduce maps from "The Coast Scenery of North Devon" by the late E. A. Newell Arber and from "Earthwork of England" by A. Hadrian Allcroft, and to the Director of the Geological Survey for permission to use the Survey photographs as illustrations. Only the views of Hastings are not by the members of the Geological Survey.

The bibliography is not intended to be a representative list of works on coastal subjects, but merely to refer to some of those that have been found useful during the preparation of this book.

E. M. W.

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ENGLISH COASTAL EVOLUTION

CHAPTER I

GENERAL CONSIDERATIONS ON THE EVOLUTION OF THE ENGLISH COAST

A GREAT part of the coastline of England and Wales is of an indented character and is marked, particularly in the south-west and in Wales, by an alternation of bays and headlands. Moreover, where the shoreline of to-day is of a smooth and regular outline it can in nearly all cases be proved by geological and historical evidence to have been once irregular and to have possessed, as still do the indented portions, the features typical of a coast where a land surface worn by stream action into hills and valleys has been partially submerged by the sea. Along such a coast the sea invades the lower ends of valleys, the uplands between which project as headlands. A past submergence of the coast is also proved by the existence in England and Wales, south of a line joining Morecambe Bay and Flamborough Head of old land surfaces, which, now buried beneath alluvium, often outcrop between tidemarks, and have been shown by borings to lie some sixty feet below the present sea-level under the marshes of such widely separated estuaries as those of the Humber, the Thames, Southampton Water, the Severn and the Mersey.[1] The remains of forests so commonly exposed at low-water along our coasts result from the outcrop of these old land surfaces upon the foreshore. It is not established whether this coastal submergence was due to earth movements or to a change in sea-level. For convenience in discussion it will be assumed in what follows that phenomena indicating submergence or emergence of the coast are due in England and Wales to earth movements. Their cause does not in any event affect the subsequent development of the coastline. The exact amount by which the land subsided cannot be stated, but it has been estimated as lying between sixty and ninety feet.[1] The date of the subsidence can again only be very approximately given. The late Clement Reid considered that the series of downward movements by which the coast was submerged came to an end some three thousand five hundred years ago, a conclusion which he reached chiefly by estimating the time required for the accumulation on a stationary coastline of existing coastal deposits.[1] That the relative level of land and sea has remained unaltered for the last three or four thousand years appears established by both archæological and geological evidence,[1] and no convincing proofs to the contrary have been brought forward, though possible doubtful and much more gradual movements of the land have been postulated for local areas.

Thus the present coastline of England and Wales owes its origin to a submergence which took place during the pre-historic period—which can indeed be more precisely dated as having occurred at a time when the inhabitants of these islands were passing

[1] *Submerged Forests.* Clement Reid.

through the Neolithic stage of culture[1]—and thus at a period so geologically recent that the surface features of the land must already have assumed their present forms.

Land surfaces exposed to sub-aerial denudation become by it channelled and grooved, whereas marine erosion and deposition combine to smooth the sea-bottom. Thus, where instead of a land surface being partially submerged the inshore sea-bottom, which is a plane surface, suffers emergence, the coastline resulting must—contrary to one created by submergence and to much of the English coast—be even in outline, low-lying, and fronted by a breadth of shallow water.

The broad outlines of the landscape inland remain to-day the same as they were when the last change of coast level took place, but the present coastline is very different from that which was familiar to our late Neolithic ancestors. Unaffected by earth movements the coast has been exposed to the sea's attack during this lapse of time, and has suffered changes which, it will appear shortly, have taken place in accordance with a definite process of coastal evolution. These changes have been imposed upon the coast by erosion, sub-aerial and marine, and by the deposition that accompanies erosion of the land waste created by it.

Sub-aerial erosion affects the coast in two ways. Weathering of those parts of the land margin that lie above high-water mark modifies their form and seaward slope and, more far-reaching in its effects, this

[1] Good evidence exists that an uplift of the coast varying from seven to nearly thirty-four feet took place in a few weeks in Alaska in 1899. See "Recent Change of Level in Alaska." R. S. Tarr and L. Marten. *Geographical Journal*, vol. xxviii.

weathering and that in progress all over the inland country contribute either directly to the cliff foot or by means of rivers to the supply of detritus upon the coast. It is, however, to marine action, to the work of waves, tides and currents, that shorelines owe their characteristic development. Erosion of the land margin is chiefly carried on by wind-formed waves, the erosive power of which is determined by their dimensions. These latter are dependent on the length of fetch of the waves, on whether or no the depth of water allows them to grow to their limiting size for any particular wind, and on the wind velocity. The possible energy of wave attack against any coastline is, therefore, governed by the degree of exposure of the latter to far travelled deep-water waves. Its aspect with regard to the prevailing and dominant winds and their force and frequency are also important factors, since waves driven directly on to the coast do the most damage and reach besides a higher level when the water is banked up by onshore winds. Hence coastlines lying athwart the prevailing winds suffer—other conditions being equal—more than those on to which they blow obliquely. Wind-formed waves may have travelled two thousand miles across the ocean, as sometimes happens with those that reach our western coasts. They may have been created by storms that die out over the open sea, swells raised by which break at last in calm weather along coasts thus affected indirectly by weather conditions in distant areas.

Storm waves in some exposed situations cause considerable damage some two hundred feet above the sea, but the maximum striking force of a wave occurs but slightly above still-water level, below

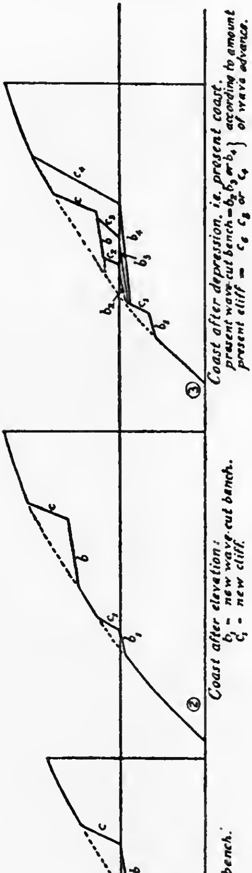

SEA LEVEL
Pre-glacial coast:
b - wave-cut bench.
c - cliff.
Coast after elevation:
b₁ - new wave-cut bench.
c₁ - new cliff.
Coast after depression. i.e. present coast.
present wave-cut bench - b₂ (b₃ or b₄) according to amount
present cliff = c₂ c₃ or c₄ of wave advance.

DIAGRAM I

which its erosive power decreases very rapidly with increasing depth. Generally the greatest erosion by breaking waves is accomplished about high-water mark, along which line the waves cut a notch into the smooth slope of the newly subsided land margin, a notch which as it is pushed inland by the waves causes the overlying rock to be undermined and fall, thus initiating the formation of a cliff. This landward advance of the sea along high-water mark entails also the formation of a wave-cut bench, platform, or shelf (see Diagram I), which consists of the breadth of rock lying between a point slightly seaward of the initial coastline and the foot of the cliffs. This bench itself suffers, though to a much less degree than do the cliffs, from direct wave erosion. When the rock surface is jointed waves exert upon it a plucking or quarrying action and it is besides abraded—as will be seen later—by shifting sand and shingle. Thus it slopes gently seawards in accordance with the longer exposure to marine erosion of its outer portions.

On a submerged and irregular coast like much of that created in England and Wales by the Neolithic subsidence, wave attack is as a rule limited to the headlands. These, formed by the partial submergence of upland ridges, slope steeply into the sea and project beyond the general line of the coast. Thus large waves can approach them unhindered by having to pass through an area of shallow water, and they occupy besides an exposed position. Moreover, the fact that waves tend to swing into a line parallel with the shore before breaking ensures an effective wave attack against either side as well as upon that end of a headland that directly fronts

ADVANCE OF THE SEA AGAINST AN ANTICLINE IN THE COAL MEASURES: SAUNDERSFOOT, PEMBROKE

PLANE OF MARINE DENUDATION: FRESHWATER WEST, PEMBROKE

the landward-moving waves. Bay shores are on such a coast relatively sheltered from wave attack both by the headlands on either side and by the breadth of shallow water covering the gently sloping foreshore created by the submergence of the relatively flat valley floor. Also the process of wave refraction that concentrates wave attack against headlands involves a corresponding dissipation of wave energy in bays,[1] and where rivers enter them bays usually become at once the seat of deposition. Moreover, as will be seen later, detritus worn from headlands is swept into and deposited in bays. The formation of cliffs and wave-cut benches along the headland coasts and of beaches due to the deposition in bays of the detritus created by the wave erosion of the headlands is thus characteristic of the first advances of the sea against an irregular coastline initiated by the partial submergence of a land surface marked by hills and valleys.

The occurrence in parts of England and Wales of such wave-formed features at varying heights above the present high-water level show that in such localities an uplift of the coastal lands, greater in vertical extent than was the Neolithic submergence, had preceded this most recent and downward movement of our coasts. (See Diagram I.) Along the south coasts of England and Wales there remain here and there above the present shore the cliffs, wave-cut benches and beaches of an earlier day, while in parts of northern England and North Wales old coastlines lie inland of, though not necessarily higher than, the existing coasts. Such remaining fragments of earlier coastlines

[1] *Shore Processes and Shoreline Topography.* D. W. Johnson.

occur at different levels in different places; in some areas a succession of old beaches may be traced one below the other, and it is clear that they are by no means all contemporaneous or have all been affected by earth movements of similar extent. It is, however, established in most cases that these inland cliffs and beaches are fragments of a pre-glacial coast and that an uplift of a pre-glacial coast, itself formed by submergence, took place before or early in the glacial period, an uplift only partially obliterated in most areas by the subsequent more limited movement of subsidence that took place in Neolithic days and that carried below the sea any

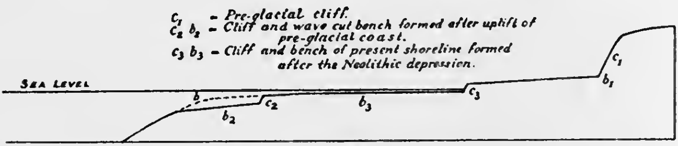


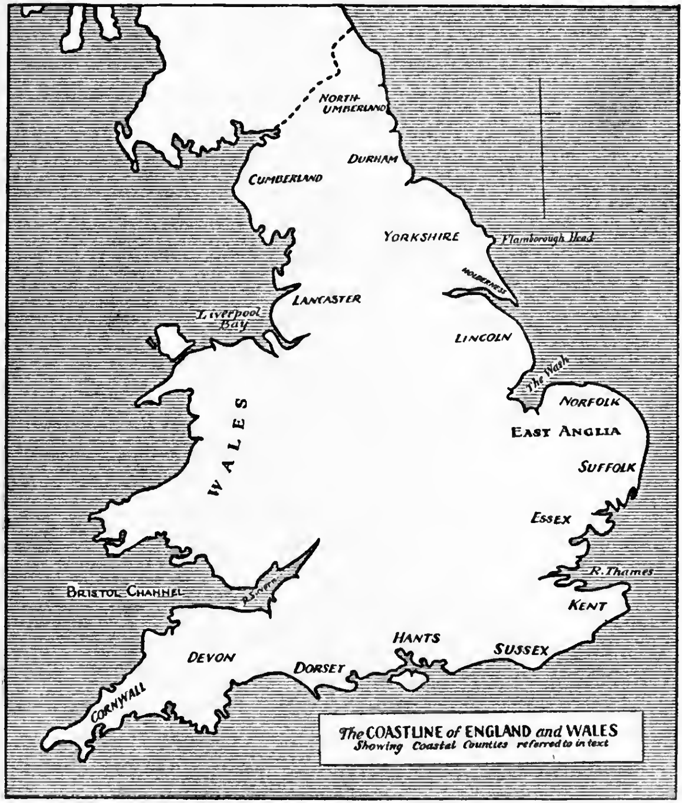
DIAGRAM II

Profile of submerged coast where pre-glacial wave-cut shelf between b and b_1, was wide, showing that the coast retains features of a shoreline of elevation in spite of the partial submergence of the upraised pre-glacial coast.

cliffs, wave-cut benches, and beaches formed along the coastline that had been initiated by the uplift of the pre-glacial coast. (See Diagram I.)

The coastline at the close of the Neolithic subsidence must therefore have shared at many points in the characteristics typical of both coasts of emergence and of submergence. It must originally have lain—except where wave advance had destroyed before the Neolithic subsidence took place all traces of the pre-glacial coast—upon the upraised and then partially submerged foreshore of the pre-glacial coast. So situated, it must have been low, fronted by an area of shallow sea and marked by some degree of irregularity due to the submergence of features created by sub-aerial denudation since the uplift of the pre-glacial coast took place. (See Diagram II.)

The complications induced by such a superposi-



The COASTLINE of ENGLAND and WALES
Showing Coastal Counties referred to in text

tion of three sets of coastal features have been manifold, and according to the relative amounts of elevation and subsidence that took place and to the extent of the sea's landward advance whilst the changes of level were in progress and during each pause in the earth movements, the coastal features of different periods are found, as will be shown later, to overlap one another to an extent varying greatly in different regions. (See Diagram I.)

The coastal lands affected in England and Wales by these various changes of level differed very much in character. Upland regions of ancient igneous and sedimentary rock, generally very resistant to erosion but whose surface was scored by prolonged sub-aerial denudation into an intricate network of valleys, dipped when partially submerged steeply below the sea except at the mouths of the larger streams. In such regions the pre-glacial wave-cut shelf was relatively narrow, and neither the movement of elevation that uplifted the pre-glacial coast nor the Neolithic subsidence can have caused the sea, in a horizontal direction, greatly to recede from or advance upon the steep seaward slope of the land margin. (See Diagram III.) The subsidence that initiated the pre-glacial shoreline still dominates in such regions the coast features, since the more recent subsidence, often nearly equal in amount to the preceding uplift, left the coast but little to seaward of its uplifted pre-glacial predecessor. The sea still enters the lower ends of the many little valleys much as it did at the close of the submergence that created the pre-glacial coast, and thus forms a shoreline of multitudinous bays and coves lying between headlands caused by the projection of upland ridges. The shores of the south-western peninsula of England or of Pembroke in South Wales are typical of this type of coastline. (See Diagram IV.)

In other regions areas of yielding and resistant

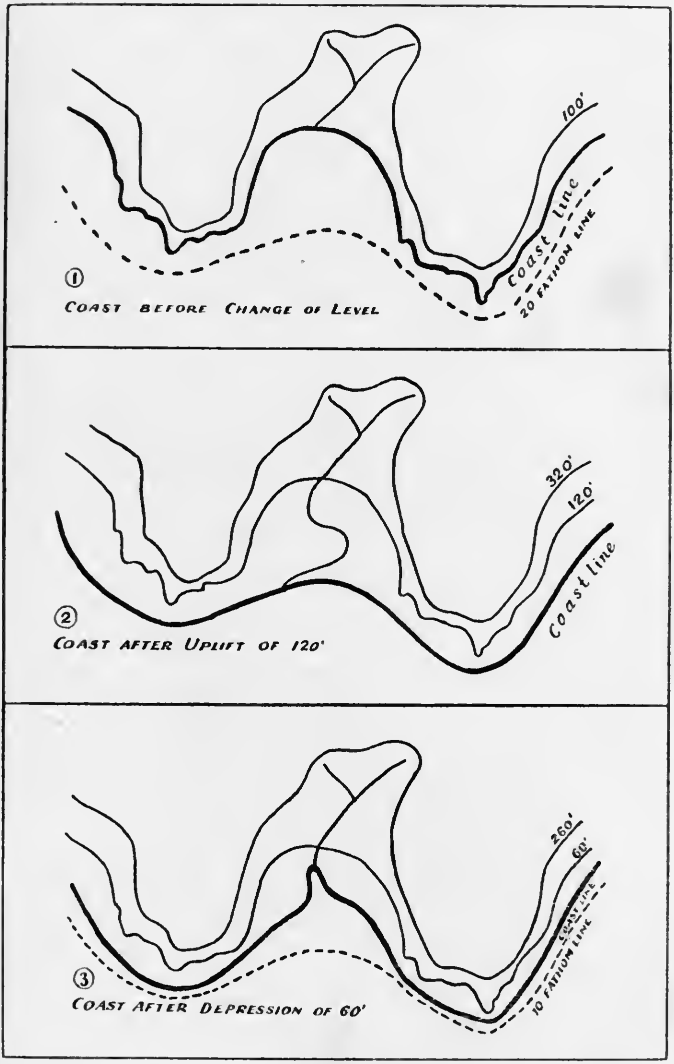


DIAGRAM III

To show relative amounts of seaward and landward displacement of the coastline owing to the emergence and submergence of flat and steep shores respectively.

strata, of upland and lowland, are broadly distributed. In south-eastern England, an area that was probably still joined to France when the pre-glacial coastline was forming elsewhere,[1] long escarpments of chalk are separated by wide plains from a central ridge of upfolded sandstone. The coastline here at the close of the Neolithic subsidence was quite distinct in character from the minutely indented shores noted above. (See Diagram V.) The high

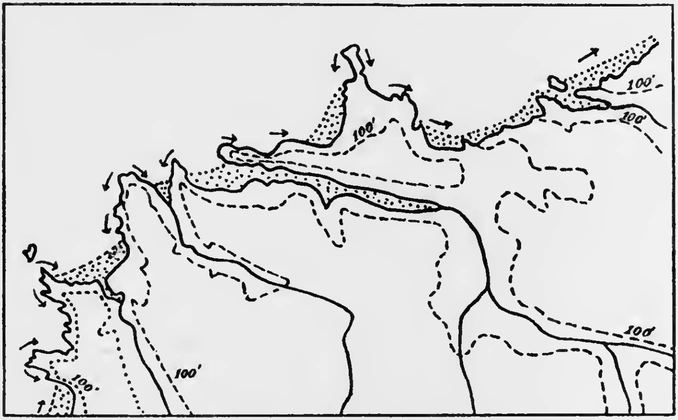


DIAGRAM IV
Irregular submerged coast: Cornish type (sketch-map of coast near Newquay), showing distribution of beach deposits, and by means of arrows an ideal system of longshore currents on such a coast.

cliffs in which the hill ridges now end and the areas of alluvium stretching inland between them show that the broader features of the landscape were reflected here in a coastline of wide bays now filled with deposits, few in number, great in extent, and separated by few but outstanding headlands now cut back into blunt cliffed projections.

Broad outlines rather like those of the south-east

[1] A. J. Jukes Browne. *The Building of the British Isles.*

coast and due again to a correspondingly broad disposition of structural features must have characterized the south coast of England at the completion of the Neolithic subsidence. Here where wide areas of weak rock crop out upon the coast the wave-cut platform formed on the pre-glacial coast was wide. Much of it remained unconsumed by wave attack

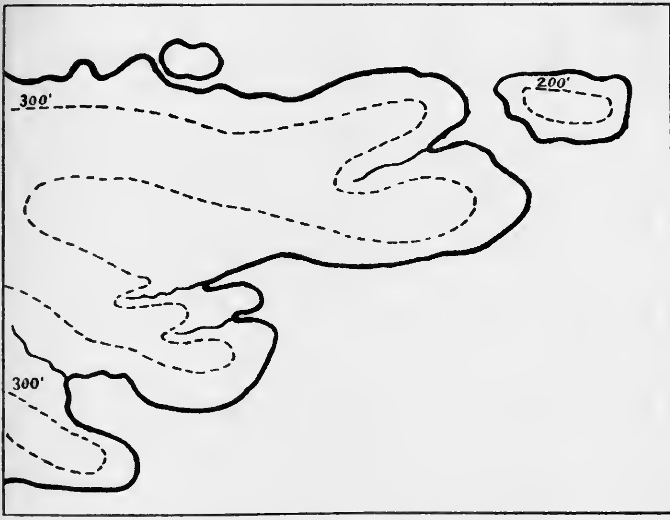


Diagram V
Broadly irregular submerged coast: south-east type.

after the uplift of the pre-glacial shoreline and became only partially submerged by the Neolithic subsidence, the coastline created by which lay in such regions well to seaward of the upraised pre-glacial coast and upon its wave-cut platform. Thus the recent deposits of the coast plain of southern Sussex overlie a broad wave-cut shelf bounded on the landward side by the line of the upraised pre-glacial coast,[1] while the existing coast is low and bordered by shallow seas, resembling in these particulars a shoreline formed by elevation.

The recent geological formations—of Pliocene and Pleistocene age—that form the eastern part of Norfolk and Suffolk are of soft and yielding character. Traces of the pre-glacial coastline are here wanting, and they may be obscured by more recent deposits. Sub-aerial denudation here carved out wide river valleys sloping with a gentle gradient to the sea, valleys the lower parts of which are now filled with alluvium that extends in tongues up the valleys of tributary streams. This alluvium shows that the Neolithic subsidence admitted the sea far up these low-lying valleys so that high-water mark followed at its close a broadly irregular line, reaching a great distance inland up the valleys and confined to the open coast along the seaward edge of the low uplands.

In regions where the land is of comparatively plane surface little cut up by sub-aerial denudation by reason of the structure or homogeneous character of its rocks, its low-lying character, or comparatively recent exposure to erosion, its partial submergence creates an even coastline. The effect of the Neolithic subsidence on the drift-plain of Holderness between the Yorkshire Wolds and the sea—a region draining inland and towards the Humber estuary—must have been to create an even shoreline, while the shores of very low-lying lands partially drowned by the Neolithic subsidence in Lincolnshire, the north of Norfolk, and along the shores of Liverpool Bay must have been characterized, if not owing to the forma-

[1] *Victoria County History of Sussex.*

tion of estuaries by the even outline, at least by the gently sloping foreshores and shallow seas already noted as typical of coastlines formed not by submergence but by emergence. (See Diagram II.)

These various types of coastlines have responded each in its own way to wave attack. The course of development may first be considered that is typical of that of a coastline indented with many small bays and headlands, and created by the partial submergence of a land surface much eroded by stream action. The commencement of the sea's attack against such a coastline is marked as already noted by wave advance and the formation of cliffs and wave-cut benches along headland coasts, which as a consequence are pushed landwards, and by the early accumulation of beach at the heads of bays—a process which begins to reduce the degree of irregularity of the coast.

The continued recession of the headlands is normally accompanied by an increase in the supply of sand and shingle. More often than not the land surface slopes upwards from the shore, and thus the cliffs gain in height as they retreat and yield for every foot of that retreat a correspondingly greater amount of detritus. The supply and distribution of shore waste are of paramount importance in determining the outline and development of a coast of this type. (See Diagram VI.) Debris that reaches the coast may be derived from inland by means of rivers, from the eroded coast itself and, to a very limited extent, from the sea-bottom near inshore. On the drainage area and character of the rivers debouching upon it depend therefore in part the supply and type of detritus upon a coast. In England those rivers draining the largest areas flow out upon the east coast. They transport to it a great amount of alluvium, of a degree of fineness corresponding with the gentle gradients and slow currents of their lower courses. Thus have grown up the warp-lands of the Humber estuary, where successive accretions of fine mud at the slack water of each flood-tide have made possible the reclamation of much extremely fertile land. The nearer the watershed lies to the coast the coarser as a general rule is the debris brought to it by rivers. Some of the short, swift streams of Cornwall and Devon carry gravel on to the shore, but usually even in this region of restricted area where watersheds must perforce be near the sea sand and mud alone reach the coast by means of rivers. They do so in limited quantities corresponding to the relative smallness of the river basins and accounting in part for the scarcity of beach material along the south-west coasts.

The sea-bottom inshore may contribute to the supply of beach where waves transport sand or shingle shorewards, a process sometimes assisted by the increased buoyancy imparted to stones by the growth upon them of seaweeds. Detritus thus accumulated may, however, not be a fresh accession to the coast. It may not have been derived from the erosion of the sea-bottom but may consist merely of sand or shingle originally worn from the coast, deposited offshore and subsequently returned by wave action to the beach.

The major part of the shore waste along an initial coastline of submergence is usually derived from the wearing back of the headlands, every cubic yard of which as they are washed away contributes its quota of detritus to the inshore waters, detritus which according to its character becomes broken and worn down into mud, sand or shingle. As will appear in a moment, this detritus may be carried by waves and currents far from its parent cliffs and may thus play a part in the development of some distant coastline comparable to that of debris brought to it by rivers.

Of whatever origin, and shore deposits may include boulders ice-borne from hills a hundred miles away, the white mobile flakes of finely ground sea-shells, lumps of peat from forests submerged in Neolithic days and now eroded by the sea, the various kinds of debris that fringe our coasts respond each in a characteristic manner to the action of waves and currents. Water moving at less than half a knot per hour can push sand along the sea-bottom, with a velocity of a knot currents can move fine gravel, of two and a half knots pebbles an inch in diameter. Where the speed reaches five miles per hour currents can transport stones weighing (out of water) twenty pounds. Combined with wave action currents may be even more effective. These velocities are frequently exceeded by the tidal currents in our shallow seas, and the regular movements of tidal streams, waves and currents driven by the prevalent winds are accompanied along our shorelines by a slower, more intermittent, but definite travel of detritus. Mud, stirred up by the faintest disturbance in the overlying water and carried in suspension so long that it may take over a fortnight to sink through a depth of five fathoms, can only come even temporarily to rest in sheltered inlets, and is therefore absent from the open coast except in suspension in the water. Sand drift may continue at great depths—off Madras sand travels in vast quantities at depths of six or seven fathoms,[1] but here the coast is one of emergence, and the sea-bottom is consequently smoother than much of that off the English coasts—but the more violent movements in the water that are necessary to transport shingle occur mainly between tide-marks, to which zone shingle drift is chiefly confined. Some movement of shingle must, however, take place in fairly deep water to account for its frequent rounding of headlands and for such cases as the growth of Dungeness in Kent, shingle supplies to which do not apparently travel along the sandy coast immediately to windward of that foreland.

Sand and shingle travel both to and from the coast and along it. Oscillatory waves that affect the coast where headlands project into deep water generally cause a predominantly outward drift on the sea-bottom they disturb. The action of the undertow is also to remove debris from the shores, but in this case from both headlands and bays, and to deposit it further out where the undertow slackens in speed. Onshore winds by increasing the head of water against the coast and hence the force of the undertow accentuate the seaward drift of detritus. Thus one gale blowing onshore may cause a whole beach, apparently unchanged for years, to be scoured away. Offshore winds on the contrary create a shoreward undercurrent that accumulates beach upon the coast, while a similar effect is caused where waves of translation, generated where the foreshore slopes gently seaward, carry detritus onshore at the

[1] *Coast Erosion and Protection.* E. R. Mathews.

heads of bays. In most regions sand and shingle oscillate, under the impulsion of one or other of these influences, from above high-water mark to beyond the outer edge of the wave-cut shelf, over which edge they are dropped into deeper water and accumulate in time so as to form a terrace built out from and continuing the slope of the wave-cut shelf. The winter storms often strip the beaches from the Cornish coves, yet by summer time the sand has imperceptibly returned and lies perhaps, as at Kynance Cove near the Lizard, twelve feet thick upon the rock floors of the sea-caves. Off the Norfolk coast the waves and undertow in an onshore gale drag shingle down from the shore and form ridges parallel with the coast and some way from it. This shingle is soon returned to the zone between tide-marks when normal weather is restored. Such a shifting of its detrital cover induces a rasping of the surface of the wave-cut shelf and its gradual lowering.

Shore debris not only oscillates along a line at right angles with the coast but also drifts intermittently, and with occasional returns upon a part of its course, along the coast. Wave motion imparts a violent though temporary movement to the water affected, and a longshore drift of debris is chiefly maintained by the oblique impact of waves. A particle carried by the slanting uprush of water in a wave breaking obliquely on the shore is dragged down again by the backwash along a line perpendicular to the coast, and hence finds itself at the close of the series of movements further along the coast by a distance dependent upon the size and obliquity of impact of the wave. Wind-driven waves are mainly instrumental in causing longshore drift. Swells that have outrun the wind that created them are of great wave length and hence disturb the water to great depths. They are thus swung into a line parallel with the shore—by the retardation of that end which first enters shallower water—before they break upon the coast, and impart therefore no longshore movement to the sand or shingle they disturb. The direction of longshore drift is therefore determined by that from which come the largest, and hence most effective, obliquely impinging wind-driven waves. In England from Flamborough Head in Yorkshire nearly to the Thames estuary sand and shingle travel as a rule southwards along a coast now almost smooth in outline, though there are several regions where shore drift is absent or indeterminate, as in Lincolnshire, and where it moves in a contrary direction, as does the westward drift along the north coast of Norfolk. The southward direction of drift on the east coast coincides with that of the flood-tide. This is an important factor where, as often occurs, the tidal stream flows in the direction of the flood-current both before and after the local high-water, in which case the upper part of the beach is exposed only to the influence of a tidal stream moving in the direction of the flood-current. The largest waves occur besides on the east coast with northerly winds under whose influence the water is banked higher against the land. Again the direction of the prevalent winds, the flood-tide, and the oblique impact of the largest waves combine to cause the longshore drift towards east and north-east that characterizes the even shoreline of the south-east and the partially smoothed coastline of the south of England, and that general movement of beach towards the north that is typical of the more regular lengths of the west coast as far north as Morecambe Bay. Beyond this wide and sand-filled bay shore drift moves from the north with the flood-tidal stream that enters the Irish Sea through the North Channel.

Wherever a coastline originally irregular has in England and Wales so resisted wave attack as to retain much of its unevenness of outline, longshore drift remains discontinuous and unimportant, as occurs north of Flamborough Head, in Cornwall, Devon and parts of Wales. On an irregular coastline headlands project from the coast and intercept the longshore movements of both wind and water. They initiate a counter-drift along their windward sides and thus cause the longshore drift to set landwards along either of their flanks. The irregularity of coastal outline is thus paralleled by a lack of uniformity in the direction of the longshore drift and a corresponding discontinuity of shore deposits, which are with such a system of shore currents swept away from the headlands and into the bays. (See Diagram IV.) Under these conditions each bay has its own system of longshore drift, its beach drawn entirely, apart from the detritus brought by rivers, from sources within its own limits, and is cut off from the shore currents and beach deposits of neighbouring bays by headlands projecting bare of beach.

The system of longshore currents that prevails on an irregular coastline thus ensures the conveyance of shore waste into the bays and towards their heads. There, as already noted, it is deposited. Deposition of sand and shingle occurs wherever the waves or currents that transport them become overburdened.

This condition may be attained by an increase in their load of debris, a decrease in their velocity and hence in their power of transport, or by a combination of these factors, and the localization of shore deposition, dependent as it is upon the interaction between coast features and the local movements in the inshore waters, becomes modified as the coastline changes. The number and variety of obstructions to wave and current motion on an indented coastline ensure the presence along it of as many and various forms of shore deposition initiated by the checking of transporting currents. Debris readily transported along the open coast is dropped where wave action is enfeebled in inlets. Moreover, the inertia possessed by the waste-burdened littoral currents and their inability to follow the sheltered coast within the horn of a bay tend to the continuance of shore drift athwart an inlet in line with the open coast on the windward side. Such spits athwart inlets are created by the drifting debris that, losing in velocity, sinks to the bottom as it enters deeper water on leaving the actual coast. They gradually rise nearer the surface until they are finally built up by wave action to perhaps five or six or, exceptionally, to twenty or thirty feet above sea-level. (Wave action is, as a rule, the immediate means by which shore deposits are raised above high-water level. Waves breaking against a beach or bar drop their burden of sand or shingle, and though a proportion of this is carried out again by the backwash, the latter except on bare rock surfaces is diminished by percolation and hence is unable to drag down as much detritus as the breaking wave flings up upon the shore.) Where a bay is narrow, and has no river or but a small one entering it, a sea-formed bank of this type may close it entirely early in the history of coastal development. The formation of bars or spits across the entrance to bays, estuaries or straits, accelerates the silting of the sheltered waters enclosed by them so that, before the coast has retreated—which it must do, as will shortly appear—behind the heads of even the most far-reaching bays or estuaries, these latter are usually filled with deposits and have ceased to affect the coastal outline. The spits of sand or shingle that deflect southward the outlets of the east coast rivers, that enclose the reclaimed tidal marshes of the Kent and Sussex coasts, that bend eastward at their mouths the rivers of the south coast and partly enclose such estuarine bays as Chichester, Poole or Weymouth harbours, the shingle ridge of the Chesil Bank that ties Portland Island in Dorset to the mainland, the natural banks that have in the Bristol Channel made possible the reclamation of Glastonbury levels, those that constrict the Welsh estuaries or force southward the outlets of the Lake District rivers, originated in most cases, as will be shown in succeeding chapters, owing to interference with the movement of longshore drift currents.

Places to windward of obstructions to the longshore drift become, like inlets, areas of deposition during the earlier stages of coast development. Sand or shingle checked or prevented by them from continuing along the coast is here deposited. To leeward of headlands or river mouths occurs a corresponding scarcity of beach. Very curious and worthy of study are the invisible checks to longshore drift that occur on some coasts. Off Sandwich in

Kent the shingle travel from the south-west along the regularized coast of Pegwell Bay comes to a stop, the pebble beach ends without any marked increase in area and sand takes its place. Why the shingle ceases here from continuing along the coast and where go the fresh supplies that must constantly accrue from the west does not appear to be known. North of the bay shore drift moves towards the south. A somewhat similar " shingle end " occurs south of Hunstanton on the alluvium-bordered east coast of the Wash.

Long after deposition in and athwart inlets has made great progress, headlands that act as divides to the longshore drift remain as bare of beach material as does a watershed of detritus. Eventually, however, as coast development proceeds and the bays become filled with deposits the headland coasts recede so far that they cease to obstruct and reverse the direction of the longshore drift currents, while at the same time the broadening wave-cut platform beneath them makes possible the shore transit of debris along it and finally permits of the deposition of a beach, for which more plentiful supplies of detritus are now available, along its inner edge. When this stage has been reached beach deposits stretch continuously along the smoothed coastline (see Diagram VI) and travel freely and with uniformity in a direction determined by the predominant longshore drift. In Cornwall and Devon the headlands remain bare of sand or shingle between bays with beaches already well developed. The chalk cliffs of the Isle of Wight though much more readily eroded than the Cornish granite still suffer from a scarcity of beach, whereas on a more developed coast

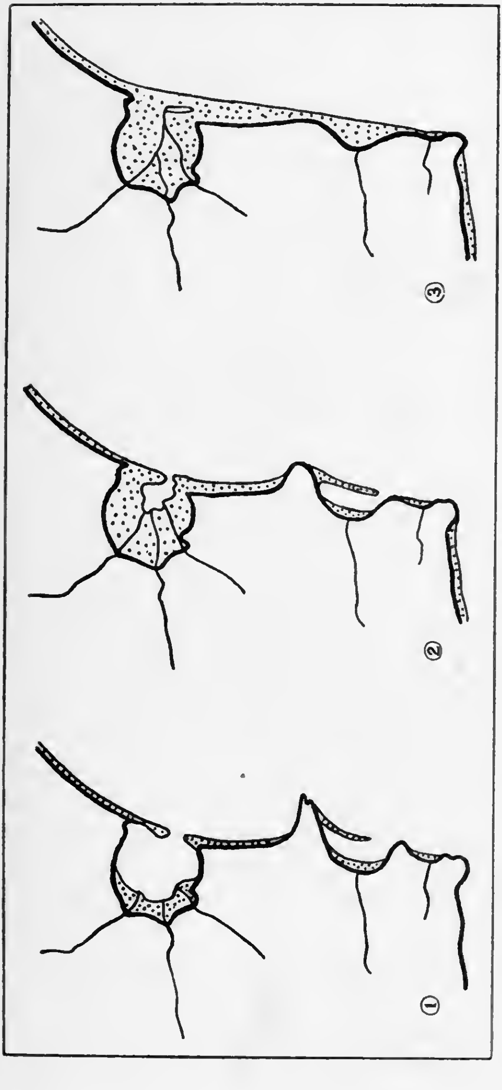


Diagram VI

Showing a portion of the earlier part of an ideal course of development of a length of coastline originally irregular owing to submergence.

like that of eastern Kent and Sussex headlands and bays are alike fringed by sand or shingle.

Each of the various forms created by shore deposition passes through a series of changes peculiar to itself and related to the development of the shoreline on which it occurs. Moreover, though the area and position of the deposit may for the time appear constant, the sand or shingle of which it is made up is but pausing in its journey from the land to that ultimate destination of all waste worn from the land—the sea-bottom beyond the reach of wave action. Beach material is itself subject to erosion. It becomes ground increasingly fine by attrition until it is finally carried in suspension out to beyond the limits of wave action on the bottom, and it is never returned to the shore. This process may take an extremely long time. Sand grains may resist attrition almost indefinitely. Even shingle may withstand for ages the grinding action of the sea, and little is known of the time required for its attrition to so fine a condition that it may be carried out beyond the reach of wave action. Stones that the waves of to-day dislodge from the pebble bed that reaches the coast at Budleigh Salterton in South Devon have a characteristic shape[1] that was impressed upon them during long travellings in the Triassic sea, a shape retained though the pebbles lose in size as they are drifted along the modern coastline. Vanished lands may thus long survive in their ultimate fragments upon a beach.

Where supply exceeds loss shore deposits grow in size until the accretion of fresh detritus merely

[1] W. Pengelly. "The Denudation of Rocks in Devonshire." *Trans. Devon Association*, 1865.

suffices to make good the wastage from the increased area of deposition. After this they remain constant in area as long as the quantity of waste supplied and the rate of its removal remain the same. The greater part of the shore deposits in England and Wales have reached a limiting size to which they tend to recur whenever exceptional conditions temporarily upset the balance between accretion and wastage. Many shingle spits, for example, have remained of substantially the same shape and size for centuries. On the south coast the Calshott spit at the west side of the entrance to Southampton Water is very much the same to-day as when Henry VIII built one of his squat grey castles upon it. The shingle spits that constrict the neighbouring entrance to Portsmouth Harbour neither lose nor gain appreciably in size. The same is true of the Hurst spit at the west end of the Solent, of the Chesil Beach in Dorset and of many another area of shore deposits; but not all have a similar stability. It has been estimated[1] that perhaps two-thirds of the existing deposits had been accumulated by the Roman period in Romney Marsh on the now almost regular coastline of south-east England. They continue to extend. The triangular shingle deposit of Dungeness at the entrance to this former bay still grows out into the Channel as it has done for twenty centuries. Spits of sand or shingle like those that on the east coast partly bar estuaries—spits like Spurn Head athwart the Humber, and the long tongue of shingle that turns the Suffolk river Alde southwards at its mouth—are liable to a limited fluctuation in length and to be broken by the establishment of new river

[1] *Submerged Forests.* C. Reid.

outlets across them. More rarely shore deposits have passed their period of growth and have entered for the present on a stage of decay. Thus Langney Point near Eastbourne, a formation south-west of and similar in character to Dungeness, has suffered for some time from wave advance owing almost certainly to a partial failure in supplies of shingle from the south coast. As a whole the quantity of sand and shingle in circulation about our coasts appears to remain almost constant in amount in spite of such local fluctuations in the extent of beach deposits. Fresh supplies derived from the eroded land serve but to compensate for the losses due to the constant attrition and removal out to sea of a proportion of the detritus. The effect of sea-walls is worthy of consideration in this connexion, since by preserving the coast from erosion they may upset this nicely adjusted balance between supplies and wastage of shore debris.

The recession of the headlands has been accompanied as we have seen by the gradual filling of the bays with beach material and river-borne deposits, so that both headlands and bays become nearly obliterated and the newly formed unbroken fringe of shore-deposits borders an almost even coastline. This regularized coastline now that bay and headland coasts stand in line along its shore is everywhere attacked by the sea and retreats as a whole, wave attack and deposition being no longer as formerly confined to distinct areas. The varying extent to which submerged and irregular coasts have advanced in England and Wales towards this condition of a regularized outline will be considered in subsequent chapters.

CHAPTER II

GENERAL CONSIDERATIONS ON THE EVOLUTION OF THE ENGLISH COAST

(*continued*)

WHEN a coastline is initiated by the partial submergence of a plane land surface and is as a result even in outline, provided the land slopes beneath the new sea-margin with sufficient steepness, wave attack is at once directed against every part of the shore. Sand and shingle as soon as it appears upon the coast is able to drift freely along it and deposition of beach takes place all along the base of the newly formed cliffs as they retreat. Thus the initial shoreline must resemble in outline and the distribution of its beach deposits the regularized shores of submerged and once irregular coasts. Of this type the initial coast of the drift-plain of Holderness may, as already noted, have afforded an example. Where, however, flat and low-lying coastal plains, like those referred to on page 14, are partially submerged, large waves approaching the shore break in the shallow water perhaps, as off South Lancashire, a mile or more from the land, and only small waves can reach the actual shoreline. As a result the coast suffers little from wave attack, whilst the submerged land slope is cut into along the line of breaking waves, and the debris derived from its erosion—possibly added to by current-borne detritus from a distance—is piled up on the landward edge of the cut where wave agitation, owing to the waves having already broken, is less violent. This bank of sand accumulates until it may rise so near the surface that the action of waves breaking upon it builds it up above sea-level to form an offshore bar. This process may be assisted by the accumulation on the bar of dunes of wind-blown sand. Such a bar though broken here and there by tidal inlets affords almost complete shelter to the mainland coast. The lagoon within the bar in time fills up owing to silting and the growth of marsh vegetation, and the coast is thus advanced seaward to coincide with the original offshore bar. The latter is eventually gradually pushed landward as the large waves breaking extend their cut into the submerged land slope. The continued retreat of the offshore bar leads in time to the disappearance of the silted marshlands of the former lagoon and to the bringing of the bar into contact with the original coast of submergence. In front of the latter, however, the water is now deeper than when the coast was first formed. Thus it is now attacked by the waves and begins to recede before the sea. The coast has at this stage reached the same condition as is attained on an irregular coast of submergence when the coastal outline has become smoothed, and its retreat henceforth resembles that of this latter type of coast.

Along various parts of the English coast flat and partly submerged coast plains of recent deposits have become below high-water mark the seat of deposition. (See Diagram VII, Chap. X.) The coast plain of Lincolnshire, until comparatively recently largely submerged and flooded by both fresh and sea water, has been silted and reclaimed behind a bank of sand and dunes that formed in early days on the foreshore. Similarly the coast of South Lancashire has been extended seawards and now follows the outer edge of a belt of dunes that protects silted marshlands from the sea.

A similar development takes place in the case of an emerged coastline.

On the other hand, as has occurred in Holland and probably in Wales, the bar may, where erosion along it becomes for any reason predominant over accretion, be permanently broken through and with the alluvial lands behind it be washed away wholly or in part long before its retreat to the mainland can be accomplished.

It must be remembered that the degree of evenness in outline attained by means of the action of the sea upon a coast must depend upon the character of the coast lands. Where a breadth of weak rock reaches the coast and is exposed to wave attack, it gives way more readily than do the more resistant areas on either side, a process accelerated by the fact that being easily eroded it probably forms relatively low-lying ground and hence must end in low cliffs that can be quickly cut back. It must continue to recede relatively rapidly until it becomes so far sheltered that its rate of retreat is reduced to that of the stronger rocks on either side. After this the coast retains its new outline during its subsequent recession. Bays bordered by cliffs and formed in this way by differential wave erosion are common around our coasts, and vary in size according to the distribution of weak and resistant rocks from tiny Cornish coves to wide openings like that of Lyme Bay on the south coast. The amount of recession behind the general line of the coast of such wave-cut openings must be determined by the degree of difference between the resistant powers of the yielding and harder rocks. When readily eroded rocks occupy valley floors, even bays formed by the submergence of the coast may so suffer from wave erosion that their heads retreat quicker for a time than do the coasts of the resistant headlands on either side. It seldom happens in this country that bay coasts are entirely sheltered from wave attack, in spite of the early formation of beaches within them upon which the breaking waves expend much of their energy, and their coasts are very generally subject to recession. In North Wales where valleys floored with glacial drift reach the coast wave erosion has in some cases caused the inner coast of the original bay of submergence to retreat a mile or two in a length of time that has not sufficed for any perceptible change in position of the headlands. Wave erosion may besides create islands and stacks, and greatly increase for the time the irregularity of the coastal outline. How long bays created by wave attack can be enlarged or remain unsilted depends on local conditions, chief among which are the quantity of beach material available and the local violence of wave attack. Where shore debris is plentiful and wave attack feeble such bays must cease to grow in size earlier than where opposite conditions prevail.

In the earlier stages of coastal development the coast suffers, as a rule, modification in both outline and position. Once the outline has become adjusted to the marine forces at work upon it, it becomes

STORM BEACHES, PWLL-DU-BAY, GOWER, GLAMORGAN

BAY BEACHES, SKRINKLE HAVEN, MANORBIER, PEMBROKE

relatively stable and one to which the coastline constantly tends to recur should it at any time be modified by some factor, like a storm of unusual violence, independent of coastal processes. The relatively even outline and uniformity of beach travel and of deposition that characterize a once irregular coastline smoothed by wave action are maintained during the subsequent retreat of the coast as a whole before wave attack, unless factors intervene unconnected with the process of evolution of the coast. Eventually, as already noted, it must recede behind the head of the most far-reaching inlets of its initial coastline and become, in consequence, everywhere bordered by cliffs. No part of the English coast appears as yet to have reached either the condition of retreat behind the heads of inlets created by subsidence, or in the case of flat coasts that of the retirement of an offshore bar upon the initial mainland coast. There has been time since the last change of level for the removal of but a narrow belt of land along the coast, varying in width from perhaps five miles in East Anglia to as many yards in parts of Cornwall. Thus a consideration of the possible further changes of coastlines during the later stages of their development cannot be illustrated by examples from the English and Welsh coasts.

As already noted earlier in this chapter the surface of the wave-cut shelf is worn down both by direct wave attack upon it and by the friction of moving sand and shingle. This erosion of the wave-cut shelf, however, lowers its surface more slowly, unless its rocks are very much weaker than those of the coastline, than wave attack can cut back the coast, hence there must come a time when further coast retreat would involve the total exhaustion of wave energy in crossing the shallow water of a wide wave-cut platform. After this condition has been reached further wave attack and coast recession are dependent on the gradual deepening of the inshore waters as the wave-cut shelf is abraded. Thus coast retreat becomes very slow, and the coast attains in position as well as outline to a condition of comparative stability. How soon the retreat of a coast may be thus retarded depends upon its degree of exposure and the relationship between the rate of its retreat and that of the abrasion of the wave-cut shelf. Frequently in England and Wales the persistence of an effective wave attack against coasts known to have receded several miles since their last change of level shows that under-water abrasion has been very active. The coast of Holderness, for example, still rapidly retreats though it has been cut back three miles since the Roman period. Here the land slope both above and below sea-level consists of glacial drift and is readily eroded.

Lowering of the wave-cut shelf may be hastened by the work of rock-boring organisms. Certain species of marine animals, by mechanical methods or the use of solvent secretions, excavate holes in rock[1]—thus the common "Piddock" may dig burrows a foot deep with its toothed white shell, and only very hard compact rocks are secure from its attack. Sponges, echinoderms, worms and crustaceans may also bore into and loosen the rock surfaces, the breaking up of which in this manner continues to an unknown depth.

[1] British Museum (Natural History) Economic Series, No. 10. *Marine Boring Animals.* W. T. Calman.

The formation of the submerged shelf that extends off Norway from three to forty miles out from the shore is attributed to wave cutting and off shore deposition during periods of differing sea-level.[1] The continental shelf, that area of gently sloping sea-floor the seaward boundary of which is the hundred fathom line, must itself be the product of prolonged wave advance against the land, accompanied by deposition and by abrasion below low-water mark and continuing during many oscillations of level.

However slow may be the lowering of the wave-cut shelf and the consequent gradual deepening of the inshore water that admits the passage of waves capable of attacking the coast, it nevertheless takes place inevitably. Thus the coast after an initial period of relatively rapid retreat must continue unless uplift occurs slowly to retire and the wave-cut shelf to widen until all the dry land is consumed. Moreover, the planed rock surface below high-water level, that is all that must eventually remain of the land, must continue to suffer abrasion and must as a consequence have its surface worn down until it has reached the depth at which wave action becomes inoperative, a depth known as wave base. The depth of wave base below the surface varies according to the size of waves commonly prevalent, and hence with the degree of exposure of the coast. It would, however, appear that on oceanic coasts there can be no very great variation in the depth of wave base, since wind-generated waves in open water reach in time a limit-

[1] "Oscillations of Shore Lines." F. Nansen. *Geographical Journal*, vol. xxvi.

ing size, and swells of great wave length, capable of eroding the sea-floor at correspondingly great depths, reach even windless coasts. There is a very general agreement that the edge of the continental shelf and the landward limit of mud deposits—both of which lines correspond approximately with the hundred-fathom line—mark also the outward limit of wave erosion on the sea-bottom. The sea-floor around the British Isles lies above wave base, and does not sink to the depth of a hundred fathoms until off the west coast of Ireland. Thus except in sheltered depressions it must be submitted to an abrasion that must lead ultimately to its lowering—with that of our islands—to the level of the sea-bottom now found off the latter coast. Below wave base except where scouring currents affect the bottom—as they may do where constricted by inequalities of the sea-bed to a depth of a thousand fathoms—deposition predominates over erosion and a film of oozy deposit thickens with such slowness that extinct organisms lie yet unburied.

It thus appears that as an inland region is levelled by erosion of the higher parts and deposition on the lowland areas, so is a coastline smoothed by the wearing-back of projections and growth of deposits in bays, but the general lowering of the land surface by denudation that may be compared to the continued recession of the coastline is carried on until base level is reached by the operation of the same forces that have been at work on it from the beginning, whereas coastal recession preludes the removal of the land and the ultimate creation by purely marine forces acting below sea-level of a submerged plain lying at the depth of wave base. In both cases, however, inland and along the sea, the detritus that assists to reduce irregularities, once a surface almost even or an outline scarcely indented has been produced, must, it would appear, hinder by retarding erosion the approach of the area to a condition of final stability in level or position.

The development of a coast in the manner already indicated is but an item in what—were earth movements not to occur—would be the ultimate destruction of the dry land. The production of an even coastal outline and the formation of a wave-cut shelf wide enough to deaden wave attack may take place during what is but the beginning of the prolonged wave assault against the land. This being so it is not surprising that the progress of the cycle of coastal evolution is usually interfered with not only by earth movements but by the advancing waves coming into contact with regions of physical characteristics different from those of the former coast lands now washed away. When this latter occurs the exposure of the new coast lands to wave attack initiates a fresh coastline upon which the sea has to begin anew its adjustments of the coastal outline. In southern Sussex on the south coast of England there extended east of Brighton as late as the Roman period a coast plain of comparatively recent deposits, the removal of which by the sea has brought the waves in contact with the chalk range of the South Downs that stood behind the original coast plain. West of Brighton a breadth of flat land yet remains in front of the Downs, and the contrast is very marked between the low coast here, rapidly cut back by the sea, and the high chalk cliffs that have already been formed east of Brighton and that recede comparatively slowly. Further north in areas affected by glaciation the removal of coast plains formed of drift deposits has brought the sea against uplands with consequences that will be considered when dealing with Wales. On the south coast of England in Dorset, west of the so-called Isle of Purbeck, the coast was once bordered by hard Jurassic limestones like those that form the southern plateau of the "Isle." It has now been cut back behind these formations and brought into contact with a region of chalk upland. The type of coastline resulting is very different from and of a much more regular character than that of the region to the east that is still wholly or in part composed of Purbeck and Portland rocks.

Another factor liable to impose a modified course of development on coastlines is a change in the supply and distribution of shore detritus, factors not solely controlled by shore processes. Thus interference with supplies of shore drift derived from regions external to the coast in question may affect the rate and character of its development. A landslip fallen athwart the beach, the erection of groynes that intercept the longshore travel of detritus, a changed rate of erosion somewhere else along the coast, or an alteration in the amount of waste brought by rivers—all such occurrences by checking the longshore drift of detritus to a particular length of coast, or otherwise affecting its supplies, modify shore deposition and thus affect at second-hand wave attack and coast recession in the area affected.

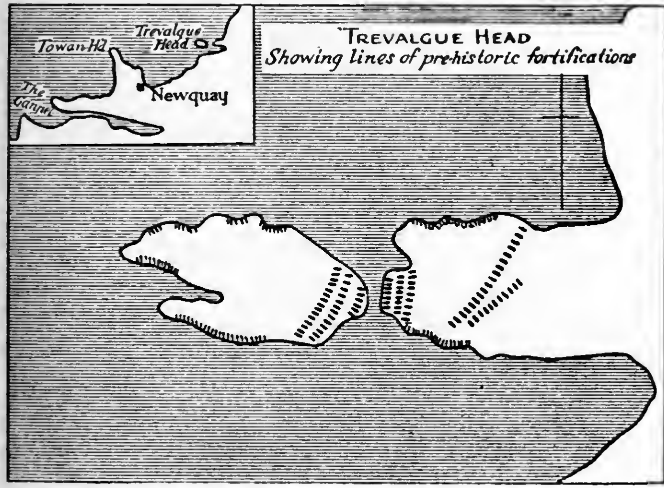
The progress of coastal evolution is thus liable to be interrupted by circumstances quite unconnected with the coast affected. It is besides of a far more complex character than has been indicated above, follows quite exceptionally a course agreeing with the ideal cycle of development, and may be accompanied by all manner of interesting features with some of which only will it be possible to deal in the ensuing chapters.

CHAPTER III

THE SOUTH-WESTERN COASTS: (I) EROSION

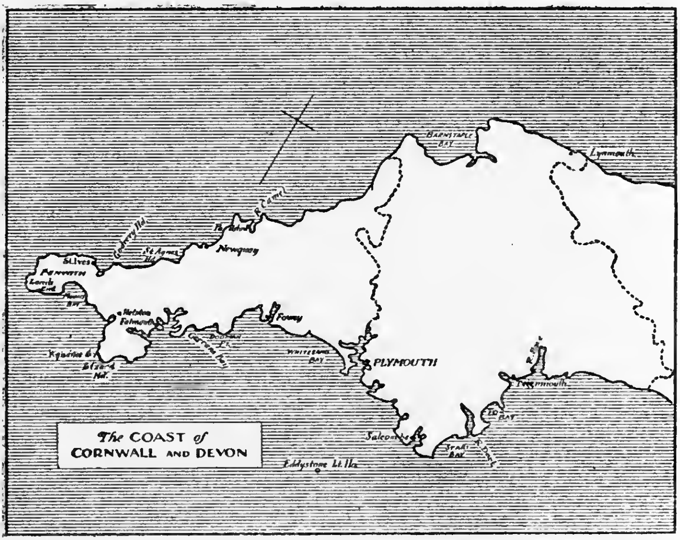
THE coasts of Cornwall and Devon offer an excellent example of shores that have been little modified by the sea since the last change of level took place. This south-western peninsula lies beyond the relatively yielding secondary rocks of the Midlands and of the south and east of England. It is formed of igneous and ancient sedimentary rocks that oppose a stubborn resistance to erosion whether sub-aerial or marine, and its coasts have preserved features that were as familiar to the men of the Old Stone Age as they are to those of the twentieth century. (See Map on page 41.) This relative permanence of coastal outline is by no means due to the creation of a coastline perfectly adjusted to wave attack and hence stable in outline, but rather to the prolongation of an early stage of coastal development owing to the extraordinarily slow response made by these coasts to the sea's attack.

As already noted in the first chapter, at various places on the coast of England and Wales occur beach deposits, old sea cliffs and wave-cut platforms, that now lie at varying heights above high-water level. These raised beaches have been proved in glaciated areas to have been formed before the Ice Age, by the deposits of which period they are overlain. Following their formation the coasts on which they lay were, as already stated, uplifted, and became fringed by a belt of lowland formed by the upraised bed of the former foreshore and varying in width in Cornwall and Devon from a mile or less to perhaps ten or twelve miles according to the seaward slope of the emerged land. The intermittent and fairly rapid submergence of the coast lands that took place during the Neolithic period had when it ceased here brought the



From "Earthwork of England." A. H. Allcroft.

coastline back with remarkable fidelity to almost the same level as had obtained when the raised beaches were formed. As a rule the depression did not quite equal in amount the previous elevation, so that the pre-glacial or glacial shoreline has been left in Cornwall and Devon somewhat above the present high-water level. In this region the coastline of to-day thus lies at much the same level as did the coast in or before the early glacial period, and the difference in altitude between the modern and prehistoric beaches seldom exceeds fifteen or twenty feet. Moreover, the outline of the raised beach coastline, preserved from wave attack during the ages of its elevation, has along a great part of these coasts survived the efforts of the waves to obliterate it during the time, very long from a human standpoint,



The COAST of CORNWALL AND DEVON

that has elapsed since it was again brought to near sea-level. From the River Exe west and north to beyond Padstow fragments of the beaches, the old sea cliffs, the wave-cut shelf formed along the earlier coast, fringe the present one and prove that estuaries like those of the Exe, Salcombe, Falmouth and the Camel, bays such as Start and Mount's

Bay, Whitesand Bay near Plymouth, Gerran's Bay, Fistral Bay, even coves like those indenting the furthest shores of Penwith, were already inlets when the icy Pleistocene sea broke upon these shores. Bideford Bay was also open to the sea in those far-off days, while many of the stacks and islets so characteristic of these coasts were already separated from the land before glacial conditions set in.

Since the period when the raised beaches of to-day were in process of formation the sea has removed from this south-western peninsula little but the low plain with which their elevation fringed the coast, a plain, moreover, partly submerged and greatly lessened in width by the subsidence of Neolithic days. In places a strip of lowland survives in bays whose sheltering arms yet hold pockets of loose and recent deposits in front of the old sea cliffs and beaches of the raised coastline. In Mount's Bay such a plain reaches a width of half a mile between Penzance and Marazion (see Map, p. 50); though here the fact that Marazion marsh behind the railway embankment lies below high-tide level points to a somewhat complex history. Gerran's Bay still has a fringe of lowland lying seaward of the raised beaches; in Bideford Bay again, and a few other sheltered spots, the old coastline lies somewhat inland of the present one. In other areas where the sea's advance has been relatively great the waves have overflowed the old shore platform, washed away the early beaches and cut anew into cliffs that had lain for ages beyond the reach of the sea. Thus the exposed western coast of the Lizard peninsula has been cut back very generally behind the line of the raised beach coast, which latter is still followed very closely by the more sheltered eastern shores of this peninsula. As a rule, however, the coastline of to-day between Padstow and the Exe approximates with fair accuracy to that of the raised beaches, which ancient shoreline lies just within or once lay just outside high-water mark along the greater part of the long peninsula. The low-lying coast plain of recently elevated and ill-consolidated strata can have offered but little resistance to the waves, but the land behind the raised beach coastline has opposed so successful a resistance to the sea's advance upon it that the latter has not exceeded one or two hundred feet, and has only reached this amount in a few exposed situations. Thus at Godrevy Head on the storm-beaten coast north of St. Ives the present coastline lies two hundred and ten feet behind a stack[1] which, from the similarity of its recent deposits with those of the mainland and the presence upon it of a raised beach, must have formed part of the mainland coast in or before the glacial period. During the same lapse of time coast lands east of the Exe have been cut back perhaps ten miles behind the line once followed by the raised beach coast.

The enduring nature of the coastal outline is, in Devon and Cornwall, in no way due to exemption from violent wave attack. The destructive power of the sea is here very great, though the absence of frost, the hardness of the rocks, and the great depth of water near to the coast all tend to lessen the amount of debris in the inshore waters

[1] "The Raised Beaches and Head . . . of the South of England." J. Prestwich. *Q. J. G. S.*, vol. xlviii.

RAISED BEACH PLATFORM, SUNNY COVE, FALMOUTH

TREVOSE HEAD: A TYPICAL CORNISH HEADLAND

and, by partly depriving the waves of a most effective tool, must moderate the power of their attack. Yet even where sand and shingle are altogether absent the great seas of the west break with such force on the Cornish coasts as would rapidly shatter and disintegrate all but the hardest and most homogeneous of rock surfaces. It must besides be remembered that though the lack of detritus lessens the abrasive force of the waves yet they are here unchecked by the wide beaches on which elsewhere their energy is often exhausted before they reach the cliffs.

The land of England and Wales here reaches furthest towards the west and stands boldly out into an ocean that stretches to the New World. Waves break upon it which have travelled from the west unchecked by any land, waves which may have come two thousand miles across the sea and which sometimes, in the case of swells, approach the shore at a speed of over sixty miles an hour.[1] The frequent cyclonic storms that march with the prevailing westerlies across the North Atlantic, combined with their exposure to the open sea, make the shores of Cornwall, with those of western France and Ireland one of the stormiest stretches of coastline in the world. Work on the foundation of the Wolf Lighthouse off the Land's End was possible for only some thirty-eight hours in the first year of its construction. The force of wave impact is besides enhanced in south-western England by the configuration of the land. Much of Cornwall and Devon consists of a low plateau that now ends above the sea in cliffs which stop and reflect the onrushing

[1] *Waves of the Sea and other Water Waves.* Vaughan Cornish.

waves, thus causing them to become compressed, with a corresponding increase in their height which enlarges the field of their attack. On a low and shelving shore such waves might advance and recoil unchecked without directly attacking the coast.

At Dunbar on the east coast of Scotland a wave pressure was recorded of three and a half tons per square foot of its surface of impact. That this is the greatest pressure as yet noted proves the scarcity of such records, since it must frequently be exceeded where the great waves of the Atlantic break along the western coasts of the British Isles. Such a pressure of water imposes a severe strain on any but a perfectly smooth and homogeneous rock surface ; and unequal impact of the wave on any irregularities of the cliff face, the compression, and subsequent release of air in joints, the tumultuous passage of water in and out of fissures—all tend to shatter cliffs exposed to such violent wave attack. The power of sea attack is further increased here by the depth of the inshore waters, which permits large waves to approach the coast unhindered. Moreover, the oceanic swells of great wave length (sometimes nearly half a mile from crest to crest) which break so commonly and sometimes in the calmest weather upon the north coast of Cornwall and less frequently upon the south coast as far east as Prawle Point disturb the bottom at depths proportionate to their lengths, and with the ordinary great storm waves which everywhere roll in upon these steeply shelving coasts are capable of eroding the submerged land slope at considerable depths. The oft-quoted case of the lobster pots, which off Land's End are in wild weather filled with coarse shingle at thirty fathoms below the surface, proves that the bottom may be actively abraded over a wide zone. Indeed the waves of this leeward shore of the North Atlantic are stated[1] to exert a strong wearing action one hundred fathoms down off Mizzen Head and to have accomplished about a half of their erosive work at depths below thirty fathoms. The land margin of Devon and Cornwall is therefore not only subjected to a formidable wave attack along the actual coast-line but must besides be exposed to considerable abrasion below low-water mark, so that deepening of the inshore waters must accompany the retreat of the cliffs before the waves. There are thus present in this region marine forces capable of causing a rapid and continued advance of the sea. That this is instead extremely slow is, as already noted, owing to the resistant character of the rocks both above and below sea-level.

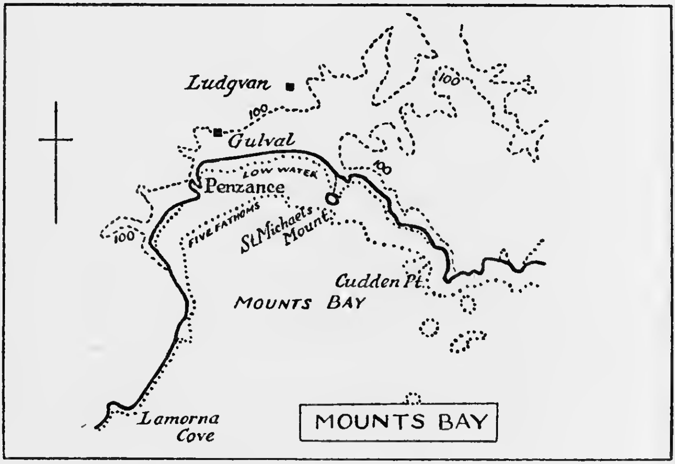
The sea during the ages that have passed since the raised beaches were formed has thus in this region modified the coastal outline but little. This latter is as yet determined more on the whole by the configuration and partial submergence of the land margin than by differential wave erosion, though in many parts, as near Padstow where igneous and relatively soft rocks alternate along the coast, or between the Exe and Teignmouth where hard conglomerates and breccias project beyond the weaker sandstones, the headlands are of hard rock while the intervening bays have been carved by the sea out of less resistant strata. More generally, how-

[1] "On the Land-slopes separating Continents and Ocean Basins." J. Y. Buchanan. *Scientific Papers*, vol. i.

ever, bays and headlands correspond with ridges and valleys and owe their origin to the submergence of an eroded land surface. Such features as Hartland Point where the abrupt bend in the coastline which gives it prominence corresponds to a parallel bend in the watershed behind the coast, Morte Point, Dodman Point, and many another headland owe their projection beyond the general line of the coast to their height rather than to any exceptional hardness of their rocks, which are similar to those on either side, though it has been suggested that their extension into water too deep for the formation of beaches has lessened the erosive power of the turbulent but clear seas that break upon them, while the erosion of the neighbouring bays has been hastened by the accumulation in them of beaches which supply the waves with shingle but are in some cases not so wide as seriously to check wave impact upon the coast. Mount's Bay, Bideford Bay and countless others, coves like Kynance or Lamorna or Poldhu, the scores of creeks and estuaries—all owe their origin to the submergence of valley mouths.

This is a coastline then that still bears in spite of past changes of level and ages of erosion the impress of submergence; still keeps, by virtue of its resistance to wave attack, in great part the irregular outline initiated by the subsidence which formed the raised beach coastline before the Great Ice Age. It must, however, be noted that the preservation of raised beach deposits in bays and their removal from headlands shows that already in many places the degree of irregularity of the coastline has been diminished.

If since the earliest days of man on our island such an extremely narrow margin has been washed away from these western lands what of Lyonesse, that forested and legendary country where King Arthur hunted between the Scillies and Land's End? Looking out from the Last House at sunset, to where the Scilly Isles lie like shadows twenty miles away, even aliens from beyond the river Tamar may almost hear the bells from the drowned spires of Lyonesse sounding through the waters, and may almost believe that the fishing boat that floats black beyond the Longships is dragging up in its net carved stonework, water-worn doors and window-frames from the houses of the drowned land. But raised beaches remain in the little coves south of Land's End—they occur again in, and are particularly well preserved on the Cornish side of, the Scilly Isles. So that probably before man arrived in Britain the Scillies and Land's End were already divided by a sea of almost the same width as now. The subsequent elevation of the land may have exposed off the Land's End a coast plain a mile or two wide—the present twenty-fathom line runs about two miles away from the shore—but even this narrow fringe must have been reduced in width by wave attack and submergence before Arthur's ancestors had emerged from the Stone Age. The legend of the pleasant country that lay beyond the Land's End can then no longer be credited. It may have originated in Mount's Bay where there has been great erosion of the low-lying land seaward of the old coast, which here runs inland through Gulval and Ludgvan, and which lies at the head of a bay sufficiently wide to admit a heavy sea. Judging from the recent rate of the sea's advance here, St. Michael's Mount must have merited its Cornish name of the "hore rock in the woode" and risen as a granite hillock above a marshy, forested plain long after the Phœnicians had traded purple cloth for tin in Ictis and gone the way of all peoples. The isle of Ictis was accessible dry-shod at low-water and antiquarians place it, amongst other localities, in the Isle of Thanet, the Isle of Wight, the Scilly Isles and St.



Michael's Mount. It is probable, however, that the latter, three thousand years ago, was still some distance from the sea. Land surfaces resting similarly as already noted, on the old wave-cut shelf and lying seaward of the raised beach coastline also suffer considerable erosion in Gerran's Bay and Bideford Bay.

Against these south-western shores the waves are as yet engaged upon only the first stages of their attack. Successive generations of men see no change in cliffs that seem eternal as the tors, with whose infinitely gradual wasting their recession has more affinity than with the rapid yielding common to less resistant coasts. Yet these cliffs are being cut back as surely as are those of less resistant areas. They have retreated since the Ice Age ; that they continue to do so is clear from their present verticality. Such steepness as characterizes the cliffs of the greater part of Cornwall and Devon can only be maintained so long as wave erosion at the base keeps pace with the sub-aerial denudation that attacks them above the reach of the sea. Wave attack that has here accomplished so small an advance in the past must yet unless earth movements intervene prevail in the future even against shores of so singularly resistant a character. It will, however, unless it gains in intensity, cause an increasingly slow recession of the coastline, since the shore lands of Cornwall and Devon, in common with those of most other regions, slope upwards away from the sea. Subsidence may reduce the peninsula to a group of islets like the Scillies of to-day. Such a group its hills must have formed when the early Pliocene seas formed long before the Ice Age cliffs[1] that are traceable still round Cornish tors that rose as islands in seas as yet untravelled by man, but even without subsidence unless elevation takes place Cornwall and Devon must one day be reduced by the sea's attack to a scattered archipelago of stacks and islands, and then to a series of reefs and finally be entirely submerged.

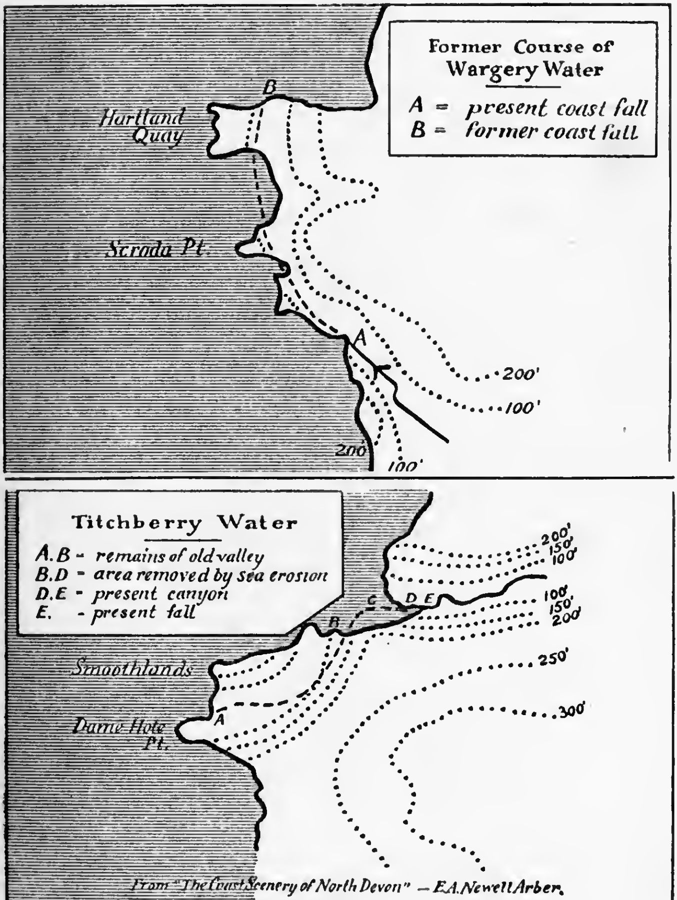
[1] *Memoir Geological Survey. Padstow and Camelford* C. Reid, G. Barrow, H. Dewey.

The effect of coastal changes upon the rivers and streams that debouch upon a coast is a fascinating and complex subject, but one too big to be considered here in its general aspects. On the North Devon coast occur, however, some beautiful examples that may be briefly noted of coastal streams cut short or intersected by wave action. Here the watershed lies near the coast, and from it to the neighbouring sea descend streams, short, relatively small in volume and of a steep gradient. Here also wave advance has been so considerable that all traces of the raised beach coastline are vanished from the greater part of the coast. The larger streams, such as Marsland Water on the Cornish boundary, or the Lyn, flow out at sea-level, but so many of the smaller ones end in coastal waterfalls as to make this stretch of coast, particularly that part of it between Hartland Point and the Cornish boundary, unique in Great Britain.[1] Such coast falls can in most cases be explained by the fact that these small streams as the waves cut away the seaward ends of their steep valleys were unable to deepen their lower reaches as fast as the sea advanced, their gradient remained unadjusted to their decreased length, and their valley floors were left above the new coastline, and separated from it by wave-cut cliffs of a height depending on the original seaward slope of the valley and the extent of the sea's advance into it.

Rivers and streams as a rule approach the coast more or less at right angles but where they flow parallel with and near to the shore before debouching upon it they are liable in this part of their course to

[1] *The Coast Scenery of North Devon.* E. A. Newell Arber.

be intercepted by wave advance, and thus their lower reaches may be cut off from the main stream



and be left as a dry depression or as a tidal strait. This has occurred in several cases in North Devon, and maps are given on the previous page illustrating two small sea-dissected valleys in the Hartland Point neighbourhood. On the south coast of Devon near Torquay have occurred similar interruptions of stream courses by the extension of coves inland athwart their valleys. Here the Bishopstowe and Ilsham valleys were once continuous, but the sea extending inland in Anstey's Cove has separated the old vale into two parts.[1]

Wave attack in the south-west has, in spite of its great violence, succeeded as yet in inducing only minor changes in the position and outline of the present coast. The latter remains unadjusted to the processes of marine erosion. It retains the irregularity of outline, and is submitted to the unequal incidence of wave attack common to coastlines in an early stage of development. The amount and distribution of shore waste along these coasts is also characteristic, as will appear from the next chapter, of coastlines but little affected by wave erosion.

[1] *The Hills and Valleys of Torquay.* A. J. Jukes-Browne.

CHAPTER IV

THE SOUTH-WESTERN COASTS: (II) SHORE-DEPOSITION

THE conditions which have led to the small response made to wave attack by the greater part of the coasts of Cornwall and Devon have brought about a type of shore deposition equally characteristic of a coastline in an early stage of development.

The resistant character of the coast allows of but a limited supply of debris. The area washed away since the last change in the sea-level has been relatively small and its water-worn fragments correspondingly few. The present slow advance of the sea creates but a small quantity of land waste every year, while the sub-aerial erosion of the cliffs above high-water mark takes place extremely slowly. Vertical faces of hard rock have indeed near Torquay remained apparently unaffected by atmospheric agencies during periods which have sufficed for an entire remodelling of the coastline.[1]

Probably a source of detritus more important than wave erosion on these coasts is the supply brought down by rivers, a quantity greatly augmented during the period of active stream tin mining by the alluvium carried down from the workings. A number of short, swift streams which flow

[1] W. Pengelly. "On the Lithodomous Perforations above the Sea-level in the Limestone Rocks in S. E. Devonshire." *Trans. Devon Association*, 1866.

from a near watershed to the sea carry gravel on to the shore. The Lyn which is about eleven miles long and debouches on the North Devon coast at Lynmouth is probably the largest stream which does so. More generally the water-courses are longer and deposit gravel in the higher part of their tidal portions, thus carrying nothing coarser than sand or mud to their mouths.[1]

A third source of detritus is indicated by the wide-spread prevalence of flint pebbles in the Cornish and Devon beaches, pebbles no longer derivable from rocks in the locality, and which appear in both the raised and modern beaches. The flint shingle of to-day is derived in part at least from the raised beach deposits. The flints in these latter came from a source not definitely known, but they point to coastal conditions and a distribution of secondary strata very different from those of to-day. The rivers of a constricted land area like that of the south-western peninsula, and the presence along the coast here and there of ancient beaches awaiting redistribution by the waves along the modern shoreline, cannot compensate for the general deficiency of beach material accounted for by the character of the coast rocks, and typical of the undeveloped condition of the coastline.

The distribution of the scanty supplies of sand and shingle is typical of that on submerged coastlines of an irregular outline and in an early stage of their development. The supply of detritus is greater at some points than at others, while the outline of the coast prevents its even distribution and favours

[1] De la Bèche. *Geol. Report on Cornwall, Devon and W. Somerset*, 1839.

a concentration of beach deposits in localities each separated from the other by lengths of coast bare of any shore deposit.

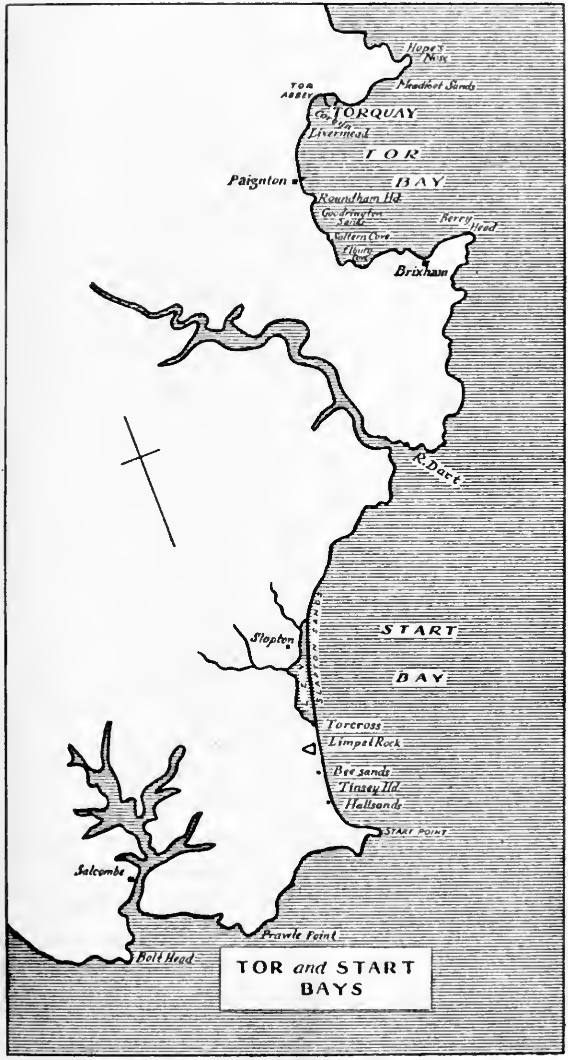
The original contours of the land mass and its subsequent changes of level have in Cornwall and Devon combined with differential wave erosion to produce, as has been seen in the last chapter, many outstanding headlands projecting into comparatively deep water. It is a debatable point at what depth the transport of shingle by wave action ceases, and though it has been stated[1] that headlands extending into water three fathoms deep prevent in Cornwall the passage of shingle around them it is probable that shingle travels under certain circumstances at greater depths. Headlands, however, certainly check the shore transit of beach material —partly owing to the fact that they possess here no wave cut shelf or only a rudimentary one to afford a pathway for such transit—and any sand or shingle which succeeds in passing them does so in deep water and may not be thrown on shore again for a considerable distance. Moreover, as already noted, a headland of sufficiently marked projection not only mechanically opposes the longshore drift of beach material but may interrupt the transporting currents which determine its direction of motion and generate currents moving landward along each flank from its outer end. Where headlands act as such drift divides they doubly interfere with the free travel of longshore drift.

The marked irregularity of the greater part of the Cornish and Devon shores ensures therefore a

[1] "On the Alluvial Formations and Local Changes of the South Coast of England." J. B. Redman. *Min. Proc. Inst. C. E.* vol. xi (discussion).

corresponding lack of uniformity in the direction of its longshore drift. The headlands separate bays, each possessing its own system of longshore drift currents and each cut off from the currents and detritus of the coast on either side; and such headlands occur so frequently that it is seldom that any considerable length of coastline is followed by one predominant littoral current and fringed with debris other than that derived from the immediate locality. Few great accumulations of sand or shingle have therefore grown up on these coasts, since their gathering ground is generally restricted within narrow limits, and this accounts in part for the comparative freedom of the estuary mouths from obstruction.

The relative scarcity of beach material and the irregularity of the coastal outline are two of the factors which contribute to that absence of beach deposits which characterizes a considerable proportion of our south-western coasts. Cliffs on the open coastline and headlands here usually descend beachless into seas that wash their base at all states of the tide. A wave-cut shelf, left bare by the ebb-tide, is often absent. The cliffs are thus shown to have receded but little since the last change of level and any detritus that may be derived from them can find no resting-place in the deep water, unsheltered and disturbed by large waves, that lies beneath them. Where a wave-cut shelf has developed at the cliff foot it is usually more or less bare, since the backwash is here not lessened in power by that percolation of some of its constituent waters which takes place on a sand or shingle foreshore, and hence it is able to remove



TOR *and* START BAYS

loose detritus from the rocky shelf. A cliff coast tends besides to be unfavourable to beach deposition, since the recoil of waves from a more or less vertical wall exerts a scouring action on the bottom—a phenomenon frequently rediscovered by seaside town councillors who decree the erection of vertical sea-walls—and the greater part of Cornwall and Devon, as already noted, ends above the sea in cliffs. Berry Head at the southern end of Tor Bay descends into water some twelve fathoms deep—beachless and with no wave cut shelf. Within the bay the cliffed headlands of Roundham Head, Livermead, and the Corbyns project with little or no beach beneath them from the wide sand beaches that lie on either side of them, but they—of softer rock than the hard limestone of Berry Head—possess already each its wave-cut shelf. In other bays, such as at Newquay for example, beaches have grown up even beneath the cliffs at the end of minor headlands, but it is rare to find a strip of beach like that which lies at the foot of St. Agnes Head, between St. Ives and Newquay, fringing the base of headlands on the open coastline. Stretches of cliff coast occupying a wide bay may, though themselves unindented, possess a belt of sand or shingle below them, as is the case with the cliffs of Beesands and Hallsands in Start Bay, and the broken cliff coast of Whitesand Bay near Plymouth. In such situations headlands and cliffs share in the conditions which lead as a rule to the more rapid evolution of the coastal outline in embayments than occurs on the open coast.

On an irregular and immature coastline such as that of Cornwall and Devon the necessary conditions for the deposition of shore waste occur principally in bays and at the mouths of rivers.

Bay beaches are, as already noted, among the first forms of shore deposition to appear on a newly created coastline, and for long ages they may remain, as they still do to-day in a great part of the south-west, the only areas of sand or shingle in a region where outside the little coves cliffs and breakers combine to render the sea unapproachable. From the days of coracles until now these isolated beaches have been of use to man, and whether by the access they provide to the sea for fishermen or bathers, the protection they afford against wave attack, the driftwood cast upon them, or the use in agriculture of their limey shell sands, they have materially influenced the distribution and well-being of human settlements along the coast.

Beaches grow up in bays for reasons more numerous and complex than those would suspect who have learnt to regard them with that lack of wonderment usually accorded to phenomena which are of common occurrence. Very usually waves, wind and tide driving into a bay set up a drift of detritus inwards along either coast of the bay and towards its head. Here the opposing drifts meet each other and the land, and here the undertow sets in which reduces the head of water in the bay. The moving waters are therefore checked and the debris transported by them is deposited. Some of this only is carried out again by the seaward drag of the undertow on the bottom, a current that may be too feeble at its commencement to remove more than a small proportion of the sand or shingle brought in by the waves. The beach thus begun grows with additional supplies until a perfect adjustment is reached between the processes of deposition and erosion in the bay—waves, undertow and ebb-tide then carry away an amount of detritus which is exactly balanced by that deposited, and the beach remains stable in size and position. The supplies of sand or shingle derived from the actual bay coasts are, as a rule, increased by the waste grudgingly yielded by the cliffs of the open coast on either side, waste which is swept away from their more exposed shorelines into the bay where comparative shelter is obtained from all but winds blowing directly onshore. Such shelter implies a lessened violence of wave motion, and hence a decreased capacity for the transport of debris and its consequent deposition.

Another reason for the accumulation of beach in recessed parts of the coastline is the obstruction offered to shore drift by one or other headland when the bay shores are followed by a littoral current sweeping from one horn of the bay to the other, while yet another and an equally important cause of deposition in bays arises from the relative shallowness of the water and the gentle seaward slope of the inshore bottom which is found whether inlets have been former by submergence or by wave advance. Such conditions, as already noted, favour the accumulation of beach onshore.

Causes such as these are amongst those determining the growth of beaches at the heads of bays. In Cornwall and Devon bay beaches of all sizes and characters occur, from the little stretches of white or golden sand beneath the dark cliffs of such inlets as

Pendour Cove under Zennor Head on the desolate north coast of Penwith, or where the little stream flows from near Lizard Town to the tourist-haunted sands of Kynance, to great stretches of beach like the sands and shingle which lie between Newlyn and Marazion in Mount's Bay, or the strip of fine sand that stretches, nearly a quarter of a mile wide at low water, for over three miles along the dune-covered eastern shores of St. Ives Bay. Tor Bay, Start Bay, Barnstaple Bay are wide inlets with considerable beaches developed at their heads—beaches in Tor Bay still separated by headlands into the distinct areas of Goodrington, Paignton and Tor Abbey sands, but which in Start Bay stretch for some seven miles along the coast, interrupted by minor headlands such as Limpet Rocks and Tinsey Head that extend out beyond the beach.

The transition from a coastline little modified by the sea to one in a more advanced stage of development is marked in the case of these larger bays. The outer coasts of Tor Bay retain the irregularity of outline, the beachless headlands and isolated coves —Meadfoot Sands, Elbury Cove, Saltern Cove— common to the open coastline. The inner shores of the bay, formed of less resistant rock and in a position more favourable for the deposition of waste are, with their large beaches and eroded headlands, in a more advanced stage of development. They are approaching the condition—already attained in Start and Barnstaple bays—when erosion and deposition shall have so far smoothed the coastal outline as to allow of an uninterrupted sweep of longshore drift along it.

Only in areas where, owing to its initial characteristics or subsequent modification, a coast presents for some distance a smooth and flowing outline can the operations of the longshore drift produce bars or spits of sufficient importance seriously to modify any remaining irregularities of the coastal outline. In Start Bay beach material, accumulated under geographical conditions different from those obtaining to-day, has been drifted at some past time in a southerly direction along the shore, so closing one after the other the mouths of the several small streams which formerly flowed out here. Barred at their mouths by banks of fine shingle through which they could escape only by percolation, the rivulets spread out in shallow lagoons behind the ridge of beach. These lagoons are known as Slapton and Torcross Ley, and are reed-grown lakelets destined to be filled up before very long by the growth of vegetation and the deposition of silt. Their waters are fresh, since the ancient shingle bank which confines them has become so consolidated that the sea-water does not percolate through it, although since there is no visible outlet for the lakes their own surplus waters can only escape by percolation to the sea. The sea has been known, though not for many years, to break through the shingle-bank and invade the Ley, a disaster to which are liable all areas defended from the waves by a wave-built barrier. One tide has been known to remove a seven-foot depth of sand and shingle from a three-mile stretch of Slapton beach.[1] Further north in a cove near Brixham the beach level was at one time suddenly raised by about a similar amount, the new level being afterwards

[1] W. Pengelly. "Submerged Forest in Bigbury Bay." *Trans. Devon Assoc.* 1865.

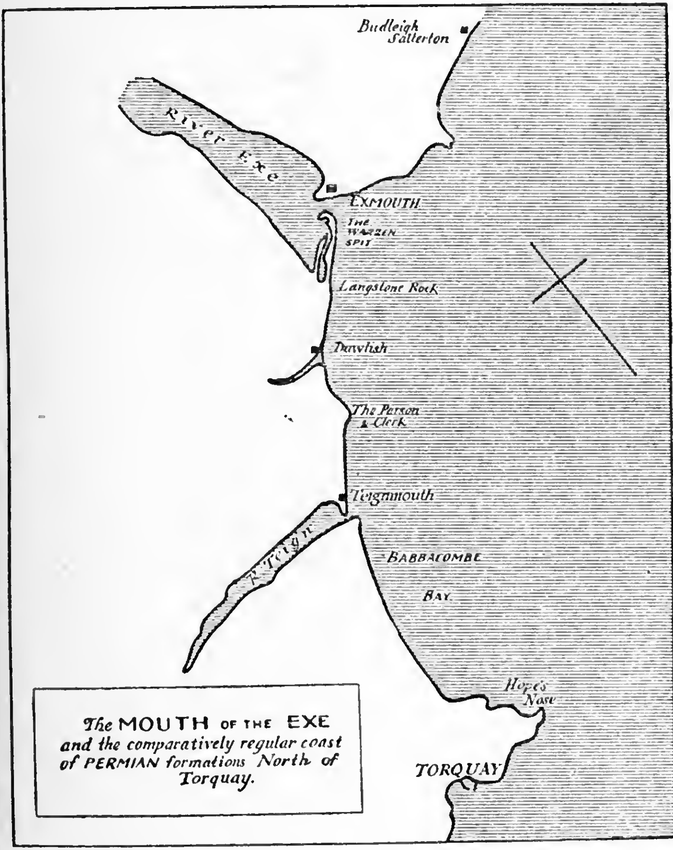
maintained at least until an observer noted the occurrence a few years after in 1866.[1] Such examples with many others show that the very general stability in size and position common to beach deposits is liable frequently enough to temporary derangement and occasionally to lasting modification without apparent cause. Changes in the amount of beach are easily induced by artificial means, as the inhabitants of the village of Hallsands—situated below the cliffs and partly on the beach in the southern part of Start Bay—learnt to their cost. They had evidently suffered somewhat from wave attack before 1841, in which year a sea-wall was built. After this the beach in front of the hamlet appears to have remained stable and the villagers were undisturbed even by the seas of a coast so exposed that dogs were trained to swim out through the rough water to catch and carry to the shore the painters of home-coming fisher boats. The beach in Start Bay—confined within the bay by the headlands on north and south—had become adjusted in size and position to the local forces of erosion and deposition. Liable to drift to and fro along the coast it suffered no permanent modification, and the scanty supply of fresh debris available must have been balanced by the wastage of the beach. In 1896 dredging operations began off Hallsands, and the beach material obtained was used in harbour works at Plymouth. Supplies of fresh shingle to replace that removed were naturally—in an area of so restricted a gathering-ground—not forthcoming, and although dredg-

[1] W. Pengelly. "Raised Beaches." *Trans. Devon Assoc.* 1866.

ing was stopped by the Board of Trade in 1902 the village, after suffering severely from the waves on several different occasions, was finally washed away in 1917. The loss of beach had resulted in a deepening of the water in front of the village and its consequent exposure to the direct attack of larger waves than those that formerly broke harmlessly on the shelving beach.

Banks of beach material have as in Start Bay dammed the outlets of small rivers in at least two other localities, and the Swan Pool near Falmouth and Looe Pool below Helston owe their origin to the blocking of land drainage by wave action. The folk of the latter town, wearying of the picturesque but no doubt tiresome process of proceeding armed with shovels to "break the bar" when land waters backing up towards Helston threatened to flood the town, are probably glad a culvert has been built whereby the waters of the little Caher River now escape through Looe Bar. So that no longer is the sea round the distant Scillies discoloured, as tradition says it used to be, by the roaring outrush of flood waters when Helston broke its bar.

Cases of rivers completely or even partially blocked by sea-formed banks rising above low-water level are, however, rare in Cornwall and in Devon west of the Exe, where the open entrances and long and winding tidal waterways of such estuaries as those of Falmouth, or Fowey, or the Helford river near the Lizard offer a remarkable contrast to the barred and silted river outlets of the south and east coasts. Here and there spits of sand or shingle have developed like those which narrow the outlet of the Teign (the northern one of which supports a great part of the ancient town of Teignmouth) or the Doom Bar



The MOUTH OF THE EXE *and the comparatively regular coast of* PERMIAN *formations North of Torquay.*

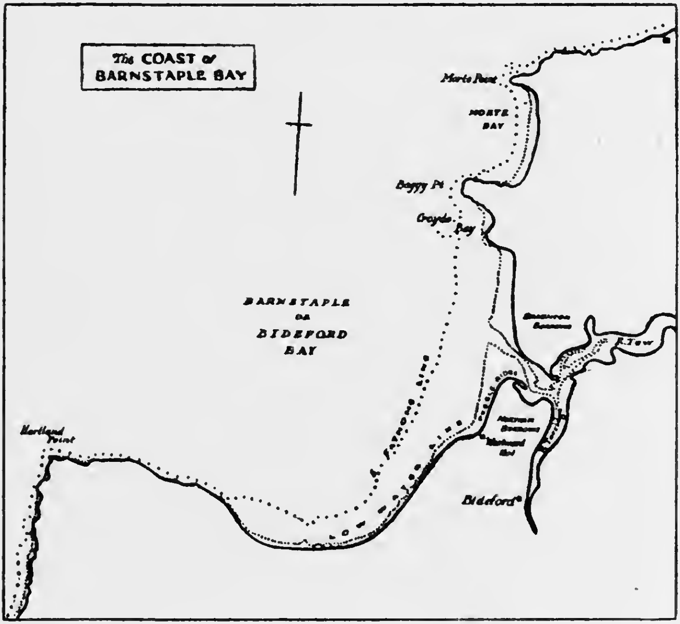
across the Camel, but the extension of bars across the mouths of estuaries so common on coastlines in a more advanced state of development is as a rule scarcely begun in the south-west—where as already explained the constant interruption by headlands of the longshore drift seldom admits of the supply of shingle in sufficient quantities to compensate for that removed by wave and tidal action in the inlet. At the mouth of the Exe, however, and in Barnstaple Bay on the north Devon coast a sufficient length of coastline to windward has been available as a source of sand and shingle to allow of the growth of the Warren sandbank in the one case which extends across some four-fifths of the mouth of the Exe, and in the other of the famous Northam pebble ridge which protects the golf links of Westward Ho! from the Atlantic.

The Warren bank or spit extends from the Permian sandstone cliffs of Langstone Point or Rock on the south-west of the estuary across to within a varying distance of the village of Exmouth on the opposite shore. Its supplies have been drawn from a fairly straight length of sandstone cliffs extending southwards as far as the point, at present the projection of the Parson and Clerk rocks, where there now begins a shore drift to the south towards the Teign estuary, cliffs very generally fringed by sand beaches and from which sand has been swept by the combined action of obliquely impinging waves, flood-tide and prevalent winds, athwart the estuary along a line continuing that of the coast to windward. This spit is a double one, an outer ridge of sandhills being separated by a low-lying area flooded at high water from an inner parallel arm, and it ends in a hook pointing up-river off Exmouth. The salient characteristics of this deposit have been the recession and breaching by the sea of its outer face, the relative stability and widening by alluvial deposition of its inner margin and the fluctuation, evident in the past and very probably to be expected in the future, of the main outlet of the river between Exmouth and Langstone Point. During these fluctuations the Warren spit has been reduced to one or more islands, or joined to the Exmouth or Langstone coast according to circumstances. This spit has for long been subject either to wastage or to a slow rearrangement of its materials, probably consequent upon a gradual recession landwards in harmony with that of its parent coast. Fears that have been entertained for over a century still prevail that it may be broken through by the sea, to the detriment of the anchorage in the Warren bight behind it. There are at present three breaches in the outer face of the Warren, but the only serious attempt at its protection has been made by the Great Western Railway Company at the south-west end of the spit.[1] The building of the sea-wall in connexion with the construction in 1846 of the railway along the coast to the west of Langstone Point, must doubtless have cut off an important source of supply from the Warren spit, but its wastage or recession had set in before this date.

In the remote future without human interference a spit like the Warren bank might be expected eventually to enclose the estuary as the bars at Looe Pool and Slapton Ley have done, but such a condition could not be attained until silting and the growth of marsh vegetation had so reduced the tidal area and

[1] From information kindly supplied by Mr. Thos. Moulding, M.Inst.C.E., City Engineer and Surveyor, Exeter.

consequently the scouring action of the flood and ebb-currents in the estuary as to enable the spit to grow across the enfeebled currents of the outlet. Such a contingency seems remote indeed—but marsh vegetation can cause great changes in a relatively short time, as has been seen in the case of



Poole estuary in Dorset. Here a type of grass growing in tidal mud flats and known popularly as "rice grass" (*S. Townsendii*) has recently greatly in-increased, and it has been estimated that the tidal capacity of Poole Harbour will be decreased by about ten million cubic yards if the mud flats are raised one foot in level by the accretion consequent upon the growth of this plant.[1]

Northam pebble ridge in Barnstaple Bay is a bank noted for the unusually large size of the shingle and boulders of which it is composed. Its materials have been drawn from the southern shores of Barnstaple Bay and largely so from the raised beach which here fringes the coast, and it extends for a distance of over two miles from the northern end of the cliffs near Westward Ho! forming a barrier between a large tract of low-lying alluvial land and the sea. It would appear that Northam ridge was drifted northward partly across the embouchure of the rivers Taw and Torridge, somewhat as the Warren spit projected athwart the Exe estuary, and that subsequent to its formation and under its shelter there grew up the alluvial lands known as Northam Burrows. This spit possesses like the Warren bank the characteristic hook-shaped end. It shares also in the landward recession common to such features on a coastline that is submitted to marine erosion and is gradually being rolled over on itself and encroaching on the levels behind, a process that must lead in time to their total loss, since they cannot long survive the sea's attack once they are left on the seaward side of the advancing ridge. These lands share in the usual insecurity of alluvial levels in their position and are occasionally flooded by the sea breaking over or through the protecting bank, a process likely to be the more frequently repeated since supplies to the pebble ridge from the raised beach to westward are said to have diminished, and

[1] *Tidal Lands: A Study of Shore Problems.* A. E. Carey and F. W. Oliver.

a rapid recession of the bank would appear to have set in. After one gale in 1896 the shingle ridge was found to have moved ten yards towards the land,[1] and it was estimated earlier, in 1884,[2] that the sea had for nine years advanced here an average distance of about thirty feet per annum. Owing to an exposed position, or to lessened supplies of shingle, Northam ridge and the alluvial flats connected with it have thus already reached the stage respectively of retreat upon the main coastline and of destruction by the sea at which such features must inevitably arrive, a stage reached in this case before the shingle ridge has succeeded in entirely strangling Devon's longest rivers—aided though it is by the projection of the triangular sandhill area of Braunton Burrows towards it from the opposing coast.

One form of coastal deposition in Cornwall merits fuller notice than it can here receive. Great areas on the north coast, particularly about the head of St. Ives Bay between Perranporth and Newquay and in the Padstow district, have been overwhelmed by dunes. Marching inland before the west wind these dunes, the sand of which is composed of finely ground sea-shells, have buried churches and villages, climbed hill slopes and made desert hundreds of acres of land.

The coasts of Devon and Cornwall thus suffer from a general scarcity of beach material and an irregularity in its distribution corresponding to that of the coastal outline. The relatively rapid recession of

[1] Wheeler, W. H. *The Sea Coast.*

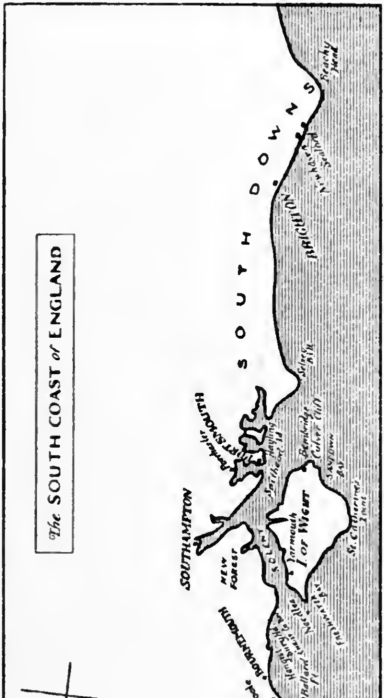
[2] Spearing, H. G. "Recent Encroachment of the Sea at Westward Ho!" *Q.J.G.S.* vol. xl.

headlands, proved by the absence from them of remains of the raised beach coast that survive in bays, is paralleled by the growth of spits and banks that—partly or wholly closing certain inlets—show that the processes of shore deposition as well as those of marine erosion are already beginning to reduce the irregularity of the coastline. The continuance of these operations must lead at last to the creation of a stabilized coastal outline against which wave attack will everywhere make an equal amount of progress.

CHAPTER V

THE SOUTH COAST: (I) EROSION

THE south coast of England consists of secondary and more recent rocks very much less capable of resisting erosion than are those of the south-western peninsula. East of the Exe the characteristic features of the coast differ as greatly as do its rocks from those of Cornwall and the greater part of Devon. The relatively yielding nature of the strata on the south coast has resulted in the formation of long stretches of regularized shore-line, worn by the sea to a smooth outline and unbroken by headlands or obstructions to the free travel of longshore drift, while the rapidity with which the coast has retreated before the waves has caused it to lie at the present day almost everywhere landward of the line followed at one time by the raised beach coast. The latter, between the eastern extremity of the south coast at Beachy Head and the surviving fragment of raised beach a little east of Brighton, lay seawards of the present coast. West from the latter town a discontinuous line of raised beach deposits—of varying age and height—extends along the base of the South Downs and continues, becoming estuarine in character, far across Hampshire. On the open coastline west of the raised beach at Bembridge in the east of the Isle of Wight only one fragment of the old shoreline remains, in the raised beach at Portland Bill, until


The SOUTH COAST of ENGLAND
SOUTH DOWNS
Beachy Head
Seaford
BRIGHTON
Selsey Bill
PORTSMOUTH
Hayling Id
Spithead
Bembridge
Culver Cliff
Sandown Bay
SOUTHAMPTON
NEW FOREST
Yarmouth
I of Wight
St. Catherine's Point
Needles
BOURNEMOUTH
Poole
Ballard Pt
Wareham
I of Portland
Weymouth Bay
Bridport
Lyme Regis
LYME BAY

at Hope's Nose just east of Torquay begin the frequent raised beaches of the south-west. The coastline, when the raised beaches of to-day were being formed, followed, it is thought, a more or less straight line across the entrance to the present Lyme Bay and, east of Portland, lay everywhere south of the existing shores as far as the eastern point of the Isle of Wight. The coast plain of southern Sussex which consists of a wave-cut platform overlain by glacial and recent deposits[1] thus alone of the open sea coast remains to seaward of the raised beach shoreline.

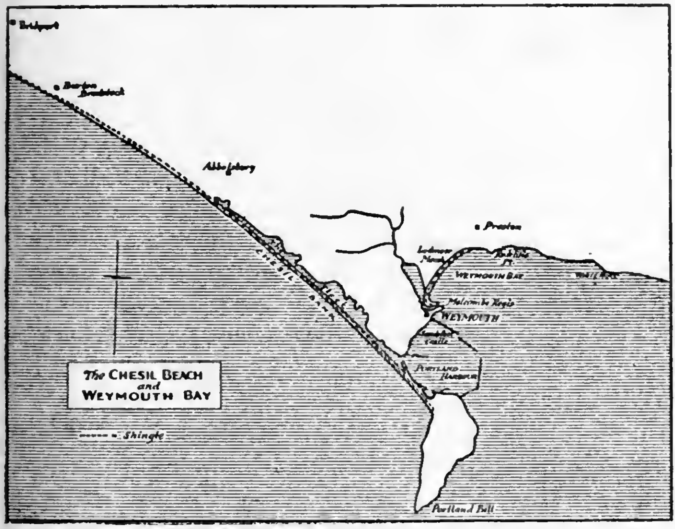
The existing coastline is probably furthest removed from that of the raised beach period between the Exe and Portland Bill. Lyme Bay, which extends, according to nautical nomenclature, between the Exe and the Isle of Portland, is a product of both wave erosion and subsidence. The uplift which followed the period of formation of the raised beaches must have left the present bay occupied by a low-lying plain which may have extended to somewhere about the present twenty-fathom line,[2] and the coast of which must have lain in this case some ten miles to seaward of the existing land of Dorset. Wave attack, aided by the subsidence which in Neolithic times submerged a part of the previously uplifted lands, washed away the coastal plain created by the elevation, attacked the cliffs and raised beaches of the old coastline and advanced beyond them perhaps five or more miles into the land. Here then, so far from lessening the

[1] *Memoir Geol. Survey, Bognor.* C. Reid.

[2] "The Raised Beaches and Head of . . . the South of England." J. Prestwich. *Q. J. G. S.*, vol. xlviii.

irregularities of the coastal outline, the sea has created a bay where formerly there was none, if the supposition is correct that the raised beach coast extended in an approximately straight line between Portland Bill and a point near the mouth of the Exe.

Forming the eastern horn of Lyme Bay the Isle of Portland projects out as far as the line of the raised



beach coast, and at the Bill the sand and shingle of the old beach remain, consolidated into a hard mass, in the cliff some twenty-four feet above the present sea-level.

East of Portland Bill Weymouth Bay has probably had a history somewhat different from that of Lyme Bay. It is supposed[1] that the raised beach coast-

[1] *Memoir Geol. Survey: I. of Purbeck and Weymouth,* A. Strahan.

line followed a scarp edge that once continued from near the present ending of the chalk on the Dorset coast at White Nose across to Portland Bill. Through this coastal ridge the waters now draining into Weymouth Bay must have made their exit to the sea, and probably it was by their estuary that the sea gained access to the lower and more easily eroded lands in the rear of the scarp edge. It is impossible to say how far the outlines of Weymouth Bay were determined by wave erosion, and how far by the subsidence of the coast lands that in Neolithic times drowned the seaward end of the lowlands north and west of Weymouth ; but that Weymouth Bay, like its greater neighbour on the west of Portland Isle, owes its origin and broad outlines to wave erosion rather than subsidence would appear evident from the fact that the Neolithic depression was of lesser vertical extent than the preceding uplift. Thus the disappearance of the raised beach coastline must be attributed to wave advance rather than to subsidence.

East of Weymouth Bay the raised beach coastline probably lay not very far to seaward of the present south coast of the Isle (so-called) of Purbeck, but between the eastern coast of this peninsula and the Isle of Wight stood a range of chalk Downs, which joining the uplands of Wight with those of Purbeck formed part of the southern watershed of a river system now invaded by the sea. The ancient Solent River—initiated probably in the early Tertiary period—gathered to itself the Dorset Frome, the Stour, and Avon, and tributaries from the south, and flowed from the west through what is now Poole Harbour along the Solent and Spithead and out to sea somewhere off Sussex. At some period the chalk Downs that stretched from Ballard Point in the Isle of Purbeck to the Needles in the Isle of Wight were breached by the sea, probably along the valley of a northward-flowing tributary of the old Solent River.[1] There is fear of a somewhat similar breach being made to-day where between chalk cliffs the lands below high-water mark that lie about the present headwaters of the Yar at Freshwater Bay are seriously threatened by the waves, and the formation of a tidal strait between Freshwater and Yarmouth on the Solent appears not improbable. Probably a considerable period elapsed before the sea, its energy restricted at first by the narrowness of its breach through the now vanished Downs, so encroached upon the lowlands north of them as to reach the main river-bed, but in time communication was established between the sea and the Solent River system west of the Isle of Wight, the lower course of the old river being thus decapitated. The Neolithic subsidence here as elsewhere must have played an important part in aiding wave advance. The chalk peninsulas that extended towards each other between the Needles and Ballard Point were gradually worn back and the advance of the sea upon the non-resistant rocks of the coasts of the present Poole and Christchurch bays continued apace. The estuary of Poole Harbour like that of Weymouth was created by subsidence.

The connexion of the Isle of Wight with the mainland is thought to have been maintained after the invasion by the sea of the Solent valley west of the

[1] I am indebted to Mr. H. J. Osborne White for the probable sequence of events in the separation of the Isle of Wight from the mainland.

island. Such invasion would not involve the insulation of the Isle of Wight unless the Solent River had been at that time estuarine below the point of its intersection, and a land connexion across what is now the western entrance of the Solent is supposed to have continued into prehistoric times. The Neolithic subsidence may by converting the beheaded lower reaches of the Solent River into a tidal strait have brought about the final separation of the island from the Hampshire coast.

The south coast of the Isle of Wight has retreated considerably from the line followed by the raised beach coast. Sandown and Freshwater bays have been hollowed out of soft cretaceous strata, and river systems that here once drained vanished lands northwards to the Solent are in greater part washed away. The Eastern and Western Yars are the decapitated lowest reaches of these river systems, while upon the coasts of either bay at Brook and Shanklin respectively still remain the uppermost part of streams once tributary to them.

East of the Isle of Wight the old Solent river is supposed to have flowed out, through lands now long washed away, some distance to seawards of the present coast between Brighton and Beachy Head. This may have occurred at various periods before the formation of the raised beaches. At the time when they were in process of deposition estuarine conditions probably extended little or no further eastwards than the present eastern end of Spithead. The raised beaches remaining in Sussex indicate that by the period of their formation lands that once extended eastwards from the Isle of Wight were already vanished. The uplift which followed originated a plain over which the Solent River (supposing it not to have been already decapitated by wave inroads west of the Isle of Wight) must have described a meandering and prolonged course to the sea. Since the raised beaches were deposited wave erosion west of Brighton has failed to obliterate the effects of this elevation, a fact which, in view of the unusual rapidity of the sea's advance here, points to the former survival even at the close of the Neolithic subsidence of a wide plain of emergence below the Downs. East of Brighton the one-time coast plain and the ancient shoreline behind it are alike gone.

The areas where marked coast recession has taken place since the raised beaches were formed are as a general rule those where the sea is advancing most rapidly to-day.

It is commonly stated that marine erosion can form bays of only a limited degree of recession behind the general line of the coast. The great incurving of the shoreline known as Lyme Bay has, however, so wide an entrance that its coasts are everywhere liable to the onslaught of heavy storm waves. The eastern coast of this bay forms indeed so deadly a lee-shore in westerly and southerly gales that it is singularly lonely and devoid of shipping, a condition brought about somewhat paradoxically by the increase in the size of ships that has taken place since the sixteenth century. For all but the smallest vessels there is no shelter in the bay except, with certain winds, at Lyme Regis. This town stands in the innermost corner of the bay and yet it has suffered for ages from wave attacks. It is supposed to have built its first breakwater or cobb in the reign of Edward I. Since then it has been engaged in repairing the existing cobb or in building a new one, and in coincidently presenting petitions to the sovereign of the moment for aid in its struggles against the sea. The periodic destruction of its harbour, its sea-walls, and a greater or lesser number of its houses, continued until modern systems of land defence checked the sea's inroads. As late as 1911 the graveyard of St. Michael's, the parish church, was in process of being washed away, though the cliff has now been adequately protected.[1] Further east, however, the accumulation of beach common on bay shores has already lessened or stopped direct wave attack upon the land.

The erosion at Lyme has been accelerated by human agency, for while the townsfolk were engaged in ceaseless warfare against the sea their best defence against it was being removed and shipped to London to supply material for the erection of stucco houses. In spite of the fact that as early as the reign of James I an edict forbade the taking of stones from the sea or seashore near the borough of Lyme thousands of tons of limestone were being quarried from the ledges of rock on the foreshore before the town in the early nineteenth century. The quarrying for lime of both reefs and cliffs continued here until recently, thus accelerating the recession of the coast both directly and indirectly through the resultant deepening of the water in front of the town.

At Lyme, apart from the results of quarrying, the influence upon coastal recession of the character of

[1] East of Lyme cliff falls continue and are endangering the road between that borough and Charmouth.

the rocks composing the foreshore below high-water mark is emphasized, since the Lias cliffs that border this part of the coast are east of the town the more readily eroded owing to the fact that here the hard limestones that form the foreshore below the cliffs to the west cease to outcrop between tide marks, their place being taken by the overlying Lias clay which offers little resistance to wave attack.

Portland Island forms the eastern horn of Lyme Bay. It owes its projection to the resistant character of its rocks, and the Oolite limestones of Portland Bill still yield very slowly to wave attack. The sides, however, of the elongated island, where the softer Kimmeridge clay crops out above sea-level beneath the Portland beds, give way more readily, and great landslips occur. The separation of the island from the mainland has occurred since the formation of the raised beaches and must have been caused by both subsidence and wave erosion. The recession of the coast of Lyme Bay on the west may, it would seem, have been accompanied, as will be seen in the next chapter, by such a development of shingle beach that the connexion between Portland and the mainland may have been maintained during and subsequent to the insulation of the island by a bank of shingle like that of the Chesil Beach which to-day ties the island to the mainland. The inhabitants of Portland, whether it was ever actually insular or no, possessed at any rate somewhat of the strong individuality common to island-dwellers. They were noted for a great skill in flinging stones, and they shared the usual dislike of islanders for their mainland neighbours, and as a rule sided against Weymouth in the Civil War.

The hard rocks of Portland Island would appear to have acted as a protection to the mainland coast in their rear which, though here of no great power of resistance, projects three or four miles southward of the general line of the coast.

A rock ledge that extends a mile seaward and to south of the Bill, with deep water on either side and off its southern end, is a relic of former land. Perhaps before it was worn down and submerged to its present depth of from three to nine fathoms below the surface it provided those relatively sheltered conditions under which the raised beach at its eastern base on Portland Bill is supposed to have been accumulated.[1]

All along the south coast such ledges continuing the line of headlands below high-water level, and rock patches far beyond low-water line, bear witness to a former extension of the land. Orcombe and Otterton ledges north of the entrance to the Exe, the Chit ledge at Sidmouth, rocky shoals off Bridport, the numberless reefs and ledges round the cliff coasts of the isles of Purbeck and of Wight, the rocks in the northern part of Poole Bay, the long rock ledge that stretches for over two miles out from Hengistbury Head east of Bournemouth, the dangerous Bridge Reef which continues the line of the Needles under water, the offshore rocks that fringe even the low-lying coast plain of Sussex, sometimes a mile out, are one and all part of the tattered uttermost fringe of the land of which at some time they formed a part.

Weymouth Bay is bounded by low-lying alluvial

[1] *Mem. Geol. Survey: I. of Purbeck and Weymouth.* A. Strahan.

land for some five miles north of the town. Weymouth itself is built on a projecting headland of Corallian rock known as the Nothe; its neighbour, and erstwhile enemy, Melcombe Regis, on alluvium and ancient deposits of sand and shingle that have grown up at the entrance of the shallow bay that once stretched inland for some three miles to the north-west of the joint towns.

Both Weymouth and Melcombe have suffered at intervals from the sea since very early days, but the construction of Portland harbour works and particularly that of Portland breakwater (begun in 1849) has been supposed[1] to have been the cause of altered conditions of tidal currents, shore drift and wave attack, that have resulted in a recent advance of the sea against Sandsfoot Castle and the adjacent coast south of Weymouth, and in the serious erosion experienced towards the northern end of the old shingle bank that shields the partly reclaimed area of Lodmoor marshes north of Weymouth from the sea. Wave advance upon the northern coast of Weymouth Bay was certainly serious in 1854,[2] but at this date it had apparently been in progress for a longer time than warrants the assumption of its being entirely due to Portland breakwater. The local account of a coast road of the time of George III, a road in use for "long after" that reign but by 1854 reported to be as far out as low-water mark, points to an advance of the sea dating back to long before the beginning of the breakwater. This advance has continued, and early in the present century the successor to the

[1] *The Sea Coast.* W. H. Wheeler.

[2] *Min. Proc. Inst. C. E.*, vol. xi. Redman, "On the Alluvial Formations and Local Changes of the South Coast of England."

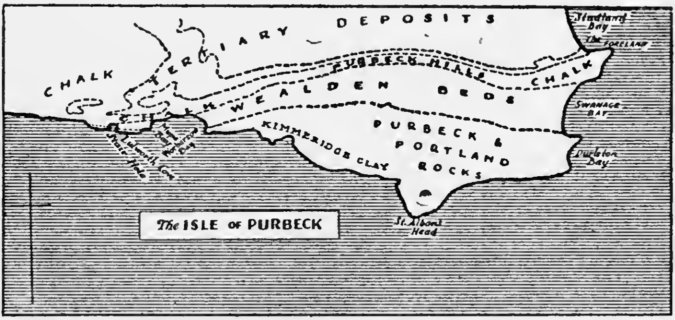
vanished coast road was itself in danger and had to be protected. Erosion here may well have been accelerated by artificial causes, but it would in any case have been experienced sooner or later. The south coast of England suffers from wave advance along its whole length; except in estuaries where silting usually predominates over wave attack, both low-lying and upland shores, whether in bays or on the open coast, of solid rock or recent alluvium, are alike attacked and alike in retreat. Even lands lying below high-water level are not exempt from wave advance, though low-lying shores tend as a rule to become the seat of deposition rather than of erosion—and the coast of the Freshwater and Sandown levels in the Isle of Wight, Thorney marshes west of Selsea Bill in Sussex, the alluvial levels at Lancing west of Shoreham, low-lying lands between Newhaven and Seaford, and in the Cuckmere valley beyond, though they all lie at or below high-water level, share in the recession common to the coastline as a whole. Even within the estuaries the monotony of broadening mud banks is varied by occasional attacks from the sea, like those that damaged the sea-wall at Southampton in 1511, or the storms that periodically drowned large parts of Hayling Island, that flat island—to-day sparsely peopled, but an area populous in the days of King Alfred [1]—which lies east of Portsmouth, and that made it inaccessible at times before the bridge connecting it with the Hampshire coast was built in 1823. Porchester, the Roman port on the inner shore of what is now Portsmouth Harbour, long left deserted behind its mud

[1] *A Topographical and Historical Account of Hayling Island.* 1826.

flats, suffered from the sea's attacks in mediaeval days, and though the growth of saltmarsh vegetation is heightening and widening the mud flats off the New Forest coast, yet marine erosion also occurs and is the more felt from the non-resistant character of the deposits.

East of Weymouth Bay the coast of the so-called "Isle" of Purbeck has been determined in outline mainly by differential wave erosion. The chalk of the Purbeck Hills—a rock moderately resistant to erosion—projects a mile or so seawards in the Foreland between Studland Bay, where soft Tertiary strata reach the sea, and Swanage Bay. The latter occupies the eastern end of the long valley that has been excavated in the relatively soft Wealden beds below the southward-facing scarp of the chalk Purbeck Hills, a valley that now ends on the west in Worbarrow Bay—the western counterpart of Swanage Bay. South of the Wealden beds the land rises where the harder Purbeck and Portland rocks emerge from beneath the Wealden strata and form the plateau, over four hundred feet high, which ends upon the coast in the rugged cliffs and headlands between Swanage Bay and the most southerly point of the coast at St. Albans Head. West of the latter headland the softer Kimmeridge clay that underlies the Portland beds is exposed and the coast recedes and is bordered by low cliffs.

Beyond the actual limits of the Isle itself the geological formations that occur in it are prolonged towards the west in the same order of succession from north to south but greatly narrowed, so that in a strip of country less than half a mile wide chalk uplands overlook a vale of Wealden strata, and this is guarded along the coast by upfolded beds of hard Purbeck and Portland rocks. The narrow band of the latter strata once extended unbroken along the coast but now survives only in fragments. At Stair Hole west of Lulworth Cove the sea has made a narrow breach in this thin rampart of hard rock and has begun to scoop out the softer Wealden beds behind it ; Lulworth Cove has been formed in the same way but has by now reached a more advanced stage of development, since here the waves have worn their way right across the narrow Wealden band and



are attacking the chalk behind it. Mupe and Worbarrow bays, east of Lulworth Cove, evidently had their protecting ridge of Purbeck and Portland rocks breached at a still earlier date. The coastal belt of hard strata has been washed away for a length of one and a half miles and the joint bays form now a long oval open to the sea and flattened on the land side by the relatively slow retreat of the chalk cliffs, compared with that of the Wealden beds. Towards the west the narrow coast band of hard rock survives only in isolated stacks, while the Wealden strata have vanished and the chalk forms the shoreline. Along this part of the coast wave erosion is at present increasing the irregularity of coastal outline, and since it is still pronounced in such inlets as Swanage Bay it may be doing so in other sections of the Purbeck coast.

The coast beyond the Isle of Purbeck and between Poole Harbour and the western entrance of the Solent, is of Eocene rocks that, consisting generally of sands and clays, offer little resistance to wave advance. The only point at which strata relatively hard reach the coast is at Hengistbury (or Christchurch) Head where beds of iron-stone cause the projection of the headland. The cliffs throughout this region seldom exceed a hundred feet in height. A loss of three hundred feet between 1886 and 1900 was noted[1] at the eastern entrance to Poole Harbour, and in other parts of Bournemouth Bay marine erosion has been considerable. Hengistbury Head, liable to landslips and reduced by quarrying, lost four hundred feet between 1847 and 1854[2] and is still being cut back by the sea, while the shores of Christchurch Bay are estimated to recede on the average three feet annually, though at some points the loss has much exceeded this, as along the innermost recess of the bay some two miles east of Christchurch harbour where the average recession for the last sixty years had in 1911 been four yards annually.[3] In 1825, the loss of land towards the eastern end of this bay was described as having been incredible[4] during the previous thirty years, and though the flint-gravel that here caps the cliffs yields

[1] Third Report of the Roy. Commn. on Coast Erosion in the United Kingdom.
[2] Wheeler, W. H. *The Sea Coast.*
[3] Roy. Commn. Coast Erosion, as above.
[4] *A History of Lymington.* D. Garrow. 1825.

quantities of shingle the shore drift sweeps much of this away eastwards to Hurst Castle, and erosion still actively continues. In view of the rapid retreat of the coast it appears at first sight curious that the small streams that reach the shore here and in Bournemouth Bay should do so at sea-level. The chines or "bunnys" by which they gain access to the sea are steep ravines, of formation geologically recent, and it has been suggested [1] that coast recession has at these points led to the intersection of river systems by the retreating cliff line, with a consequent diversion and shortening of the stream which would then fall over the cliff on to the shore at the point of intersection and soon (in such soft rocks) wear itself a steep little valley emerging at sea-level on the beach. The steepening of gradient consequent upon the advance of the sea against the lower ends of streams flowing at right angles to the coast may also here have so accelerated the lowering of their beds that the steep narrow chines, debouching at sea-level, were formed within the gentler slopes of the original and wider valleys.[2]

Wave erosion has on this length of coastline produced smooth shorelines bordering in an even curve lands whose topographic inequalities are slight and now produce no corresponding irregularity in the coastal outline. Higher and lower cliffs recede at so nearly equal a rate that the harmonious curve imposed by the sea upon the shoreline is maintained. The one projection, that caused by Hengistbury

[1] "On the Superficial Deposits of the South of Hampshire and the I. of Wight." T. Codrington. *Q. J. G. S.* vol. xxvi.

[2] "The Chines and Cliffs of Bournemouth." H. Bury. *Geol. Mag.* Feb., 1920.

Head, beyond the smooth outline must at some time be removed, and it appears possible that the Head may become an island through the establishment of a tidal connexion with Christchurch Harbour across the low neck of land that lies just west of the headland. Its entire demolition by the waves would follow.

The Isle of Wight, like the Isle of Purbeck, affords an example of a coast determined in outline by the varying powers of resistance of its rocks. Uplands of chalk form the coastal projections of Culver Point on the east, the Needles on the west and St. Catherine's Point on the south, while bays like those of Freshwater, Sandown, Whitecliff, Alum or Compton occur where relatively soft rocks of Lower Cretaceous or Tertiary age reach the sea.

At the present time wave attack actively continues in the Isle of Wight, aided by the tendency of much of the coast to slip seawards in vast landslides.

East of the Isle of Wight lies the much eroded coast of southern Sussex. A notable point in the wave erosion of this coast is the great and rapid loss of land that has gone on for ages and still continues, a loss particularly marked in those regions that lie to seaward of the raised beach coastline but everywhere apparent. The original Brighton, an important fisher town in Norman times, stood on a strip of coastal plain that then lay seawards of the raised beach coast at this point, a plain which probably extended below the Downs for some miles east of the site of the town even as late as the Roman period.[1] By the Middle Ages an upper town

[1] *Victoria County History of Sussex.*

occupied by landsmen had grown up on the top of the cliffs above the coast plain. The old town on the flat had from very early days suffered from the sea and it was finally washed away in the early part of the eighteenth century—the beach for years after remaining covered with fragments of the ruined walls of its houses. Both before and since the final destruction of the original Brighton the town on the cliff top has been vigorously assaulted by the waves, various portions of it toppling into the sea from time to time—a process checked by the erection and extension of groynes and sea-walls that has gone on here for over two centuries. Local authorities intent upon preserving their own seaside lands seldom pause to consider the fate of the shores lying to leeward of their coast defences. Thus the groynes of Seaford by holding up shingle which would otherwise spread eastward have caused the cliffs as far as the Cuckmere River to suffer an accentuated wave erosion, the coast east of Brighton is denuded of beach by the groynes of that enterprising town and loses at some points as much as five feet per annum—the lengthening of their west pier by the Shoreham Harbour authorities in 1874 caused a lack of beach and consequent erosion at Hove and Brighton—while Shoreham and the lands to west of it have suffered in their turn from a lowering of beach level and an accentuated wave attack as a result of the erection of groynes at Worthing.

The low coast of the plain that west of Brighton still remains in front of the raised beach shoreline, that here follows the southern slope of the South Downs, has suffered from wave attack for many hundred years. Its cliffs, of clay or sand, are only a few feet high and the coast has receded fully a mile since Roman days. At Selsea nearly a mile has been lost since the first cathedral was established on a site now long under the water. Records of losses extend back to very early times and various villages —such as Cudlow, Middleton, Pende, Aldrington—have wholly or in great part disappeared. The site of Middleton church, the graveyard of which was being washed away in 1838, lay by 1911 a quarter of a mile out to sea, while east of Worthing the sea advanced about a hundred yards [1] in the fifty years before the latter date. The continuance of so rapid a coast recession after an advance by the sea of at least a mile within the historic period points to a rapid abrasion of the wave-cut shelf here, though the low and yielding shores would continue to recede behind a breadth of shallow inshore water that would so enfeeble wave attack that the retreat of more resistant cliffs would be checked. The continued and rapid retreat of the coast of the Selsey peninsula is noted as dependent upon the degradation of the soft and easily eroded rocks of the flat foreshore that surrounds it,[2] a wave-cut platform that is being worn down by boring mollusca as well as by wave erosion.

The South Coast of England has suffered extensive loss of land since the period when the raised beaches were formed. Wave erosion still continues. The present coastal outline is determined by the varying powers of resistance of the coast rocks; upland areas and those formed of hard rock project in advance of the general line of the coast. The existing coast seems to be of an outline more irregu-

[1] Royal Commn., Coast Erosion.
[2] *Ibid.*

lar on the whole than was that of the raised beaches, and since wave advance actively continues in bays this irregularity may be increasing. For the greater part of the south coast it is, however, easy to conceive of the ultimate creation of a smooth and broadly curving outline independent of topographic inequalities, an outline such as is apparently already created in the western part of Lyme Bay. Here between the River Axe and the flatter country east of Bridport the smooth coastal outline has ceased to reflect the topographical and geological differences of a hilly and diversified coastal region, a state of affairs that should gradually extend along the whole south coast if the latter follows a normal course of development.

CHAPTER VI

THE SOUTH COAST: (II) SHORE DEPOSITION

BETWEEN the river Exe and Beachy Head much land, as has been seen in the last chapter, has been washed away since pre-glacial times, yet shore deposition has wrought greater havoc than has marine erosion on most of the once famous seaports of the south coast. Porchester, Wareham, Axmouth, Seaford, Shoreham, and many another—busy ports once—lie to-day with their sea-ways choked behind banks of shingle or of mud.

Lands long washed away survive in the sand and shingle deposits that fringe the present coasts. From them much of the existing beach material must have been derived, since under present conditions of its supply and transport such accumulations as the Chesil Bank that stretches for miles west of the Isle of Portland or the great shingle banks that lie before Pagham and Shoreham in Sussex, could scarcely have grown up. Wave erosion maintains to-day a supply which suffices to keep fairly constant the amount of beach material already in circulation on this coast.

Sand and shingle are present on this coastline in quantities far exceeding those that occur further west. Their distribution is, moreover, markedly different from the movement and disposition of shore debris typical of most of the coastline of Cornwall and Devon. The general direction of the longshore drift of sand and shingle is on the south coast from west to east, following the direction of the flood-tide, prevalent winds and heaviest seas. Only exceptionally is this direction reversed, or the eastward drift stopped by natural obstructions. Along great lengths of coast shore debris travels predominantly in one direction and the land is fringed by a continuous belt of shingle beach, drawn possibly from distant sources and destined to travel equally far—beach that, constant in area and position, is yet made up of pebbles continually withdrawn and renewed. These less-resistant coasts of smooth and flowing outline are separated by lengths of uplands and hard rock where the shore conditions of Devon and Cornwall are reproduced. Between Lyme Regis and the Exe, headlands, such as Otterton Point or Beer Head, obstruct the even flow of shore drift so that the bay beaches at Budleigh Salterton, at Sidmouth, or across the mouth of the Axe, are each to a considerable extent distinct from its neighbour and have been created mainly by local and independent systems of longshore drift. From Lyme to Portland shore waste, checked but not completely stopped by the high blunted headlands of Golden Cap and Thorncombe with their projecting reefs, travels eastward until, where Portland Island projects its diminishing wedge athwart the littoral currents, its further progress is barred. No shingle succeeds in passing Portland Bill, though the tidal current round the end is swift enough to transport coarse gravel. This is accounted for by the presence of a counter-drift, induced by the island, which tends to carry debris away from the Bill and northwards along the west coast of the island till it meets the eastward-moving drift off Chesilton. East of Weymouth and in the lee of Portland Island another counter-drift follows the shore of Weymouth Bay and transports sand and shingle west and south towards Weymouth, while beyond, the indented coastline of the Isle of Purbeck gives rise to local and independent systems of shore drift. East of Poole the local drift in the west of Poole or Bournemouth Bay sets, like that in Weymouth Bay, from the east while the normal movement from the west common to the rest of the bay is checked at Hengistbury Head, where hard rocks break the even line of the coast and act as a partial natural groyne. From Hengistbury Head to the entrance of the Solent the main littoral drift once more follows a smoothly curving shore and travels towards the east.

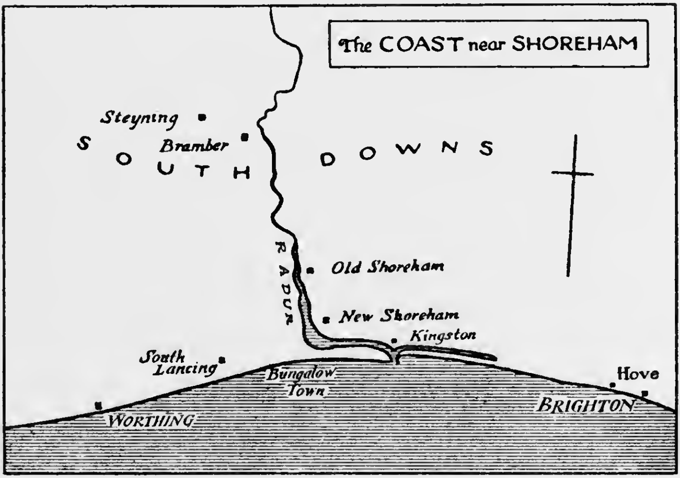
Beyond the shelter of the Isle of Wight, behind which occur exceptional conditions, the coast of Sussex is fringed by shore deposits everywhere moving eastwards towards Beachy Head except where west of Selsea Bill the longshore drift travels north and west towards Chichester, and where a counter-drift, induced or accentuated by Newhaven breakwater, sweeps shingle away from the coast west of the coastguard station near Seaford and toward that channel port with the New Haven that superseded in the sixteenth century this once-important member of the Federation of the Cinque Ports. The Isle of Wight, which is cut off from the littoral drift and detritus of the mainland coasts has, like the region between Lyme Regis and the Exe, no uniform system of shore drift.

East of Lyme the south coast is then, apart from some minor exceptions, of smooth and evenly curved outline and bordered by freely drifting shore waste except at the Isle of Portland, on the Purbeck coast, and in and behind the Isle of Wight. The coasts of the Solent and Spithead are unique in the south of England. Sheltered behind the Isle of Wight, cut off by Hurst Castle shingle spit at the western entrance of the Solent from all longshore drift from the west, and largely bordered by mud which unlike shingle is affected by no definite movements of longshore drift, these low-lying shores have little or no regular travel of debris along them and retain in great part their initial irregularity of outline.

The smooth outline and unobstructed shore drift of much of the south coast has resulted in a widespread distribution of beach deposits, which everywhere border the coast except in those areas, specified above, which are characterized by the irregularity of outline and discontinuity of longshore drift, the naked headlands and bay beaches, typical of coastlines in an earlier stage of development. Harbour and coast defence works induce, however, in several places an artificial scarcity of beach to leeward.

The condition of river outlets is, as has been noted for the Cornish and Devon coasts, some indication of the stage of development attained by the coast on which they occur. Of the south coast streams and rivers the only one of any size that follows a straight and undeflected course at its outlet is the Lymington River which, flowing past Brockenhurst in the New Forest, enters the Solent at a point where, for reasons which will appear later, longshore drift is non-existent. Practically all other river outlets between the Exe and Beachy Head are deflected, partially closed, or blocked by sand or shingle banks.

Budleigh Salterton in South Devon was a wool port once, but the haven of the Otter estuary was " clene barred " when Leland wrote in the middle of the sixteenth century, and to-day the Otter is pressed against the cliffs of Otterton Head by a great bank of shingle that extends from the western shore. Further east the Axe is similarly deflected and Seaton, a port of some little note in the adventurous days of Edward III, is shut in by the inevitable shingle spit. The little Char east of Lyme Regis is bent eastward at its mouth. The Avon estuary on which stands Christchurch is nearly closed by sand and shingle spits. The Beaulieu, the Hamble and the Meon, streams of the Solent and Southampton water, have their low-water channels deflected east or south, while the four Sussex rivers are all shingle barred and their outfalls have had as many vicissitudes as have the once noted ports dependent on them. These streams and rivers are all deflected by the predominant longshore drift of debris, but they still in most cases maintain an open though variable channel to the sea. The Dorset Axe and the Sussex Cuckmere are both, however, liable to be choked temporarily by the extension of the shingle banks right across their outlets. A few streams are entirely closed by shingle, through which they percolate naturally or outfall by artificial means. Of such is the Sid in Dorset—a little river only some six miles long whose estuary nevertheless afforded good shelter between its red sandstone cliffs to the vessels of the thirteenth century and supported the port, borough and market town of mediaeval Sidmouth. The Brit and its two tributaries that unite below Bridport, and into whose tiny estuarine harbour schooners have to-day to be dragged with ropes by an artificial cut through the shingle banks (and Bridport once was noted for shipbuilding), are similarly choked, as is the little



Bride that flows past Burton Bradstock on the east to leak invisibly out to sea through masses of shingle.

From right across the Sussex Weald the river Adur flows past Bramber through the South Downs to the sea at Shoreham. The Roman Portus Adurni may have stood at its mouth—some antiquarians deny this, but, as Hilaire Belloc says, everything is denied. The Adur was certainly possessed of an estuary navigable far inland until long after the Roman roads to London were left silent and neglected amongst the Wealden oak woods. As late as the time of Edward the Confessor the harbour, now long vanished, of St. Cuthman's Port stood near Steyning on the north side of the river gap through the Downs. The subsidence of this coast in the Neolithic period, which affected the land for perhaps ten miles[1] from the sea, was responsible for the formation of the long tidal estuaries that once penetrated inland into the Sussex Weald—estuaries now silted and replaced by marshy flats below high-water level, though the tides still ebb and flow in the Ouse above Newhaven and in its tributary Glynde Reach to a point some miles north of the Downs.

Old Shoreham stands north of New Shoreham on the Adur estuary. It was an important seaport in Saxon days, but in the early twelfth century, about the time that the bridge at Bramber was built—and such an obstruction to navigation would no doubt not have been permitted unless the river above was already become nearly useless—Old Shoreham found its own accessibility so decreased that its seafaring activities were transferred to a site nearer the sea and the port began life afresh as New Shoreham. The shingle bars that are recorded as having led to the obstruction of the Old Shoreham harbour must have accelerated the silting of the river higher up at Bramber.

The great shingle banks west of the deflected river mouth that to-day support Bungalow Town in a charming but precarious position between the estuary and the sea are apparently relics of a high shingle beach that, in the time of Elizabeth,

[1] *Submerged Forests.* C. Reid.

stretched between Littlehampton and Brighton, enclosing behind it a long backwater. This beach must have lain seawards of the present coast, with which those parts of it still remaining have receded landwards. In the sixteenth and seventeenth centuries a spur of land, no doubt of marine or alluvial deposits, which had apparently deflected the Adur outfall eastwards, was gradually reduced to tidal marsh and washed away. With it vanished, as is supposed, the lost village of Pende. Its erosion may imply some temporary failure in the supply of shingle from the west, during which period of shortage the materials of the existing banks would gradually be removed towards the east and leave alluvial lands, formerly sheltered behind them, devoid of protection. Or it may have been due to normal coast recession. A map of 1698, however, shows that a shingle bank had by then once more deflected the river eastwards, and that behind it lay marshlands on the west side of the land-locked estuary. At about this date began the reclamation of these marshlands on the windward shores of the deflected river outlet—reclamations similar to those carried out to windward of the Exe, the Otter, the Axe, and the Ouse at Newhaven, and to that of the Lodmoor marshes north of Weymouth. The eastward deflection of the lower reach of the estuary and the general tendency for the river channel to move away from its western shore, while admitting of reclamation to windward, involved an accompanying erosion of its leeward or east bank. Thus Old Shoreham and its later successor both suffered at intervals during their long history from tidal inundation. Old Shoreham appears to have lost some seven hides of land between the days of Edward the Confessor and the compilation of Domesday, while New Shoreham is described by Camden in the reign of Elizabeth as being mostly drowned.

To-day the great shingle banks that for century after century have lain in shifting masses along the inmost bight of Shoreham Bay reach from west of Lancing to near Hove. Through them the Adur has made its instable outlets. For some time prior to 1760 the river escaped opposite New Shoreham, its deflected course of 1698 being by now abandoned for a straight cut out to sea. Shortening such as this of a river's course occurs generally in time of storm, when the waves may breach the deflecting shingle spit towards its windward and usually relatively narrow end, and the flood-waters from inland seek at the same time the most direct outlet to the sea. In 1760 a new opening was made artificially opposite Kingston and near the earlier exit, and from this date onwards the river outlet, impelled by the lengthening of the western shingle spit, moved east until by 1810 it lay south of Portslade. The old outlet opposite Kingston was reopened in 1816 and harbour works were constructed in 1821 to make it permanent, the backwater stretching behind the shingle eastwards to near Hove being subsequently converted into docks. Such fluctuations of the river mouth—which was occasionally quite choked with shingle—must have taken place ever since the eastward-travelling shingle found temporary lodgement in the great banks that fringe this slightly embayed shoreline. They were a constant embarrassment to the port of Shoreham since the river gap through the shingle was liable to changes of disconcerting sudden-ness, and it was in spite of many difficulties that Shoreham even in the palmy days of its shipbuilding activities in the early Middle Ages, and again in the prosperous times of the seventeenth century, maintained its reputation and trade.

At the present time the river outlet is restrained from its wanderings and artificially retained opposite Kingston. The western of the two piers which stand on either side of it has caused a great accumulation of shingle to windward. This shingle would normally long ago have drifted eastward and pushed the river mouth before it, and by now it has so increased that some is at last drifting round the end of the pier and obstructing the harbour to some extent as in the good old days when the "Dover," built at Shoreham in 1654, could scarcely be got out to sea through the encumbering banks. Thus if no preventive measures were taken here the natural instability of the river outlet might be resumed and it might yet fluctuate, as in early days, between Lancing and Hove. The shingle trapped by the west pier is badly needed to protect the eroded coast east of Shoreham. In its present position it is a nuisance to the port authorities and has been exported even as far as to South Africa.[1]

Shingle on this coast, in common with other banks on a receding shoreline, is moving inland. Between 1875 and 1891 the bank opposite Lancing travelled landward distances varying in different localities from seventy to three hundred and twenty feet.[2]

[1] Mr. A. J. Catt, Harbour Master of Shoreham, informs me that some 90,000 tons of shingle are annually removed from west of the harbour and between the piers, the greater part of which is dumped on the depleted beach east of the harbour.

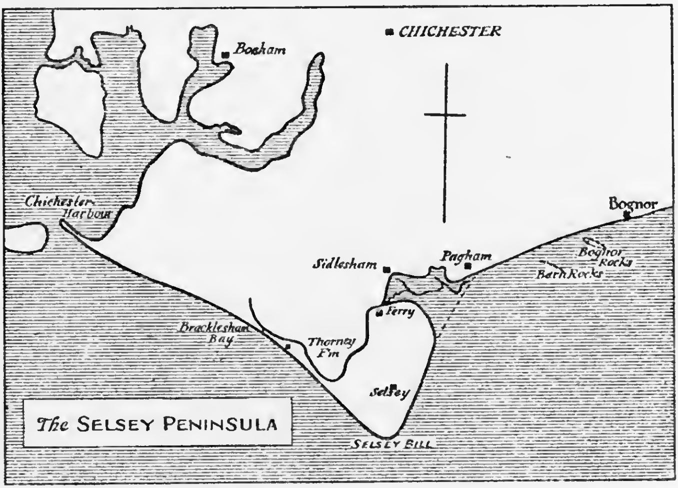
[2] Wheeler W. H. *The Sea Coast.*

Storm waves carry shingle up the sea face of the great bank, and overtop it occasionally at a low-lying part. This occurred in 1899 when lands below high-water level were flooded at Lancing, and at Shoreham in 1913. Then the surface shingle is swept inwards and with it go any of the bungalows of Bungalow Town that happen to be in proximity and that have not had the forethought to anchor themselves by piles to the deeper and undisturbed layers of shingle.[1] Both sides of Shoreham Harbour this landward movement of the shingle bank goes on, though the planting of a tamarisk hedge along the summit has done much to trap the shingle, heighten the ridge and restrain the pebbles from extending inwards. It seems, however, inevitable, that, soon or late, the natural tendency of the shingle to travel eastward must reassert itself here in spite of artificial obstructions, and, since the coast on either side of the Adur shingle continues to recede, that the gradual rolling over and displacement of the banks towards the land must prevail in the end.

Wider estuaries, where low-lying lands of some extent were submerged in the Neolithic subsidence, are on the south coast generally partly closed by spits that have grown from either side of the entrance and approach each other as nearly as the increased tidal scour in the narrowing channel will permit. Chichester, Langstone, Portsmouth and Poole harbours are thus partly enclosed. Southampton Water and Weymouth Harbour, with the Calshott shingle spit at the entrance to the former, and the ancient bar north of the latter that now protects the Lodmoor marshes from the sea are both narrowed by

[1] *Tidal Lands.* A. E. Oliver and F. W. Carey.

one spit only. All these estuaries have long and eventful histories; and full of interest is the story of their gradual silting, of the glories and disasters and sad eighteenth-century decay of towns like Weymouth and Melcombe Regis; Wareham and its successor Poole; Southampton; the Roman Porchester; Chichester, once the headquarters of Vespasian—but the silting of wide and shallow bays may with more profit be dealt with in the section on



The Selsey Peninsula

Romney Marsh and the south-east coast, while a discussion of the growth of sand spits across estuaries will be reserved for the account of the Humber and Spurn Point. One little drowned bay in Sussex may, however, be briefly considered here. Pagham Harbour lies on the eastern side of Selsea Bill and once formed part of a tidal strait that separated the then island of Selsea from the mainland. When the Venerable Bede described the region in the seventh century this strait was silted through the agency of shore drift at its western outlet in Bracklesham Bay, so that what he calls the peninsula of Selsea was by then accessible across a narrow neck of land on the west. By Domesday all the former strait had become silted except the eastern end, where a shallow tidal bay, larger than it is now, occupied the site of the present Pagham Harbour. Various historical authorities state that Pagham Harbour was formed by a sudden irruption of the sea shortly before the middle of the fourteenth century. If it is correct that the harbour was reopened then it follows that the area had since the Norman Conquest become silted and subsequently been reoccupied by the sea exactly as has occurred in recent times.

Records and maps of the region show that the tidal area was increasingly lessened by silting and reclamation. In 1587 forty-ton boats could reach Sidlesham, now a mile and more inland. By the early nineteenth century the upper ramifications of the estuarine bay were all reclaimed and the shingle bank, some three miles long and two hundred to three hundred yards wide, that must since very early days have stretched more or less completely across the entrance, had temporarily almost closed it. Subsequently the harbour, that could never have been of any great usefulness, was itself reclaimed. By 1879 its site was occupied by pasture land, behind a sea-wall (which followed the course of an earlier embankment) and the protecting bank of shingle. Thus man took advantage of natural tendencies, accelerated and, as then appeared, made permanent the substitution of land for water in this shallow inlet.

In 1910, however, sea-walls notwithstanding, coastal evolution here resumed its normal progress and gave violent illustration of the general law that land reclaimed by marine agencies is always liable to be retaken by the sea. During a heavy gale in December of that year the sea burst through the shingle banks which defended at Thorney the western end of the old tidal strait. Simultaneously the waves broke suddenly with a great roar through the Pagham shingle spit, and by the end of an hour had deeply overflowed some fifteen hundred acres and had reached a high bank at Ferry, against the other side of which lapped sea-water spread from the Thorney breach along the marshlands of the former strait. So Selsea was once more an island save for this one bank between Sidlesham and Ferry. The waves broke through Pagham shingle bank at a point where it was low in height and which lay to windward of the Pagham Harbour Company's defence works at the former mouth of the harbour. The breach was widened during succeeding days and the great outrush of water during ebb-tide soon scoured away the shingle and exposed the underlying clay. A fortnight after the storm the shingle banks at Thorney were already being rebuilt by the waves, and the land between here and Ferry has subsequently been once more reclaimed, but Pagham Harbour has been allowed to remain a tidal inlet. As a result the lowlands reaching from Pagham far inland towards Chichester are now in some risk of inundation, the sea having already broken through one line of defence between Sidlesham and Pagham. The inundation of Pagham Harbour is an illustration of the well-known fact that one great storm may undo the work of years of normal coast development and cause havoc never entirely repaired.

A minor point of interest was the formation, after some months, of subsidiary spurs of shingle[1] on either side of the gap through Pagham bank—that formed by shingle drift from the west curving seaward from the west end of the main bank, that due to tidal inflow and derived from the bank east of the gap running in towards the harbour from the eastern boundary of the breach. These smaller spurs afford a good example of the overlapping of deposition features—that due to the predominant drift from the west lying seawards of the spur formed by a local counter-drift.

The vicissitudes of Pagham Harbour considered in careful detail would involve many theoretical problems, and cast, no doubt, valuable light on the course of coastal change elsewhere, yet the complicated history of the region is but an incident in the ultimate removal by the sea of the whole Selsea peninsula.

Similar in many respects to the Pagham bank is the Chesil Beach, the largest shingle accumulation of its type in Europe, which extends from near Bridport to the Isle of Portland. Its length is given by different authorities, who, no doubt, choose differing spots for its point of commencement on the west, as anything from ten to eighteen miles. It rises at its highest point at the eastern end to a height of thirty to forty feet above high-water mark of spring tides, whereas such shingle banks as a rule do not exceed ten feet in height. From Bridport as far east as Abbotsbury the beach lies along the shore, but beyond this point it forms the seaward bank

[1] For an account of these banks I am indebted to the Rev. G. G. Knox, of Pagham.

of the Fleet, where it replaces the vanished south-western side of what was once a partially submerged river valley and is now a tidal lagoon. The irregular landward coast of the Fleet shows no signs of any past exposure to serious wave attack,[1] wherefore it would seem that the Chesil Beach must have been in existence before the valley wall was finally washed away and that it must have moved landward as the latter was cut back by the waves until, the last strip of land intervening having been removed, it abutted directly on the waters of the Fleet which it continued to shield from direct wave action as had the formerly existing land slope. Beyond the East Fleet the mainland coast bends sharply north-east, but the Chesil Beach continues upon its course, and, deserting the land, spans the two miles of open sea between the Isle of Portland and the mainland, ending in Chesil Bay on the north-west coast of the island, which it thus unites to the land.

This great bank of shingle has, like Pagham bank, remained unchanged in its general characteristics for centuries. A balance must therefore have been reached between the supply of fresh shingle to the beach and that removed from it, and since the littoral movement of detritus here, already described, makes impossible the escape of shingle alongshore from either end, probably the only wastage that has to be made good is that due to the slow attrition of pebbles and the ultimate removal of the waste in a fine condition by wave action. The small amount of loss from the Chesil Beach is balanced by a correspondingly small supply of shingle since at the

[1] *Mem. Geol. Survey: I. of Purbeck and Weymouth.* A. Strahan.

present day few pebbles, and those very small, drift round the headlands of Golden Cap and Thorncombe from the west,[1] and the supply to the beach from quarries on Portland Island is small.

When the Chesil Beach was growing the coastal outline and conditions of shore drift must have been different from those of to-day. The shingle consists largely of flint pebbles derived from gravel beds that must once have occupied the surface of lands now washed away, and there are included in it many pebbles from Budleigh Salterton beach. It seems probable then that this great accumulation is a heritage of the drowned lands of Lyme Bay[2] and that it grew up when shore drift moved freely from the west along a straighter coastline than that of to-day. Here then wave erosion, in scooping Lyme Bay out of the raised beach coastline, has caused an interruption in the former more unbroken sweep of longshore drift.

Changeless though it appears the Chesil Beach is moving. The great bank is slowly advancing landward, encroaching on and narrowing the waters of the Fleet—rolling over on itself like the Shoreham bank and moving faster probably at its eastern than its western end.[3] Its invasion of the Fleet is aided by the flow of pebbles induced down the landward slope of the beach by the percolation of water at high-tide through the bank to the surface of the backwater, some ten feet below the level of the open sea at that time.[4] Moreover, like other banks of shingle the Chesil Beach is liable to sudden failure as a coast

[1] Vaughan Cornish. "On Sea-beaches and Sandbanks." *Geog. J.* vol. xi.

[2] *Mem. Geol. Survey: I. Of Purbeck and Weymouth.* A. Strahan.

[3] *Ibid.*

[4] *Tidal Lands.* A. E. Carey and F. W. Oliver.

defence and the security of years may be upset in an hour. In 1824 during a great storm the villages of Chesilton and East Fleet were largely swept away with many of their inhabitants, the sea having burst over the Chesil Beach and flooded the area behind from Abbotsbury swannery to Portland. One ship at least has been carried clean over the high ridge of pebbles from the shrieking welter of waves and shingle on the fatal lee-shore of " Deadman's Bay " into the calm waters of Portland Harbour.

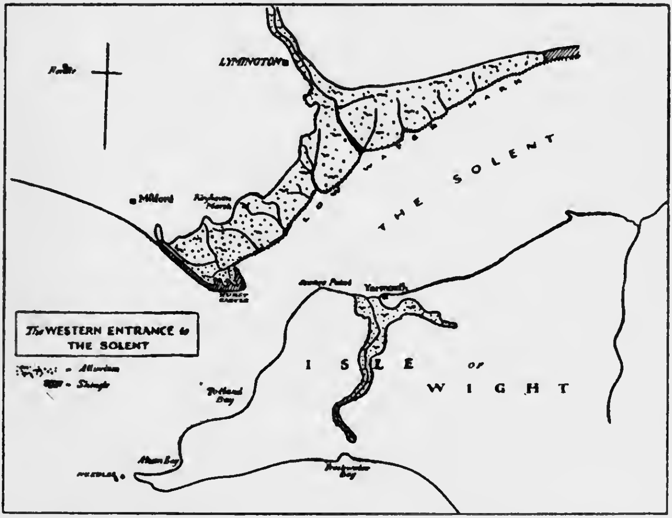
It has been suggested[1] that formerly the Chesil Beach joined Portland Island at its southern extremity, at a time when, no doubt, the mainland coast lay much further out than it does now. The extension of the shingle bank from the mainland towards Portland may have been determined, supposing it to have been formed after the insulation of the latter, by the inability of the waste-burdened littoral current, following the coast from the west, to adapt itself to the sudden change of direction that here occurs in the mainland coastline. The shallowness of the area behind the island and the interference of the latter with the flow of the tidal streams would also tend to the deposition of sand or shingle between it and the mainland. The Portland Beach, which lies east of the Chesil Beach and carries the road and railway that have replaced the former ferry from the mainland, has been formed by shingle drift moving northwards along the east coast of the island. It has so far failed quite to reach the mainland and the outlet from the Fleet is crossed by a bridge. If the future fate of Portland resembles that of other such " tied

[1] *Mem. Geol. Survey: I. of Purbeck and Weymouth.* A. Strahan.

WEYMOUTH BAY FROM THE NORTH, SHOWING THE SHINGLE BEACH SEPARATING THE MARSHY AREA OF LODMOOR FROM THE SEA—WEYMOUTH IN THE DISTANCE

CHESIL BEACH FROM TOUT QUARRY, WEST CLIFF, PORTLAND, DORSET. THE CHESIL BEACH OCCUPIES THE CENTRE OF THE PICTURE ENCLOSING (IN THE DISTANCE) THE LAGOON KNOWN AS THE "FLEET." THE ENTRANCE TO THE FLEET IS PARTIALLY CLOSED BY THE PORTLAND BEACH

islands " it may become more broadly united with the land as silting proceeds under its shelter and that of the two shingle banks of the Chesil and Portland Beaches. Meanwhile its own area must be steadily lessened by wave attack, and the alluvial area behind it might well survive for a short time the entire disappearance of the island. The normal processes of coast erosion and deposition have how-



ever been modified in this region by Portland Harbour works.

One more typical form of shore deposition on the south coast must be briefly noted. The Hurst Castle and Calshott shingle spits which project, formed of mobile masses of loose pebbles, far out into the swift tidal streams of the Solent and Southampton Water present many problems, but here only the most typical characteristics of one of these spits—that of Hurst Castle—can be considered. This remarkable shingle spit, with the narrow neck and broad end so characteristic of such formations, projects boldly into the sea, for a distance of one and a half or two miles, from the extreme eastern end of Christchurch Bay. It continues the general line of the coast to windward and resembles the Chesil Beach (and many another shingle accumulation) in that deep water lies close inshore on its steeply sloping seaward side, and the height of the shingle ridge and size of its constituent pebbles increases as the seaward end is approached.

For many centuries the spit has in size and position suffered no substantial permanent change, so that accretions of fresh shingle must, now that the period of growth is over, be balanced by wastage from the spit. Possibly surplus shingle finds its way on to the Shingles shoal, which extends from Hurst towards the Needles and was in 1908 thought to be still growing south-westward.[1] The position and curvature of the narrow neck of the spit are obviously related to those of the coast of Christchurch Bay—shingle drift from which, maintaining a course in line with the coast, has created the whole spit. As growth continued outwards the lengthening bank became increasingly affected by the tidal streams through the Solent, which began to impose a check on further extension athwart their course. Shingle travelling along the narrow straight ridge from the mainland coast could no longer maintain its course but was drifted inwards towards the Solent by the inrush of the flood-tide. Thus grew up the success-

[1] *Channel Pilot.* Tenth Edition. Part I. "South Coast of England."

ive landward-pointing hooks, enclosing between them tidal lagoons of mud and marsh—hooks created by successive accretions of shingle following in each case a more broadly curving course overlapping that of pre-existing deposits. Hooks of this type owe their preservation to their sheltered position in the lee of the main bank. The ebbing tidal stream here forms only minor deposition forms. It can bear with it no load of shingle from the muddy Solent shores, but may re-arrange material at the end of the main spit. The Hurst Castle spit, or rather that disposition of shore currents which has created it, interposes a barrier between the longshore drift of Christchurch Bay and that eastward movement of mud and fine pebbles which takes place along the New Forest shores beyond Lymington. No shingle under normal conditions passes the point of Hurst spit, and under its shelter the Lymington river as we have seen flows undeflected to the Solent through wide mud banks. Occasionally, however, conditions are abnormal, as in the famous storm of 1824, when the Hurst spit was shifted bodily some forty yards up the Solent, its clay foundations exposed, and shingle, from the wave-battered spit itself or the coast to windward of it, was strewn over the marshes round Lymington. This occurrence and the rapid reversion of the spit to its old site prove that its stability of position is due in no wise to any peculiarly resistant qualities possessed by its constituent materials or inherent upon its shape, but solely to the local conformation of the coast and the set of its inshore currents.

The future of this singular bank depends mainly upon that of the coast to windward. Any considerable change in the rate of erosion here would be reflected by a growth or shrinkage of the spit, which besides must continue to follow a course according in direction with that of the coast from which it springs. A modification of the system of shore drift, or the exposure upon the coast of rocks of different character from those now forming the cliffs of Christchurch Bay, may also induce renewed extension or a diminution of the Hurst spit. Similar results may be brought about by alteration, consequent upon coastal changes, in the violence of wave attack upon the spit itself. Like the Northam pebble ridge of Bideford Bay, Hurst Castle may become joined to the land by silted marsh flats. One thing is certain—that on a coast whose outline has been determined by wave action such spits as this will have no more place than the irregularities in coastal outline to which they owe their origin.

Shore deposition along the south coast is in harmony with the yielding character of the greater part of the coast rocks. The extensive recession of the coast has supplied masses of sand and shingle, and the creation by the waves of smooth lengths of shoreline has ensured its widespread distribution. Only in a few areas where—owing to the resistance of relatively hard rocks or to an unusual degree of shelter—coastal development has been retarded do there occur conditions, such as absence of beach and discontinuity of shore drift, common to a stage of coastal development less advanced than that of the greater part of the south coast. In such areas alone do conditions here approximate to those obtaining in the south-west.

CHAPTER VII

EAST ANGLIA AND HOLDERNESS: (I) EROSION

BETWEEN the cliffs of Flamborough Head and the coast immediately south of it, where the chalk of the Yorkshire Wolds ends along the sea, and the chalk cliffs at Hunstanton which extend for rather more than a mile along the north-eastern shore of the Wash, lie ninety miles of coastline everywhere consisting of soft and recent deposits of glacial drift, alluvium or blown sand. East of Hunstanton low-lying marshlands, sand-dunes and shingle banks again border the coast, bounded by chalk hills on the landward side, as far as Weybourne where begin chalk cliffs that extend to Sheringham. Beyond the latter town chalk appears only on the shore below the cliffs, and still further east, just beyond Cromer, it ceases to outcrop between tide-marks, and both cliffs and foreshore are made up of soft Pliocene and glacial deposits. Save for these brief appearances of the chalk strata upon the coast of East Anglia the shoreline between the Thames and Flamborough is formed of boulder clay, glacial sands, the soft formations of Pliocene age known as "crag," and in southern Suffolk and Essex of London Clay where the actual shore is not fringed by wide flats of alluvium. Where the coastline is bordered by cliffs they are nowhere south of Flamborough Head of any great height and except


The EAST COAST
Flamborough Head
YORKS WOLDS
Hornsea
HOLDERNESS
Spurn Point
THE HUMBER
LINCOLN WOLDS
THE WASH
Hunstanton
Holkham
Weybourne
Sheringham
CROMER
Mundesley
Happisburgh
Horsey
Winterton
NORWICH
Gt. YARMOUTH
LOWESTOFT
Southwold
Dunwich
Thorpe Ness
Aldeburgh
HARWICH
Walton on Naze
R. THAMES

in north-eastern Norfolk, where they rise to some two hundred and fifty feet from somewhat west of Cromer to beyond Mundesley, seldom reach a hundred feet above sea-level and are generally of considerably lower altitude. Great lengths of the coast, as will appear later, are low-lying and in many places lands below high-water level are only secured from inundation by natural or artificial banks. Between the Thames and Flamborough Head the coastline is from the character of its rocks incapable of seriously resisting wave attack, and except in Lincolnshire and northern Norfolk wave advance is pronounced and has been very considerable in the past.

Along the inland boundary of the boulder clay of Holderness, that southward-pointing lowland peninsula that is enclosed between the Yorkshire Wolds, the Humber and the North Sea, an old coast has, however, been discovered in a line of pre-glacial cliffs and beaches that follow the lower seaward slopes of the chalk Wolds and reappear in Lincolnshire lying along the eastern border of the Lincoln Wolds. Holderness and the marshy lands on the open coast of Lincolnshire thus lie like the coast plain of Sussex to seaward of an ancient shoreline. Elsewhere this pre-glacial coast has not been located.

In the early days of the New Stone Age East Anglia and the land as far north as Flamborough Head were joined to Europe by a swampy plain lying where is now the southern bight of the North Sea. The depression of the land that subsequently took place caused the sea to encroach an unknown distance upon this plain, so that it is impossible to be certain where lay the eastern English coastline at the close of the period of subsidence. It may have stood five or ten miles seaward of its present position. From the Thames to Flamborough Head the coastline of to-day must therefore be but the latest and most westerly of a succession of coastlines that, each characterized by an outline and form peculiar to itself, must have gradually developed from and merged into each other as the North Sea gained upon the land.

Historical records of the advance of the sea are numerous but naturally relate chiefly to those parts of the coast adjacent to towns. Many villages and townships have been washed away in Holderness. This region consists of a low-lying area of glacial drift—formerly largely covered with meres and marshes—that has been deposited on the sloping chalk floor of a bay that formerly stretched as far inland as the Yorkshire Wolds. The cliffs are low—the highest point on the coast reaches only a hundred and forty-six feet above sea-level—and their base is washed by the sea at high water. This area is estimated to have lost to the sea one hundred and fifteen square miles[1] since the excursions of Julius Cæsar in our island, at which time the coast lay two and a half or three miles seaward of the present shoreline. Lack of space forbids an account of the piecemeal destruction of villages and fields that has gone on along this coast. Those seaside settlements that remain to-day do so only by virtue of their capacity for growing westwards as fast as the sea has washed away their eastern portions—or because they were originally inland and have only recently attained the

[1] "Coast Erosion," E. R. Matthews. *Geog. J.*, vol. xxviii.

doubtful advantage of a sea-frontage. Thus the existing Kilnsea takes the place of an earlier township, the last house of which was destroyed in the eighteenth century. Hornsea about the time of Elizabeth stood a little way inland up a creek, yet the present town, like Kilnsea, has retreated before the sea to its modern site. The intermittent erosion that accompanies deposition in estuaries has in the Humber been responsible for the loss, among that of other towns, of Ravenser, or Ravenspur, and Ravensrodd, noted ports in the time of Edward I that stood on alluvial deposits off the present Humber coast of Holderness near Spurn Point.

No notable permanent advance of the sea during the historic period is recorded along the Lincolnshire coast or that of northern Norfolk, where the sand dunes at Holkham had been formed before the coming of the Danes[1]. The north-east of Norfolk has, however, for long suffered losses probably nowhere exceeded along the English coastline, and from somewhat east of Weybourne as far as Happisburgh, and to a lesser degree on to Winterton, the sea's advance has been great and has resulted in a flattening of the north-eastern bulge in which Norfolk here projects into the North Sea. Like that of Holderness it is estimated that this coast has retreated between two and three miles[2] since the Roman period, and besides several villages the town of Shipden, a mediaeval port when Cromer was still an inland village, has been washed away, while Cromer itself has suffered great losses and has only maintained its existence by retiring inland.

[1] Shelford, W. "On the Outfall of the R. Humber." *Min. Proc. Inst. C.E.*, vol. xxviii (discussion).

[2] *Victoria County History of Norfolk.*

South of this region of maximum recession accretion has in many places checked the waves' advance but between the areas of shingle and sand deposit much land has been lost in the historic period. Easton Bavent—between Lowestoft and Southwold—was once a projecting cape. It now forms part of a straight length of shore and lies perhaps two to three miles westward[1] of its position in the time of the Romans. To the south lay Dunwich, a great port in the days of Edward the Confessor and a flourishing city in the earlier Middle Ages, although it had already begun to fall into the sea. The waves washed away street after street, encroached upon the Market Place, destroyed by 1702 the Town Hall, and in the middle of the eighteenth century the city—long fallen from its proud estate—was represented by but a few " mean buildings " that harboured about a hundred inhabitants.[2] By 1816 only forty-two houses and part of one of its many churches were left; in 1919 storms removed all but half of the western tower of this last church of old Dunwich, which is now entirely washed away. A village with a new church still perpetuates some way inland the name of the ancient city. The failure of Dunwich to retain, retiring landwards meanwhile, something of its former glories was probably due to the same factors as caused the decay of so many of the mediaeval ports. In addition to its destruction by the sea it had to contend with the choking by littoral sand drift of the creek which formed its haven on the north, and, as was also usual, with the perversity of its neighbours. The men of Southwold cut an out-

[1] Redman, J. B. " The East Coast between the Thames and the Wash Estuaries. *Min. Proc. Inst. C. E.* vol. xxiii.

[2] Gardner, Thos. *An Historical Account of Dunwich.* 1754.

let for the haven through the sandbanks and near their own town in 1590, an operation that is noted as having been performed " disagreeable " to the men of Dunwich and to their great loss.[1] In spite of this want of neighbourliness, Southwold has built sea-walls and outlived Dunwich, by virtue of a popularity for sea-bathing that was not quenched even by the advice of a writer in 1839 that bathers at Southwold should on no account fail to immerse all parts of the body at once.

The town of Aldeburgh, still further south, has again had to retire before the sea, a process checked with what threatened to be disastrous results to their prosperity when the migrating townsfolk reached the limits of the municipal property. The town lay once a quarter of a mile seaward of the present shore, and in 1559 there were sandhills or " denes " between it and the sea. Fortunately its adoption as a watering-place was rendered less adventurous by the growth of sandbanks which protected it from violent wave attack, and early in the nineteenth century it had built a " magnificent promenade more than a quarter of a mile in length " and was letting lodgings at the rate of 7s. each room per week.[2] By 1861[3] the sea was, however, again encroaching here, and in recent years the waves have at times overtopped the shingle banks and, as in 1898, damaged the town severely.

Harwich, or rather its southern extension of Dovercourt, has suffered from considerable wave erosion, as might be anticipated from its position immediately

[1] Wake, R. *Southwold and its Vicinity.* 1839.
[2] *Aldborough Described.* (Ipswich, 1820 ?)
[3] Walcot, M. E. C. *The East Coast of England from the Thames to the Tweed.* 1861.

south of an estuary which stops the inshore travel of shingle from the north that is so marked a feature south of Aldborough. Walton-on-the-Naze has also had its vicissitudes, and was except for four houses at one time washed away. But from here south to the Thames accretion has predominated over erosion and land has on the whole grown seaward.

Thus between Flamborough Head and the Thames the coast of Holderness and that of eastern Norfolk and Suffolk have retreated miles since the last change of sea-level, while the low coast lands of Lincoln, north Norfolk, and Essex have, though liable to temporary inundation by the sea, so far from retreating grown out seawards owing to the deposition upon them of shingle, sand and alluvium.

The advance of the sea continues unabated—except where checked by artificial means—along the lengths of eroded coastline. It has in many cases tended to increase in rapidity, since with the era of road-making that began in the eighteenth century the demand for shingle has led to the serious depletion of many lengths of beach.

There is, it would appear, no likelihood of the opposition of any effectual resistance by the land to the sea's advance in this region, because both in Holderness and East Anglia (except where, as already noted, chalk out-cropping on the foreshore retards submarine scour) the soft rocks that form the cliffs extend to below low-water mark and are as readily abraded as the cliffs are pushed back. The advancing waves in Holderness are cutting out a shelf in the glacial drift that here buries the chalk floor of the pre-glacial bay to an average depth of one hundred and twenty feet. Both cliffs and sea-floor thus consist here of soft and recent deposits, and considerable submarine scour takes place. The rocks that are detached from the eroded boulder clay cliffs as they retreat sink in time to a depth of several fathoms, with but little horizontal movement, owing to their clay foundation being undercut by the action of the sea.[1] Where stood a cliff once thirty to forty feet above high-water mark was five fathoms of water at low tide about four hundred years after it had formed a part of the coast of Holderness.[2] During this period the shoreline retreated one thousand yards, so that the waves while cutting a shelf of this breadth into the land lowered its outer edge by a vertical distance about one-hundredth part that of the horizontal advance accomplished. The site of the former village of Auburn has been so eroded that at high-water spring-tides it is covered by nearly three fathoms.[3] Generally the sea is about two fathoms deep for about a mile off the coast, but beyond this it deepens somewhat suddenly to six and seven fathoms. It would be interesting to know the cause of this change of slope in the sea-bottom off Holderness and whether it denotes a former pause in coast retreat, during which submarine scour would continue unabated, followed by a renewal of rapid coast recession and the formation of a fresh wave-cut shelf a mile in width. At Sheringham in north-east Norfolk Lyell[4] has recorded that in 1829 the water was twenty feet deep where forty-eight years before had stood a cliff

[1] *Mem. Geol. Survey : Holderness.* C. Reid.
[2] Pickwell, R. "Encroachments of the Sea from Spurn Point to Flamborough Head," *Min. Proc. Inst. C.E.* vol. li.
[3] *Coast Erosion and Protection.* E. R. Matthews.
[4] *Principles of Geology* (tenth edition).

fifty feet high. The lowering by several fathoms of the sea-floor off Cromer is attributed[1] to the action on the chalk sea-bottom of rock-boring molluscs and annelids, and though the sea-floor is here protected by a covering of flints derived from the denudation of the chalk the waves pluck out these stones and readily abrade the rock, already honeycombed as it is by the marine organisms. The late Clement Reid has noted[2] that in one storm the sea-bottom off Norfolk at a depth of five fathoms was scoured out in places to a depth of fifteen fathoms, though it subsequently silted again to its original level. Lowestoft Roads are recorded as having formed part of the land in the days of Henry VIII, but by the time of Elizabeth they were already under three fathoms of water.[3] At Aldborough the sea was twenty-four feet deep over the site of the former town some quarter of a mile out at sea when Lyell[4] wrote in 1866. This inability of the sea-floor to withstand abrasion has made possible the continued rapid retreat of coasts that have already been pushed back for miles.

Offshore scour is increased in East Anglia by frequent sandbanks offshore, which lying parallel to the coast and at varying distances from it increase the force of the tidal currents between them and the land. Between Covehithe Ness and Winterton extend such banks, some dry at low-water, lying from half a mile to two miles out from the shore. Indeed the whole length of coast south of the Humber is bordered by seas under twenty fathoms

[1] Roy. Commn. Coast Erosion.
[2] "Coast Erosion." C. Reid. *Geogr. Journ.*, vol. xxviii.
[3] Gillingwater, E. *Historical Account of Lowestoft.* 1791.
[4] *Principles of Geology* (tenth edition).

deep with many and dangerous sandbanks—which occur in ridges parallel to the coast, are separated by comparatively deep channels, and lie in some cases as far as forty-five miles from the shore.

Banks such as these though they may increase tidal scour in the channels between them and the land protect the coast to a varying degree from wave attack, and affect also the local range of the tides. To their existence and shifting character is attributed the intermittent character of coast erosion often noticeable in East Anglia—an intermittency that has been more marked than can be accounted for by the usual succession of cliff fall, formation of protecting talus of landslip debris, removal of talus by the waves, and renewed fall of the cliff. The increased frequency in the early years of this century of breaches by the sea in the dune ridges that protect much of the coast between Happisburgh and Winterton, in north-eastern Norfolk, was attributed[1] to changes in the offshore banks. The coast of Suffolk has suffered from periods of wave erosion interspersed with a series of years when wave attack was greatly decreased in violence. Lowestoft, for example, seems to have been immune from damage by the sea for a long period prior to 1860. In 1861 the "denes," a low-lying accumulation of sand and shingle that here projects beyond the original coast, were described as never over-flowed by the sea.[2] Since then this area has suffered severely, the increased wave attack being attributed,[3] in part at

[1] Roy. Commn. Coast Erosion.
[2] Walcot, M. E. C. *The East Coast of England from the Thames to the Tweed.* 1861.
[3] Roy. Commn. Coast Erosion.

least, to the lowering of outlying sandbanks which —formerly dry at low-water—were early in this century submerged two or three fathoms deep at this time. At Easton Bavent, Southwold, Dunwich, the same history of alternate wave attack and comparative security is repeated. At Dunwich about 1860[1] the accumulation of beach by the waves was commonly followed by a cessation of cliff retreat, and the growth of vegetation on the temporarily stabilized cliff face. Then the sea used to sweep away the beach and once more attack the cliff. In 1887 erosion at Dunwich was described as having been very slight for many years, but by 1905 it had been renewed and has since then continued.

The outlying sandbanks are liable to considerable change. In 1580, for example, a sand island grew up off Yarmouth (like that part of the Scroby sands which since 1921 has formed a similar island here), became grown with vegetation and the resort of picnic parties, and by about 1619 had moved over two miles to the south and its site become the "main sea" once more.[2] Their general movement is a southward growth accompanied by wasting on the north. Any considerable diminution in these offshore banks would have disastrous consequences, since besides checking the advance of the waves against the coast they rise near enough to the surface to reduce considerably the rise and fall of the tides between them and the land, and large areas of low-lying country in the Yarmouth district where the tides at present rise only some six

[1] Walcot, M. E. C. *The East Coast of England from the Thames to the Tweed.*

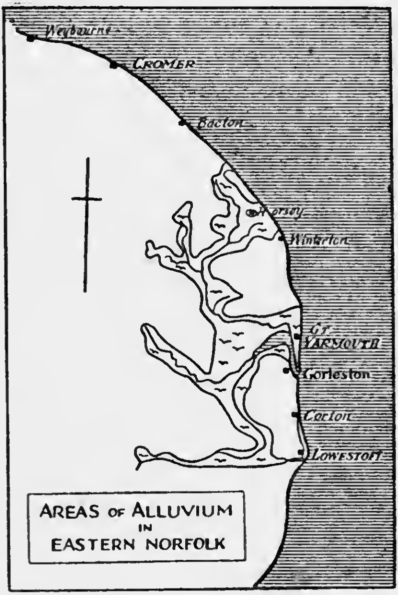
[2] *The History of Gt. Yarmouth.* H. Manship (1619), ed. C. J. Palmer, 1853.

feet would be submerged at high-water were the tidal range not diminished by offshore banks.[1] The significance of parallel offshore banks in relation to the sea's attack upon the land and the evolution of the coastline will be considered later.

A changed rate of cliff recession may be induced by alteration in the outline of the coast, as well as by changes in the offshore banks. Thus increased wave advance at Southwold and Dunwich was attributed[2] to the wearing back of the headland at Easton Bavent, which must at one time have given some degree of shelter from northerly winds. A map of 1575 shows a marked headland at Easton Bavent projecting about a mile beyond the coastline to south of it and forming the northern boundary of Soul Bay. This vanished bay was bounded on the south by a headland, now also gone, that lay south east of Dunwich. Erosion at Dovercourt near Harwich has likewise in part been attributed[3] to the recession of Naze Point on the south. Where, however, headlands can at any time have been but few and widely separated, as on this coast, their effect in modifying erosion must have been small. The point, however, raises the more interesting one of how the outline of the coast has changed during its long retreat. Has it grown progressively smoother—or has the creation of an evenly curved outline been but the prelude to its destruction and the initiation of a coastline of fresh irregularities subsequently themselves smoothed out? Before the historic period and during its earlier

[1] *Submerged Forests.* C. Reid.
[2] Roy. Commn. Coast Erosion.
[3] Redman, J. B. "The East Coast between the Thames and the Wash Estuaries" (discussion). *Min. Proc. Inst. C. E.*, vol. xxiii.

centuries the East Anglian coast was extremely irregular, owing not to the formation of wave-cut bays separated by headlands but to the invasion by the sea, consequent upon the Neolithic depression, of low-lying areas widely ramifying inland. These irregularities have been destroyed by the natural deposition of sand and shingle across the entrances



AREAS OF ALLUVIUM IN EASTERN NORFOLK

of the various estuarine areas, so that now the coast-line is smooth and almost devoid of indentations, but the marshlands subsequently reclaimed behind the sheltering banks are below high-water level and, unless man can prevent it, it seems inevitable that in its advance the sea must periodically break through the narrow belt of dunes or shingle ridges and inundate all the low-lying country in the triangular area between Lowestoft, Norwich and Happisburgh. Other smaller regions to the south are equally dependent on sea-banks, such as Minsmere Level south of Dunwich and the alluvial flats about Aldborough and north of the Deben estuary. Periods of inundation such as this would also be those of renewed irregularity of coastal outline, but the creation of a smoothed coastline would as constantly recur and such would naturally tend to be the stable condition of the coastal outline. Accretion may, as will appear in the following chapter, create temporary irregularities of outline. Thus the old Soul Bay is to-day replaced by a shallow recession in the coastline between the projections of Covehithe Ness on the north and Thorpe Ness on the south, both of which are triangular deposits of sand and shingle.

The possibility of a return to the conditions which obtained when the main area of the Broads, and many subsidiary regions, were covered by the tides is emphasized by records of the sea's attack upon the banks of dunes or shingle which alone protect these reclaimed areas. Between Happisburgh and Winterton sea breaches of the dunes have frequently occurred in the historical period. One inundation, that of 1615, is reported as having extended twelve miles inland,[1] and it is a fact that forty thousand acres would be flooded if the dunes here gave way. In 1781[2] breaches in the sea-banks between Waxham and Winterton endangered all the lowlands as far as Norwich. These breaches had apparently been formed in 1773 and had increased in width. In

[1] Manship, H. *History of Great Yarmouth.*

[2] Armstrong, M. J. *Essay on the Contour of the Coast of Norfolk.* 1791.

1791 a breach near Horsey was two hundred yards wide and in 1792 the salt water reached Hickling Broad, three miles behind the coast, and killed the fish in it. During this one year it is stated[1] that the dunes were broken nine times between Waxham and Horsey. Various breaches have occurred since then, but it was noted in 1890[2] that they naturally tended to become closed by blown sand in the course of a few days. As already stated breaches were becoming more frequent in the first decade of this century, and the lines of dunes require constant supervision. They are under the control of the Commissioners of Sewers for the Eastern Hundreds of Norfolk, to whose care is attributed the fact that no serious breach has occurred for over a century, though the dunes—as might be expected on a receding coast—are being gradually driven landwards with the resultant loss of land and buildings which (like the famous tower of Eccles Church) after being buried in the migrating dune-belt are finally left exposed on the seaward side of the protecting barrier.

The alluvial areas south of Yarmouth—whether consisting of reclaimed marshes behind sea-formed banks or of accretions of sand or shingle—are all liable to inundation from the sea except where they are artificially protected. There is no space here to describe the storms and floods which have since early days periodically inundated the marine deposits of Yarmouth and Lowestoft denes, swept the sea inland up the old tidal channel that once connected Lake Lothing and the river Waveney with

[1] *Mem. Geol. Survey: Yarmouth and Lowestoft.* J. H. Blake.
[2] *Ibid.*

the coast just south of Lowestoft, broken over the shingle banks into the former estuaries of Benacre and Easton Broads, surmounted the shingle at Aldborough and swept the pebbles into the marshlands of Slaughden behind, and flooded the low areas of Bawdsey Alderton and Hollesley Levels north of the Deben estuary. It is clear in East Anglia, as in other regions, that the sea does not permanently bar itself out from an area it once overflowed, and hence that where artificial defences are absent or ineffectual the tides may at any time temporarily reoccupy areas stretching far inland behind the present skeleton coastline of dunes or shingle ridges.

The coastline of East Anglia has attained, through the operation of natural processes, and because of the general homogeneity of its rocks, the readiness with which they yield to erosion, and the plentiful supply of sand and shingle yielded by them, a remarkable smoothness of outline. This evenness is a recent development only attained within the last few centuries. Naturally it would in this region constitute the stable condition to which the coastline would constantly tend to recur during its continued retreat before the waves, since no rocks of a character markedly different from those now on the coast or likely to oppose an increased or irregular resistance to the waves occur for a long distance inland.

It is, however, open to question whether or no the erection of defensive sea-walls and groynes along the cliffs, the regions from which fresh supplies of shore waste are derived, like those at Sheringham, Cromer, or Southwold, and those before alluvial accretions as at Yarmouth or Lowestoft, may not so have interfered with the supply and littoral drift of sand and shingle which here travel southwards along the coast that—deprived of some of their supplies—the natural barriers before the lower lands may not permanently be breached. In this case the security of the seaside towns will have been obtained at the price of widespread loss and destruction, and of the reversion of the coastline to an earlier stage in the cycle of its evolution.

CHAPTER VIII

EAST ANGLIA AND HOLDERNESS: (II) SHORE DEPOSITION

BETWEEN Flamborough Head and the Thames the shore is almost everywhere fringed with sand or shingle. Lengths without beach occur south of Flamborough Head, where is felt for some three miles the effect of this headland in holding up the shore drift of debris from the north, in the lee of the Harwich estuary, and in Essex where beneath the low cliffs of London Clay the foreshore is often bare. Practically everywhere else, however, a beach of sand, shingle or both borders the coast of these regions. Widely distributed as it is beach material is, however, comparatively small in amount, except in Lincolnshire and north Norfolk or where it is accumulated in local areas of deposition. In Holderness there is a general deficiency of shingle and in parts a scarcity also of sand, while high-water spring-tides rises some three feet up the cliffs. Here in one gale the shore may be completely denuded of beach though at other times great accumulations may be deposited. In East Anglia also the beach is generally limited in amount below the cliffs and liable as in Holderness to be scoured away in storms.

Sand and shingle travel in Holderness southward along the shore. Harbour works and groynes in Lincolnshire where shingle is practically absent have arrested but little sand which here apparently does not drift along the coast. East of the Wash sand and shingle are carried westwards along the north coast of Norfolk from a point on the coast near Weybourne and, continuing this line of drift, to the south along the north-eastern coast of the Wash itself. East and south of the drift divide near Sheringham shore drift moves from the north along the east coasts of Norfolk and Suffolk.

The southward-moving littoral drift common to the greater part of this coastline is determined by the direction of the flood-tidal stream that here travels from the north and by the fact that northerly winds raise on these shores the largest waves and increase besides the rise of the tides[1]—high-water in shallow estuaries and harbours may be raised three or four feet above its ordinary level by north-west gales and depressed an equal amount by gales from the south-west. Lincolnshire lies between two great estuaries, each with its own system of currents, and between the opposing shore drifts of Holderness and northern Norfolk. The westward drift in the latter region appears to be induced partly by the interception of tidal streams and wind-driven waves from the north by the projection of north-eastern Norfolk and partly by indraught to the Wash—west of a line from Flamborough Head to Cromer the tidal stream is rotatory.

Besides the beaches that border the actual coasts there occur in this region, as already noted, vast

[1] This was evidenced by the extensive floods that occurred along the East Coast during the high tides and northerly gale of December, 1921.

deposits of sand offshore. The southern arm of the North Sea is gradually shoaling owing to the meeting within it of various tidal streams and the fact that little or no detritus escapes from it southwards by Dover Straits.[1] Sandbanks are formed which off eastern England lie more or less parallel with the coast and share, as already stated, in a general southward travel of their constituent particles. Some of them are dry at low-water, and they may lie, as noted in the last chapter, as far as forty or more miles from the coast. Banks such as these, widely distributed over a large area, must, in many cases, have originated independently of the actual coastline and deposition in this narrow arm of the North Sea would seem to resemble rather the gradual silting of an estuary or bay than to represent an effort by the sea to rectify the coastal outline or the gradient of the foreshore.

An almost universal distribution of beach material and its uninterrupted drift along great lengths of the coast characterize the eroded coastlines of Holderness and eastern Norfolk and Suffolk. Sand and shingle have here been derived in part from the lands washed away, and in view of the great extent of these it appears a little remarkable that debris does not occur in greater quantities. The erosion of the coastline that still continues unabated keeps up a supply of detritus, and the long rivers debouching on the east coast carry large quantities of finer debris to their estuaries. There are thus plentiful sources of beach material in this region.

The free longshore travel of beach material along

[1] "On the North Sea with remarks on some of its Friths and Estuaries." J. Murray. *Min. Proc. Inst. C. E.*, vol. xx.

the coasts of Holderness, Norfolk and Suffolk is made possible by their regularity of outline. Those partial interruptions to shore drift that yet remain are due to the existence of estuaries that like that of the Humber or of the Orwell at Harwich are too deep and wide to have been entirely barred by shore drift of detritus. Other ancient points of tidal access to areas lying behind the general line of the coast are now either closed by shore deposits, as at Horsey, or Caister, or so narrowed that longshore drift—where it is not artificially restrained—continues across them.

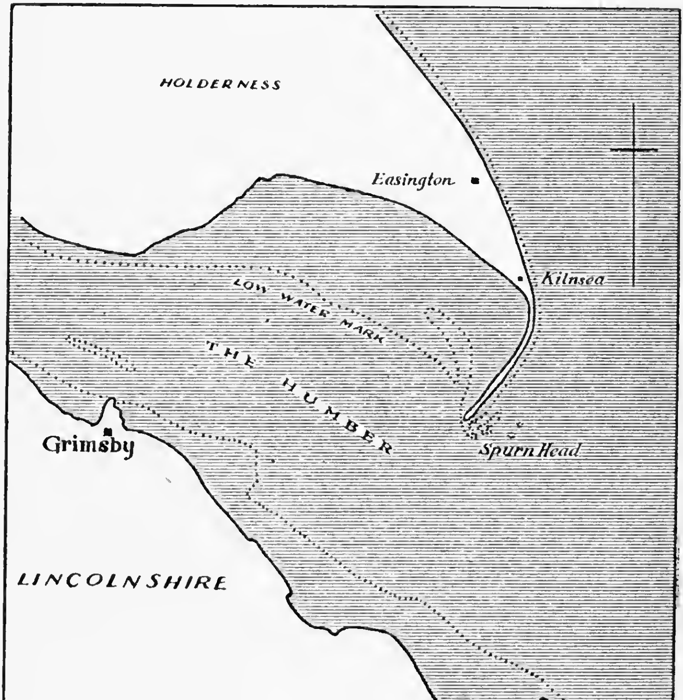
The considerable recession of this coastline and the creation of its present even outline have then been accompanied by an almost universal distribution of shore deposits and their free drift along great lengths of the coast. Only in a few places, however, have shore accumulations of sand or shingle afforded the coast any substantial protection against wave attack.

Leaving for a later chapter a consideration of the coasts of Lincolnshire and north Norfolk it appears that between Flamborough Head and the Thames the remainder of the coast is characterized by exceptional accumulations of shore material, firstly, where river outlets oppose some check to its longshore drift and, secondly, where a combination of circumstances has led to the growth of those projections of sand or shingle known as nesses or forelands, and of which Lowestoft Ness is a typical example.

The drainage of Holderness mostly flows inland and away from the coast, which has no shore deposits beyond the ordinary beach until the Humber is reached. Partly across this great estuary extends from the north the sand and shingle spit of Spurn Head. In eastern Norfolk again much of the drainage is at first away from the sea but it is ultimately gathered into the Yare system, the estuary of which is barred by Yarmouth sands. South of Yarmouth only small streams reach the coast until the Alde estuary is reached. This is barred by the shingle of Orfordness. The river Deben on the south flows out through shingle banks drifted from the north, while south again the Orwell and Stour form a wide estuary at Harwich that is, like the Humber, only partially closed, in this case by the shingle of the triangular projection known as Landguard Point. South of Harwich the low Essex shores belong rather to the estuary of the Thames than to the open sea-coast. In addition to the main river-outlet deposits of Spurn, Yarmouth, Orfordness and Landguard, five nesses of sand or shingle (or both) occur in this region. Winterton Ness forms a slight seaward bulge on the coastline some nine miles north of Yarmouth. Lowestoft Ness is a pronounced salient, Covehithe Ness about six miles south of Lowestoft a less-marked one. Thorpe Ness three miles north of Aldeburgh is small, but Orfordness, grown out from banks that deflect the Alde outlet southwards, is a large accumulation of shingle.

Spurn Head, Yarmouth sands and Lowestoft Ness may now be briefly considered as shore deposits typical of their class.

Spurn Head, created by the southward drift of sand and shingle from the coast of Holderness must have been in being as long as this drift has existed, and been checked in its southward course by the cross-currents of the Humber estuary. Spurn Head, like the boulder-clay of Holderness, does not date back beyond the Ice Age, and when first formed its base at least must have lain, with the coast from



The entrance to the
HUMBER ESTUARY

which it draws its supplies, some miles east of its present position.

The spit of Spurn Head is composed of shingle and sand, some of the latter having been blown into low sandhills about ten or twenty feet high. It is about two and a half miles long and has, though not at present to a marked degree, the broad outer end and narrow neck characteristic of formations of its type. Its length is determined by the relationship between the supplies of shore drift from the north, the violence of wave attack against the spit, and the scouring action of the tidal currents in and out of the Humber—the increasing check imposed by the latter as the spit extends leading to a blunting and broadening of the growing point. The position and curve of the spit are determined by the direction followed by the littoral drift where it leaves the southern extremity of the Holderness mainland and by the subsequent effects upon it of the currents of the Humber estuary. At present the neck of the spit soon after leaving the mainland becomes bent inwards, and the whole spit forms a hook pointing upstream, showing that the waste-burdened flood-stream moving south and into the estuary combined with the action of the North Sea waves tend to displace the line of deposition increasingly upstream as the spit lengthens. Ultimately when the spit is nearing its maximum length any shore debris reaching its outer end tends to be swept round to its leeward side with a resultant broadening of the head and check to the southward extension of the spit. At present Spurn Head extends into water nearly five fathoms deep at its southernmost end.

In Danish times Spurn Head must have been in existence, since the Danish port of Ravensburg, or Ravenspur, subsequently washed away, was built within the sheltering arm of a spit that was obviously the Spurn Head of those days. The Spurn spit was half a mile long in the thirteenth century, but in the Saxon period Kilnsea, the village on the extreme south point of the land of Holderness, was an island and cut off from the mainland by a tidal creek on the north of it, a state of affairs that would appear unfavourable for the maintenance or growth of a spit south of Kilnsea. Again, when Camden wrote in the sixteenth century, in spite of the fact that the first lighthouse had been erected on Spurn Head by 1428, he refers to Holderness as ending on the south at Kilnsea. These apparent contradictions in the records of Spurn Head arise from the fact that the deposits composing it have been alternately joined to the land and separated from it by the breaking of the narrow neck. It was estimated in 1885 that the spit as it was at that time might have been formed in four hundred years.[1]

Spurn Head is not, like the Hurst Castle spit in Hampshire, a stable deposit remaining apparently unaltered for centuries. It is subject to growth, deformation and re-formation. It resembles Hurst Castle in being attached to a coast that is being cut back so quickly that the spit as a whole must be liable to a comparatively rapid displacement in accordance with the recession of the coast. The point of Spurn has extended southwards at varying rates. Between 1676 and 1766 it gained in length at the average rate of twenty yards a year.[2] This increased to fifty-six yards during the next five years but recent rates of advance have been less both in the early nineteenth century and since the arti-

[1] *Mem. Geol. Survey: Holderness and the adjoining parts of Yorkshire.* C. Reid.

[2] "On the Outfall of the River Humber." W. Shelford. *Min. Proc. Inst. C. E.*, vol. xxviii.

ficial protection of the spit began in 1852. Between 1873 and 1902[1] the point grew south on the average only some three or four yards annually. In 1914 Spurn spit was two and a half miles long. Incomplete records of its average annual extension show it to have grown over one and a half miles to the south in the short period that has elapsed since 1676. It is therefore obvious that the spit must constantly tend to attain a limiting length beyond which growth is prevented, and that during its periods of maximum extension one of several conditions must obtain. Either all supplies of fresh detritus from Holderness are absorbed in making good the losses by erosion from the lengthened coastline of the spit, or shore waste travelling along it from the north and unable to accumulate at the southward point of the Spurn owing to the increasing violence of the Humber currents, is swept either across the Humber to the Lincolnshire shores or on to the shoals that encumber the entrance to the estuary both within and outside the spit. Since it has apparently been possible in the past for the detached head of Spurn to cross the Humber to the Lincoln shore it is probable that the length of the spit is limited rather by the ratio between supplies of detritus and the amount lost from its own increasing length of coastline than by its projection into the deeper waters and swifter currents of the middle of the estuary.

Apart from its southward growth Spurn Head would, were it not for its artificial fixation, continue as it has in the past to recede along its sea-coast and grow by deposition on its inner shore-line with a

[1] *The Sea Coast.* W. H. Wheeler.

resultant gradual upstream displacement of the whole deposit. If this westward movement has in the past kept pace with the recession of the Holderness coast, the base of Spurn Point must a thousand years ago have lain over a mile to eastwards of its present position.

The continued southward growth of the point of Spurn has, as already noted, been accompanied during its long history by the periodic detachment of the head of the spit from the mainland owing to a breach of the narrow neck. The island head, then largely cut off by the new strait from fresh supplies of detritus, must be driven southwards, and it appears probable that its destination has been the Lincolnshire coast. At Donna Nook nearly due south of Kilnsea there is an ancient accumulation of shingle, now cut off from the boulder-clay of the Lincoln coast by alluvial flats six miles in width, an accumulation that judging from present conditions cannot have been derived from the Lincolnshire shores and is presumably due to shingle travel from Spurn Point.[1] At present shingle does not appear to cross the Humber. During the periods of active growth of the Spurn spit it would probably not do so, and before coast defence works interfered with the normal development of the spit it was still extending in length.

As late as 1905 the sea, as in Saxon times, flooded the narrow breadth of alluvial land between Easington and the little area of boulder-clay on which stands Kilnsea so that the latter with the Spurn spit became an island, but the last recorded breach by

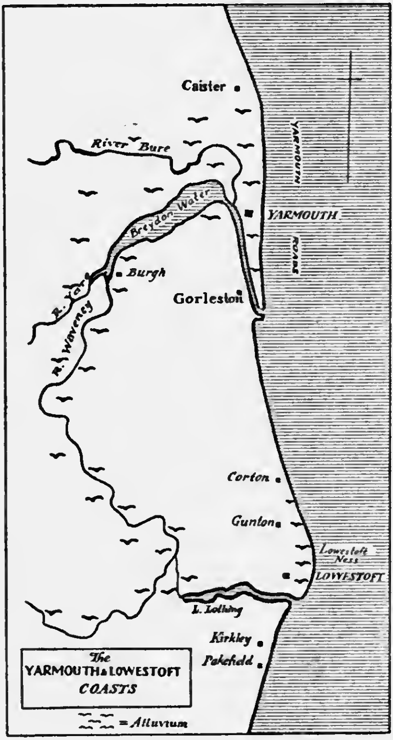
[1] *Mem. Geol. Survey: Holderness and the adjoining parts of Yorkshire.* C. Reid.

the sea of the actual neck of the spit occurred in 1849 since which date groynes have prevented the formation of any gap through it.

Many of the characteristics of Spurn Head, such as its growth in length within defined limits and its movement as a whole in accordance with that of the coast to windward, its shape, the tendency for its narrow neck to be broken through, are features constantly repeated in similar deposition forms round our coasts and which appear to be associated at one stage or another of their development with such accumulations of debris as occur where the longshore travelling beach material is checked at the entrance to an inlet.

The effect of spits like that of Spurn on the tidal range of the area within them is often of importance. Fluctuations of high-water level at Hull have been attributed to the varying effects of Spurn, in different stages of its growth, upon the tides; and in many regions the low-lying coasts of bays or estuaries would be flooded at high-water were the spits that restrict free communication with the sea and reduce the rise and fall of the tides to be shortened or broken through. Since such deposition forms exert so profound an influence on tidal range and are often enough liable to rapid modification, it behoves those seeking evidence of changes of sea-level to be on their guard wherever there occur banks or spits, above or below sea-level, that may obstruct the flow of the tidal streams.

Yarmouth sands appear at first sight to have little in common with Spurn Head. The deposit of sand, with shingle in lesser quantities, extends to-day from Caister on the north to Gorleston on the south—a distance of five or five and a half miles along the coast. From a quarter to half a mile in width it lies between Yarmouth Roads on the one hand—a channel bounded on the east by sandbanks parallel



with the coast—and on the other flats of alluvium that stretch from Caister to the higher land of Gorleston. Through these flats the waters of the Bure, Yare and Waveney rivers make their way, rivers that with their tributaries drain an area of

1,420 square miles. They join above Yarmouth to form Breydon Water, the water from which escapes southwards almost parallel with the coast and separated from the sea only by the long spit of Yarmouth sands until it enters the sea at Gorleston. Its close adherence to the coastline differentiates the Yarmouth deposit from such a spit as Spurn Head; but when the Bure, Yare and Waveney were tidal far up their valleys, and a wide estuary extended nearly to Norwich with its entrance stretching from Caister to Gorleston, the conditions affecting the growth of a shore deposit originated probably by the longshore drift of beach material from the north must have been very similar to those obtaining at the Humber mouth.

The Romans had a station at Caister, some three miles north of Yarmouth, and one at Burgh some way up the estuary and three miles inland from Gorleston, between which latter place and Caister extended, as noted above, the entrance to the vast and shallow estuary then in existence. Probably the earliest mention of the occurrence of banks in the mouth of this estuary occurs in connexion with the Saxon invasions of England, it being stated[1] that one Cerdic, a Saxon prince, landed on what later became Yarmouth sands. These latter, according to some authorities, had become dry by the year 495, shortly after which date the Saxon town is said to have begun to arise. The port is reputed to have become opulent by the time of Edward the Confessor and was certainly important by the time of Henry I. Before the Conquest Yarmouth sands formed an island in the middle of the entrance to the then-

[1] *An Historical Account of the Ancient Town of Lowestoft.* E. Gillingwater.

existing estuary and it was on this island that the famous Yarmouth fair and the town itself had grown up. Soon after 1066, however, the channel known as Grubb's Haven between Caister and the north of this island began to be choked and by 1347 it was closed, and the Portsmen had to rely in future on the southern outlet for their harbour. It is possible that the sand island of the earliest Yarmouth grew up owing to the operation of causes that determine the growth of centrally placed sandbanks at the outlets of estuaries, but it seems more likely that it owed its origin to longshore drift from the north and that its early condition as an island was due to similar factors as have determined the periodical detachment of Spurn Head from the mainland. That Yarmouth sands have not again been cut off from the land at Caister by the formation of a channel north of the present town is probably due to the successive harbour works initiated by the townsfolk, works which by attempting to restrict the southward movement of the Yare outlet must have facilitated the escape of flood waters from inland and reduced the possibility of a breach in the sands north of the town.

Like the Spurn the Yarmouth sand spit has grown from north to south. Here, however, the advancing spit grew right athwart the entrance to the shallow estuary, south of which it followed the land, being separated from it only by the river channel whose outlet it pushed south. Under these circumstances the Yarmouth sand spit grew to a greater length than did Spurn Point. So far as is known at its period of greatest extension the southern end of the long spit that extended from Caister reached as far as Gunton, a little place lying only about a mile north of the outer limits of Lowestoft. At this time the spit was about ten miles long. The river waters confined between it and the land escaped in 1347, by which date the northerly Grubb's Haven was closed, at this southern end of the spit, opposite Gunton, and some five miles south of their present outlet at Yarmouth harbour. Such a state of affairs could obviously be but a temporary one. It was besides very inconvenient for the trade of Yarmouth, the inhabitants of which embarked at this time upon the commencement of their long struggle to create an outlet for the land waters that should be both permanent and sufficiently near the town. Up and down the long spit between Yarmouth and Corton (which lies a mile north of Gunton) the citizens between 1347 and 1560 cut their successive havens, dug channels for the river waters through the drifted sands—channels that were with certainty and sometimes very rapidly choked, one after the other. Meanwhile the land waters continued to cut themselves fresh outlets at inconvenient places or, as happened occasionally when all outlets were blocked, they percolated vaguely through and across the sands, flooding meanwhile during westerly winds the landward side of the port. Eventually in 1560 the townsfolk opened a seventh haven opposite Gorleston on the site of one created in 1528. A thousand persons laboured at the works and at last "the waters did run forth." At the same time the southward flow of the river along the coast beyond the new haven was checked—temporarily, as appeared later, for shortly afterwards the land waters once more forced a passage down the old channel between the sand spit and the land towards Corton. At last some six or eight years after the haven was created were built by a Dutch engineer works which ensured its permanence, and since then the river waters have issued at this point.

Supposing Yarmouth spit at its longest to have reached no further south than Gunton (and it appears highly improbable from considerations concerning Lowestoft Ness that it has extended further than this since perhaps the Saxon period), it must by 1347 have attained its maximum length and have reached a condition as nearly approaching stability as is attainable where such sea-formed banks lie between the waters of river and sea. Between that date and the creation of the harbour in the middle of the sixteenth century it appears that the spit altered little in length since the Yare escaped down its old channel towards Corton after the opening of the latest haven in 1560. The final fixing of the outlet a few years later has resulted in the disappearance of that part of the Yarmouth spit that lay between the harbour and Gunton, a disappearance due to wave erosion and to the continued southward travel of its sands and shingle, now no longer replaced from the north since the harbour works have held up all shore drift.

The landward displacement common to deposition forms on a receding coastline has not been noticeable at Yarmouth. A certain amount of sea advance has occurred here and there and parts of the area with some portions of the town have occasionally been flooded by the sea, but as a whole the deposit appears singularly permanent. Coast defence works are not necessary, though the sand shelves steeply into the sea, and accretion predominates on the whole over erosion. This security of the Yarmouth area (and much of the region is below or scarcely above high-water level) must be brought about in part by the protection afforded it by the offshore banks that form the eastern boundary of Yarmouth Roads. The arrest at the harbour mouth of the southward-moving shore drift has enhanced this security and led to such an accretion along the Yarmouth coast that by 1902 it lay six hundred yards to seaward of the shoreline to south of the harbour, a result achieved as usual at the expense of the coast to leeward which has here and nearly as far south as Lowestoft suffered severely from wave attack.

Yarmouth spit unlike that of Spurn has succeeded in almost closing the estuary across which it has grown and in so doing has created an even line of coast where formerly lay the entrance to a wide and far-reaching inlet. Its barring of the old estuary has had besides important effects on the lands behind it. So narrow now is the channel between Breydon Water and the sea that the tides within the spit at Yarmouth bridge rise and fall only three to four feet whereas on the open coast at Yarmouth they rise to six feet. This lowering of high-water level has admitted of the gradual reclamation, beginning at an unknown and early date, of lands that in Roman times were covered at every tide, while the deposit of silt from inland has been accelerated by the reduction in tidal flow and the shelter afforded by Yarmouth spit. A consideration of parish boundaries has led to the conclusion that the rivers occupied channels similar to those of to-day as early as 900.[1] Now the Bure, Yare and Waveney are restricted between narrow banks; and the bed of the former estuary, often enough below high-water level, has been reclaimed, though large areas are dependent on pumping for their preservation. The effect that any widening of the tidal channel through Yarmouth spit, or the creation of an additional channel, would have on these low-lying lands is evident from the increased difficulty recently experienced in keeping the embanked rivers within bounds owing to the Yarmouth harbour authorities having deepened their haven. The resultant freer admission of the tidal stream caused such a rise in the high-water level of the tidal rivers as seriously to embarrass those responsible for the security of the low-lying areas.

The formation of the Yarmouth spit has promoted the regularization of the coastal outline and led to the disappearance of an ancient, far-spreading arm of the sea. Lowestoft Ness, an area of shore deposits lying immediately south of the former end of the Yarmouth spit, increases on the other hand the irregularity of the coast and forms a salient of deposition. The town of Lowestoft is built on the edge of cliffs that were created by wave attack. In front of these cliffs has grown out an area of sand and shingle known in part as the denes, that to-day forms a rounded projection extending over six hundred yards out between the base of the cliffs and the point of the Ness. It has been formed like Covehithe Ness or Orfordness by successive accretions of sand and shingle, and most of the area lies little above mean sea-level and is dependent on

[1] *On the Geology of Eastern Norfolk.* R. C. Taylor.

the coastal sand dunes for its security. The deposits of the ness fringe the coast from Corton on the north to Lowestoft Harbour, where they are now artificially restrained from extending further south.

During the Roman period it is supposed, a pure conjecture, that Lowestoft cliffs were washed by the sea.[1] If this is correct the present ness has formed since then. It grew up between the deflected mouth of the Yare and the tidal channel that once communicated with the River Waveney immediately south of Lowestoft and north of Kirkley. It thus developed between two tidal inlets, and was no doubt encroached upon at times by the scouring currents of the Yare outlet while itself tending to block the Kirkley Haven south of it.

The date of origin of Lowestoft Ness is not very clear. Supposing its commencement to have been subsequent to the Roman period, it may have commenced to grow soon afterwards. The marsh-land mentioned in the Hundred Rolls in the time of Edward I is thought to refer to the denes.[2] By the reign of Henry VIII the present Lowestoft Roads are stated to have been land then being actively cut back by the sea,[3] so that by this period of the earlier sixteenth century it would appear that the ness had already grown to far beyond its present proportions and was entered upon a stage of decay. By the time that harbour works modified the normal course of coast development here the ness had considerably decreased in size and appears to have attained a condition of relative stability. Lowestoft harbour

[1] *An Historical Account of the Ancient Town of Lowestoft.* E. Gillingwater.

[2] From information kindly supplied by Mr. V. B. Redstone.

[3] *An Historical Account of the Ancient Town of Lowestoft.* E. Gillingwater.

works were built about 1844, being preceded in 1832 by jetties. Like those at Yarmouth, these works have held up the longshore drift from the north. The period prior to the formation of the harbour appears to have been characterized by neither marked erosion nor growth of the ness. It is recorded[1] that in 1791 former encroachments of the sea had ceased at Lowestoft and that erosion was by then increasedly active north of the town. The ness was eroded but little until in 1860 commenced the long-continued recession of its north-eastern coast-line, a recession accompanied by accretion north of the harbour and a consequent gradual southward shifting of Ness Point the most easterly projection of the area. The erosion of the north-eastern coast of the ness, a part that might be expected to have benefited by now from a northward extension of the accretion initiated by the harbour works, has been attributed to the effect of certain coast defence works north of it at Corton and, as already noted, to changes in the offshore banks. The harbour works themselves have led to an increased rate of wave advance to leeward of them and the erosion at Kirkley and at Pakefield to south of it has been very serious. North of the harbour high-water line lay in 1921 630 yards east of its position in 1836, while south of the harbour—where the coast is now artificially protected—it was 50 yards west of its earlier position.[2]

Kirkley Haven probably owed its origin to the sea breaking through into the Waveney river system at a

[1] *An Historical Account of the Ancient Town of Lowestoft.* E. Gillingwater.

[2] From information kindly supplied by Mr. S. W. Mobbs, Borough Surveyor, Lowestoft.

low part of the coast immediately south of Lowestoft, though by some writers the tidal channel that in early days existed here between the sea and a westward-flowing tributary of the Waveney is believed to have formed at one time the outlet of that river. The channel, that must have resembled the conjectural one at Horsey north of Yarmouth, appears from an early date to have been liable to be choked by shore deposits. From references in 1652 to damage caused by the " sea breach " between Lowestoft and Kirkley it is evident that the old channel had recently been reopened at that time and that a sea-wall had been erected across it at an unknown date prior to 1652. Before 1712 the sea had evidently once more broken through into the Waveney system and was again building barriers against itself, for it is noted[1] that in that year the sea maintained only a small communication with the Waveney and that after a final irruption in 1717 into the lowlands it remained shut out behind an isthmus that grew to be a quarter of a mile wide. This isthmus of shore deposits that had made the old island of Lothingland, on which stood Lowestoft, into a peninsula was finally artificially broken through soon after 1830, when the existing channel of Lowestoft Harbour was created, joining the Waveney system once more to the sea.

The history of Kirkley Haven provides but one more instance of the closing, so common on these coasts, of tidal inlets by means of shore deposition. Had an artificial channel not been cut here it seems probable that the sea would itself have formed one,

[1] *An Historical Account of the Ancient Town of Lowestoft.* E. Gillingwater.

as in the past, after fresh supplies of sand and shingle from the north had been cut off by Lowestoft harbour works. It would be interesting to investigate any connexion that may exist between the periods of growth and decay of Lowestoft Ness and possibly corresponding periods of tidal advance and retreat at Kirkley Haven as shore waste from the north was absorbed by the growing ness or liberated from its eroded shores to travel southwards past Kirkley.

The factors that bring about the formation of nesses or forelands of sand or shingle, whether they originate as at Lowestoft at the base of cliffs or are based as at Covehithe Ness on a low-lying length of coast, are as yet obscure in many cases, and a detailed investigation of each area could alone warrant a discussion of the causes that originate such forms of deposition.

Orfordness—thirty miles south of Lowestoft—is a projection of shingle built up of successive curved shingle ridges based on a long shingle spit that since the days of Henry VIII has driven the outlet of the river Alde some ten miles south along the coast. This spit is liable like other similar formations to be broken through, and the outlet through it of the inland waters has varied greatly in position. It possesses also the typical characteristics of ness formations in that the height of its shingle banks increases seawards while a lack of parallelism exists between the older and more recent ridges of shingle.

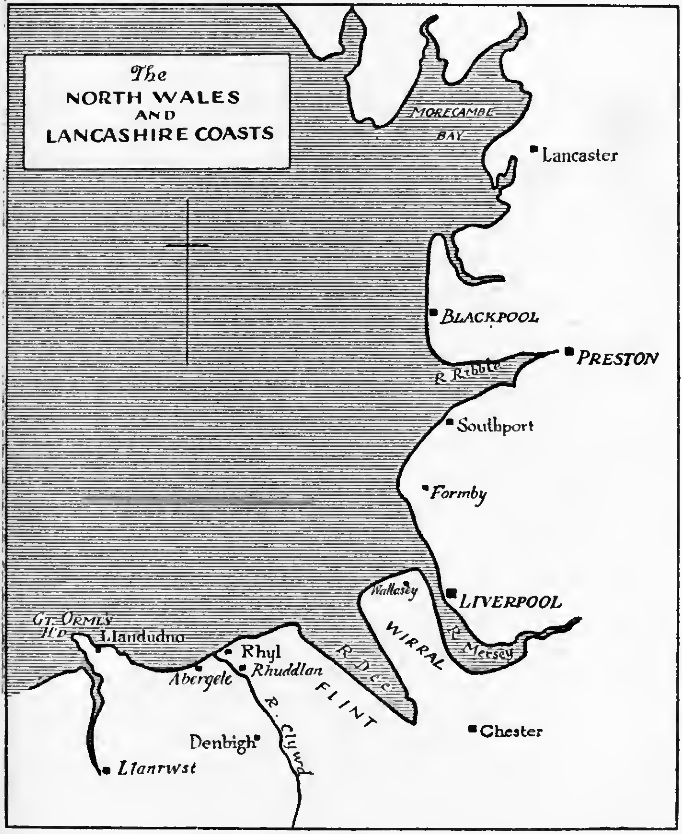
South of this great accumulation the deposits at the mouth of the river Deben and that of Landguard Point opposite Harwich have already been mentioned. The latter formation has suffered great changes in shape and position, and has at least once been an island.

The lands of Holderness and those of eastern Norfolk and Suffolk end along much of the coast in cliffs above the sea, cliffs, as we have seen, of regular outline and fringed by continuous belts of beach frequently scanty except where occur accumulations like that of Lowestoft Ness. Between the lengths of cliff in East Anglia lie lands like those behind Yarmouth very generally below high-water level, areas once tidal and owing their present condition to the formation of a protecting beach along their seaward edge. Opposite such low-lying areas the shore deposits are as a rule more plentiful, and though their general effect is to obliterate former irregularities they may form accumulations in advance of the general line of the coast and so create salients like those of the various nesses. Some characteristic features in the development of very low-lying coast-lines will be considered in the next chapter.

CHAPTER IX

THE DEVELOPMENT OF FLAT COASTS: LINCOLNSHIRE, NORTH NORFOLK AND LIVERPOOL BAY

THE coasts of Liverpool Bay and of that other great but nameless indentation on the east coast that is bounded by the shores of Lincolnshire and north Norfolk, possess certain features in common that distinguish them from the generality of coastal types so far considered. From a point near Colwyn Bay, on the North Wales coast, the shores of Liverpool Bay to the east and north and as far as Morecambe Bay are bordered almost uninterruptedly by low-lying plains, bounded inland by rising ground. Similarly on the east coast the shore lands between the Humber and the north-east projection of the Norfolk coast are formed of flats lying to seaward of uplands. These coastal flats of North Wales, the Wirral peninsula of Cheshire, south Lancashire, Lincolnshire and north Norfolk, consist of deposits of peat, submerged forests and alluvium overlying glacial drift. They are so low-lying that they are as a rule only saved from inundation at every high-tide by coast banks of dunes or shingle, or, where these are absent, by sea-walls. These defences are liable in the greater part of the area referred to to give way in exceptional storms, when the alluvial flats behind are flooded to an extent varying with local conditions. The flatness of the coast levels within the shore banks is paralleled by the flatness of the foreshore in these regions. The sea is very shallow off these coasts, the tide recedes



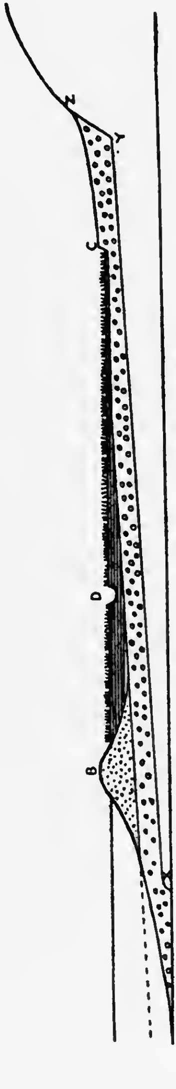
a mile or more at some points, and vast deposits of shifting sands extend for miles from the land—some dry at low-water.

The coasts both of the Liverpool Bay area and of those corresponding regions on the east coast can receive but few supplies of sand or shingle by means of shore drift from other lengths of coast. The alluvial strip on the North Wales coast is bounded on the west by an irregular coastline where longshore drift must be discontinuous, while the Fylde coast of Lancashire north of the Ribble along which shore drift moves to the north is separated by Morecambe Bay—a meeting place of tidal streams and of longshore currents—from the southward-travelling sand and shingle of the coasts of Cumberland. The Lincoln coast on the opposite shore is cut off by the Humber estuary from Holderness and is like the south Lancashire coast characterized by an absence of longshore drift, while the north Norfolk coast, in spite of its westward-travelling shore drift can receive no direct supplies from the coast east of it, since at its eastern boundary near Sheringham the direction of shore drift is changed, as already noted in Chapter VIII, from a westward to a southward-travelling one.

Both these regions, however, comparatively isolated as they may be with regard to longshore drift, form a kind of great pocket in the general outline of the coast, are open to those winds, from the west and north respectively, which create on these coasts the most powerful waves, and form natural areas for the deposition of sand that may have travelled in deep water and from great distances. Their exposure to waves of great wave length might be supposed to hinder deposition, but the shallowness of the sea both in Liverpool Bay and its eastern counterpart must ensure the changing of oscillatory waves into those of translation, which latter tend to accumulate sand onshore. The larger waves are besides forced to break far out from the land, and there drop any sand they may be transporting. The seaward slope between the coast in South Lancashire and the ten-fathom line does not exceed three and a half feet per mile, and the sea-bottom is covered with quartz sand for, as a rule, about twelve miles from the shore[1] so that there is here ample opportunity for onshore action to cause accretion. Off Lincolnshire the wide sand beaches are uncovered at low-water for a mile out in places, and northern Norfolk and the more easterly part of the North Wales coast are also fringed by sand flats. Off Rhyl a mile of sands are laid bare at low-water. Also local supplies of detritus accrue from the wave erosion of parts of these coasts and from the quantities of fine sand brought down by the local rivers.

Inland of the present coastal flats the occurrence has been established[2] in North Wales of a line of cliffs, believed to be pre-glacial sea cliffs, along the foot of the hills that overlook the coast plain. These old cliffs are partly buried in glacial drift that covers a floor of rock gently sloping seawards and is banked against the base of the hills, while along the Dee estuary are post-glacial sea cliffs behind the coastal flats.[3] Thus the alluvium of the coastal flats here evidently overlies an old wave-cut shelf. (See Diagram VII). In South Lancashire again evidences exist[4] of a pre-glacial coastline inland of

[1] *Handbook British Association.* Liverpool, 1896.
[2] *Mem. Geol. Survey : Rhyl, Abergele and Colwyn.* A. Strahan.
[3] From information kindly supplied by Mr. Bernard Smith.
[4] *Mem. Geol. Survey : The Superficial Geology of the Country adjoining the Coasts of S.W. Lancashire.* C. E. de Rance.



Profile of emerged or partially submerged flat coast
(Adapted in part from D.W. Johnson)

XY = pre-glacial wave-cut shelf.
YZ = pre-glacial sea cliff.
∴ = glacial drift.
▬ = silted lagoon
B = off-shore bar.
C = cliff formed before silting of lagoon.
D = tidal creek.

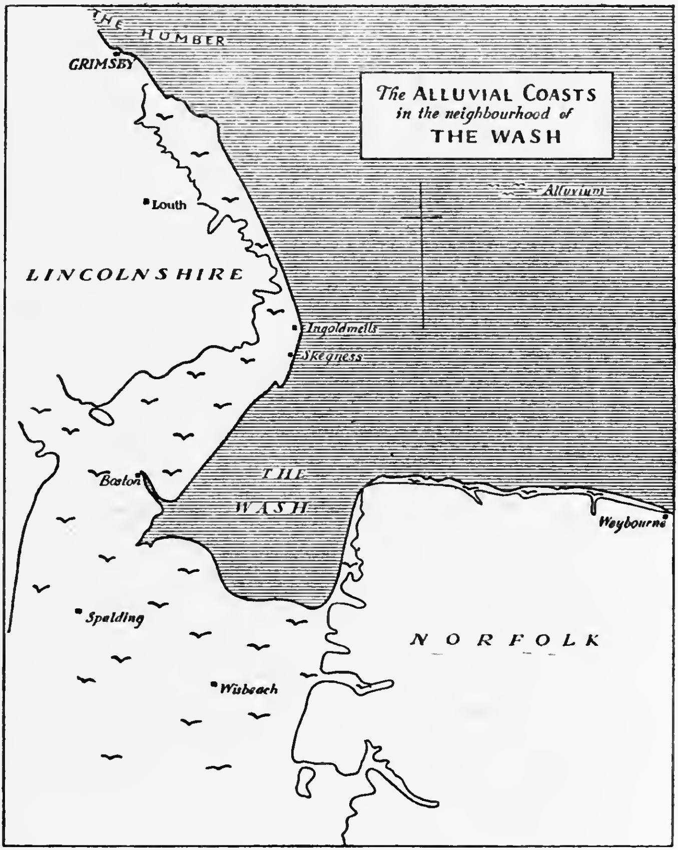
DIAGRAM VII

the coastal moss-lands, which here, also, overlie a rock floor that is apparently an old wave-cut shelf, while such a shoreline certainly lay along the eastern base of the chalk Wolds[1] in Lincolnshire behind the reclaimed levels of the coast. The chalk hills that slope in north Norfolk beneath the alluvium and drift of the coast flats must also almost certainly have lain once upon the coast, though the old coastline here has not as yet been detected. The original shores of the Wash itself (now far inland behind the silted flats of the Fens) are unlikely to retain marks of wave action. The Wash was created in pre-glacial times by processes analogous probably to those that have led to the formation of Bournemouth and Weymouth bays, and its shores, exposed only to seas entering the slowly widened breach through the chalk scarp that once stretched from the Lincoln Wolds to Norfolk, can at no time have suffered a wave attack sufficiently violent to leave a marked impress. Thus in North Wales, Lancashire, and Lincolnshire the recent deposits of the coast plains overlie on the open coast almost certainly a pre-glacial wave-cut shelf, and the probability that the adjacent and similar coast lands in Cheshire and Norfolk do so as well seems very considerable.

These regions underwent a partial submergence during the same period as did the coasts elsewhere in England and Wales.[2] There exist, as noted in the first chapter, buried land surfaces beneath the marshlands of the Humber, Ribble and Mersey, and their adjacent coasts, while submerged forests are

[1] A. J. Jukes-Browne. *The Building of the British Isles.*
[2] *Submerged Forests.* C. Reid.

of common occurrence on the foreshores off all these coasts, and the river mouths are of an estuarine character. To such a partial submergence



in Neolithic times of drift-covered pre-glacial, wave-cut shelves may be attributed those features already described as characteristic of these coasts, namely, the existence of alluvial coast-flats, bordered on the one side by the line of a pre-glacial coast, on the other by banks of shore deposits, and fronted by shallow, sand-encumbered seas.

Since these coastal plains are formed of recent alluvial deposits, both freshwater and marine, it is obvious that they have only recently become land. Though their present condition is directly due to artificial reclamation and draining, such works would not have been possible, and the deposits they have reclaimed could not have grown up, lacking the shelter afforded by natural banks of sand or shingle that formed along the seaward edge of what has now become dry land.

The partial submergence of the original wave-cut shelves must have left the coastline thus created behind a wide belt of shallow water. Off such a shore large waves breaking far out would form, as already noted in the first chapter, a bank of sand that would be gradually raised above high-water level and enclose a lagoon between it and the mainland shore. Such a lagoon would become the seat of deposition (see Diagram VII). Detritus carried into it by rivers and by the flood-tide through gaps in the offshore bar would accumulate in the still waters. The growth of salt-marsh vegetation would increase the rate of silting which might proceed until the surface had been raised sufficiently high to support forests. The subsequent history of such alluvial flats would depend, apart from the possible occurrence of changes of level, on that of the sheltering offshore bar. Such ridges are liable to be broken through. The amount of tidal inflow admitted through the gaps thus made determines the type of deposition on the alluvial flats behind and the kind of vegetation that may establish itself upon them, and both these conditions consequently vary with the degree of continuity of the offshore bar or dune belt. The alternations of layers of peat, with those of salt-marsh vegetation, sand, marine and fresh-water silt may, without invoking the aid of past changes in level, frequently be sufficiently accounted for as they are in Holland by past changes in a coastal dune belt. It appears that the plain of Holland, about two-thirds of which lies under three feet above high-water level, was formed in this manner by deposition behind a dune belt that had grown up by means of wind or wave action or both on a flat foreshore[1].

The coastal flats of northern Norfolk are in their present condition protected by a belt of dunes, and in the east by the Blakeney shingle ridge. Coast defence works, save for a few groynes at one point and a derelict sea-wall at another, are absent, and the alluvial levels are liable to occasional incursions by the sea when the coastal dunes are broken through. Similarly in Lincolnshire occur occasional eruptions of the tides over or through the banks, here largely artificial, and dating in part from the Roman period, that guard the coastal plain. In November, 1919, the sea breached the bank near Ingoldmells Point north of Skegness, and flooded hundreds of acres, and in 1920 two tidal inundations occurred in the same region.

That part of the alluvial plain of the North Wales

[1] "The Winning of Coastal Lands in Holland." A. E. Carey (correspondence on paper). *Min. Proc. Inst. C. E.*, vol. clxxxiv.

coast that lies west of the River Clywd is guarded by a sea-wall for part of its length. The remainder is dependent for its security on a belt of dunes, breaches in which threatened in 1917 some four thousand acres of Rhuddlan Marsh. Had these breaches not been successfully closed by works begun in 1920 the Marsh would have been completely inundated at high-water. East of the Clwyd a belt of dunes follows the shore, but it is worn thin in places, has in part been created by artificial means, and appears to be wasting quicker than fresh supplies accrue from the foreshore. Across the Dee the alluvial flats of the north coast of the Wirral peninsula lie for the greater part below high-water level, and were at one time protected by dunes. They are now, however, dependent on the long line of the Leasowe embankment, over or through which the waves occasionally break, with consequent flooding, as occurred in 1920. Before the erection in 1829 of this embankment incursions of the sea were numerous. Those dunes still remaining east of the Leasowe wall are being eroded. They protect a large area of low-lying land which would be inundated if the dune belt became breached in its retreat—an event the more likely to happen since its western end is based on a fixed point, the eastern end of the Leasowe embankment, which sea-wall besides has led to a succession of supplies formerly derived from the erosion of the coast to windward of this dune-bordered shore.

Between the Mersey and the Ribble estuaries in south Lancashire the shore belt of dunes is at the moment better developed than in the other regions of recent coast plains so far considered. The formation of some kind of dune belt must have preceded the deposition of the alluvium that forms the " moss " area of the Lancashire coast, but such a dune belt would appear to have suffered vicissitudes. Relics of early dunes occur in the Shirdley Hill sands that as a rule overlie the boulder-clay and occur mainlyin land of the present moss lands. Shirdley Hill itself, a noticeable knoll formed of these old wind-blown sands, recalls the green mounds now known to be dunes of Quarternary age that bound the low plain of Les Moëres, to-day far inland in Flanders.[1] A map by John Speed in 1610 shows the moss land extending to the actual coast north of Formby in south-west Lancashire, and tradition asserts that sandhills only appeared upon the Formby coast after 1690. It is difficult to conceive what, supposing coastal dunes to have been absent, could have saved these low-lying lands, inhabited at the time, from inundation by every high-tide, though doubtless their surface level was higher before they were artificially drained. It is possible that even during a temporary absence of shore dunes, owing to their wastage having for the time exceeded accretion, the sea may have been kept out by the surface of the moss bordering the coast having previously been raised by the deposition upon it of sand blown from the eroded dune belt. To-day the true surface of the moss is only found perhaps a mile inland from the edge of the sandhills, beyond a long eastward-sloping belt of moss land covered with blown sand that decreases in thickness away from the dunes.

[1] " L'origine des Moëres de la plaine Maritime de Flandre." Raoul Blanchard. *La Géographie*, vol. xxxi. 1917.

Since the seventeenth century the dune belt has grown and widened seaward on this coast, aided by the planting of shore dunes, by the great tidal range that lays bare wide flats of sand and by its position facing the westerly winds that dry the sand and carry clouds of it landward. Moreover, the dune belt has become cusped in outline by the formation of Formby Point—a ness or foreland of sand at the point of which the dunes cover a belt three miles wide. There is at present no possibility of the sea breaking through these Lancashire dunes.

The flat lands behind these coastal dune belts remained until they were artificially reclaimed in an amphibious condition. Such alluvial coast plains are peculiarly susceptible, by reason of their flatness, to interference with their drainage. They are as a rule more or less waterlogged and the slow currents of the streams that wander deviously over them are readily deflected or choked by the growth of shore-deposits through which more powerful streams would maintain a channel. It thus follows that these regions are characterized, in their natural condition, by the existence of fresh-water lakes caused by the expansion over the surface of the waters of obstructed rivers, while those the mouths of which remain open admit the tides far into the heart of the country. So necessary was it that the sluggish current of the River Alt in south Lancashire should flow unimpeded that a fine of £50 with the alternative of a period not exceeding twelve months in the " house of correction " used to be the penalty for throwing rubbish into the stream.

A great part of the Lincolnshire coast plain remained under water well into the historic period, and the meres of South Lancashire were at one time famous and occupied considerable areas now drained and reclaimed. The largest—Martin Mere—that lay just south of the Ribble estuary was caused by the growth of shore deposits obstructing the outflow of the drainage from a large area lying below high-water mark. The reclaimed area is still dependent on pumping, without which it would revert to a submerged condition. In France it has been surmised that the "étangs" or meres of the Landes coast were formed by the sand dunes holding up before them in their landward march before the wind waters that formerly drained seaward[1]. Thus may be explained the unfortunate fate of those Landes villages that were first inundated and subsequently buried in sand during the landward extension of the dune belt and its attendant lakes. At present, however, the little ditches of the country bordering the Lancashire sandhills drain very often inland, following the general landward slope to the moss lands. Both the coast plain of North Wales and that of the Wirral peninsula possessed at one time one or more fresh-water lakes.

Reclamation of the areas behind coastal dune belts has, however, the effect of lowering the surface level of the former marshlands and thus rendering wider areas liable to submergence by tidal inundation. The lowness of level typical of such alluvial coast lands is accentuated by the settling and compression of the loose deposits as time goes by, a process accelerated by the shrinkage in thickness of the wet and marshy layers that takes place when the areas are drained.

[1] "Quelques faits relatifs à la formation du littoral des Landes de Gascogne." G. Beaurain. *Revue de Geographie*, vol. xxviii. 1891.

Reclaimed polders in Holland that now lie over six feet below high-water mark lay between twelve and twenty inches above this level when they were first reclaimed.[1] A settling of the superficial alluvial deposits, the more pronounced the earlier the region in question was drained, has been apparent also in the various marshy areas that lie behind the dunes of the French coast.[2]

The tendency of spongy alluvial land to subside under the weight of houses and roads and eventually to engulf heavy objects once resting on its surface has unjustifiably been held to support theories of recent coastal subsidence in Lancashire and North Wales.

Reclaimed alluvial coast plains behind shore banks of dunes or shingle are liable, as already noted, to inundation by the sea should the protecting coastal ridges be broken through. They must besides suffer, as has already been explained in the first chapter, from a general advance of the waves once the coastline has been advanced seaward to coincide with an original offshore bar. Such shore ridges, whether consisting of shingle banks piled up above high-water level or of sand dunes, are powerless to resist the landward advance of the waves. Attempts at their fixation are apt, where they are naturally in retreat, to result in their disappearance unless a local accretion can be induced. They survive only by virtue of their power of retiring as a whole before wave attack,

[1] "The Winning of Coastal Lands in Holland." A. E. Carey. *Min. Proc. Inst. C.E.*, vol. clxxxiv (see correspondence on paper).
[2] "L'origine des Moëres de la plaine maritime de Flandre." Raoul Blanchard. *La Geographie*, vol. xxxi. 1917.

and can form but a mobile and fluctuating coastline, here bent inwards by wave advance, there growing out owing to localized accretion, but, so long as their continuity is unbroken, forming an efficient barrier between the lands behind their shifting line and the sea.

At the present time, of these low-lying coastal plains, that fringing the north Norfolk coast is gradually diminishing under wave attack. The dunes are being slowly driven landwards, and the great shingle ridge of Blakeney spit that extends westwards from Weybourne is being rolled inwards and its masses of pebbles are gradually spreading over areas of reclaimed marshland that once lay sheltered behind it. The Lincoln coast appears to be stationary apart from local erosion and accretion and the incursions already noted of the sea through gaps in its coast banks. It does not suffer from the coast recession common to other regions on the lee side of wide estuaries; but here the progress of normal coast development has been interfered with by the erection of artificial coast defences.

The alluvial flats of the North Wales coast are now being diminished by wave attack, and have suffered great losses in the past according to the statements of a number of writers both ancient and modern—losses borne out to a large extent by historical evidence. The sea coast of Flint, according to the testimony of old maps, has receded three or four miles since the time of Elizabeth.

The coast plain of the Wirral peninsula has suffered similarly to that of North Wales and continues to recede where it is not artificially protected. The coast of south Lancashire between the Mersey and the Ribble and immediately north of the latter appears to have suffered no permanent loss during the historic period, and is at present, except for a local area south of the outlet of the Alt, extending seawards owing to the growth of successive curved lines of dunes. North of Blackpool the Fylde coast has long suffered from wave attack and continues to retreat.

The incidence of wave attack against the type of coasts now under consideration is determined in many places by the distribution of sandbanks, which may or may not dry at low-water, on the foreshore. Such deposits off a coast reduce both tidal range and the violence of wave attack along the coasts they shelter. The great bight between the Humber and north-east Norfolk is dangerous for shipping on account of its numerous banks and shoals; so, even more notoriously, is Liverpool Bay. Changes liable to occur at any time in the position, height and extent of these offshore banks may exert a profound influence on the adjacent coasts. A shifting of the offshore banks that admits the tidal stream more freely to a coast will cause a rise of high-water level and may reduce to tidal flats, with every appearance of land surfaces submerged by subsidence, areas formerly well above the highest tide-mark, while a length of shore formerly sheltered from wave attack may be left exposed and be rapidly cut back in consequence. In addition to their effect upon tidal range and the degree of exposure of a coast offshore banks may induce great changes in the outline of the coast when they are impelled bodily towards and finally join the land. They are then raised in height by wind-drifted sand, and eventually cause a forward projection of the high-water line. Moreover, sand is then blown from them inland, an occurrence that affects coastal development inasmuch as such sand is henceforth lost to the coast and no longer helps to shelter it from wave attack. In the seventeenth century the township of Formby in south-west Lancashire, a place of Danish origin, was overwhelmed by drifted sand, a phenomenon attributed to the shoreward movement of a sandbank that had encroached upon and finally closed an old channel that once ran between it and the shore. It thus became joined to the land and the source of clouds of sand carried inland by the west winds. The Horse Bank off Southport, some miles north of Formby, is to-day being pushed eastward. It may in time close the Bog Hole channel between it and the foreshore of the town and give Southport a chance of arising afresh, like the more modern parts of Formby, on the buried remnants of its former streets.

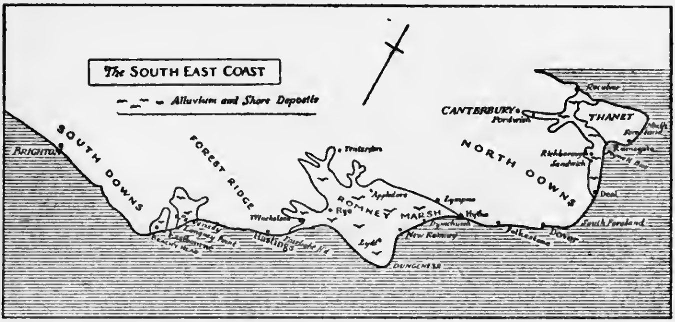
Seaward outgrowth of the land induced by shore deposition continues as a rule for a time that regarded geologically is but short. The ultimate destiny of alluvial coastal plains is, like that of higher coast lands, destruction by the sea, and such destruction is only postponed by a seaward advance of the coast. The sea, as we have already seen, disposes of its excess burden of sand and shingle, and at the same time steepens the gradient of the foreshore by building the land outwards as far as the line where a more powerful wave attack can remove as much detritus as is supplied to the coast. The coast retreat that ultimately sets in is afterwards determined by and dependent upon the slow deepening of the inshore waters that accompanies normal coast development. In north Norfolk, North Wales, the Wirral and the northern part of the Fylde coast of Lancashire this last stage may have been reached unless the coast recession here belongs to but a passing phase. In any event the coast plains considered in this chapter can survive only as long as the sea is engaged in rectifying the slope of the foreshore. Once this is sufficiently steepened for the removal of sand or shingle to equal or exceed its deposition the coasts must become liable to that retirement before wave attack that is common to other coasts.

CHAPTER X

THE EVOLUTION OF THE SOUTH-EAST COAST: (I) THE HASTINGS COASTLINE

BETWEEN Beachy Head and the North Foreland lies the coast of the Weald. This region as a whole is bounded by the scarp edge of the chalk Downs which run from Dover and the South Foreland westwards into Hampshire and thence south and east again to Beachy Head. Held enclosed within them are the low-lying plains of the Kent and Sussex Wealds and the central line of hills that separates these vales and is known as the Forest Ridge. Athwart the eastern portion of this region of concentric ridges and vales lies the Channel, cutting short hills and plains alike. There is thus a singular symmetry of view from the heights of Fairlight, where the Forest Ridge ends upon the coast. The cliffs which here stand above the sea are repeated in faint silhouette where the Downs on north and south come out to the coast, and between these clear and solemn ridges and the yellow gorse on Fairlight lie the flat pastures of the old salt-marshes of Pevensey and Romney levels. Beyond Dover and the North Downs a downfold in the chalk underlies the plains of the lower River Stour, above which, upfolded again, the chalk forms the low plateau of Thanet, bounded by a coast of steep cliffs lower than those of the three hill ridges to the south. Along this channel coast stand therefore the four cliff lengths of Thanet, the South Foreland, Fairlight and Beachy Head; and held enclosed between them lie the flat levels about Pevensey and Romney—levels so flat that from the Channel only their sea-walls of stone or shingle are visible against the sky—and the lowlands that form the coasts of Pegwell Bay, south of Thanet.

From geological evidence and historical records one may with very fair certainty reconstruct the outline of this Wealden coast as it stood at the close of the Neolithic depression and follow the course of



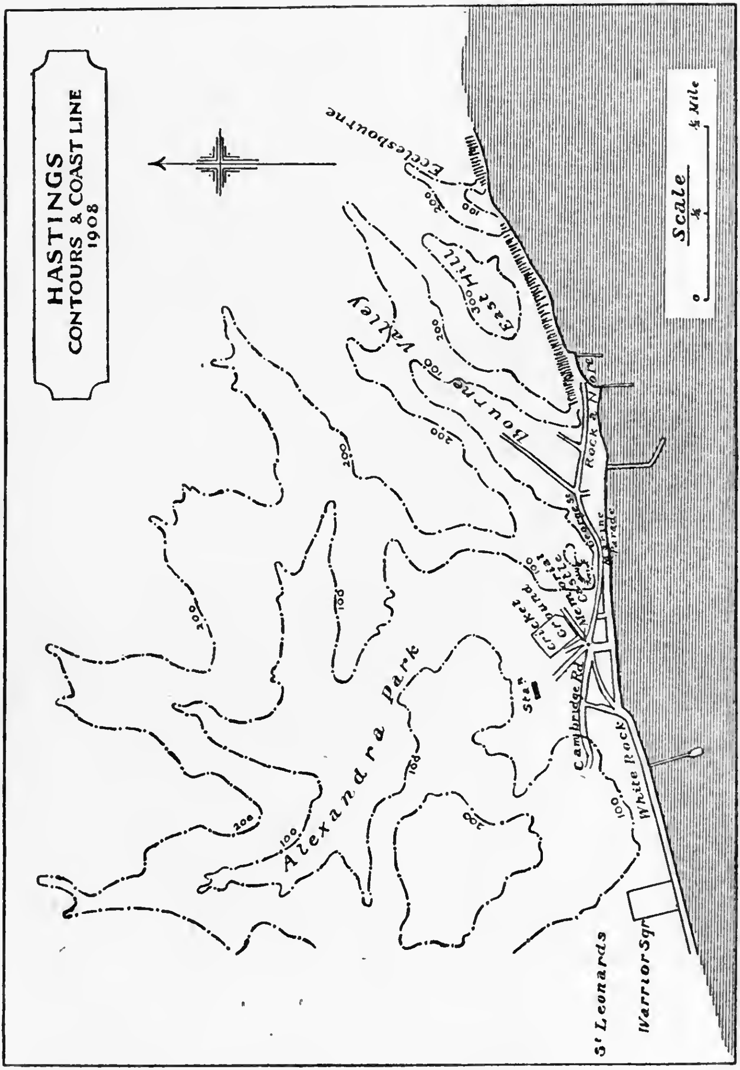
the changes that have brought it to its present condition.

Cliffs are a proof of coastal recession. Hence the uplands of this coast must once have projected further out into the Channel tides. The low coast lands of alluvium show that in earlier days the tidal waters stretched inland between the four great headlands. To-day headlands and bays are alike vanished,—cliffs and low shores stand in an almost even line along the sea though the sand and shingle from the eroded headlands yet drifts about the coast and lies athwart the former bays they sheltered,—while inland on the flats the stillness in the dykes that marks high-water on the coast is the sole memory of former tides.

Along the cliffs of the upland ridges were repeated in miniature the features of the whole coastline. Here little valleys ended in toy estuaries, each sheltered between headlands that on any but a large-scale map showed but as roughnesses in the general outline of the cliffs. Harbour towns early grew up on these headland estuaries, towns whose history reflects the advance of coastal development as in its irresistible progress it wiped out headlands and haven alike and left the citizens sheltering their remaining trade behind breakwaters or subsisting harbourless on summer visitors. The story of any one of these ports is typical of all, the coastal changes identical with those which on a grander scale have brought the whole coastline to its present condition, so that a brief account of the evolution of the Hastings coast, or that of Dover or of Folkstone should make clear the history of coastal development between Beachy Head and the North Foreland.

Hastings stands where the Forest Ridge reaches the sea. This range and its lower spurs form the coastline for five or six miles from the west of Bexhill to the green plains of Romney Marsh, and its seaboard is furrowed by a succession of little valleys where small streams, developed after the English Channel was formed, flow out to the coast. Between Bexhill and St. Leonards is the Asten valley. St. Leonards itself is spread over a series of gentle undulations that end to-day in the long line of its parades but must once have formed a wild coastline of alternate cliffs and bays. To the east modern Hastings lies sprawled athwart the sharply defined Priory Valley that debouches between the Castle Hill and the high ground of St. Leonards. Eastward again where the Bourne Valley slopes to the sea stands the old fisher town, narrowly constricted between the green slopes of the Castle Hill and the East Hill. Beyond the valley of the now-vanished Bourne rise the wild uplands that, intersected by Ecclesbourne and Fairlight glens, stretch to the reclaimed flats of Romney Marsh. Here then, as did the greater inlets and headlands of this Wealden coast, valleys and headlands alternated along the shore, and here also they unite in forming to-day an even coastline following a straight line across the ends of valleys and of truncated uplands alike, and everywhere fringed by a sand or shingle beach.

Geological and historical evidence prove moreover that the early coastline here was as irregular, on a smaller scale, as was the whole shoreline of eastern Kent and Sussex. The cliffs in which the various hill ridges end to-day extend discontinuously from west of Bexhill to Romney Marsh. They are masked at St. Leonards and in western Hastings by buildings, but elsewhere they rise steeply, increasing in altitude from the low clay cliffs at Bexhill to some two hundred feet at the Castle and over three hundred feet near Fairlight. Everywhere where not artificially protected they are being actively cut back by the waves. The hill ridges must once, then, have extended further seawards. The cliffs in which they end must have been developed during their recession. The



HASTINGS
CONTOURS & COAST LINE
1908
Ecclesbourne
East Hill
Bourne Valley
Rock a Nore
George St
Marine Parade
Cricket Ground
Memorial
Cambridge Rd
Alexandra Park
White Rock
St Leonards
Warrior Sq
Scale
½ Mile

Asten and Priory valleys are occupied by low-level tracts of alluvium which show that once they were arms of the sea; the flat ribbon of alluvial lands winds up the Priory Valley for one and a half miles from its mouth and is still below high-water mark.

The former irregularity of the coastline is then evident. The exact distance to which the headlands extended seawards at the beginning of the present period of unchanging sea-level is discussed in the next chapter. It can obviously only be roughly estimated. The average rate of recession of the Fairlight cliffs at a few points of maximum retreat is now three feet per annum.[1] This may have been less in the immediately preceding past, as before the Hastings groynes held up the long-shore drift from the west a shingle beach must have helped to protect this part of the coast. Writing in 1851 Redman[2] states that shingle extended at that time, except across the harbour mouths, from Langney Point near Eastbourne to Dungeness. To-day the foreshore below these cliffs east of Hastings is bare of shingle.

The sea-level outfall of the local valleys and the formerly estuarine condition of the Asten and Priory streams make it appear probable that the recession of the headlands since the latest subsidence cannot have been very great, since small and geologically recent streams like these are unlikely to have had such flat lower reaches as to have allowed of the sea flowing far up them when the coast was depressed. They are besides possessed of such relatively feeble

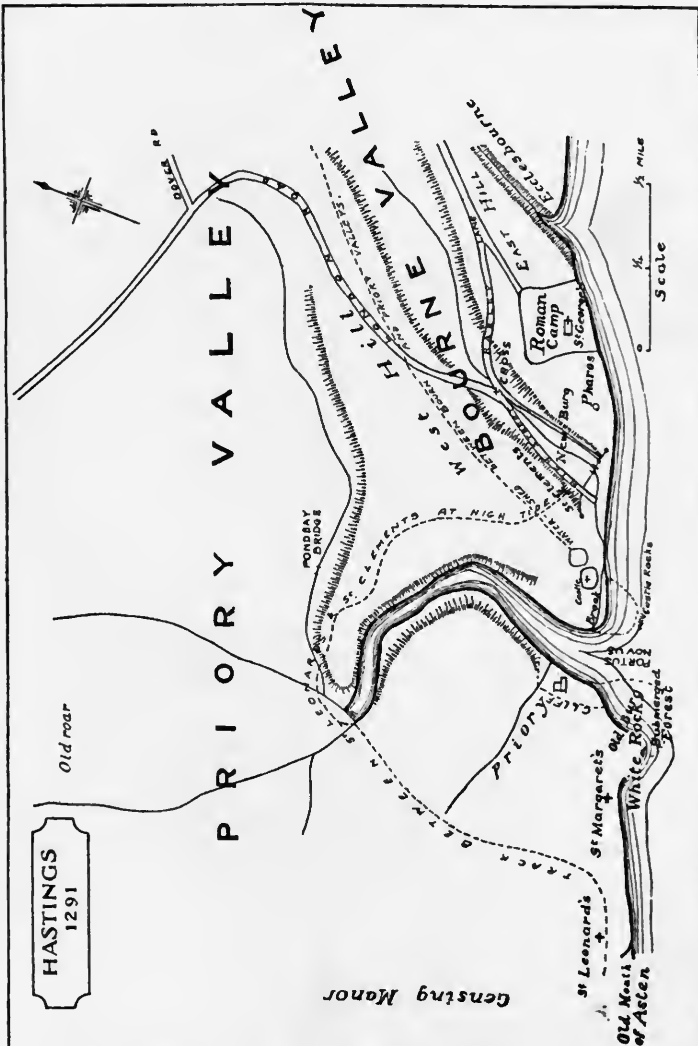
[1] From data kindly supplied by Mr. P. H. Palmer, M.I.C.E.

[2] "On the Alluvial Formations and Local Changes of the South Coast of England." J. B. Redman. *Min. Proc. Inst. C. E.*, vol. xi.

powers of excavating their beds that it seems very improbable that their present sea-level outfall can be the result of their lowering the seaward ends of their valleys in adjustment with a constantly and rapidly advancing coastline. Ecclesbourne Glen is an exception, since here the streamlet falls over a little cliff to the shore, but a cliff so low that the vanished mouth of the glen lay almost certainly not far beyond its present end.

The once irregular Hastings coast has been smoothed to its present even outline by wave erosion and the action of longshore drift. Here the coast is exposed to the attack of very heavy storm waves, the largest and most destructive of which are brought by south-west winds. Winds from west and south blow for nearly half the days in every year, and of the total number of gales annually over one-third are from the south-west. Thus marine erosion is here powerful. The tidal range reaches a local maximum on this part of the coast, and at spring-tides the line of breaking waves rises and falls through a vertical height of twenty-four feet.

The tidal streams that pour ceaselessly to and fro through Dover Straits seldom exceed offshore a speed of three knots an hour on the surface and two knots on the bottom, but velocities such as these enable currents to move sand and fine shingle. The east-going tidal stream very generally lasts a shorter time and flows more rapidly than that towards the west, and, moreover, lasts off Hastings from some three and a half hours before the time of local high-water until about two and a half hours after it. Thus a predominant drift of the coarser debris



(from Cole's Antiquities of Hastings. Reproduced with some omissions) towards the east might be expected, while the upper parts of the beach are frequently exposed to none but east-going tidal streams. This prevalence of the east-going tidal stream for some hours before and after high-water, combined with the predominance of westerly winds and the fact that the largest waves are driven from the west, ensures a general drift of beach material alongshore from the south-west and towards the north-east. Waves erode the shoreline; obliquely impinging waves, wind-driven currents and tidal streams urge the products of erosion north-eastwards.

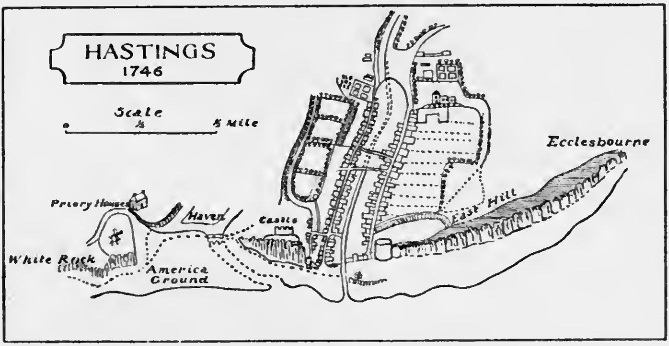
The history of the changes that have affected the Priory Valley and its headlands is typical of that of the whole coastline of the Forest Ridge. It appears certain that the original Hastings, though the town itself and most likely its actual site are long vanished, lay in Saxon days at the mouth, and probably on the western side, of the river-like estuary that then extended up the little valley. This town had grown to be a great port by the time of Edward the Confessor. It harboured its fleets in the land-locked estuary and was itself sheltered from the more violent seas by headlands now gone with the port they protected. Above the estuary on the east the Castle Hill stood out somewhat further seawards and more to the west than it does now. On the opposite side of the haven and immediately west of the thriving port the land rose and projected out to sea in the vanished headland of White Rock. Very early, like all its brilliant fellows of the Confederation of the Cinque Ports, the Saxon Hastings fell on evil days. By the eleventh century much of its old glory was already vanished owing to many factors, but amongst them that of the sea's relentless advance. It appears from a record of the bursting of embankments in 1325 that the town was defended by sea-walls and hence stood upon low ground. This seems to imply that by this time an area had been reclaimed on the windward side of the estuary as has so commonly occurred at the mouths of south coast rivers. Periodic descents of the French hindered at Hastings as elsewhere on this always warlike coastline the normal conduct of affairs. The sea-walls were not adequately restored and by the end of the fourteenth century the site had become uninhabitable, and the citizens migrated to a suburb which had grown up at the mouth of the Bourne Valley in the eleventh century and to a settlement that had begun to cluster, for reasons which will appear later, round the Castle Hill. The famous Priory stood near the present Hastings railway station, and by 1412 the monks had finally to abandon the site, which had become too water-logged even for their ascetism and was "laid waste by the sea." By this date therefore a considerable tract of low and probably reclaimed land at the mouth of the estuary had been washed away or reduced to a swampy condition.

This advance of the sea upon the low land at the valley-mouth was the necessary accompaniment of the erosion of the headlands that formerly protected it on either side. By 1440 the parishes of St. Leonards and St. Margaret's that lay west of the Priory Haven, as well as those at its mouth, were noted as having suffered great losses by the waves. The Castle Hill was also being actively cut back at this time—indeed, in 1331 it is recorded that a large part of the castle was already fallen into the sea. Thus the cliff-coasts on either side of the old town and its harbour were suffering erosion. Their recession had already originated an affliction of a different character, one from which the mariners of the Saxon town had suffered before its final loss. As the successive headlands to windward were cut back so littoral drift from increasing lengths of coastline to the west was swept towards Hastings, and by 1380 the traitor headland of White Rock had in its recession allowed so much shingle to pass it that the Priory Haven was barred across and its outlet deflected against the Castle cliffs to leeward. Some records appear to suggest that the haven had become nearly useless for navigation as early as the twelfth century, and if land had been reclaimed under the lee of White Rock it must have been done under the shelter of shingle banks. Round the new outfall from the harbour settled, as already noted, some of the refugees from the Saxon town.

Almost enclosed in the fourteenth century by shingle banks which must have lain considerably inland of the present beach, the little estuary where ships of war had once anchored became increasingly silted, so gradually that in the sixteenth century a considerable tidal inlet yet remained and by the close of the eighteenth century high-water still flowed a mile or so up the valley and the site of the present railway station was a "boggy reed bed."[1] A map of 1746 shows a wide tract of land lying between the haven, that is still marked as such, and the sea. This was an uninhabited waste of shingle known as the America Ground, that had grown up as

[1] *Hastings of Bygone Days and the Present.* H. Cousins.

the original spit across the estuary widened seawards, a widening that must have been due either to the accumulation of shingle checked from at once continuing eastwards by the Priory brook or to an outward swinging of the line of longshore drift caused by changes in the coast to windward. Across its eastern end flowed the Priory Brook, spanned where it left the haven by a bridge and entering the sea by the present Pelham Place. In 1783 this brook entered the sea west of its outfall in 1746 and near the present Queen's Hotel, at almost



the same point as it does to-day. The present cricket field was then occupied by a pond, and a lagoon lay on either side of the brook behind the shingle beach. These lagoons had disappeared when the Ordnance Survey was made in 1823, and to-day the Albert Memorial looks out on radiating tramway lines from the site of one of the Priory bridges. Early in the nineteenth century the broad shingle area west of the Priory Brook had become so far secure from too frequent incursions by the waves as to harbour, besides a rope-walk, a lawless and unauthorized population, living in makeshift dwellings and no doubt in danger of periodic inundation.

By this time the third and modern Hastings had begun to grow westwards from the now old town in the Bourne Valley. It spread down the western slope of the Castle Hill and enclosed ever more narrowly the diminishing area of the old estuary.

Meanwhile the erosion of the coast had continued apace. The silting of the Priory Haven led to repeated attempts to provide a new shelter on the exposed and now harbourless coast. In 1597 the pier of that day was being rebuilt and " behold, when men were most secure and thought the work to be perpetual, appeared the mighty force of God, Who, with the finger of His hand, at one great and exceeding high spring-tide, with a south-east wind, overthrew this large work in less than an hour, to the great terror and amazement of all beholders." The sea attacked without intermission. In the nineteenth century the recession of the St. Leonards cliffs entailed the diversion of the coast road inland. Martello Towers built in 1805 were washed away. Prints and maps of the early nineteenth century show a rough trackway between the sea and the base of White Rock—so that by now this rocky headland was so far receded as to harbour beneath it a considerable accumulation of beach. In 1833, however, this road was washed away and the headland itself much broken up by storms, whereupon the Hastings Corporation, faithful to early Victorian traditions of the beautiful and anxious to improve its communications with Brighton and the west, removed the shattered rocky point and cut back the land behind it

THE OLD CASTLE AND ROPE WALK FROM THE WHITE ROCK, HASTINGS, 1817

to make room for the straight-faced houses and level parade still known as White Rock. East of the haven, until the fourteenth century, the Castle cliffs appear to have been directly attacked by the waves. Subsequently the deflected Priory Brook and its attendant shingle banks stretched round the base of the Castle Hill and a widening shingle beach accumulated which became built over after about 1800. Behind it, as in the case of White Rock, cliffs loosened by erosion were artificially cut away to make room for buildings. The shingle beach had also widened in front of the Old Town in the Bourne Valley. This little vale, to-day only some two miles long, seems to have had no estuarine haven. The low land at the mouth of the valley is reputed to have suffered in very early days from the sea's advance, but the town itself, whose walls extended almost to the beach, was not encroached upon, and now a wide bank of shingle, bearing huts for fishing nets and capstans, extends in front of the town which has itself expanded seawards from the line of its old sea-wall. The broad expanse of shingle here may be due to the longshore currents, which increasing in inertia as they gained in volume with the regularization of the coastline may have ceased to follow the actual coast of the slight embayment and have extended in a more direct line from Castle Hill to Rock-a-Nore, the eastern headland of the mouth of the Bourne Valley.

By about 1850 the shingle area at the mouth of the Priory Valley was laid out, behind a sea-wall, in the present terraces and parades that lie between Cambridge Road and Carlisle Parade, certain of the streets being raised above sea-level with earth from the railway tunnels. To-day the region is indistinguishable from the rest of the town, and behind it the finally reclaimed alluvial flats of the old estuary extend inland from the Albert Memorial via the cricket ground and up into the Alexandra Park.

The whole sea-front of Hastings and St. Leonards is now defended by one long line of sea-walls and parades, the first of which was erected below the eastern Castle cliffs in 1812. Thus the natural course of coastal development has for the last hundred years been here obstructed. It is, however, quite obvious that the waves have by no means abandoned their attack upon this length of coast. The parades themselves are defended by massive sea-walls, and huge stone and timber groynes trap and hold shingle below them. Yet in storms even they suffer damage. Mr. Louis L. Jennings in his *Field Paths and Green Lanes* describes the effects of a storm he witnessed at Hastings on New Year's Day, 1877: "Before 12 o'clock, the esplanade all along the town was cut to pieces by the waves, the large slabs at the edge were flung about like pebbles, beach houses were swept off and the pierhead carried away. In Robertson Street a river had formed, along which boats were rowed to the rescue of persons imprisoned in their houses. The row of dwellings known as 'Beach Cottages' had all their windows and doors beaten in, and the furniture in the rooms was knocked into shapeless masses and flung into corners. The kitchens and basements were completely filled up with water and shingle, and all traces of the ordinary road were effaced. Similar havoc was made at the west end of the Marina."

HASTINGS FROM NEAR THE WHITE ROCK, BETWEEN 1817 AND 1834

VIEW OF WHITE ROCK, HASTINGS CASTLE IN BACKGROUND, 1920

Opposite the fisher town the breakwater of the latest (and seventh) unsuccessful attempt at harbour construction, built in 1893, is already falling into ruin. The clay cliffs on either side of Bexhill are owing to their ruinous condition labelled " dangerous " by the careful Hastings Corporation. Off Bulverhythe, south of St. Leonards, five hundred feet have been washed away since the middle of the eighteenth century, while east of the last sea-wall the cliffs of Fairlight retreat steadily before the waves. Landslips, concave to the sea, extend inland across cliff-paths ; the early coastguard station at Ecclesbourne has been washed away, and the now deserted coastguard cottages which have replaced it are already in danger. The steps down to the shore from this glen have recently been destroyed and a low cliff now makes communication with the shore impossible.

The Priory Brook to-day flows under the streets and reaches the shore through a culvert, yet the flood-tide before a gale still occasionally flows up its former course and, lapping round the base of the Albert Memorial, runs on over the bed of the old estuary that still lies below high-water level, to the cricket ground some three hundred yards inland.

This whole length of coast continues then to be exposed to wave attack that seems to have suffered no diminution as yet from the increased breadth of the coastal shelf it must have carved out. Beaches of sand or shingle had accumulated, before the erection of groynes, below the cliff sections as well as, in broader areas, before the valley outlets—beaches drawn from distant sources, since the silting of Pevensey Bay and the recession of Beachy Head must by now have allowed the shore transit of material which they had probably at one time obstructed. (Serpentine from the Lizard has been found on Hastings beach but it cannot be proved that it reached there by natural means.) Everywhere fringed by beach the modern coast is a straight one. The topographic inequalities of the shore lands have ceased to produce a corresponding irregularity in the coastal outline so that the coast of to-day bears but little resemblance to the Saxon coastline, which approximated more nearly to that of Neolithic days than it did to the present coast. This length of coast may then be regarded as having passed through one definite phase of its process of development. It is more or less regularized in outline, but it continues, wherever the Hastings Corporation permit, to retire rapidly before the waves. The possible future history of such a coast as this may with greater profit be discussed for the whole length of shore between Beachy Head and the North Foreland, a coast whose development to its present outline has followed a course identical with that of the Hastings shoreline.

CHAPTER XI

THE EVOLUTION OF THE SOUTH-EAST COAST: (II) BEACHY HEAD TO THE NORTH FORELAND

THE coastline between Beachy Head and the North Foreland affords, like the small part of it along the end of the Forest Ridge, an example of coastal evolution so perfect as to be consoling to the theorist. The general features of this coast have been described in the last chapter where also were noted the broad deductions that may be drawn from them as to its past outline. The three hill ridges that reach the coast at Beachy Head, Fairlight and the South Foreland respectively end in cliffs that rise in places to five hundred feet above the sea, but the chalk cliffs of Thanet are lower and do not exceed an altitude of one or two hundred feet. Now if the land washed away from these four regions of upland were known to have sloped uniformly either towards or away from the sea the height of the cliffs would be an index of the amount that had been worn away. Since the configuration of lost lands can only be known where the sea has advanced quite recently, estimates of coast-retreat based on cliff altitude must necessarily be unreliable. It is, in the British Isles at least, usual for the coast-lands to slope towards the sea, so that the height of the cliffs increases as the coast recedes and wave advance must proceed more and more slowly. Often, however, valleys more or less parallel with the shore break this general seaward slope, and in regions where the sea is already attacking the seaward watershed of such depressions wave advance becomes increasingly rapid as the cliffs grow lower in their retreat towards the valley bottom. South-west of Dover the coast road follows such a valley, bounded on the east by the steep grassy slopes of chalk that end along the sky above the high cliffs. Here, as at Shakespeare's Cliff, the waves will cut inwards with increasing ease as every year the cliff summit is lowered. Deductions from the present rate of cliff recession must be equally hazardous as those based on their height, since this factor is governed very largely by the height of the coast, besides being affected by its exposure and by other factors dependent upon its position and outline. There can therefore be no certain indication of how far into the Channel these hill ridges projected at the close of the subsidence of Neolithic days, but various considerations make it probable that they did not at that time reach out to more than a mile or two beyond their present positions. The cliffs of Thanet receded, it was estimated about 1866,[1] between two and three feet annually. They are relatively low and receive little protection from an unusually scanty supply of shingle, but suffer more from weathering than from direct wave attack. The higher cliffs of hard nodular chalk at the South Foreland scarcely yield appreciably to erosion and do not retreat on the

[1] *Principles of Geology*. Sir C. Lyell (tenth edition).

average more than half an inch a year. The estimated present loss of three feet annually east of Hastings is abnormal as these cliffs stand to leeward of the Hastings groynes. Beachy Head is very slowly worn back. Supposing, as the late Clement Reid has suggested, that the coast ceased to subside three thousand five hundred years ago an average recession of two feet a year would have meant a former projection of the headlands to a point rather over a mile in advance of their present ending. As already stated estimates of this sort are quite unreliable, but they may serve in some degree as a check on figures obtained from other lines of reasoning.

The sea-level of the stream outlets near Hastings has been mentioned already as an indication of a limited recession since the last change of level. Where steeply sloping tributary valleys debouch into a larger valley with a low seaward gradient subsidence might submerge the main valley for a long distance, when subsequent wave erosion of the open coast would cause the mouth of each little stream to lie in turn upon the sea coast. Their sea-level outfall would in this case be no proof of a small amount of coast recession. On these south-eastern headlands, however, the main valleys are scarcely long or well-graded enough for such conditions to obtain. Another argument against any considerable recession of the headlands is that since the beginning of the historic period great areas that were then tidal bays have been converted into land, a process certainly somewhat hastened by reclamation but that has been accompanied along the headland coasts by changes rather of outline than of position. It thus seems highly improbable that in the period—probably relatively short—that elapsed between the close of the Neolithic subsidence and the coming of the Romans, a period during which it has been estimated[1] the estuarine bays received perhaps one-third or one-half of the deposits now filling them, any very marked recession of the headlands can have taken place.

The original limits of bays may be accurately determined from the extent of the alluvial deposits that fill them, and in some cases low cliffs formed before the inlets were silted are as yet sufficiently marked to be recognizable along the former coast-line. Between Beachy Head and the lower slopes of the Forest Ridge at Bexhill the sea covered what is now Pevensey Level as far as a point north of Hailsham and some six miles from the present coast. Where to-day is the great area of alluvium commonly known as Romney Marsh (the name actually of but a part of it), the sea once covered between the Forest Ridge and the North Downs all the region now lying seawards of Hythe, Appledore, Rye, and Winchelsea. Appledore is to-day some seven miles from the nearest part of the coast and the tides extended further than this into the country up the river valleys. The third area of recent alluvium on this coast lies between Thanet and the North Downs. Here the tidal waters formed a strait between the Thames and the Channel and penetrated besides up the river Stour, thus isolating the island of Thanet and bringing Canterbury even as late as the early Middle Ages

[1] *Submerged Forests.* C. Reid.

almost within reach of the sea, its outport at that time being Fordwich, three miles down the Stour. At the close of the period of subsidence the south-east coast was therefore very irregular, deeply recessed bays reaching far inland between out-standing headlands. The process of the conversion of this coastline, created by subsidence, into one adjusted to wave attack has been accompanied by the changes that have led to the formation of the existing coastal outline.

The incidence of wave attack was irregular along this submerged late Neolithic coastline. Its intensity was greater against the projecting headlands than along the inner shores of the bays or inlets, and this initiated the subsequent creation of an even coastline. At the same time began the accumulation in the bays of waste worn from the eroded headlands, in addition to that derived at first from the relatively feeble wave attack upon their own shores. It cannot be stated at what period the recession of Beachy Head had permitted the travel of shingle from the south coast along the broadening wave-cut platform beneath it. Thus it is impossible to say whether the south-east coast was at any time, and if so for what length of time, cut off from supplies of shore waste derived from the south coast and thus from sources external to it. The few small rivers that flow out upon this coast can have supplied but little waste. It seems, however, certain that contributions of shingle from the gravel deposits of the eroded coast plain in Sussex must have long been rounding Beachy Head before the barring and silting of the

Pevensey and Romney bays could have been accomplished.

The earliest historical account of the south-east coast is derived from records of the Roman occupation. By this time a considerable period had elapsed since the last change in the relative level of land and sea, and the sea had had time to set a marked impress on the coastline.

The Romans had five chief stations along this coast. They created the ports of Regulbium (Reculver) and Rutupiæ (Richborough), situated respectively at the northern and southern ends of the Wantsum strait that formed in those days the usual approach to the Thames and London. They settled at Dubris (Dover) on the estuary of the little river Dwr, at the vanished Portus Lemanis near Hythe on the northern edge of Romney Marsh, and at Anderida, now Pevensey, on the western margin of the still submerged Pevensey Levels. They also occupied Ramsgate, using the haven here as an outport to Richborough. Each of these Roman ports except that of Dover grew up in connexion with great tidal inlets that are now vanished, and the silting of which was already considerably advanced by the time of the Roman occupation. The early possession by Dover of an estuarine haven shows that the cliff coasts were still indented with minor bays and headlands when the Roman ports were founded.

It is unnecessary to follow here in any detail the development of the headland coasts since the history of Hastings on the Forest Ridge is typical of that of the other headlands. Accounts of Dover show that the estuarine haven of the little Dwr river, whose valley extends for some five miles inland, was choked by shingle as early or earlier than the time of Edward the Confessor. The later history of the harbour, by then situated in the eastern part of Dover bay, records much the same story of wave attack and shingle drift as occurred at Hastings. The headlands, that at one time afforded some shelter to the anchorage, receded before wave attack and thus made necessary the erection of a protecting bank or pier, possibly as early as the eighth century, certainly in the reign of Henry VII. The artificial harbour subsequently suffered from shingle drift as had the original estuarine haven; and this factor, combined with a wave attack that was emphasized whenever one of the frequent landslips west of Dover fell athwart the shore and temporarily held up the shingle drift from the west, involved Dover in a ceaseless struggle with the sea. Here obtained the old Cinque Ports custom by which the mayor could summon all citizens to repair with shovels to the harbour and clear it of shingle.

Coastal changes at Folkestone followed the same course. The early haven here, at the mouth of a little valley, had to be protected by harbour works as the headlands formerly projecting on either side were cut back by the waves. The harbour suffered like that of Dover from a periodic destruction of its defences and from shingle drift around the windward pier—difficulties only overcome, as at Dover, in recent years. Whether they are permanently overcome is another question.

It is thus evident that since the Roman period the cliffs along the headland coasts have been regularized or smoothed in outline, without any notable recession of the coasts as a whole having taken place. The erosion and retreat of their minor headlands, at once supplying waste and admitting of its shore transit beneath them, led to the barring by shingle of the little estuaries of submergence, the subsequent silting of which combined with the continued recession of the subsidiary headlands has led to the creation of an even line of coast. Similar processes have resulted in the obliteration of the greater irregularities of the south-east coast as a whole.

Over Pevensey Level between the South Downs and the Forest Ridge the sea still extended some five or six miles inland when the Romans built Anderida, late in their period of occupation. William the Conqueror landed here in 1066. In 1208, however, the inhabitants of Pevensey, the Saxon township that had grown up outside the walls of the Roman fortress and was still a notable port, applied for licence to build a new town nearer the sea and to have the privileges belonging to Pevensey transferred to it. This project came to nought and the decline of the port owing to the sea's withdrawal was completed by the fifteenth century. The area of Pevensey Level was permanently drained by 1698, though for some while after this it was possible for small vessels to reach Pevensey bridge by way of the stream that drained the Levels and as late as 1833 a lake existed behind the shingle accumulation that had formed on this coast. Shingle banks had extended from the cliffs of Beachy Head on the west, bars that must first have closed the tidal inlet behind Eastbourne that is known as Willingdon Level and that subsequently grew across the entrance to the shallow estuarine bay of Pevensey, driving the outlet of the haven north-eastwards as they grew. Behind them the marshy area silted and was reclaimed until now all of the sea that remains to the old port is the sound of the waves on the distant shingle banks. To-day a high bank of shingle protects the green flats between Eastbourne and Bexhill from the sea. Through it the stream that passes Pevensey now flows out by a sluice, and over it occasionally the waves sweep and flood the flat lands behind.

From the shingle banks that barred Pevensey Haven there grew the triangular projection or shingle foreland of Langney Point. It does not appear certain when this deposit began to accumulate. It had not done so in the Roman period—at which time no doubt the shingle banks were already growing across Pevensey Bay—and no projecting point is shown on a map of 1689. Langney Point had attained its maximum projection and was being eroded by 1724, and between this date and 1851,[1] it had been cut back over half a mile. It grew up, like the similar formation of Dungeness, to windward of a tidal inlet, and thus at a point on the coast where shingle accumulation would naturally occur. Shore deposits of this type may be regarded as temporary expedients by the sea for the disposition of sand or shingle that owing to an excess in supply or local changes in the coastline cannot at once be distributed along the actual shoreline. The growth and decay of

[1] "On the Alluvial Formations and Local Changes of the South Coast of England." J. B. Redman. *Min. Proc. Inst. C. E.*, vol. xi.

Langney Point have been associated by some writers with the erosion and destruction of the raised beach at Brighton, and though this deposit can only have been a minor source of shingle supply it is certain that changes on the south coast are reflected along the shores beyond Beachy Head. Coast defence works that have held up the shingle drift before Newhaven and Seaford have been cited as the cause of a diminished supply of beach at Eastbourne.

From what can be gathered as to the history of the gradual disappearance of the bay that once lay seaward of Appledore it is evident that it presented no unusual features. The silting of the estuarine bay behind shingle bars, the wandering courses of rivers across the rising surface of alluvium, the periodic incursions of the sea, the rise in level of the alluvial deposits towards the coast, and the formation of a cusped projection of shingle seaward of the original bars are all features commonly associated with the closing of tidal inlets by coastal processes.

In the case of Romney Marsh a voluminous literature is available for reference—so voluminous that it is not always easy to distinguish established fact from plausible surmise. The fate of six ports has been bound up with that of Romney Marsh and it is from their histories that an account of the silting of the area may chiefly be obtained. The matter is complicated by the fact that historians are not agreed as to the site of the Roman Portus Lemanis or even as to the existence of the supposed River Limen, the mouth of which according to some authorities formed its haven. The Limen may have flowed from Appledore along the base of the greensand scarp that overlooks Romney Marsh from the north and reached the sea through shingle banks at the north-eastern corner of the Marsh. On this scarp either at the present Lympne or nearer Hythe stood Portus Lemanis. The fact that at present the level of the alluvium is lower at Appledore than nearer the supposed mouth of this river does not necessarily disprove its past existence in view of the changes in level to which marshy surfaces are liable.

It is definitely established that Romney Marsh east of Appledore and Romney was reclaimed by the time of the Romans. This reclamation was made possible by the existence of shingle bars along the seaward edge of the area, bars that appear to have given efficient protection against the waves. The western edge of the reclaimed marsh was protected by the Rhee Wall, an artificial bank of Roman or pre-Roman date that extended from Appledore to what had been, before the reclamation, the island of Romney. The river Rother flowed out west of the Rhee Wall between Romney and the shingle island on which grew up the Teuton port of Lydd. West of the Rother and the Rhee Wall the sea still reached inland as far as Appledore and beyond it up the river valleys, though shingle banks must already have extended, broken here and there by tidal gaps, from the Fairlight cliffs to Lydd.

At the close of the Roman occupation the Teuton invaders created the five ports of Hythe, Romney, Lydd, Rye and Winchelsea. Hythe at the base of the greensand scarp in the extreme north-east corner of the Marsh was dependent for a haven on a lagoon behind the shingle bars. It had ceaseless struggles with the drifting shingle and was already relatively unimportant when the Federation of the Cinque Ports was established. Romney had for haven the mouth of the river Rother. Records of Lydd, on the opposite shore of the Rother mouth, show that Dungeness had begun to form before the year 774, when marshes seaward of Lydd were reclaimed. Rye stood on a rocky island and the original Winchelsea on a low shingle bank two or three miles south-east of the present town. Thus by the early days of the Teutons shingle deposits of some stability had grown up across the wide entrance to the inland sea of Appledore Bay, the eastern part of which was already reclaimed.

The tidal area west of the Rhee Wall gradually silted and was reclaimed like the marshes east of the Wall. The process was accompanied by occasional tidal inundations, the most noted of which in 1287 flooded all the flat lands from the Fairlight hills to the greensand scarp on the north, washed away the old town of Winchelsea on its shingle bank, choked the outlet of the Rother at Romney and deflected this river westwards to flow out past Rye. Winchelsea was re-established on its present site occupying the eastern end of a promontory then washed by the sea. In the reign of Henry V the area of the town was reduced owing to the decrease in trade and population consequent upon the sea's withdrawal, and by the end of this century all merchants had left the port. To-day from the ruined gateways of Winchelsea the sea is visible beyond more than a mile of flat green levels, amidst which may lie the lost site of the older Winchelsea. At Rye, formerly secure owing to its insular position, land-defences became necessary in the fourteenth century owing to the retreat of the sea. During the fifteenth century, that which saw the decline of Winchelsea, the sea still reached far inland between Rye and the Rhee Wall, touching the parish of Tenterden behind Appledore at two points, but silting and reclamation were gradually reducing the total area. Camber Castle was built in the reign of Henry VIII on an eastward-pointing peninsula of beach between Winchelsea and the sea. At this time Winchelsea and Rye were still separated at high-water. The Castle soon became useless for purposes of coast-defence and was left stranded inland.

Eventually the whole area of Appledore Bay was reclaimed. Only Rye, situated where three rivers unite, has kept open its communication with the sea—and even it has an outport in the village of Rye Harbour where the Rother reaches the present coast. The old town of Hythe, behind saltings and shingle banks, has established a new settlement on its present sea-front, and New Romney, now a country village, has the modern suburb of Littlestone-on-Sea. Lydd and Winchelsea are now both inland.

These silted and reclaimed levels of the old Appledore Bay lie below high-water level and would at once be flooded with the alluvial flats that stretch beyond them up the river valleys were it not for the protection of natural and artificial coast banks.

The growth of the shingle foreland of Dungeness has accompanied the silting of the Romney Marsh area. It is not known at what date the shingle bars stretching out north-eastwards from Fairlight began to be formed into a cuspate projection. It is probable from the curve of the shingle ridges near Lydd that in the eighth century such a formation existed and that its point then lay south-westward of Lydd.[1] Since this date Dungeness has grown at varying rates—its point extending seawards sometimes eight yards in a year and sometimes not at all. It has also suffered a change in shape. Erosion of its south-west coast has been long in progress, and this combined with deposition on the leeward side of the point has caused this latter gradually to shift towards the north-east. Dungeness now extends about six miles beyond the marsh coast on either side, and its extension into water thirty feet deep and exposure to more violent wave and tidal action accounts for its projection being now somewhat blunted in comparison with the sharper point shown on early maps and indicated by the curve of the remaining parts of the older ridges of shingle.

This vast accumulation of shingle has been attributed to various causes but a satisfactory explanation of its formation has not been forthcoming. It lay originally, like many similar deposits, to windward of a river outlet. It received an ample supply of shingle that must have increased in amount as the gradual smoothing of the coastal outline to windward permitted its travel from regions increasingly remote. As it extended the growing point acted like a natural groyne and

[1] "Dungeness Foreland." F. P. Gulliver. *Geog. Journ.*, vol. ix.

eventually it stopped all shore travel of shingle from the west, thus absorbing the considerable supplies derived from erosion of the coast to windward. To-day Dungeness continues to grow out into the Channel. The immediate source of its supplies is the area of shingle that has accumulated west of Rye Harbour, where the outfall of the Rother holds up the great masses of beach that here drift from the west. East of the Rother the coast was until recently for some distance sandy and devoid of shingle, and it appears that shingle must have travelled to Dungeness in fairly deep water across Rye Bay.[1]

The growth of Dungeness has affected the development of the coast to leeward. The old shingle-beaches that fringed the coast of Romney Marsh towards Hythe were by the growth of Dungeness Point eventually cut off from further supplies. The existing beaches were depleted and drifted eastwards along the coast until the natural defence of Romney Marsh proper was gone and the area had to be protected by the Dymchurch sea-wall, an embankment now fronted by wide sands. The accumulation of shingle induced by modern groynes further east at Hythe shows that pebbles now succeed in rounding Dungeness, though here, as on the immediate west of the point, they do not follow the actual coast. The Dymchurch wall is exposed to a violent wave attack and suffers damage nearly every winter.

[1] Mr. A. G. Bradley informs me that during the last few years shingle has rounded the piers of Rye Harbour and accumulated in ridges, that are rapidly extending towards Dungeness, on the formerly sandy shore. Thus both the relatively recent deflection of the Rother to its present course and the harbour works have by now proved ineffectual in checking shingle drift from the west.

Space does not permit of an account in detail of the gradual closing of the Wantsum strait. It occupied an area extending from Ramsgate and Deal on the Channel to the Thames between Reculver and a point west of Birchington-on-Sea. It was already somewhat silted by the time of the Roman period. By the middle of the sixteenth century the northern branch was closed. This accelerated the silting of the southern reaches, silting already promoted by the growth of sand and shingle spits across the mouth of the remaining inlet in Pegwell Bay. The Roman Richborough had been superseded by the Teuton ports of Sandwich and Stonor which lay nearer the retreating sea. Stonor was built on the southern extremity of a shingle spit that had grown from the Thanet shore southwards nearly across this entrance to the Wantsum, pushing south before it the tidal channel of the Stour. Facing it across this channel stood Sandwich, then probably on the open sea coast. Subsequently, after Stonor had been washed away in a storm, sand drift from the south deflected the Stour outfall to its present position under the Thanet cliffs and nine miles north of its former mouth at Sandwich, leaving the Stonor shingle spit stranded inland. Thus a deposition form, created by a local shore drift opposite in direction to the general movement of beach material on this coast, has been overlapped by a spit formed by the normal north-eastward drift that has—as the local coastal outline became regularized—replaced the local drift originated by the temporary irregularity of outline.

The Wantsum, like the other tidal inlets on this coast, is now silted and reclaimed. Of the ancient ports dependent on it, Reculver, on the Thames coast, has suffered severely from wave advance; Stonor was washed away before it could share the fate of Richborough and Sandwich and be left deserted by the sea; only Ramsgate with its artificial harbour remained a port until works begun at the "mystery port" during the War once more gave Richborough access to the sea.

Along the south-eastern coast the production of a relatively smooth coastal outline has been accompanied by a widespread distribution of beach material along cliffs and alluvial shores alike and by its unobstructed drift north-eastward along almost the whole coastline. The only considerable natural interference with the shore drift of shingle that yet remains is the projection of Dungeness, and this, like the mouth of the Rother west of it, only checks shingle travel along the actual shore. East of Dungeness where the tidal streams run slowly, there is a local counter-drift from the east towards the old haven of Romney Hoy. In Pegwell Bay occurs the remarkable "shingle end," noted in a previous chapter, where the shore belt of shingle ends at a point that moved northward some two and a half miles between the days of Elizabeth and the middle of the nineteenth century. Possibly the growth of such formations as Langney Point and Dungeness to windward of this area so starved it of shingle that the limited supplies were insufficient to extend across the tidal currents of the former Wantsum strait.

The creation of a regular coastline, a process accelerated it must be noted by reclamations, has done away with the former irregular incidence of wave attack. Both headlands and the alluvial coasts of former bays are now almost everywhere being eroded by the sea. All four headland coastlines continue to retreat. The shores of Pevensey Level have long suffered loss, the sea-walls of Romney Marsh are violently assailed by the waves, the coasts of Pegwell Bay suffer serious erosion and are about to be protected by a sea-wall as the road to Sandwich is endangered. Erosion and recession of the silted bay coasts is an inevitable accompaniment of the continued cutting back of the headlands.

The possible future course of development of a coast of this type is clear enough in theory. It must eventually recede to a position where the coastline will lie behind the inmost coasts of the former bays, by which time all areas of marine alluvium will have been swept away. It may still be fairly regular in outline, though the coast lands will vary greatly in height, but the waves must ultimately create a coastal outline adjusted to the differing powers of resistance of the upland and lowland coasts and remaining after such adjustment constant in outline. Such a future coast would be indented to some extent; the coastline curving broadly landwards along the yielding clays of the Wealden plains, and projecting in blunted headlands caused by the relative projection, then probably slight, of the stronger rocks of the three hill ridges. By then Thanet may be supposed to have vanished with the alluvial area behind it.

It must, however, be remembered that in Dungeness is an enormous store of shingle drawn from distant sources that must when the time comes for the erosion of this deposit be dispersed along the coast; also that supplies of shingle travel round Beachy Head from sources external to the south-east coast and hence in quantities unaffected by the progress of local coast development. The presence of an amount of beach material in excess of that which would be derived from local coast erosion must ultimately delay the erosion and retreat of the coast even though it is accumulated for the moment in deposition forms like those of Dungeness and Langney Point.

The normal course of coastal evolution is, however, here as elsewhere, interrupted by coast-defence works, which by protecting certain areas from erosion and by checking the free travel of longshore drift affect the supplies of beach to leeward, induce localized areas of accretion and erosion, and thus lead once more to an increased irregularity of coastal outline.

CHAPTER XII

THE COAST OF WALES

THE Welsh coast possesses along great parts of its length those features already noted as typical in other areas of coastlines created by submergence. The lower ends of river valleys are drowned by the sea and much of the coast is very indented, submerged forests and old land surfaces occur between tide-marks here and there along the whole length of shore, while the marshes of the Mersey and Dee on the north and the Severn on the south of Wales are known as we have already seen, to be underlain by buried land surfaces now some sixty feet below sea-level. In Wales, as in England these coastal features, typical of submergence, were produced by a subsidence of the coast lands, occurring probably during the Neolithic period.

Inland of the present coastline there occur on the south coast of Wales remains of a pre-glacial coastline, showing that here at any rate elevation as in England preceded the latest movement of subsidence. This elevation created coastal plains. Remains of former land surfaces show that many square miles of the present Carmarthen Bay were land and formed a plain lying in front of the uplands at a time when they were inhabited by pre-historic man.[1] The line of old sea cliffs on the north

[1] Leach, A. L. *Archæologia Cambrensis*, 1913; and *Proc. Geol. Assoc.* vol. xxix, Part II, "Flint-working Sites off Pembrokeshire."

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coast of Wales have been already noted. It is probable that traces of pre-glacial cliffs and beaches are masked in other regions by glacial drift. Thus wave-cut platforms and cliffs overlain by drift occur on either side of the Castle Rock at Criccieth.[1] That the present coastline is nowhere far removed from the line followed by the pre-glacial coast appears clearly established. The Anglesey shores[2] are to-day broadly coincident, as will be noted shortly, with those of the period preceding the Ice Age, and the Welsh coast where both drift deposits and raised beaches are absent is of such a resistant character that the present coastline cannot have been pushed far inland of the pre-glacial one. The approximate coincidence that exists—not only in Wales and southern England but along about a thousand miles of the coasts of England, Ireland and France[3]—between the present shoreline and one of a pre-glacial time links present-day conditions with those that obtained before man reached our islands. Even more remarkable are cases where the coastal conditions of a much earlier geological period are reproduced to-day. In Barry Island (now joined by artificial means to the mainland) on the coast of Glamorgan the two headlands that to-day project into the Severn Sea from the south coast of the island are shown by the disposition of the Trias deposits to have formed headlands in a Triassic sea.[4] So the present shores of Tor Bay in south

[1] "Tremadoc Slates and Associated Rocks of S. E. Carnarvonshire." Fearnsides, W. G. *Q. J. G. S.* vol. lxvi.

[2] *Mem. Geol. Survey : Anglesey.* Ed. Greenly.

[3] *The Quarternary Ice Age.* W. B. Wright.

[4] *Mem. Geol. Survey : Country round Cardiff.* A. Strahan and T. C. Cantrill.

Devon are believed to approximate to those of the earlier Triassic period.[1] Such repetition on a coast of features that existed in earlier geological epochs is in view of the power of wave attack a significant commentary on the instability of level common to coastal regions.

The shoreline of Wales is as yet but imperfectly adjusted to the sea's attack. The irregularity of outline, discontinuity of beach deposits and irregular incidence of wave attack that is typical of a great part of the Welsh coast allies it with those of such regions as Devon and Cornwall where the rocks are also hard and ancient and the coastal outline equally undeveloped. In Wales such conditions typical of coastlines as yet unadjusted to sea attack are found along the rocky coast between Penarth west of Cardiff and Porthcawl at the eastern entrance to Swansea Bay, in the Gower peninsula that juts out between that bay and Carmarthen Bay, along the Pembroke coast from its eastern boundary west and north to Fishguard, in the peninsula of Lleyn that forms the northern horn of Cardigan Bay and projects into ten and fifteen fathoms of water, and along much of the Anglesey coast. The shoreline of Cardiganshire north of Fishguard and as far as Aberystwith is also characterized by steep cliffs rising above a bare rock foreshore, what beaches there are occurring as a rule at the mouths of cwms. Its comparative regularity of outline is due rather to the homogeneous nature of its hard and ancient rocks than to the regularizing effect of wave action. Like the south

[1] *Mem. Geol. Survey: Country round Torquay.* W. A. E. Ussher.

coast of England, this length of coast displays a remarkable parallelism with successive lines of upfold and downfold that form a notable geological feature of the land behind it.[1]

Generally throughout these lengths of relatively undeveloped coastline the bays occur in soft strata, in shales, coal-measures or glacial drift—while headlands are of hard rock, like the igneous projections that form St. David's and the Strumbles Head in Pembroke or the headlands of Lleyn. Bays and headlands of this type were originated when sub-aerial denudation began to attack the land surface and to lower its level unequally so that when the land margin was submerged the sea flowed in over the low areas and formed bays between the projecting uplands. But very often on the Welsh coast wave erosion has increased and is increasing the initial unevenness of outline, a fact proving that the present degree of irregularity of the coast is not in many parts sufficiently pronounced to correspond with the marked differences that exist between the resistive powers of the bay and headland coasts. Wave erosion has in Glamorgan detached Sully Island and Barry Island from the mainland; it has scooped out such bays as St. Bride's Bay and Whitesand Bay in western Pembroke from soft coal-measures and boulder-clay respectively, and worn back the heads of the bays in Anglesey and the rocky Lleyn peninsula so rapidly that their low cliffs of glacial drift may as at Aberdaron in Lleyn or in Red Wharf Bay in Anglesey be a mile or more further recessed between the resistant headlands

[1] "The Geological Structure of Central Wales." O. T. Jones. *Q. J. G. S.*, vol. lxviii.

than at the beginning of the historic period. It is obvious that the deposition of glacial drift imposed an artificial regularity upon the coastline, a process that is being undone by the sea as it scoops out the drift that fills the lower ends of valleys. The coast of Anglesey, to give one example only, would be much more irregular than it is were it to be stripped bare of drift deposits.

Along these coasts lie many islets and stacks, such as Bardsey and St. Tudwal's islands off the shore of Lleyn, or those fragments of igneous rock that extend westward for fifteen miles out from the southern peninsula of St. Bride's Bay in Pembroke, or Anglesey, with its attendant islets of Holyhead and Puffin Island. These islands owe their origin to subsidence, ice erosion, wave erosion, or a combination of these agencies, and demonstrate by their continued existence the relatively undeveloped condition of the mainland coasts. Wave attack has not yet succeeded in removing them ; while swift tidal streams race between them and the land, from which they are often separated by deep channels, so that it has been impossible for them to become joined, as has the Isle of Portland in Dorset, by beach deposits to the mainland. The inhabitants of Bardsey Island reach occasionally the verge of famine, as for weeks the passage to the mainland of Lleyn may be impracticable in stormy weather owing to the dangerous currents and heavy seas.

These lengths of little-developed coastlines retain with their irregularity of outline a scarcity and discontinuity of beach deposits equally typical of the early stages of coastal evolution. Beach deposits are almost entirely limited to the heads of bays. Commonly the lower ends of valleys sloping down to the coast are occupied by an alluvial flat behind a dune or shingle ridge, conditions that occur also in Devon and elsewhere. In such cases the sea, as in Lydstep Cove near Tenby, Cwm Col Hugh on the rocky coast between Swansea and Cardiff, or at Newgale in St. Bride's Bay, has barred itself out from the lower end of the valley by a ridge of beach. The pebble bank which, one and a half miles long, stretches across the outlets of the Newgale Brook and Bathesland Water is bordered on the inner side by old, grass-covered, blown sand and marsh, and is gradually being pushed inland by the waves and advancing up the valley. Thus here the coastal outline has been regularized and the shores of the silted inlet now suffer from wave advance where formerly deposition predominated. In the Lleyn peninsula bays on its southern coast are similarly fringed by marshlands lying within sand dunes.

At the northern end of the nearly straight cliff-coast of Cardiganshire is the Dovey estuary, which divides that rocky coast with its scanty supplies of beach from the very different shoreline, fringed by dunes and alluvium, of north-eastern Cardigan Bay. This estuary, too wide to be as yet completely barred, is like those of the rivers Dysinni and Mawdach north of it partially closed by a spit of beach that has grown out from the southern bank impelled by the longshore drift from the south that prevails along this coast. The entrance to the Dovey estuary must once have been about four miles wide and have extended between Aberdovey and a point south of Borth, where is now the southern base of the great shingle ridge on which stands Borth village between the sea and the alluvial flats in the rear of the bank. Nearly the whole area behind this shingle and sand spit that reaches within half a mile of the Aberdovey shore is now silted, and a project, now abandoned, was considered in 1919 for the reclamation of some eight square miles of fertile alluvium by means of a barrage across the Dovey south of the little port. Borth village has suffered from the insecurity inherent upon its situation, and has been damaged by the sea breaching and overflowing the shingle bank to flood the marsh behind. The Dysinni river is nearly closed by a spit from the south, behind which it broadens into a lake bordered by flats liable to flood at high-water. The Mawdach estuary is similarly almost barred by a long finger-like spit of sand and shingle that has grown north across the estuary from the shore near Fairbourne to within nearly a quarter of a mile of Barmouth and behind which lie typical alluvial flats.

The sea has done its best to close the western end of the Menai Straits between Anglesey and the Carnarvon shore. The sand and shingle spit of Abermenai stretches, with the thin neck and broad head typical of such features, from the coast of Anglesey half-way across the Straits and is nearly met by a long broad finger of sandy deposits that reaches out from the Carnarvon coast. The narrow neck of Abermenai spit, like that of Spurn Head, is liable to be breached by the sea, and is now artificially protected. Conway Bay at the eastern entrance to the Menai Straits is full of sandbanks, and the mouth of the river Conway south of the Orme's Head is constricted within a narrow channel between the sand dunes on its eastern bank and the opposite projection of the Morfa Conway—a triangular area of alluvium and beach deposits that lies below the abrupt slopes of Conway Mountain.

The distribution of shore deposits on the coast of Anglesey[1] itself is, except on the south-west, typical of that on an irregular coastline of submergence. The more marked headlands—like that of Holyhead Mountain—descend bare of beach into the sea. Shore deposition has, however, already modified the coastal outline in places, as where the silting of a former tidal strait west of Cemlyn Bay at the north-west corner of the island has joined the one-time island of Trywn Cemlyn to the mainland. Similar processes have closed the old strait behind Tre-Arddur Bay that once separated Holyhead Island into two parts. On the south-west coast, facing the prevailing winds, great quantities of blown sand have accumulated, which as in other dune areas have encroached on cultivated lands besides aiding in the reclamation of former inlets sheltered behind lines of dunes. The low belt of Malldraeth Marsh, separated by but a slight watershed from the lowlands towards Red Wharf Bay has been reclaimed. At high-water the sea at one time extended nine miles into the land here. Had the Marsh been a tidal strait, crossing like the Menai Straits the whole width of the island, the tidal scour would no doubt have postponed reclamation indefinitely. An example of a sudden change

[1] *Memoir Geological Survey, Anglesey.* Ed. Greenly.

subsequently perpetuated in a beach deposit is afforded by the shingle ridge that in Cemlyn Bay—above alluded to—partially encloses a tidal lagoon. This ridge was raised to its present height of twenty feet above ordnance datum during one storm in 1859. Before this date it was much lower and was sufficiently consolidated to support a road.[1]

On the lengths of coast so far considered glacial drift occurs in no great quantity. The more southern projections of the South Wales coast lie south of the local limit of glaciation, and on the other lengths of indented shorelines the occurrence of drift upon the coast is now confined to valley mouths. It is, however, very evident that the presence of glacial drift must have greatly affected the past development of many coastlines from which it is now absent in any quantity and that coastal conditions where it still forms the land margin are sharply differentiated from those obtaining where it is not present.

Deposits of glacial drift are chiefly preserved to-day on lowlands or in valleys, and in Wales lowland areas of drift alternate along the coast with rocky shores where the uplands reach the sea. Many of these upland coasts were themselves formerly fringed by a shore plain of glacial drift. The Isle of Anglesey,[2] for example, was bordered at the close of the Ice Age by plains of boulder clay that occupied a total area of perhaps fifteen or perhaps thirty square miles. These plains are

[1] *Mem. Geol. Survey: Anglesey.* Ed. Greenly.
[2] *Ibid.*

by now washed away, a process aided no doubt by the Neolithic subsidence. Their removal has brought the sea into contact with the pre-glacial coastline, itself determined by wave erosion that had even before the Ice Age swept away all but the hard nucleus of ancient rock that forms the island. Here as elsewhere the previous existence of coastal plains of drift is evidenced by the fact that the present coasts remain as yet almost unmarked by wave action. Thus along much of the Anglesey coast the land slopes as it was left by the moulding action of the ice, unbroken by sea-cliffs into the water. Had such slopes long been exposed to the very formidable wave attack experienced in Anglesey—concrete blocks weighing two hundred tons have been displaced and overthrown in Holyhead breakwater—a cliff and wave-cut shelf must have begun to form where they enter the sea. (On the north coast of this island the sea has, however, already at some points advanced against the solid rock; near Trywn Bychan where landslips have aided wave attack a cliff a hundred feet in height with a wave-cut shelf of from one hundred and fifty to two hundred and fifty feet in width have been formed since the close of the Glacial period.) Headlands on the eastern shore of Conway Bay—like those of Penmaenmawr or the Great Orme—similarly descend to the sea with their slopes of solid rock unmarked by any pronounced sea-cliff. Conway Bay, as will be seen in a moment, is the site of legendary lands the probability of whose former existence is thus supported by the form of its eastern coast. In the Aberystwith neighbourhood again on the Cardigan Bay coast hill slopes rise directly from the shore unbroken by sea-cliffs. In their present condition these coast hills resemble those north of the river Dovey that slope untouched as yet by the waves to coastal flats of drift and alluvium. Off these coasts also lay according to legend lost lands.

The coasts of Wales, like those of Cornwall, are haunted by legends of lost lands, such legends seeming, oddly enough, to linger along resistant coasts rather than where the sea makes rapid and continuous inroads. The loss of land to seaward of the raised beach shoreline in Cornwall or along the drift plains of the Welsh coast offered presumably so violent a contrast to the general stability of these rock-bound coasts as to seize upon the popular imagination. It is probable that the legends of tidal inundation and of the drowning of great areas of inhabited lands off the coast of Wales arose owing to the early reclamation and subsequent loss of wide coastal flats underlain by glacial deposits and lying behind coast banks, part natural, part artificial. Romney Marsh was reclaimed either in or before the Roman period and there seems no reason why similar works should not have been undertaken on the Welsh coast by the time of the Saxons, during which period (in the fifth century) the supposed inroads of the sea are stated to have occurred. Drift deposits yet fringing either shore at the eastern entrance to the Menai Straits and bordering the north-eastern and parts of the northern coasts of Cardigan Bay add to the credibility of the stories of vanished lands that lay according to legend where are the waters of the present Conway and Cardigan bays. It must, however, be remembered in this connexion that Anglesey was already an island when the Roman legions made their difficult crossing of the Menai Straits, and that any land in the present Conway Bay during the Saxon period must have been separated at least by a tidal strait from the island.

The breaking of a sea-bank may lead, as has occurred in the Netherlands, to the sudden and lasting inundation of large areas. The loss of the fabled Cantref-y-Gwaelod in Cardigan Bay, which is described as having been guarded by sea-walls, is attributed in the legend to a water-gate having been left open by a drunken guardian of one of the sea-walls. " The moste delicate fruytfulle and pleasant vale " that is supposed, and according to historians on good authority, to have lain between Bangor and the Orme's Head, where is now Conway Bay, was also lost according to the legend owing to a sudden inrush of the sea. If the various legends have a basis of fact and have not in some cases grown up owing to the effect on the popular imagination of the frequent exposures of submerged forests along these coasts they imply the past extension of low plains of glacial drift, bordered by dunes or shingle, covered more or less with alluvium, and lying in front of coasts where now hills rise directly from the shore or are separated from the sea by but a narrow fringe of flat land. Loss of regions of this character would adequately be accounted for by wave attack. Evidence for the coastal subsidence to which such catastrophes are popularly attributed is in the case of Wales unreliable and based on phenomena explicable by a prehistoric subsidence or by wave advance. It must be remembered that roads and houses may lie below high-water level behind coastal banks, that foundations of buildings may on some coasts occur even below low-water level under these conditions, and that swampy plains, as already noted for South Lancashire, while liable to suffer a lowering of surface-level on being drained may also engulf structures of any weight resting upon them. Thus the past existence, however well established, of roads or buildings in areas now under water is a type of evidence that requires the most careful investigation on the spot before it can be accepted as supporting a recent subsidence of the area.

The ultimate removal of a coast plain of glacial drift brings the sea, as was noted in the second chapter, into contact with a region different from the former coast lands and responding in a manner of its own to wave attack. Thus the rapid advance of the sea against the drift lands once bordering Anglesey has by now resulted in their destruction and the exposure to wave attack of the nucleus of hard rock that, as already noted, forms the island.[1] In Cardigan Bay south of the River Dovey the marshy coast-plains overlying glacial drift that border so much of the coast to the north give way to a cliff-coast of a totally distinct character. Here the sea is attacking the Silurian rocks themselves after, in all probability, having washed away a former coast plain of glacial drift. This rocky coast shows the probable future condition of that north of the Dovey.

The presence of intermittent deposits of glacial

[1] *Mem. Geol. Survey: Anglesey.* Ed. Greenly.

drift along a coast involves as a rule rapid changes in the coastal outline. Those parts of the coast of Wales that yet remain fringed by glacial drift deposits are in nearly all cases being rapidly eroded by the sea. Lengths of coast generally bare of drift often retain pockets of it at the mouths of valleys, as occurs in Anglesey or on the south coast of the Lleyn peninsula; and the erosion at such valley mouths rapidly increases, as already noted, the irregularity of the coastal outline. Similar conditions exist on the north-east coast of England between the River Tees and Flamborough Head.

Certain lengths of the Welsh coast have for long been the seat of shore deposition. Wave attack can never, owing to their relatively sheltered position, have been of very great importance in these regions, and their mainland coasts are by now protected from it by the accumulation of shore deposits.

In South Wales alluvium derived from all up and down the Severn estuary forms the coast flats that, below high-water level and protected by artificial banks, form east of Cardiff the Wentloog and Caldecot Levels. The estuary of the Severn[1] has reached a condition of equilibrium with regard to deposition and erosion along its shores. The broad areas of alluvium that fringe either side of the estuary as far seawards as Cardiff on the north and Bridgwater on the south are practically stable in area. The vast quantities of mud that drift up and down the estuary with the Severn tides ensure that

[1] "On the Estuaries of the Severn and its Tributaries." W. J. Sollas. *Q. J. G. S.*, vol, xxxix,

any losses due to wave erosion shall be made good and the affected coast built out again to the limit beyond which increasing exposure prevents its extending. These alluvial flats have long been of their present extent as is shown by the ancient sea-walls that guard them.

On the other side of the blunt projection of the Glamorganshire coast that lies west of Cardiff is Swansea Bay, already the seat of vast sand deposits. From the rocks of Sker Point at the south-eastern entrance to the bay as far as Swansea, part of which is built on blown sand, extend for ten miles the dune areas of Kenfig, Margam, Aberavon, Baglan and Crymlyn Burrows. Inland of the dune belts is a strip of alluvial marsh, and this is bounded on the land side by low cliffs of glacial drift. At low-water sands are left uncovered for distances varying from half a mile to two miles seaward of the dune belts. The coast to the westward from which the prevailing longshore drift, here moving towards the east, would carry detritus into Swansea Bay is very irregular, but sand travels at considerable depths and may round the headlands in deep water. Several rivers also enter the bay. On the gently sloping foreshore sand has accumulated, to be blown into dunes when the tide receded over the flat shore. Behind the dunes, as in Lancashire or Holland, marshlands have grown up at the base of the low cliffs that had been formed by wave attack before the growth of the dune belts and their attendant marshes.

The sands of Kenfig Burrows, which lie immediately north of Sker Point, have encroached on a Roman road and on the old town of Kenfig which is supposed to have been abandoned owing to the sand that "came up like snow and buried the houses" in the fifteenth century. The present village is still engaged in a struggle with the sands which drift before the west winds, and laws prohibiting the removal of the plant-covering of the dunes and enforcing the planting of *Arundo arenaria* are in force at Kenfig as they were formerly in the south Lancashire dune area. West of the village, itself built on sand and dammed up by sands advancing from the west, is Kenfig Pool surrounded by dunes and of fresh-water, although it lies below sea-level. Beneath its waters, legend says, an old town is drowned. This pool recalls the "étangs" that, as noted in connexion with South Lancashire, are pushed inland before the blown sand of the Landes coast of France, and in their landward movement flood villages subsequently buried under the advancing dunes. The waters of Llyn Maelog at Rhosneigr in south-west Anglesey are similarly held up by wind-blown sand.

Like Swansea Bay Carmarthen Bay, west of the Gower peninsula, is bordered between Pendine, where begins the rocky coast typical of Pembroke, and Rhoscilly Bay in Gower by wide sands and alluvial flats that as a rule lie in front of low cliffs of glacial drift. Between Pendine and the Taf estuary the dune-bordered strip of estuarine alluvium lies, however, below cliffs of Old Red sandstone. Some erosion has occurred in the bay—a lost village at the eastern side of the entrance to the Towy estuary is reported to have been originally defended by a

RHOSSILI BAY, GOWER, GLAMORGAN: COAST STRIP OF GLACIAL DRIFT BACKED BY HILLS OF OLD RED SANDSTONE

SEA CLIFFS WEST OF ABER CAWELL, ANGLESEY: ICE MOULDED CLIFFS FORMERLY SEPARATED FROM THE SEA BY A STRIP OF GLACIAL DRIFT, AND AS YET UNMARKED BY A WAVE-CUT CLIFF

line of dunes, as are the alluvial flats remaining to the south and east.

In Carmarthen, as in Swansea Bay, the foreshore is encumbered with sands that dry far out at low-water and make navigation most hazardous, in conjunction with the swift tides and heavy ground-swells to which the bay is exposed. On a windless night in 1868 no less than sixteen vessels were wrecked in the sandy shallows of Broughton Bay, north of Rhoscilly Bay, owing to a ground-swell and powerful flood-tide.

West of Carmarthen Bay shore deposits are scanty and discontinuous, as already noted, until the north-east corner of Cardigan Bay is reached. This angle of the coast is the meeting-place of the longshore drift from the south that follows the coast of Merioneth and that from the west that moves along the northern shore of the bay, and it has thus become the seat of extensive deposits. The several rivers that debouch on this coast add to the supplies of detritus, and shore deposition and reclamation have proceeded rapidly in this region while those estuaries that remain open are encumbered with sandbanks. The Traeth Mawr, formerly an estuary stretching inland towards Snowdonia and covering some ten thousand acres, is now reclaimed, and west of it to beyond Pwllheli the coast is mainly flat, marshy and dune-bordered. A shingle bank east of Criccieth that formed across the outlet of the waters of Llyn Ystumlynn barred the former inlet that existed here and made possible some two centuries ago the reclamation of four hundred acres of land. On the south-eastern part of this coast between the Mawdach and the Traeth Bach, an estuary north of Harlech, lie the Morfa Dyffryn and the Morfa Harlech, two triangular areas of shore deposits that form each a marked salient in front of the general line of the coast. They consist of marsh-lands bordered by dunes, and between them lies a narrower strip of similar deposits that has been eroded by the sea until the old church of Llandanwg now stands on the very edge of the dunes. These triangular deposits show that a plentiful supply of shore waste is present but, as noted elsewhere, a satisfactory explanation of the origin of such deposition forms has not yet been given. Still further south between the rivers Dysinni and Dovey lies Towyn Marsh, an area formerly often flooded by the sea. It forms part of a belt of alluvium and sand dunes lying between the hills and the sea. The Dovey estuary forms, as already noted, the boundary between the region of plentiful accumulation of shore deposits in the north-east of Cardigan Bay and the bare cliffs and bay beaches typical of the coast to the south.

It is impossible here, though it is hoped to do so at a later time, to discuss in any detail the many interesting problems presented by the coast of Wales. From the above brief notes on some of its features, it is evident that the Welsh coast is very far from attaining such a condition of relative adjustment to wave attack as has been reached by the eastern and south-eastern coasts of England. Those portions of the coast where glacial drift reaches the sea form already but a small proportion of the whole coastline, and are destined to be washed away with the marsh and dune areas they underlie. Then the sea will everywhere attack the base of the

Welsh uplands themselves as it now does along the cliff-coasts of Anglesey, Lleyn, Cardigan and Pembroke, and, though the deposits of the Ice Age must leave a legacy of beach material that will long survive them, the coastline as a whole, like the resistant shores of Devon and Cornwall, must develop so slowly that it will long remain in the earlier stages of its evolution.

CHAPTER XIII

MAN AND THE EVOLUTION OF COASTLINES

THE conditions of the life of coast-dwellers differ from those of the inhabitants of inland regions. Proximity to the sea affects human activities in divers ways into which it would be both impossible and irrelevant to enter here. Besides the differences that exist between a maritime and an inland environment there are, however, from a human standpoint infinite distinctions between different types of coastlines, and the usefulness of a coast to man varies not only according to his state of civilization but also with the stage of evolution reached by the coast. An indented coast of bays and headlands, straight lines of cliffs, a low alluvial shore bordered by a shallow sea—each presents its own problems of navigation, access to the sea, coast-defence and the exploitation of the marine harvest. Thus the progress of coastal evolution profoundly affects the life of coast-dwellers, and the maritime activities of one period may be destroyed at a later stage of coast development and be perforce superseded by others of a quite different nature. Thus have the mild pursuits of sea-bathing or golf taken the place of the activities of naval warfare on the greater part of the historic coast of the Cinque Ports.

The influence of coastal conditions may reach very far inland. Wave attack against some length of coast gave in the old days the charitable throughout the kingdom a chance of subscribing to the relief of some affected town. Similarly when the continued eastward drift caused Dover Harbour to fill with shingle churches all over England held collections towards the cost of clearing it out. The decay of harbours that results, whether owing to wave erosion or to deposition, from the regularization of the coastline may affect the movement of trade and relative importance of routes far inland. With their objective gone roads to the coast are neglected whether they end in some forgotten port or are cut short on the cliff edge. Coastal deposition often determines besides the area of habitable land, and farms, villages and towns miles from the coast may owe their continued existence to shingle banks or sand dunes that keep out the distant sea, and the failure of which would admit the tides far into the countryside. The condition of the coastal outline may influence human affairs inland in some not very obvious ways; thus the barring at the mouth of the Thames estuary might, while it embarrassed the Port of London authorities, relieve the custodians of St. Paul's from anxiety, since the tides in the river once affected the foundations and the stability of that building.

If man is affected in many ways and in regions far from the sea by coastal conditions, he in turn reacts upon the coast. By his efforts the course of coastal evolution may be hindered or accelerated. He can by draining and sloping a sea-cliff induce in it, as has been done at Frinton-on-Sea in Essex, the gentle gradient characteristic of cliffs on a coast where wave attack has diminished in violence. In a silting area man can introduce into a salt-marsh a type of vegetation characteristic of a later phase of marsh development and thus accelerate the silting and reclamation of the area. By his sea-walls and groynes he can retard the recession of headlands, check or hasten the silting of inlets, and thus influence the outline of the coast. The effects of his activities range from such achievements as the creation of hundreds of acres of new coast lands, or the stopping in their landward march of waves capable of displacing masses of stone weighing two hundred tons, to such involuntary results as the fostering of parallel lines of vegetation that spring up where the sand of coastal flats is in cart-tracks compressed into comparative stability.

As coastal conditions may exert an effect on human activities even in distant inland places, so all kinds of remote events may react indirectly upon the development of the coast. The embanking of an inland river may result in the rapid growth of a delta and the creation of a salient on the coast where it debouches, since embanked rivers flow more swiftly and carry more sediment to the sea. In Cornwall the activities of tin-miners at work in the river valleys inland have resulted in the carrying of vast quantities of silt to the sea and the rapid silting of estuaries. Money is needed to oppose coastal changes, and on the prosperity of a coast town depends its power of modifying the course of local coastal evolution. It has thus happened that, among others, such diverse factors as the variable wanderings of the pilchard shoals, the popularity of sea-bathing, the decline of salt manufacture from the sea water as salt-mines inland were increasingly developed, the degree of prosperity of the Newfoundland Fishery, the choice of a seaside resort by members of the Royal family, the pilgrim traffic, or enemy attacks upon our trade or ports have all in their turn affected the power of resistance of coast towns to coastal changes that displeased them and hence at second-hand the progress of such changes. One must thus recognize in that migration from inland spas to seaside resorts that was so marked a feature of the eighteenth century a factor of the first importance as regards the coast, for the efforts of wealthy seaside towns to stay the operation of natural laws and preserve their own sea-frontage from the fate of all coast lands have probably interfered more than any other factor with the natural evolution of the English coast.

The recession of headlands and the silting of inlets that accompany the marine erosion of a coastline initially irregular have each their peculiar effects upon the life of coast-dwellers. Wave attack upon headlands creates cliffs that vary in height and steepness according to the altitude and nature of the land. A cliff coast is one from which access to the sea is as a rule difficult. There may be no path down the cliff and no beach at the base of it, and the people who live behind such a coast carry on inland activities, and plough and sow their fields to the extreme edge of the cliffs, apparently unaffected by their nearness to the sea. Projecting headlands even without cliffs offer a formidable obstacle to communication along the coast, a fact emphasized by the early history of the road round the great projection of Penmaenmawr on the Carnarvon coast, a road from which if the traveller should fall, "sea and rocke, rocke and sea, woulde strive and contend whether of both shoulde doe him the greatest mischief."[1]

The relative inaccessibility of headlands made them desirable places of retreat to our prehistoric ancestors, as already noted in connexion with Cornwall. When men went to sea in small boats and fought frequently with their neighbours, a coastline with many small indentations afforded security to themselves as well as their craft, and the gradual obliteration of the irregularities would be a disadvantage to a primitive coast people who remained primitive during the process. Actually the evolution of such a coastline is generally accompanied by a more rapid advance in civilization of the local inhabitants, so that the final disappearance of a fortified headland or a little bay harbour, comes to be of no significance to a people who think in terms of Dreadnoughts.

The general increase of shore deposits and silting of inlets that accompanies headland recession affect mankind in less spectacular but more far-reaching ways than does wave attack against the headlands. When shore deposits are raised by wave or wind action above the normal level of high-water, the human population of the coast lands may extend over them and they may become the site of permanent dwellings—dwellings as permanent at least as the sea will allow. Thus the Warren spit across the Exe, the shingle beach at Lancing in Sussex,

[1] *An Ancient Survey of Penmaenmawr.* Sir John Wynn. Edited by J. O. Halliwell.

the barren acres of Dungeness, the sandy point of North Haven Spit at the entrance to Poole Harbour, the high shingle ridge that guards Pevensey Level, Spurn Point, and many another deposit support dwellings of one kind or another from week-end shanties to coastguard stations. Henry VIII was addicted to building his ugly castles on shingle spits, and in Hampshire Calshott and Hurst castles each stand near the end of a hooked finger of shingle, while Camber Castle near Winchelsea was originally somewhat similarly situated on a spit of beach. Areas of deposition artificially induced also serve to accommodate the overflowing population of seaside towns. Shingle accumulated to windward of Lyme Regis cobb had been built upon by early in the nineteenth century though subsequently in the famous storm of 1824 the area was badly damaged by the sea. At Folkestone the great area of shingle that supports the buildings of the Marine Parade—an area familiar to soldiers during the war as Number One Rest Camp—owes its existence to the harbour pier east of it. Sand-dunes and shingle accumulations yield besides fresh water that may supply a great population—thus Amsterdam draws its supplies from the quantities of fresh water that, affected by the tidal rise and fall, are contained in the coastal dunes.

The growth of shore deposits affects more rapidly than does wave erosion the navigability and harbours of a coast. The shingle ridges of Dungeness, so low-lying as to be scarcely visible from a distance, project out into deep water so that vessels receive no warning of their vicinity and numberless ships have been wrecked upon them. Spits of sand or shingle, though they may afford shelter to leeward, everywhere add to the complexities of navigation, besides exerting an influence, as already discussed in the foregoing chapters, on the silting of the inlets they partially close. They may affect also the tidal range upon the local coasts, and here the maintenance of a relatively constant sea-level in an inlet may be more advantageous for shipping than an alternation of a great depth at high-water with an ebb so low that the harbour dries at low-tide.

Where shore deposition has led to a seaward advance of the land or to the accumulation of wide sand-flats access to the sea from such low coasts is as difficult as from cliffs, while navigation is perhaps more dangerous among the sandbanks of Liverpool Bay with low surf-fringed coasts to leeward than off the Cornish cliffs. So difficult is it to launch a boat at low-tide across the wide sands of the Wirral coast that the Hoylake lifeboat is in future to be conveyed out to the sea by a caterpillar tractor, suitable horses for the team by which it was formerly drawn being now difficult to obtain.

Seaside resorts on coastlines that are growing seawards endeavour to counteract the gradual retreat of the sea by the erection of long piers, like that at Southport in south Lancashire which—second in length in this country only to that at Southend—reaches out for fourteen hundred and sixty-five yards across the sands to where a channel remains full even at low-tide and gives a local maritime atmosphere amidst square miles of golden sand. Streets and houses may also advance seaward across the newly formed land but this usually involves trouble with occupants of the original sea-front.

Dwellers on the Strand at Torquay and the promenade at Southport have so far successfully maintained the right of the existing roadway to remain the foremost sea-front whatever harbour works or building extensions may have been projected. The growing foreshore in areas of accretion may react on the town's finances to the contentment of the local ratepayers. Where such waste lands belong to the corporation they may be a source of profit to the town and reduce the rates. In other regions where an old port was forsaken by the sea before the rise of sea-bathing, it may have lapsed like New Romney or Hythe into an inland village and only subsequently have established a seaside suburb to meet the demands of summer visitors.

The sand that accumulates on low coasts is a danger when it tends to encroach upon cultivated lands, and the inhabitants of regions to leeward of areas of sand dunes are subject to laws and restrictions peculiar to their situation. It was in earlier days an offence in south Lancashire to cut or injure the bent or star-grass (*Arundo arenaria*) the growth of which fixes the mobile dune surfaces, while anyone taking up a lease of land had to undertake to do his share of planting this grass. Sandhill regions may in time be reclaimed for cultivation, once the blowing sand that injures all but the toughest plant-fibres is checked by the planting of the dunes, or they may become building sites or be grown over with pine trees, as in Gascony. So reclaimed they add to the habitable area of the land and cease to threaten the security of fields and villages behind them.

The regularization of the coastal outline and the seaward growth of certain lengths of shore are but incidents in the long retirement of the coast before wave attack. The recession of a coastline involves the displacement of the seaside population which, like the sand or shingle beach, is pushed inland before the advancing waves. Towns free to grow indefinitely landwards may maintain their integrity during retreat, as do dune or shingle ridges, but where such inward movement is stopped they, like shore deposits in similar circumstances, disappear.

The advance of the sea results ultimately in an irrecoverable loss of land, and tenants whose holdings lie on a retreating coast may be obliged, like those farmers who occupy shore lands west of Hastings, to have their lands regularly surveyed so as to avoid the payment of rent on lost areas. One farmer at Bexhill lost forty acres in fifty years.

In striving to alter coastal conditions to his liking rather than to adapt himself to them as in the cases so far considered, man works in one of two ways—he either aids or opposes the action of the sea. In either case his efforts are predisposed towards ultimate failure, since the local acceleration or retardation of coastal processes that he may induce must create an unstable condition that requires to be maintained against further action by the sea. Ultimately though they may yield as slowly as a granite cliff coastal works of whatever type must suffer destruction by the sea with the land they were designed to protect, unless man can devise some means of checking the gradual deepening of the inshore waters that must at last lead to an increased wave attack and the destruction of defensive works however elaborate. It was noted in the Third

Report of the Royal Commission on Coast Erosion that by 1911 a general steepening of the foreshore had taken place for the United Kingdom generally.

Human interference with the natural progress of changes on the open coast is generally concerned with two main objects, the preservation of land that would otherwise be washed away and the improvement of access to the sea, under which head is included the construction of harbours. Whatever its object it affects the evolution of the coastal outline. The creation of an even coastline is hindered by the artificial protection of headland coasts against the wave attack that is normally their portion. Thus the Hastings Corporation are with their sea-walls and groynes maintaining in its present position part of a headland coast, the relative projection of which must continually increase unless the eroded shores of Bexhill and Fairlight on either side of it are similarly protected. The drainage and reclamation of silting inlets behind barriers whether wholly or partly artificial promotes on the other hand an even coastline, and may prevent those periodic reversions to an earlier coastal outline that occur when such areas are temporarily reoccupied by the sea. The low-lying alluvium of bays and estuarine areas may not only be protected against the sea's inroads, but the deposition of silt may be artificially accelerated in such regions and the level thus raised, within limits, to a desired height before the new land is enclosed from the sea.

In other cases the preservation of a harbour may postpone the silting of an estuary or bay and thus maintain the irregularity of the coastline. A modern suction-dredger can lift ten thousand tons of sand from a depth of seventy feet below low-water in fifty minutes—a fact which implies not only the clearing of channels that would otherwise be choked but also the artificial distribution of vast quantities of sand along other parts of the coast. A considerable redistribution of shingle must result in some areas from the continued abstraction of beach to serve as ballast for ships. Fishing vessels have, it is estimated, abstracted eleven thousand tons of shingle from the Hastings shore, which shingle has been dropped on the floor of the Channel. In the reign of George II Poole Harbour was becoming so silted that vessels were forbidden to empty ballast into the harbour.

The activities of man affect the coastal outline in other ways besides those of the checking of headland recession and reclamation of inlets. Local coast-protection works may be erected in pursuance of very varied interests or because of circumstances unconnected with the actual coast. Thus the existence of the tall towers of the late mediaeval church at Reculver, on the Thames estuary west of Thanet, and their accustomed use by mariners as a sea-mark have led to the protection of the coast, the erosion of which had placed the church towers in danger. Here the religious faith of a long-vanished generation may lead centuries after their day to the creation of an artificial salient in the coastline. In Norfolk the reluctance of Cromer to share the fate of its predecessor, the drowned port of Shipden, has led to the construction of coast defences so efficient that by the middle of the nineteenth century the natural curves of the coastal outline had here been reversed, the bottom of a valley projecting seawards at Cromer beyond the higher lands on either side. The piers of Southwold in Suffolk may prevent, it is stated,[1] the formation by the sea of a bay that were they absent might be created between Covehithe Ness and Thorpe Ness.

The longshore drift of sand and shingle that is so largely instrumental in modifying the coastal outline is itself often affected by human action. The removal of rock from headlands and reefs may lead to the passage past them of shore waste previously checked by their acting as natural groynes. The projection of Hengistbury Head east of Bournemouth was so affected by the quarrying carried on there that shingle by the middle of the nineteenth century began to drift round it, where only sand had travelled previously, towards the mouth of the Avon. The taking of stone from the reef known as Bognor Rocks in southern Sussex appears to have had a similar effect on shingle drift there. The deposit of sand and shingle at Landguard Point near Harwich grew in extent after quarrying on the coast at Felixtowe permitted a freer passage of longshore drift from the north. The erection of coast defence and harbour works also interferes almost always with the normal longshore drift. Cases where groynes or piers have held up the shore drift to the detriment of the coast to leeward have already been referred to in previous chapters and are too numerous to mention here, but occasionally a reversion of the normal shore drift has been attributed to coastal works. Newhaven pier has been cited as the cause of the westward travelling shore drift that follows the

[1] Roy. Commn. on Coast Erosion.

coast between it and a point half way to Seaford, beyond which point the normal eastward drift is resumed.

Compared with his success in modifying the coastal outline by his protection of headlands and reclamation of alluvial flats deposited in bays or estuaries, man can do but little in inducing or checking accretion on the open coast or in opposing the gradual retreat of the whole land margin before the waves. He may create lines of sand dunes to seaward of a flat shore and maintain and increase them, or the natural dune ridges, by planting—such species as *Arundo arenaria* being so constituted that they continue for a long period to grow upwards through fresh deposits of wind-blown sand. A belt of dunes may be induced, by means of two lines of fencing parallel with the shore, to form and grow to a considerable height in as short a space of time as two years. Dunes artificially created help to maintain the security of low coast lands near Prestatyn in north Wales, in south Lancashire, and Lincolnshire. Shingle accumulations as well as sandhills may be rendered comparatively stable by planting them with suitable species of plants. A tamarisk hedge helps, as already noted, to restrain the Shoreham shingle beach from encroaching landwards, and such shingle areas as the Chesil Beach in Dorset, Calshott Point in Hampshire or Blakeney Point in Norfolk are more or less colonized with such plants as *Sueda fruticosa*, sea-kale, samphire, blackthorn or Corsican pines.

An undesirable extension of dunes is sometimes caused by human agency—thus when during mining operations in Cornwall a little stream was covered in near Gear the Perran sands formerly confined to the seaward side of it encroached upon fertile lands beyond. Of more direct effect upon the actual coastline has been the seaward growth of dunes in south Lancashire consequent in part upon the erection of sea-walls and in part upon drainage operations that prevented the surface drainage from flowing across the foreshore, the sands of which, formerly wet from the outflow of surface water from the land, were blown up into dunes when dry.

Accretion may be caused by the presence of wrecks. A shoal extended a mile in length in less than a century after the sinking towards the close of the eighteenth century of a vessel outside Poole Harbour, and the decline of Sandwich Haven had at the end of the sixteenth century been accelerated by the accumulation of sand and mud induced by the presence of a Spanish vessel that had run ashore and could not be removed.

The general retreat of the coast before wave attack is resisted by each succeeding generation according to the way that seems to it best. Wave advance may be opposed by the erection of massive sea-walls, by the inducing of accretion, or by a combination of both these methods. Often enough effects opposite to those desired have been obtained. Vertical sea-walls were found to induce a scouring away of the beach below them, and many a fine beach, like the sands that once covered the now somewhat bare foreshore at Tor Abbey near Torquay, have been lost owing to the erection of sea-walls, which latter had as a consequence to resist an increasedly violent wave attack. Unsuitable coast defence works on the Dymchurch shore of Romney

Marsh led in the early part of the reign of Victoria to a great depletion of the local beach and a violent wave attack. The addition of groynes when a sea-wall is built usually prevents loss of beach but entails as noted already a loss of sand or shingle from areas to leeward of the groynes. The protection from wave attack of certain lengths of coast involves also a diminution in the general supply of shore waste and thus affects the subsequent development of the coastline, leading in particular, apart from the action of groynes, to an increased rate of wave advance to leeward of the protected area.

One method of saving from the sea lands threatened by wave advance is to dump great quantities of shingle on the shore of the eroded coast, shingle which, if groynes are erected at the time of its deposition, may be retained in position and fulfil its object of deadening wave attack. The people of Seaford in 1850 blew up part of the chalk cliff near the town in the hope that the heap of debris so obtained might check the sea's inroads. Naturally, however, the detritus so formed was washed away as had been the original beach. Shingle dumping has, however, been practised successfully in several places, as at Hove west of Brighton and on the coast between Seaford and Newhaven. Such operations, unless the shingle is brought from inland, are equivalent to robbing Peter to pay Paul—sand and shingle exist only, as already noted, in limited and fairly constant quantities around our coasts and its accumulation at one point must mean its withdrawal from others. More serious have been the effects on coast erosion of the long-continued removal of sand and shingle for use inland or in coast defence works in another district, in which cases it is permanently lost to the coast from which it has been taken. Shingle from Cromer is used for pottery manufacture in Staffordshire and the flint gravel of Langney Point near Eastbourne is suitable for the same purpose, beach pebbles at Aberthaw in South Wales have been largely burned for lime, and the use of shingle in road construction has been widespread. Recently the Board of Trade has forbidden, as did James I at Lyme Regis, the removal of beach from many lengths of coast dependent for their protection on the preservation of the shore deposits.

The extensive use as manure of the deposits of shell-sand on the north coast of Cornwall led at one time to the transference inland of vast quantities of sand.[1] On the Doom bar across the Camel estuary were in 1836 some eighty men constantly at work, and it was estimated one hundred thousand tons of sand were removed from it annually, causing it to diminish in size. Sea sand was used in Cornwall for agriculture as early as 1602. Bude sands were one great source of supply, and four thousand horse-loads were known to have been taken from Bude in one day. In 1811 the carriage of sand inland was estimated to cost in Cornwall over £30,000 annually, and it was calculated in 1839 that perhaps five million six hundred thousand cubic feet of sand were taken yearly from the coast and used as mineral manure—the shell sand containing forty to seventy per cent of calcareous matter.

Dredging and rock removal immediately offshore has, as previously noted, increased the violence of

Geological Report on Cornwall, Devon, and West Somerset. de la Bèche.

wave attack at many places, an effect which usually appears to have been ignored by the authorities concerned. Sandgate Castle near Folkestone was built in the reign of Henry VIII on the coast and partly from rock obtained from reefs situated below high-water level near the works. The castle was attacked by the waves from its erection, and its partial destruction by the sea must have been accelerated by this ill-advised quarrying.

By means of coast defence works, and of devices for hastening or retarding the deposition of beach or alluvium, by quarrying coast rocks and redistributing shore material, human beings can influence the course of coastal development. As already noted, however, unless man can contrive that his coastal works shall, like a line of dunes or a shingle ridge, be capable of retreat without suffering damage, they must inevitably give way at last before the advance of the sea—an event, however, that may indefinitely be postponed as increased efficiency is attained in coast protection. Moreover coast protection works that aim at putting an end to marine advance must of necessity be discontinuous, since even if all coastal areas could afford the expense of coast defence works the protection of the whole coast would result in a cessation of the supplies of beach formerly derived from the wasting land, the existing beaches would gradually disappear and the sea-walls be left unprotected. Being discontinuous the protected lengths of coast may have their ultimate destruction by frontal wave attack forestalled by being outflanked as the unprotected areas on either side are worn back. By means of a recent invention known as the Brasher air-reef, advancing oscillatory waves are neutralized by a rising wall of compressed air, forced upwards from perforated pipes on the sea bottom. Under the invisible shelter of this air-reef at El Segundo in California ships rode safely in storms though the ordinary pier had previously been seriously damaged.[1] This invention although too costly in working for general use suggests the possibility of a future mobile system of coast defence—a system that might perhaps also retard to some extent the degradation by wave action of the inshore sea-bottom, and hence postpone that deepening of the inshore water without which wave advance becomes in time impossible.

[1] *Tidal Lands.* A. E. Carey and F. W. Oliver.

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