Some aspects of the geomorphology of the Durham coast

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SOME ASPECTS OF THE GEOMORPHOLOGY OF THE DURHAM COAST

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No part of the following material has previously been submitted for a degree in any University.

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INTRODUCTION

1. Extent, Scope and Aims of Study

The present form of the coastline of Co. Durham results from the effects of both natural and artificial forces and factors, and in this discussion an attempt has been made to assess their relative importance in fashioning both the general trend and intricate details of the present coast.

The Durham coast is one of the most interesting in the country. It has fine cliffs, deep bays and inlets, and numerous off-shore stacks; it has submerged forests and possibly raised beaches; it has sand dunes and deeply entrenched river gorges; above all, it has Permian Magnesian Limestone Strata uniquely outcropping along almost its whole length.

But this is merely a statement of the natural features which may be seen along the Durham coast. There are also the artificial or Man-made features which may be locally of dominant importance in determining coastal forms.

There are no fewer than three major and two minor harbours in this stretch of twenty-seven miles of sea coast. Each of these has extensive pier and breakwater works projecting far into the sea, which hinder or prevent longshore drifting of beach material. Numerous sewer outfalls built across the foreshore have similar, though smaller, effects. The seaside resorts and towns have many miles of protecting sea walls and promenades, and these impose completely artificial conditions upon the beaches.

The collieries as well as the sea-ports have had an important effect on the development of the Durham coast. Many of the small streams flowing to the coast have increased flows as a result of the running of waste colliery waters into them, and occasionally the stream courses are completely blocked by colliery tip heaps. Bulky colliery waste material from coastal collieries is often dumped directly on to the beaches, adding considerably to the amount of beach material on which sea waves may expend their strength. Before the days of water ballast, colliers coming to the north-east coast ports carried ballast boulders and flints from the south of England, and these have contributed greatly to the supply of beach material. Much ballast was dumped on the land fringing the coast, and this has changed substantially the shape of the contours around such ports as Sunderland and South Shields.

From this summary it is apparent that a satisfactory way of tackling the problem of coastal evolution in Durham is to consider it in three parts:

I. The natural geological and physical basis of the Durham coast.

II. The influence of human activity.

III. The resulting pattern of recent coastal evolution.

2. Previous Work and Literature

Very little geomorphological work has been done in East Durham and its physical geography is almost unstudied. Geological workers have been more interested, and rightly so, in mapping and classifying the extremely variable Magnesian Limestone rocks, and in attempting to explain satisfactorily the unique structures and forms within those rocks. That they have not succeeded as yet is evidence of the extreme geological complexity of East Durham, a complexity resulting from the varied structures and lithology of one series of rocks rather than from a multiplicity of types of strata.

Sedgwick's memoir on the Magnesian Limestone has never been superseded as the classical description of the rocks in general terms, and more detailed local studies have been made by Lebour, Woolacott and Trechmann. No Geological Survey Memoir has been written to accompany the primary geological survey of East Durham, but the geological mapping of East Durham is being revised at present, though the results will not become available for some years.

In 'The Coastline of England and Wales', Professor Steers rightly stressed the importance of geological considerations in attempting to explain coastal morphology, and he made an important contribution to an understanding of the coastal geomorphology of East Durham.

Before the publication of that book, there were many isolated references in obscure periodicals and journals to some of the coastal features of Durham, but there has been no broad assessment of the coastal forms.

In 1949 and 1950 Dr. C.A.M. King studied wave action and beach processes in Marsden Bay,[1] this being the first recorded instance of any coastal research being undertaken in the area.

The present work was undertaken in an attempt to fill part of this gap in our knowledge of the British coasts, a gap all the more deplorable as it is only in Co. Durham that Magnesian Limestone forms the coastline. There is no other Magnesian Limestone coast in the world.

The almost complete lack of geomorphological writings on East Durham has also attracted the attention of Mr. R. Hopkinson,[2] who has been making a detailed study of the whole of the Magnesian Limestone area of Co. Durham. Mr. Hopkinson has made a special study of Tertiary drainage and Pleistocene Chronology, and has made accurate surveys of the long profiles of some of the small coastal streams.

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1 Trans. Inst. Brit. Geog. No. 19, 1953, pp 13-23.

2 Department of Geography, Birmingham University.

Unfortunately, the results of his work are not available and cannot be incorporated in this work. The sections dealing with these topics have been curtailed to avoid needless repetition, though they are of great interest to the present discussion.

3. Methods of Work

(1) Field Work

(a) Field Mapping: The greater part of the field work carried out during this research has been based on O.S. Six-Inch Maps of East Durham.[1] On account of the interests of Mr. Hopkinson, intensive field mapping on this scale has been limited to the northern and eastern areas of the Permian, the most intensive field work being conducted along the river valleys and the sea cliff edge. Before field work was commenced the relevant Geological Survey maps were consulted[2] and much information was transferred from them to the field sheets. None of the field sheets has been presented with this discussion of the Durham coastal morphology as the mass of information is not easily assimilated, and throughout the whole of this work the evidence and information has been presented as clearly, simply and precisely as possible. Whenever possible a map has been drawn, both to clarify the point made and to reduce the length of the text.

During the detailed mapping of the cliff face and cliff top it soon became evident that the Six-Inch Maps were inadequate to record satisfactorily the significant

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1. All maps required for the field work have been obtained for me by the Department of Geography, Durham Colleges, or by the Nature Conservancy.
2. The Divisional Geological Survey Officers, Newcastle, have been most helpful in all respects.

details of geology and topography. Accordingly, the whole of the Durham coast has been mapped on 25-Inch O.S. Plans to indicate the above features. In addition, such plans were used as base maps for the field mapping of the lower reaches of the river valleys between Sunderland in the north and Hartlepool in the south.

In the west of the Durham Permian region, the field work near the escarpment has been based on the O.S. 1 : 25,000 maps.

(b) <u>Surveying Methods</u>: The chief surveying methods adopted were four-fold:

(i) Aneroid Levelling
(ii) Engineers' Levelling
(iii) Profile Levelling
(iv) Chain Surveying

The type of levelling used depended upon the type of topography to be surveyed, the atmospheric conditions experienced, the amount and quality of labour available, and the accuracy desired.

(i) <u>Aneroid Levelling</u> Considerable use was made of a $3\frac{1}{2}$-inch Compensated Mining Aneroid Barometer fitted with a vernier scale reading to two feet of altitude for levelling work in the densely wooded denes. Survey work by any other method in these valleys is most laborious. The deeply entrenched rivers flow between steep banks where the movement of soil under the processes of rain wash and creep is important, and the trees are very susceptible to movement. After a heavy shower of rain the river courses are often blocked by fallen trees and broken branches, especially during the winter months when the vegetational cover has died off and the soil around the roots of the trees is most strongly scoured out by heavy rains and running rivulets. Flooding and fallen trees make it almost impossible to advance through the gorge sections of the denes during the winter months, and the streams remain full until the tree foliage begins to thicken in the Spring, making it impossible to use telescopic levelling instruments.

Good results were obtained during the levelling of the lower reaches with an Engineers' Level, but the accurate levelling of the streams was later discontinued to allow Mr. Hopkinson a free course. Nevertheless, it was felt that some attempt should be made to obtain an approximate profile of the streams, to see if any evidence could be found indicating changes of base level of the drainage. It was believed that an aneroid barometer survey would provide such evidence.

The results of the aneroid barometer traverses were quite good, though not as accurate as some which have been recorded by other observers. The instrument used appeared to have a variable ability to record changes of altitude, and this 'sticking' has been reported by other users of aneroid barometers for survey work, suggesting that claims of accuracy to within four feet are rather optimistic. In short traverses of less than half-an-hour's duration between O.S. Bench Marks, accuracies to within four feet were recorded, but there is obviously no guarantee that all intermediate heights were of this accuracy, and check readings tended to indicate that this was not the case.

Aneroid observations were attempted elsewhere in the field but these were unsuccessful on account of sea breezes or gustiness.

(ii) Engineers' Levelling This was used to determine the heights of temporary bench marks established along the beaches as vertical control for beach profile measurements. Such levelling was also used to establish the height control in small surveys carried out on the beaches and shingle ridges at various points along the coast.

(iii) Profile Levelling As it was impossible to rely on voluntary levelling assistants during the winter months, it was necessary to devise a method of work which would allow beach profiles to be measured single-handed. After consultations with Commander D.H. Fryer,[1] it was

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1. Reader in Surveying, King's College, Newcastle-upon-Tyne.

decided to use a 'quick-set' level to record differences of level indicated by ranging poles sub-divided into divisions of three inches, and spaced at measured intervals along the profiles. Readings were made to the nearest ¼-inch, and except on one occasion, whenever checks were made, the errors of reading did not exceed that figure.

(iv) Chain Surveying This method of survey was used occasionally to fill in detail on bay head beaches and wave-cut platforms, the most extensive work being done on the 'raised beach' north of Souter Point. Such surveys were restricted to days when assistance was available and when the features being mapped justified the amount of work involved.

(c) Wind Statistics: Much information has been obtained during the past few years of wind conditions along the Durham coast. Whenever beach profiles were surveyed, observations were made of the direction and force of winds, and these have been compared with the anemometer readings at Tynemouth Weather Station. After discussions with the Meteorological Staff at the R.A.F. Station Acklington and the Coastguards of the Tynemouth Division, it was decided to accept the Tynemouth readings as a standard for the whole coast between the Tyne and the Tees. The anemometer at Tynemouth suffered from various defects, mentioned more fully in Chapter 5, but the readings were more easily obtained there than elsewhere along the coast, and comparison of Tynemouth readings with field observations was considered to be adequate for the purposes of this study.

The wind statistics obtained have been used in an attempt to determine the relationship between wave incidence, wind direction and beach changes.

(d) Longshore Movement of beach material: Numerous attempts have been made to trace the longshore movement of beach material along the coast of Durham. One of the great difficulties has been to find an indicator rock which is sufficiently distinctive not to be confused with the material which is already free on the beach, yet cheap and readily obtainable in bulk.

Experiments to determine the rate of movement of beach material have been carried out using marked limestone pebbles, bricks, and shales, but in every case the samples have been quickly lost to the sea. The results of enquiries regarding the possible use of radio-active methods to trace the movement of beach material were not encouraging, but more will be said of this in a later chapter.

On several occasions sand samples were taken from the beach off Castle Eden Dene to see if any movement of pyrites-laden sand could be traced by analyses of successive samples. It was first believed that the pyrites was all derived from Horden Colliery, but after the gales of January and February 1953, it was noted that the pyrites was also being derived from the tip heaps at Easington and Blackhall Collieries, and the sampling method had to be abandoned.

(2) Office Work

(i) Statistical

The present topography of East Durham indicated on O.S. maps has been examined by four common statistical methods, viz. (a) Altimetric Frequency Curves, (b) Generalised Contours, (c) Superimposed Profiles, (d) Area Height Curves. Of these (a), (b) and (d) have been based on O.S. One-Inch Maps, and (c) has been based on O.S. 1 : 25,000 Maps. Details of the methods of analysis have been included in Appendix B.

(ii) Boring Information

All available boring records have been consulted, and the information obtained has been used to supplement field evidence proving the position of the sub-drift surface.

One of the most complete records of old borings in Durham is that included in the four volumes of 'Borings and Sinkings', published by the North of England Institute of Mining Engineers 1878-1910. Although some of the boreholes could not be sited accurately from the information given, the publication is of great value. These old records, together with many more recent boring logs, were examined at H.M. Geological Survey District Office, Newcastle.

Many of the more recent borings were made under the auspices of I.C.I. Limited (Billingham Division), Cerebos Salt Limited, Sunderland and South Shields Water Company, Washington Chemical Company, etc., and often they have been unwilling to consider their borings as other than confidential.

(iii) Map Evidence of Coastal Changes

Coastal changes since c. 1856 may be clearly seen by comparing successive O.S. maps. For reasons given later (Chapter 9), the evidence obtained from maps preceding the O.S. First Edition is not satisfactory and must be discarded except in very general terms. An extremely detailed and finely drawn Admiralty Survey of 1831 is on rather too small a scale to be directly compared with the succeeding O.S. First Edition.

The relevant maps of all four O.S. 25-Inch Editions covering the Durham coast were examined at Chessington, and direct tracings have been made of each sheet. Those maps which were no longer available at Chessington as a result of war damage (usually First Edition) were consulted at the British Museum, though the method of binding and storage there had often reduced their value as accurate maps.

When instances of this nature were noted, later attempts were made to obtain the appropriate map from local sources within Co. Durham.

Maps and charts of particular towns and harbours in the century before 1856 do not on the whole suffer from the same defects as the 'county' maps, and they have been freely consulted and used.

(iv) Written Evidence of Coastal Changes

There are a great number of 'histories' of Co. Durham but few of the writers were interested in coastal scenery. After exhaustive examination of such histories, some isolated references were found of significance to the present discussion and these have been incorporated in the text.

PART I

THE NATURAL GEOLOGICAL AND PHYSICAL BASIS OF THE DURHAM COAST

Chapter 1. Topography and Geology

There are three broad topographic divisions in East Durham: (See Fig. 1.)

1. The western Coal Measure Region, including the whole of the River Team Valley, the River Wear Valley from Witton-le-Wear[1] to Claxheugh, and the area around South Shields.
2. The Magnesian Limestone Plateau Region, between the main part of Region 1 and the sea, and bounded in the south by an ill-defined line between Piercebridge and Hartlepool.
3. The Triassic Region of red soils between the Magnesian Limestone and the lower Tees.

The greater part of his discussion will be concerned with the Magnesian Limestone area.

The East Durham Limestone Plateau forms a triangle with its apex at South Shields and its base along a line between Piercebridge and Hartlepool. The limestone dips gently south-east towards the low, cliffed coast and the Triassic Plain of the River Tees. The elevation of the plateau

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1. National Grid References of all place names mentioned in the text will be found in Appendix A.

locally exceeds 600 feet[1], but is usually about 150 feet lower.

The Permian rocks form a well-marked, irregular escarpment in the west averaging 500 feet in elevation and rising from 250 to 300 feet above the drift-covered surface of the Wear Valley. The escarpment reaches a maximum elevation at Warden Law (646 feet) where, however, the limestone is capped by a kame-like deposit of gravel and sand about 150 feet thick. At Penshaw Hill (456 feet), Hastings Hill (412 feet), Boldon Hills (307 feet) and Cleadon Hills (277 feet) the limestone forms the top of the escarpment. This elevated ridge is formed of Upper Concretionary Limestone only at Cleadon Hills, of Middle and Lower Limestones, Marl Slate and Yellow Sands at Boldon Hills and Claxheugh, whilst from Penshaw southwards it is formed of only Lower Limestone, Marl Slate and Yellow Sands. In this part of the county, where the regularly bedded Lower Limestone underlies the surface, a large area east of the escarpment has the nature of a dissected plateau.

The escarpment is eroded to a varying degree and is completely breached within the county in three places: by the pre-glacial drift-filled Fulwell valley between Fulwell and Cleadon Hills; where the overflow from the glacial lake in the Wear Valley cut the gap at Sunderland;

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1. Throughout the text, unless otherwise stated, all heights are referred to Ordnance Datum.

and at the dry overflow channel at Ferryhill. Pre-glacial and more recent obsequent streams flowing to the Wear have cut back into the escarpment which now resembles a series of lobes jutting out into the Wear Basin (see Fig. 2). These westerly extensions are, from north to south, Flinton Hill with Penshaw Monument; Newbottle and Houghton-le-Spring; Moorsley and Pittington; Sherburn Hill and Heugh Hall near Bowburn. South of Raisby the escarpment trends from east to west.

A line of low hills through High Barnes, Humbledon Hill, Tunstall, Dalton-le-Dale, Hesledon, Hawthorn, Easington and Horden forms a distinct physiographical feature (see Fig. 9.B.). This ridge is formed of the more resistant, fossiliferous, unbedded type of Middle Limestone, the yellow, bedded Middle Limestone and the breccias derived from them generally forming low ground.

A third minor ridge in East Durham is produced by the outcrops of the Upper Concretionary Limestone on Fulwell Hill (230 feet) and Building Hill (about 200 feet).

The general fall of the plateau surface eastwards from a height of 450 feet in the west is usually quite gentle, but in places the drop in elevation is quite sudden to the coastal plain at about 100 feet O.D. (Plate I). This plain is of variable widths below half a mile, but tends to broaden south from Easington Colliery towards the

River Tees.

South of Ferryhill, the altitude of the Permian country declines rapidly and it merges into the thickly drift-covered Trias area of the Tees Valley. This low, red-soiled country between Darlington and Seaton Carew owes its soft outlines and colour to the presence of the easily eroded salt-bearing Triassic strata.

A statistical analysis of O.S. maps illustrating these features is given in Appendix B (see Figs. 3 to 6, inclusive).

The drainage of the plateau is largely accomplished by the swift, quite short, rivers flowing down the dip slope through the deeply cut denes (see Fig. 2.) In their upper reaches, these dip streams often flow along the drift-filled courses of pre-glacial dip streams, but in their lower parts they have cut new courses for themselves through limestone. The main watershed in East Durham lies close to the escarpment in the west, but none of the dip streams is longer than nine or ten miles, and most of them are considerably shorter. The best known of the deeply entrenched valleys is probably Castle Eden Dene, but they all display similar features.

Towards the south of the plateau drainage is towards the River Tees, though often by a circuitous course. In its upper reaches the River Skerne flows eastwards from near the western escarpment through a valley considerably broader and larger than befits the small stream. This is true especially between Trimdon Village and Trimdon Grange. At Hurworth Burn the stream changes its course and flows south-west across the plateau south of Ferryhill Gap and then via the Aycliffe Gap to the River Tees. In the Bradbury and Mordon area the river valley is broad and shallow, and the River Skerne marshes were, until quite recently, lakes developed in late and post-glacial times. The Upper Skerne may originally have flowed to the south bank tributary of Crimdon Beck flowing past Sheraton before it was beheaded by the Lower Skerne. Alternatively, the former channel may have been blocked by glacial material and the stream diverted to the glacial lake of the Bradbury and Mordon Carrs.

Any understanding of the coastal morphology of Durham requires some knowledge of the main events in the geological history of North-East England, and of the characteristics of the chief cliff-forming rocks within Co. Durham. It is upon the latter that the coastal morphology is largely dependent and a simple statement of sedimentary disposition is very relevant.

Pre-Permian

The greater part of North-East England was formed during the Carboniferous epoch, and the warping of that period is still reflected in its existing topography. The

Lake District, the Pennines and the Cheviots are ancient features formed by Carboniferous and Permian warping which also initiated the Rivers Tyne and Tees. These broad topographic features were wholly or partially covered by later deposits which preserved that landscape, which is again being revealed as the cover is removed by denudation.

The Carboniferous Limestone and Millstone Grits of Co. Durham dip eastward beneath the succeeding Coal Measures, in which there are some twenty workable coal seams in less than 2,000 feet of sandstones and shales.

The Coal Measures were faulted and folded before Permian times to make the North-East coalfield a geological basin, the trough of which crosses the River Tyne between Newcastle and the sea, and thence runs south-east under Sunderland and out to sea (see Fig. 7). Many of the Coal Measure faults do not extend into the overlying Permian strata, and many have a reduced throw in the latter beds.

Uplift of Northern England resulted in the denudation of Upper Carboniferous rocks between the Durham and Yorkshire coalfields, and because of pre-Permian denudation the full former thickness of the Coal Measures is unknown. The fact that the Hutton Seam is 1,400 feet beneath the base of the Permian at Sunderland, 458 feet at Marsden and 833 feet at Horden Colliery gives some indication of the extensive denudation of the Coal Measures before the deposition of the overlying Permian beds.

Permian

The Permian and Triassic rocks were laid down unconformably upon the denuded and disturbed Coal Measure surface (Fig. 8), apparent cases of conformity in a few localities resulting from either accidental accordance or confusion between stained Coal Measures and Permian rocks.

The North-Eastern Permian rocks show extremely wide local variations, and consist of desert sands, red lacustrine or fluviatile sands and brick-red marls with beds of gypsum, anhydrite and rock salt, and magnesian limestone, with only local accumulations of stunted marine, or brackish water, fossils. Sedgwick's classical memoir[1] was the earliest general description of the rocks and this was followed by numerous more specialised studies.

The Permian disposition is simple in outline but complicated in detail on account of thrusting, abnormal junctions, and collapse following solution (Fig. 9).

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1. Sedgwick, A. On the Geological Relations and Internal Structure of the Magnesian Limestone. Trans. Geol. Soc. Ser. 2, Vol.III 1829, pp. 37-124.

The Permian Sequence (after Stewart[1])

Based on work by Trechmann[2] and Robertson[3]

	Approx. thickness in feet
Upper Magnesian Limestone	
Upper red beds with salt (found only in borings in S.E. Durham).	350
Hartlepool and Roker Dolomites - often oolitic.	100
Concretionary Limestones - dolomites with secondary calcitic concretions.	up to 250
Flexible Limestone - dolomitic with occasional fish remains.	10
Middle Magnesian Limestone	
Dolomitised bryozoan and shelly reefs, flanked to the west by sparingly fossiliferous dolomite, and to the east by non-fossiliferous dolomite. Flanking deposits are well bedded, but often highly brecciated.	up to 300
Lower Magnesian Limestone	
Bedded dolomite and limestone.	40 to 200
Marl Slate	
Flaggy dolomite with fish, plant and shell remains.	0 to 12
Yellow Sands	
Unconsolidated, false-bedded, sands.	0 to 180

1. Stewart, F.H. Permian Evaporites and Associated Rocks in Texas and New Mexico Compared with those of Northern England. Proc. Yorks. Geol. Soc. Vol. 29, Part 3, 1953-54, pp. 185-235.
2. Trechmann, C.T. The Permian Formation in Durham. Proc. Geol. Assoc. Vol. 36, 1925, pp. 135-145.
3. Robertson, T. The Permian Sequence of South-East Durham and North-East Yorkshire. Proc. Yorks. Geol. Soc. Vol. 27, 1947-49, pp. 199-205.

Yellow Sands: The basal unsorted Yellow Sands are often absent and never more than 180 feet thick.[1] The sands fill up the hollows in the denuded Coal Measure floor and are there thickest, becoming thin or absent altogether where the floor rises into diminutive hills. The Yellow Sands appear to be, in part at any rate, an aeolian formation and may represent sand dune deposits fringing the subsiding margin of the old Permian Gulf, though Green[2] suggested that the sands may originally have been a delta formation, derived from rocks lying to the west and north-west.

Although the lowest Permian beds are not visible along the Durham coast, apart from a small exposure in Frenchman's Bay, they are excellently exposed in Cullercoats and Tynemouth cliffs, and the formation may be traced almost continuously along the base of the Permian escarpment by the line of gently sloping country, or by the line of springs that occurs along part of its outcrop. The Yellow Sands are the chief water-bearing deposit in East Durham, and have given great trouble to colliery engineers in the construction of shafts to the underlying Coal Measures.[3] Browell and

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1. See Lebour. Trans. Inst. Min. Eng. Vol. XXIV, 1902-03, p. 370, for full description of Yellow Sands.
2. Green. A.H. Geol. Mag. Vol. IX, 1872, p. 101.
3. The overlying Marl Slate is practically impervious, and the underlying shales of the Coal Measures are to some extent impervious, so that the Yellow Sands are often in the very best conditions for water-bearing.

Kirkby[1] state that one cubic foot of incoherent Yellow Sands absorbs six to twelve pounds of water.

Marl Slate: The advancing Permian Sea encroached on these sands, redepositing their upper layers and laying down a bed of laminated mud, the Marl Slate. It is a thinly laminated passage bed from the arenaceous beds beneath to the calcareous above. It is often three to five feet thick and very persistent. The Marl Slate is characterised by a great number of fish and plant remains and may be a lagoonal[2] or estuarine deposit[3].

Magnesian Limestone: Magnesian Limestone overlies the Marl Slate with perfect conformity, and constitutes the greater part of the Durham coastline. Woolacott[4] has studied the stratigraphical and structural features of the northern

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1. Browell, E.J., and Kirkby, J.W., 'On the Chemical Composition of the Magnesian Limestone and Associated Beds of Durham'. Nat. Hist. Trans. Northumberland and Durham. Vol. I, Part II, 1866, pp. 209-213.

2. Lebour, G.A. Trans. Inst. Min. Eng. Vol. XXIV, 1902-03, p. 381.

3. Howse, R., 1889. Guide to collection of local fossils in Nat. History Museum, Newcastle.

4. Woolacott, D. The Stratigraphy and Tectonics of the Permian of Durham. Proc. Univ. Durham Phil. Soc. Vol. 4, Part 4, 1911-12, pp. 241-313.

The Magnesian Limestone of Durham. Geol. Mag. Vol. 56, 1919, pp. 452-465, pp 485-498.

Permian, and Trechmann[1] has examined its lithology and composition.

The Lower Limestone is always distinctly and regularly bedded (Plate II). It thickens from 30 feet in Frenchman's Bay to 250 feet beneath Humbledon Hill, and then thins to the south. Its middle beds are often cellular and have incipient concretionary structures developed in them. It is yellowish or yellowish-brown weathering to dark brown, and it is often spotted with manganese dioxide.

The Middle Limestone occurs as three distinct facies and his has been one of the main difficulties in understanding the stratigraphy of the Magnesian Limestone.

'Reef' limestone forms a ridge of high ground down the centre of the Durham Permian from Bolden Hills, by Claxheugh, Humbledon Hills and Tunstall Hills to the coast at Hawthorn, and then by Horden Colliery and Blackhall Colliery to Blackhall Rocks. In the north the ridge is much dissected by denudation (fragments of it appear to have existed on Tynemouth Cliff)[2], but it widens and thickens

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1. Trechmann, C.T. On a Mass of Anhydrite in the Magnesian Limestone at Hartlepool, and on the Permian of South Eastern Durham. Quart. Jour. Geol. Soc. Vol. 69, 1913, pp. 184-218

   On the Lithology and Composition of Durham Magnesian Limestones. Quart. Jour. Geol. Soc. Vol. 70, 1914, pp. 232-265.

2. Trechmann, C.T. Proc. Geol. Assoc. Vol. 36, 1925

to the south. Its knoll-like outline is best seen at Tunstall Hills, Beacon Hills, and behind Horden and Easington Collieries.

The reef appears to have originally formed a bank of shells some ten or twelve miles from the western shore of the Middle Permian Sea[1] and marks a portion of that sea fresher than the rest. The rock is often soft, yellow and highly magnesian (40-45%) but also occurs as hard, crystalline, cellular, highly calcareous non-fossiliferous rock produced from the softer yellow rock by the leaching out of the magnesian carbonate and the segregation of calcium carbonate with the obliteration of fossils.[2]

The reef beds thin eastwards, being replaced by non-fossiliferous bedded dolomites. These are greatly altered and brecciated and have frequently slid or collapsed down the eastern side of the reef. They occupy much of the coast between Salterfen Rocks and Horden Colliery, and form low ground.

West of the reef the bedded yellow dolomites have a limited fauna and are less disturbed than the eastern dolomites.

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1. Trechmann, C.T. Quart. Jour. Geol. Soc. Vol. 70, 1914, p. 259.

2. Woolacott, D. The Geology of North East Durham and South East Northumberland. Proc. Geol. Assoc. Vol. 24, 1913, pp. 87-107.

The Upper Limestone occurs mostly as finely laminated, soft yellow limestone, with occasional beds of harder non-magnesian rock and some banks of oolite. These beds are often concretionary, especially at Roker and Fulwell, where the 'cannon-ball' limestones assume an astonishing variety of forms. This series lies in a syncline between Marsden and south of Sunderland and forms Cleadon, Fulwell and Building Hills. It is faulted in at Seaham Harbour. Lying on the Concretionary Limestone is about 100 feet of yellow bedded limestone, best exposed at Roker and the Hartlepool district. It is sometimes compact and crystalline but is often pseudo-oolitic in appearance.

Though never a true dolomite, the Magnesian Limestone frequently contains a high percentage of magnesium carbonate.[1] Browell and Kirkby (1866) showed that in general the earthy marls and friable yellow limestones are the most magnesian, the compact non-crystalline and non-concretionary limestones are intermediate in character, while the crystalline and concretionary beds contain still less magnesia.

This mixture of lime and magnesium carbonates has given rise to a unique series of concretionary structures, the lime in many of the beds having separated out from the

1. Calcium carbonate varies from 99% to 38%, Magnesium carbonate from less than 1% to 50%. The amount of silica, alumina, and oxide of iron varies from less than 1% in the purer limestones up to 30% in the more marly varieties. See Woolacott, 1913.

mixture of the two carbonates to form a diversity of concretionary forms, in may places and at many horizons (Plates III and IV). These were first described by Sedgwick (1829, p.37), but no adequate explanation has been provided for the actual making of the varied forms. Garwood[1] has shown that the spheroidal cannon-ball concretions are due to the segregation towards centres of the calcium carbonate, and Woolacott[2] found that the cellular structures seemed to have been produced by the removal of magnesium carbonate.

Brecciated beds are confined to the Middle Limestone and the lower part of the Concretionary division. Some breccias have resulted from slumping down the side of the reef knolls; others from the falling in of caves, forming 'breccia gashes'[3]; others have been attributed to the volume-change resulting from hydration of anhydrite, and the change from calcite to dolomite (Green, 1882; Guy, 1911). Woolacott (1913) attributed brecciation to horizontal thrusting occuring during the supposed post-Permian accentuation of the Coal Measure basin under Sunderland, but Trechmann[4]

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1. Garwood, E.J. On the origin and mode of formation of the concretions in the Magnesian Limestone of Durham. Geol. Mag. Vol. 8, 1891, pp. 433-440.
2. Proc. Univ. Durham Phil. Soc. Vol. IV, 1911-12, p. 251.
3. Lebour, G.A. Trans. N. England Inst. Min. Mech. Eng. Vol. 33, 1884, pp 165-177.
4. Trechmann, C.T. Thrusting and other Movements in the Durham Permian. Geol. Mag. Vol. 91, 1954, pp. 193-208.

attributed the thrusting to volumetric changes following segregation.

The Middle Limestones on the east of the reef have abundant collapsed and bedded breccias (Plate V). The angular collapsed fragments have frequently been cemented together by secondary dolomitic matter, and now appear as portions of a solid mass of breccia, so solid that several have become more resistant to erosion than the original rock, and now stand out as sea stacks.[1]

The whole Magnesian Limestone sequence in this area gives a clear picture of a shrinking inland sea becoming progressively more saline with the passage of time. The Upper Limestone rests in places on the Middle Limestone Reef but never occurs west of it; and the Middle Limestone never occurs west of the Lower Limestone, showing that the sea was shrinking eastwards.

Post-Permian

The variation in thickness of the Permian[2] fostered the

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1. For example, Lot's Wife, near Marsden Rock.

2.

Beneath Sunderland	250 feet	Whitehouse (Norton)	299 ft.
Horden	420 "	3 miles west of Whitby	4194-5050 (Permian)
Blackhall	688 "		
Hart Railway Stn.	718 "		
Seaton Carew	878 " (below Triassic red beds)	Whitby	850 ft.
		Cleveland Hills	550 "

suspicion that the Permian may have been, in part, denuded before the deposition of the succeeding beds.[1] It is not possible to define any clear cut boundary between the Permian and the overlying Triassic Sandstones,[2] though the presence of mica, the absence of 'millet-seed' grains and occasional marly partings indicate deposition in water rather than by wind.

The close of the Triassic was marked by the deposition of Keuper marls in the extreme south of Co. Durham beneath the Tees estuary, whence they pass under the Rhaetic and Lias of Cleveland. They were evidently deposited in a shrinking lagoon where 'Caspian' conditions prevailed, and the salt beds are associated with layers of gypsum and anhydrite.

It is possible that Jurassic and Cretaceous sediments were subsequently spread over the region at the close of the Triassic, though there is no trace of any post-Triassic deposits in Co. Durham until the Pliocene had passed away and the Ice Age had come into being. The conception that Mesozoic rocks were not deposited on the Pennines was founded on the belief that the latter were elevated as a N-S anticline by the Hercynian earth movement, but Trotter and Hollingworth[3] have shown that these movements actually depressed the Alston Block

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1. Lebour, G.A. Geology Section in 'Durham', F. Whellan, 2nd Edition, 1894.
2. Trechmann, C.T. The Relations of the Permian and Trias in North-East England. Proc. Geol. Assoc. Vol. 41, 1930, pp. 323-335.
3. Trotter, F.M. and Hollingworth, S.E. The Alston Block. Geol. Mag. Vol. 65, 1928, p. 433.

Trotter believed that both Triassic and Liassic rocks formerly stretched across that 'block', and there was no evidence that Oolite, Lower Cretaceous and Upper Cretaceous strata were not deposited.[1]

Woolacott was also of this opinion, though he pointed out that there was little evidence of this Cretaceous cover, apart from the widespread distribution of flints and Chalk pebbles in the kames of south-east Durham and in other pocalities. Recent work by Professor Linton[2] has given further support to this view.

Trotter believed that as a consequence of post-Cretaceous uplift, the Alston Block was tilted to the east and consequent streams cut deeply into the land surface which extended across the present North Sea. After mid-Tertiary uplift of the Tertiary peneplane and doming of the Teesdale Anticline, the north flowing subsequents had greater power, and the subsequent developing along the edge of the Permian outcrop successively captured the headwaters of the Twizzell, Browney, Deerness, Stockley, Wear and Gaunless, and diverted their waters to the Tyne. Trotter recognised the former courses of these streams in the Magnesian Limestone escarpment, but this part of his work is extremely suspect and many of his supposed instances of river capture are completely untenable.

1. Trotter, F.M. The Tertiary Uplift and resultant drainage of the Alston Block and Adjacent Areas.
2. Linton, D.L. Some Problems of Scottish Scenery. Scot. Geog. Mag. Vol. 67, 1951, p 70.

Summary and Conclusions

The topography of East Durham has been determined to a marked degree by the variations in lithology and stratigraphy of the Permian rocks. Details of the structure are sometimes hidden beneath superficial deposits, but the character of the East Durham Plateau results essentially from the presence of the youngest of the Upper Palaeozoic strata.

The East Durham Plateau is terminated in the west by an escarpment overlooking the Coal Measure vale of the Wear Valley. This escarpment is formed of the lower Permian beds throughout the greater part of its length, but north from Penshaw the Middle Magnesian Limestone becomes important and at Cleadon the escarpment is totally in Upper Limestone. A discontinuous line of hillocks on the plateau surface results from the outcrop of the 'shell' limestone which is more resistant to erosion than either of the other facies of the Middle Limestone, which tend to form low ground. A third break of slope results from the outcrop of Concretionary limestone in the Sunderland area, showing yet again the close relationship between solid geology and topography and coastal morphology.

The great variability of the limestone in all respects results in an extremely heterogeneous cliff face being exposed to wave attack, and differential weathering and denudation are strongly marked characteristics of the Durham cliffed coasts. The reasons for the development of such complex beds are unknown, but their effects are quite remarkable and produce a variety of erosional features.

The drainage of the plateau is accomplished mainly by deeply entrenched dip streams, but the nature of the development of the drainage pattern is not known for certain. The evidence suggesting the gradual development of consequents down through an uplifted Cretaceous surface, followed by capturing of their headwaters by a north-flowing subsequent, has been considered and found unsatisfactory. The number of parallel consequents envisaged by Trotter is unlikely in such a small area as the Alston Block, and certain of the 'captures' are almost impossible to conceive.

Chapter 2. Pre-Glacial Drainage Pattern

The determination of the shape and nature of the pre-glacial surface of East Durham is of great importance in the study of its present form. The outcrop of a drift-filled pre-glacial valley in the present cliff face results in the cliff being formed of less resistant superficial deposits instead of the more resistant Magnesian Limestone. One would expect erosion to be greatest in such localities, but this is not always the case.

Previous attempts to deduce the pre-glacial drainage pattern have been made by Woolacott (1905) and Trotter (1927) and, more recently, by H.M. Geological Survey Officers and others. The evidence now available is considerably greater than when Woolacott wrote in 1905,[1] but it has merely served to fill in a few more details in his general plan of the pre-glacial drainage pattern, and little of his work in this area has been shown to be incorrect. Trotter suggested a continuation of the tributaries of the present River Wear eastwards across the Permian during Tertiary times, and pointed to the deep notches in the Permian escarpment as evidence of the former presence of large rivers. In his view these were formerly consequent rivers which were later captured by a north-flowing tributary of the pre-glacial 'Tyne'[2]

1. The Superficial Deposits and Pre-Glacial Valleys of the Northumberland and Durham Coalfield. Quart. Jour. Geol. Soc. Vol. 61, 1905, pp. 64-95.
2. Whenever the pre-glacial feature is referred to the name is in quotation marks, e.g. Rivers 'Tyne','Wear'.

There are large pre-glacial valley sections outcropping at the present coastline, but it is not possible to prove their extension westwards towards the present Permian escarpment as Trotter suggested. Many attempts to draw rock head contours have been made on the basis of Trotter's hypothesis, but now that his work has been found suspect by Professor Dunham and by Dr. Maling[1], the rock-head contours must be based on proven evidence and then interpolation, in that order, and not on pre-conceived ideas.

At present it is impossible to determine the topography of the sub-drift rock surface in East Durham with sufficient accuracy to be able to map fully the pre-glacial drainage pattern. The reasons for this are not readily appreciated by workers in other coalfield areas, who may obtain a great deal of information from colliery shaft sections and borings made in search of coal. Despite the presence of vast amounts of coal beneath the surface of the eastern part of Co. Durham, there are relatively few borings made from the present surface. It has been mentioned in Chapter 1 that the Permian series of strata forms a gigantic aquifer, and attempts to bore through the limestone and underlying sands have usually been exceedingly costly and laborious. Consequently it has been usual for colliery borings to be started from seams and levels already being worked within the coalfield, and these are of

1. Maling, D.H. Unpublished Ph.D. thesis, Durham University, 'The Geomorphology of the Wear Valley'.

no use for determining the thickness of glacial overburden. There is, however, an almost complete network of collieries in East Durham, and at each of these at least one shaft section proves the thickness of the overlying glacial material. At some of the older collieries in the west there are two or three shaft sections providing local detailed information, but on the whole the evidence available as a result of coal mining activities is disappointing.

In exploiting the water-bearing capabilities of the Yellow Sands, many wells and water-bores have been made, and the resulting sections supply further evidence of the position of the sub-drift rock floor. The boring logs of the Sunderland and South Shields Water Company have recently been made confidential, so that the evidence which is available for publication is considerably reduced. The positions of all known water bores are indicated in Fig. 10, however, and Fig. 11 has been based on the maximum amount of evidence available, though the abstracted logs of many of the borings cannot themselves be published.

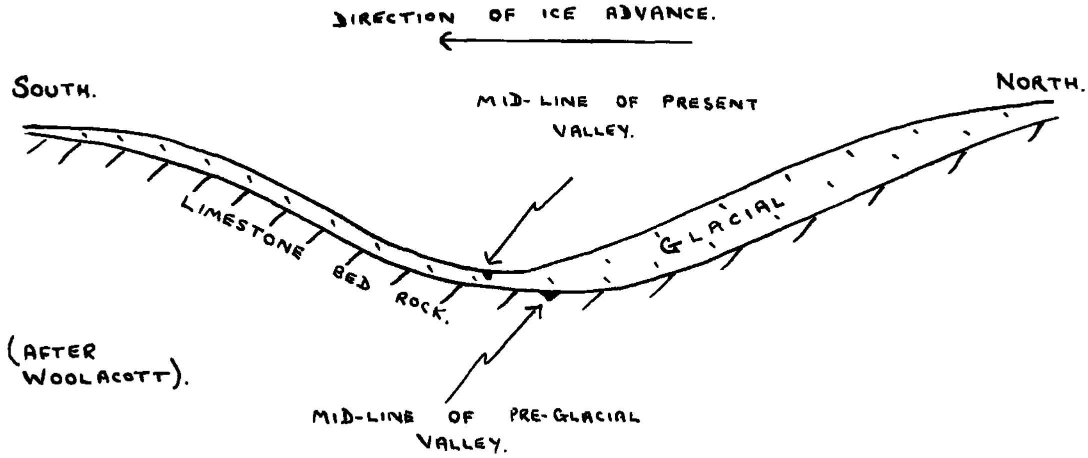
The extreme variability of the Magnesian Limestone has led to many disappointments in quarrying projects, and East Durham is dotted with small abandoned quarries. Most of these have been examined in the field and the thickness of glacial overburden measured by the author and by Geological

Survey Officers, thus allowing the height of the rock-head to be established at a great number of points. Field mapping of escarpment, dene and cliff outcrops of limestone has provided further evidence.

The total boring and field evidence is indicated in Figs 10 and 12. Fig. 11 is a tentative map of the pre-glacial topography and drainage in North-East Durham, but as each new boring is made the map has to be modified accordingly.

The evidence available for drawing rock-head contours in East Durham is not evenly distributed: it is quite considerable where the superficial deposits are thin or entirely lacking; it is very complete along the coast; and it is very considerable around the mouth of the Tyne, at Sunderland and at Hartlepool. Except along the sea coast, where the sub-drift slopes appear quite gradual, wherever the boring and field evidence is good the sub-drift surface appears to be very complex and of quite varied relief, so that any interpolation between known heights is extremely suspect. This is especially so in the case of the small valleys found throughout the area of the Permian Plateau, but may also be true of the larger valleys such as that of the 'Cleadon', or even the 'Tyne'.

Woolacott seems to have been the first to note a tendency for the mid-line of west-east rivers in Northumberland and Durham to be on the southern side of the mid-line of pre-glacial valleys.



He attributed this tendency to the likelihood of more glacial material being deposited on the lee slope of ice advance than on the exposed slope, though this is a matter of some dispute. Smythe also observed the tendency for greater deposition of glacial material on the lee side of valleys at right angles to the direction of ice advance. This distribution of the drift forced the post-glacial streams towards the comparatively drift-free side of the valley.[1] The River Wear between Durham and Chester-le-Street is developed on rock and clay on the 'exposed' slope of the pre-glacial valley. Similarly the Tyne and the Tees have developed on the south side of the pre-glacial rivers.

Comparatively recent borings made in connection with the proposed Tyne Tunnel between Howdon and Jarrow, about four

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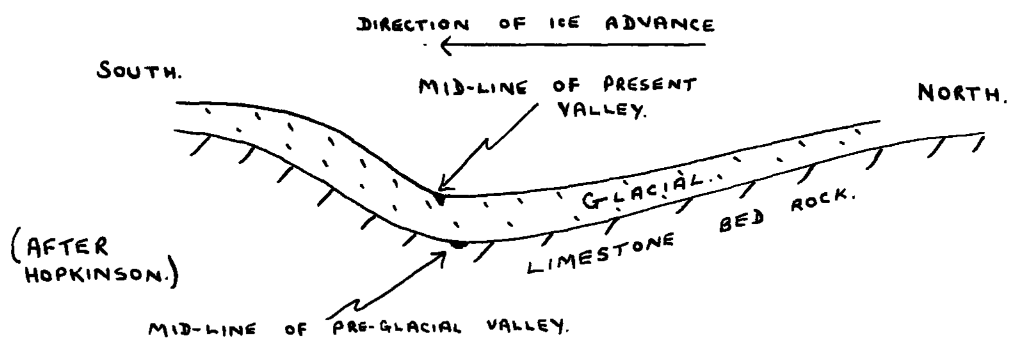
1. Smythe, J.A. Glacial Geol. of Northumberland. Trans. Nat. Hist. Soc. Northumberland and Durham. Vol. 4, 1912, p. 104.

miles from the sea, show that the solid rock surface slopes northwards beneath the superficial deposits to about 140 feet below O.D. at a point about one-third of a mile north of the present river channel[1], and this may be the centre of the pre-glacial 'Tyne' valley. The present Tyne has notched the southern bank of the old valley at about 82 feet below O.D.

The pre-glacial valleys across the Permian were at right angles to the direction of ice movement along the coast, and the same features of asymmetry are there developed, the denes being on the southern slopes of the old pre-glacial valleys.

The conception of uneven distribution of superficial deposits in pre-glacial valleys has been attacked recently by Mr. Hopkinson[2], who suggests that asymmetrical valleys were typical of East Durham before the Ice Age on account of differences of exposure between the north and south facing slopes. He supposes an even distribution of boulder clay and sands would give features such as are seen today.



1. Armstrong, G., and Kell, J. The Tyne Tunnel. Geol Mag. Vol. 88, 1951, pp. 357-361.
2. Unpublished Ph.D. thesis, Birmingham University.

Throughout his argument he has repeatedly compared the present conditions in the denes with those in the pre-glacial valleys, completely overlooking the vast differences in the shape and form between those two types of valley.

In pre-glacial times the drainage of East Durham was quite distinct from that of the west. The Permian escarpment was then a more complete feature and was only broken along the line of the 'Cleadon' valley (A-A in Fig.11), and at the mouth of the 'Tyne'.

In addition to the 'Tyne' there are five other buried valleys within the area covered by Figs. 10 and 11. Their closeness to each other suggests that they formed the higher parts of a river system graded to a lower sea level and a coast further east than at present. These five are (see Fig. 11):

1. The 'Cleadon' Valley, A-A, between Fulwell and Cleadon Hills.
2. The 'Jarrow' Valley from Washington to Jarrow. (This valley is not indicated in Fig. 11).
3. The 'Hendon' Valley, B-B, from High Haining to the coast between Sunderland and Salterfen Rocks.
4. The 'Herrington' Valley, D, from near Hasting Hill towards Burnmoor along the course of the

present Herrington Burn.

5. The 'Farringdon' Valley from South Farringdon towards the 'Herrington' Valley at New Herrington.

Most of these valleys may be recognised by an observer standing on Fulwell Hills.

<u>The 'Cleadon' Valley (A-A)</u>

Between the drift-free areas of Cleadon and Fulwell Hills, rising to heights of 280 feet and 230 feet, respectively, is a wide valley at an elevation of about 70 to 80 feet O.D. If the flat-topped covering of superficial deposits known as 'Boldon Flats' was removed, an even more developed valley would be revealed, extending to below present sea level. This pre-glacial valley is proved, not only by the cliff sections but also by borings within the valley form itself. At Fulwell Pumping Station (68 feet O.D.) the limestone is overlain by some 73 feet of clays, sands, and gravels, and towards Harton the rock-floor is at least 35 feet below O.D., falling to 48 feet below O.D. towards Tyne Dock. There is no evidence to prove that these borings have been on the mid-line of the pre-glacial valley, but the available evidence suggests that the river in this old valley flowed from east to west and was a tributary of the 'Tyne'.

Many sections of this valley have been drawn by Woolacott,[1] and these need not be repeated. In 1897 he suggested that the 'Wear' may have flowed along this valley, but he later changed his opinion and believed it to have been a tributary of the 'Tyne'.

The 'Jarrow' Valley

Between Washington and the River Tyne the present land surface of superficial deposits slopes gently northwards towards Jarrow Slake, concealing the rock-floor which is at about O.D. at Boldon Colliery and 55 feet below O.D. at the Slake. This is without doubt a buried tributary of the 'Tyne'.

The 'Hendon' Valley (B-B)

The 'Hendon' Valley is one of the most important pre-glacial valleys in East Durham, and the resulting clay cliffs south of Sunderland are in a particularly vulnerable position for extensive marine denudation. The presence of this valley has been a most significant feature in the evolution of the Durham coast.

Borings towards the head of the valley suggest that a change in the drainage pattern has occurred, though there is no evidence to show whether it resulted from river capture by the swift-flowing obsequent stream or from drift-plugging during the glacial period. The small secondary

1 Proc. Univ. Durham Phil. Soc. Vol. 1. 1896-1900, p 247, and Quart. Jour. Geol. Soc. Vol. 61, 1905, p. 66.

valley has been termed the 'Farringdon' Valley, and its connection with the 'Herrington' Valley seems fairly certain.

The 'Herrington' Valley (D)

There is considerable doubt concerning the eastern extension of this obsequent stream, though some boring evidence suggests that it may have breached the Permian escarpment completely in the neighbourhood of Hastings Hill. This cannot be proved, as the boring information in the Sunderland area shows that the sub-drift surface is there very irregular in form, and interpolated contours must be used very cautiously.

The Sunderland Area

One of the main difficulties in drawing rock-floor contours is that it is not always possible to accept the boring log recorded. Many of the wells and sinkings are of great antiquity and the logs have been written by unqualified persons. In such cases the height of the rock floor is uncertain, and extra care has to be taken whilst plotting. Whenever doubtful records were found, they were checked in the field or at H.M. Geological Survey Office, Newcastle. There are several instances in the Sunderland area of well sections being incorrectly recorded or incorrectly copied from originals, and when careful checking is carried out major errors have been found.

The information available is as yet inadequate to indicate anything more than two hollows in the rock floor at Sunderland, one on either side of the River Wear, and additional evidence is necessary before they can be considered part of a pre-glacial valley.

The Tunstall Hope

One other feature indicated in Fig. 11 needs to be considered in greater detail than can be obtained from an examination and comparison of Figs. 10 and 11, and an O.S. topographical map. This feature is the well-developed overflow channel on the south side of Tunstall Hills, which indicates the outlet of a glacial lake which had developed in the Newport area to the west. This channel is indicated at C-C and is a marked morphological feature, the deep trough being flanked on either side by bare limestone hills. The associated superficial deposits around Tunstall will be considered in Chapter 3.

Comparison of Figs. 10 and 12 shows that the evidence available for drawing rock-head contours in the southern part of the Durham coast is not nearly so complete as in the north. The number of rock outcrops or areas of thin drift is considerably less and the spread of boring information is very poor. There are a few borings in the Seaham Harbour area and at each of the collieries, and a number of confidential borings around Cold Hesledon for the Washington

Chemical Company, but elsewhere the available evidence is not sufficient for the drawing of rock-floor contours.

The possible outlets in the present coastline for pre-glacial streams are shown in Fig. 12 by breaks in the solid black line, indicating a change-over from the solid cliffs of limestone to more recent deposits. South from Crimdon Dene the coastline is formed of sand dunes and other recent deposits, with the exception of the limestone outcrop at Hartlepool promontory, and there is ample room for the mouth of a buried valley. Borings just north of Hartlepool Cemetery proved the rock-head at 121 feet below O.D. Other borings further inland showed the rock-head at 32 feet below O.D., and both Radge and Agar have mapped by borings the course of the pre-glacial 'Tees' near the present coastline.[1] Radge has shown that the broad valley of the 'Tees' cut in Triassic-marls and sandstones has its lowest parts along the northern edge of the present alluvial plain and then swings northwards to the west of Seaton Carew and out to sea between Hartlepool and Crimdon Dene.

There are at least three other areas along the coast mapped in Fig. 12 where a pre-glacial stream may have

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1. Radge, G.W. The Glaciation of North Cleveland. Proc. Yorks. Geol. Soc. Vol. 24, 1939, pp. 180-205.
   Agar, R. The Glacial and Post-Glacial Geology of Middlesbrough and the Tees Valley. Proc. Yorks. Geol. Soc. Vol. 29, 1953-54, pp. 237-253.

reached the present coast. In each instance there is at present a stream flowing along a drift-filled depression, though not along its mid-line. An attempt was made by the writer to draw rock-floor contours on the basis of cliff and dene sections, but it proved impossible to connect the valley forms across the intervening interfluves.

There appears to be little correlation between the direction of the pre-glacial streams and the basal Coal Measure geological structure, and this is not surprising since most of the movement affecting the Coal Measures was pre-Permian. Yet the gentle eastward tilt of the seams and strata of the North-East Coalfield at about 100 feet per mile, or 1 in 50, corresponds strikingly with the dip of the overlying Permian, and must therefore represent the result of post-Permian movement. Many Coal Measure faults do not extend to the rocks above, but it is interesting to note that the trend of the 'Cleadon' Valley (Fig. 11) corresponds to some extent with the deep, broken, Coal Measure syncline (Fig. 7) running south-east through Jarrow to Hylton, and traceable to Sunderland. In a few cases the forms of outcrops of the Permian base suggest substantial displacement of these rocks along the line of subjacent Coal Measure faults, e.g. the westerly continuation of the Seaham fault south of Houghton-le-Spring, and the Butterknowle fault south of the Raisby Hill Quarries.

There can, of course, be no significant connection between the direction of Permian faulting and the drainage pattern, as the Permian has few clear indications of displacement, and there are probably none of any considerable magnitude. Occasional instances of synclinal valley development have been noted, of which the pre-glacial 'Castle Eden' Valley is the best example. South of West Hartlepool a small drift-filled pre-glacial valley about 30 feet deep is shown by borings to coincide with the faulted junction of the Limestone and Triassic red beds.

The broad drift-filled depression with no particular shape on the north and west of Hartlepool has been ascribed by Trechmann to the solution of an extensive bed of anhydrite included in the limestone, and has no connection with the pre-glacial drainage system.

It may not be out of place to note at this stage that there is boring evidence which suggests that the lowest part of the 'Tyne' does not occur at the present sea coast but some way inland, and Woolacott has suggested that differential earth movements may have been responsible. Similar features have supposedly been shown to exist in many glacial overflow channels[1] and there may be some general explanation.

1. Maling, D.H. Unpublished Thesis, 1955.

Boring evidence of 'reversed slopes' is not conclusive unless there is proof that the mid-line of the buried valley has been found. Often the pre-glacial streams were deeply incised, and a very close line of borings is needed before the shape and nature of a buried valley can be deduced. Until further evidence becomes available the 'reversed slope' theory cannot be considered proved.

From the above summary it is apparent that the available evidence for drawing rock-head contours in East Durham is not satisfactory, though there is sufficient to indicate the general trend of the pre-glacial drainage pattern.

The drainage of East Durham was to a base level some hundred or so feet below present sea level at a coastline many miles further east than that of today. The closeness and complexity of the river pattern wherever boring and other information is good, indicates that East Durham acted as a gathering ground for eastward flowing surface waters. The development of a subsequent stream along the Permian outcrop has beheaded a number of consequents flowing eastwards from the Alston Block, and diverted these waters to the 'Tyne'. Obsequents flowing down the escarpment slope cut deep notches to make the line of outcrops more intricate. It is upon this relatively simple drainage pattern that the post-glacial drainage has been superimposed and the close correlation between the two patterns in East Durham is quite remarkable. The age of these buried mature valleys has been disputed[1], but the suggestion that they were formed during an interglacial period following the deposition of the Scandinavian Drift is quite untenable. The bottom of these valleys is concealed by many feet of drift, and as yet there is no evidence to show that Scandinavian Drift is present, but the finding of such material would prove that they are older than the Scandinavian Drift. From the point of view of this study, the really important point is that the valleys have been formed and they have been filled with glacial material of less resistance to denudation than the solid Magnesian Limestone cliffs. They have a great effect, therefore, on the recent morphological evolution of the Durham coast.

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1. E.g. Trechmann (1919)

Chapter 3. Pleistocene Chronology and Superficial Deposits.

A detailed statement of glacial events in East Durham would be out of place in this thesis, but some reference must be made to the capping of sand, gravel and clay which almost everywhere forms the upper part of the sea cliffs of Co. Durham. (Fig. 13).

The direction of ice movement over North-East England was determined largely by the presence of the surrounding heights of the Cheviots, the Lake District and the Cross Fell Range, and the presence of Scandinavian ice "offshore". The south-flowing Scottish ice was split into two streams by the Cheviots, one stream joining the northern Lake District ice flowing down the Tyne Valley, and the other, kept "inshore" by the Scandinavian ice to the east flowed over the coastal areas of Northumberland and Durham. The main mass of the Lake District ice, unable to cross the Cross Fell Range, flowed through the Stainmoor Gap into Teesdale. These facts give the key to the source of boulder clay and erratics found in East Durham.[1]

The Main Cheviot Drift

The largest single mass in the sequence of superficial deposits in East Durham is the Main Cheviot Drift, which is

1. See Woolacott. Geol. Mag. Vol. 58, 1921, pp. 26-27 for evidence from striae of the direction of ice movement.

considered to be the product of maximum glaciation, though it may have obliterated and incorporated among its own rubbly debris the material of earlier stages of glaciation.

There appears to be a broad two-fold division of the Main Drift into (a) stony boulder clay and (b) sand and gravel, and water-sorted boulder clay.

(a) Stony Boulder Clay

The unstratified tenacious brown or red clay is best seen at Hendon Banks. It contains Whin Sill with Carboniferous material and relatively small proportions of far-travelled rocks. Lake District and Borrowdale rocks take second place to Cheviot erratics, except in some stony clays and on the western limits of the Durham area where they are particularly abundant.

The quantity of Borrowdale erratics in the gravels, stony clays and morainic drifts suggests that Stainmoor and Tyne ice at some stage had practically uninterrupted access to the coastal area.

Towards the south, to a distance of three or four miles from the sea, the drift is largely red, friable, sandy, stoneless material arranged in stratified order, often so well bedded as to be mistaken for Permian or Triassic red beds. The line of demarcation between the northern brown boulder clay and the red Tees Valley boulder clay appears to be in Castle Eden Dene.

A Brown Columnar or Prismatic Clay weathering to vertical columns which often stand out as buttresses extends across a great amount of the above-mentioned boulder clay and sands. It occurs almost continually along the cliff top, and is almost uniform in thickness.

(b) Sand and Gravel and Water-Sorted Boulder Clay

During the melting of the ice, extensive spreads of sand and gravel were formed in South Durham, especially at Elwick, Brierton, Greatham and Throston. Greatham itself stands on a 50-foot ridge of gravel, and at Claxton, one mile to the west, 25-foot spreads of gravel are quarried, and there may be as much as 45 feet of glacial beds beneath. The material is a current bedded shelly gravel with flints and pieces of Chalk, and Trechmann imagined it had been swept inland from an interglacial shoreline. The shelly fragments are found in all the gravels associated with stony clays but are never found in the stony clay itself, or in the red sandy drift. The shells are especially common in kames.

The Sheraton kames are near the western boundary of the Cheviot material, rest on boulder clay, and are aligned N-S near Elwick and E-W near Sheraton and south of Hesledon. These elongated or rounded hills of gravel, sand and boulders are clayey in part, the finer portions showing current bedding. A small marsh is usually associated with the clay deposits. The much smaller kames between these and the coast were formed during the easterly retreat of the Cheviot ice.

No Cheviot rocks have been found in either Warden or Batter Laws, and the abundance of Millstone Grit suggests that they are both kames left on the edge of the Pennine ice sheet. Smythe[1] has shown that the western ice from South-West Scotland and the Lake District retreated before the Cheviot ice, so that the Grindon and Warden Law kames were formed on the free margin of the Tweed-Cheviot ice.

The western limit of Cheviot erratics in Northumberland between the Tyne and the Wansbeck is about 12 miles from the coast, but in Durham the distance of the western limit from the coast increases southwards from 3½ miles at Grindon Kame to 5 miles at Wingate and 8 miles at Trimdon. If this line were continued south it would pass close to Ingleby Arncliffe, which Kendall considered marked the western limit in North Yorkshire where Cheviot material formed a notable element of the drift.

At Limekiln Gill a wedge of current-bedded and largely calcreted gravel inter-bedded in red sand occupies a washout in Concretionary Limestone. A more extensive bed of

1. Smythe, J.A. The Glacial Geology of Northumberland. Trans.Nat.Hist.Soc.Northumberland and Durham. Vol.4.1912.p.104.

apparently water deposited gravel occurs in a depression in calcareous brecciated limestone north of Horden Point, reaching a thickness of forty feet and underlying much sandy, stony drift. Other gravels are found north and south of Ryhope Dene. These gravels are somewhat analogous to gravels half a mile north of the River Wansbeck occupying a depression in Coal Measure Sandstone and overlain by boulder clay, which Smythe considered marked the site of an early glacial stream flowing south-west towards the pre-glacial 'Wansbeck'.

The erratics in these gravels are all from Scotland, the Cheviots, the Pennines and the Lake District. The high proportion of Scottish erratics indicates that they were deposited at an early stage when Scottish ice had relatively free access to the Durham coast before the maximum development of Pennine and Cheviot ice. There are few shell fragments, and the gravels are no doubt associated with early-glacial streams.

Scandinavian Drift

In 1915 Dr. Trechmann[1] found a basal clay beneath the Cheviot Drift in Warren House Gill containing no English or Scottish erratics. He considered that all the included striated and polished erratics were Scandinavian, in the main from Southern Norway. Isolated Scandinavian rocks had been

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1. Trechmann, C.T. The Scandinavian Drift of the Durham Coast and the General Glaciology of South East Durham. Quart. Jour. Geol. Soc. Vol. 71, 1915, pp. 53-82.

found previously in Durham, as at Trow Rocks and in Castle Eden Dene, but this was the first major find. This chance preservation of basal clay in a pre-glacial valley suggests that the Scandinavian ice sheets were at a maximum before the British ice sheets had reached the coastal area. Lamplugh considered the basal clay equivalent to the Holderness Basement Clay, but it may be slightly older as the latter has Scandinavian boulders mixed with English erratics. Wright[1] considered it equivalent to both the Norwich Brick Earths and the Oxford Plateau Drift. The dark, compact, tenacious clay is clearly separated from the main drift, though the line of demarcation is disturbed.

Some fissures in the limestone between Crimdon Dene and Seaham Harbour are filled with red, mottled sandstones and variegated marls which may have been pushed inland by the advancing Scandinavian ice sheet, or, alternatively, they may be fragmentary evidence of the former existence of overlying Upper Permian Beds. Nothing in these fissures has been proved Scandinavian as yet.

The Interglacial Problem

On the whole there is insufficient evidence to postulate an Interglacial Period in North-East England following the deposition of the Scandinavian clay, though Dr. Trechmann had found some interesting loess-like material at Warren

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1. Wright, W.B. The Quaternary Ice Age, 1937.

House Gill.[1] The problem was reviewed by Woolacott in 1921[2], and little further evidence which tends to clarify the issue has become available.

The material which Dr. Trechmann believed to be loess is physically, chemically and stratigraphically similar to European loess. It is a brown, grey and bluish clay, with organic remains, banked against the north-facing slope of the pre-glacial valley by wind action, and overlain by partly redeposited 'loess'. It is homogeneous, shows no stratification, tends to break along vertical clefts and cracks, and contains structures similar to the 'loess dolls' of the Continent. But the significant feature of true loess is its wide extension in homogeneous sheets, and the Durham 'loess' has only a very limited extent. Nevertheless, it may mark an important episode between the deposition of the Scandinavian and British Drifts. No true loess has ever been found in Britain in connection with local Glacial Drifts, probably because the climate was Oceanic rather than Continental, and the conditions were unfavourable for its formation.

Dr. Trechmann suggested that the shelly fragments included in the kames of south-east Durham which indicate a

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1. Trechmann, C.T. On a Deposit of Interglacial Loess and some Transported Freshwater Clays on the Durham Coast. Quart.Jour. Geol. Soc. Vol. 75, 1919, pp. 173-203.

2. Woolacott, D. The Interglacial Problem and the Glacial and Post-Glacial Sequence in Northumberland and Durham. Geol. Mag. Vol. 58, 1921, pp. 21-32, 60-69.

North Sea fauna similar to that of today were derived from an interglacial and not a pre-glacial shoreline. They do differ markedly from the more Arctic shells found in the Scandinavian boulder clay, but are explicable if one considers the different assemblages of fauna at differing sea depths.

Trechmann also considers that the pre-glacial valleys at 'Castle Eden', 'Crimdon' and 'Hawthorn' are interglacial, as he sees no reason why Scandinavian ice should fill the pre-glacial 'Warren House Gill' and not the other wider and deeper valleys if they were already in existence.

Superimposition of drifts does not imply an interglacial period, but it does suggest a time interval to account for the shifting of directions of flow and the readjustment of ice sheets. Where superimposition has occurred, the sequence appears to be:-

(a) Scandinavian Drift.

(b) Drift with western erratics.

(c) Drift with Scottish, Cheviot and Western boulders.

Multiglacialists v. Monoglacialists

The problem of correlating Pleistocene events in Northern England with those elsewhere in this country and on the Continent has not been solved satisfactorily, though Trotter and Hollingworth[1] state that "a stratigraphical

1. Trotter, F.M. and Hollingworth, S.E. Correlation of the Northern Drifts. Geol. Mag. Vol. 69, 1932, pp. 374-380.

sequence of four distinct boulder clays separated in places by interval deposits is present in the North-East of England, and additionally a fifth boulder clay is recognised in the Solway Region. This last would correlate with the Buhlstadium of the Continent if the Continental equivalents of the other four are Günz-Wurm." In an attempt to present a solution, Dr. Carruthers[1] has put forward arguments in favour of only one glaciation in Northern England and his viewpoint has been accepted by many local glaciologists, of whom Dr. Raistrick is now his strongest supporter.

Dr. Carruthers has tried to show that all the features and pecularities of the superficial deposits in Northern England can be ascribed to one glaciation, with oscillations of the ice front as differing centres of ice dispersal reached their maximum. He believes that both the tills and the interbedded sediments had their origin in a melt which spread upwards through stagnant ice.

The 'upper' and 'lower' boulder clays separated by 'sands and gravels' which have been considered indicative of at least two glaciations in Durham are not widespread features. Of the many sections examined in the field none yielded evidence to prove more than one glaciation, and the

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1. Carruthers, R.G. On Northern Glacial Drifts. Quart. Jour. Geol. Soc. Vol. 95, 1939, pp. 299-333.
   The Secret of the Glacial Drifts. Proc. Yorks. Geol. Soc. Vol. 27, 1946, pp. 43-57.
   Glacial Drifts and the Undermelt Theory, 1953.

changes from gravel to clay, to sand, to gravel were so random and haphazard that no classification could be attempted.

Dr. Carruthers and his supporters are steadily accumulating additional evidence, and it does seem likely that the work now being undertaken in this connection will provide a stimulus for further glaciological studies in Northern England.

Retreat Phenomena

East Durham seems to have escaped the erosional power of the ice sheets to a marked degree. The pre-glacial river valleys were slightly modified in section, and local striations developed, but there are no known instances of deep ice ploughing. Many of the most interesting results of glaciation in Durham were produced during the retreat stages when melt waters were often ponded back to form lakes which overflowed periodically along definite and well defined channels.

East Durham remained covered by ice for some time after the Pennine slopes had become ice free, and the Pennine drainage became impounded to form one of the largest and most persistent of the late glacial lakes. It eventually overflowed and cut the remarkable gap in the Permian escarpment at Ferryhill. Lake clays and muds were formed within the lake and these occur at c. 320 feet O.D. all over the middle Wear valley (Fig. 14). Many of the laminated clays have been examined by Carruthers, who considers they are shear clays formed by an ice sheet and not true lake deposits. He experiences great difficulty, however, in accounting for these clays at such well defined horizons.

The escaping melt waters spread a thick mantle of sand, gravel and clay over the land to the south of Ferryhill Gap. This area remained covered by small lakes and pools of water until quite recent times when it was artificially drained to form a flat platform at about 240 to 260 feet O.D. in the Bradbury and Mordon areas.

As the ice retreated from East Durham a lower outlet became available for the impounded meltwaters and they cut a gorge from Hylton to the sea, which has remained the outlet of the post-glacial River Wear. The old channel of the 'Wear' towards the 'Tyne' has been deserted and remains filled with boulder clay and laminated lake clays, and is only occupied by the tiny River Team. A mass of pebbly clay containing Lake District rhyolites, but no Cheviot rocks, is banked against the southern side of the Hylton gorge east of the Queen Alexandra Bridge (Sunderland) suggesting that a tongue of Tyne ice had been thrust at least that far into the depression through which the impounded melt waters eventually flowed. East from that bridge there is no drift within the gorge though thin clay occurs on both sides at the top of the gorge for over a mile. Cheviot drift is present at the river's mouth at Hendon and Roker.

During the retreat of ice from East Durham there was local ponding of melt-water, but there was insufficient water for any major overflow channels to be formed. Probably the largest and best developed example of such a channel in East Durham is at Tunstall, where the overflowing of a lake in the Sunderland area cut a deep gorge between Tunstall Hills and High Newport. The heavily laden waters deposited sands and gravels over the land to the east of the overflow channel and along the Ryhope coast are great spreads of gravel apparently in a deltaic form (Plate VI). The convex layers of superficial deposits may be the result of the seasonal flow of meltwater through the above-mentioned channel. Continued ice retreat allowed this pent-up water to escape at a lower level, probably through the 'Hendon' Valley, or Old Gill Cemetery, and the old overflow channel was abandoned.

The gravels are being worked extensively, and sections in the quarries at Ryhope show clearly the diversified nature of the deposit, though there is no artificial section to compare with the fine sections being exposed by marine denudation. The lake itself may have originated from the drainage of Grindon Kame. Other overflow channels were developed in the Haswell and Hetton-le-Hole areas.

Recent Deposits

In addition to superficial deposits associated with the Ice Age, there are other more recent deposits which are of considerable importance in any coastal study. Within the boundaries of Co. Durham there are four areas of sand dunes of sufficient size to be considered the main barrier against the attacks of the sea. From north to south these are:-

1. South Shields to Trow Point.
2. Whitburn Steel to Parson's Rock.
3. Crimdon Park to Hartlepool.
4. Seaton Carew to Seaton Snook.

1. The River Tyne appears to have had at least three mouths during its history, and it has carved for itself an extremely broad valley such as would be necessary to drain almost the whole of Co. Durham and parts of Northumberland. The present Tyne is probably only a small river compared with the river existing when the 'Wear' drainage joined that of the 'Tyne' at Gateshead. The broad valley of the pre-glacial 'Tyne' has been partially re-excavated by the present river, but large areas remain filled by boulder clay and other glacial deposits. Marine denudation of these deposits has assisted the development of an extensive area of beach on the southern side of the river mouth. Much of the beach material has been heaped into sand hills, and continued accumulation of fine material has enabled these sand dunes to extend inland and northwards and cover large areas of glacial deposits.

2. To the north of Sunderland there has again been a tendency for sand hills to be developed at the mouth of a pre-glacial valley, though often they have been almost completely washed away by the sea. Even within historical times there have been at least two occasions when the sand hills have been completely denuded.

3. The two areas of sand hills in the south of Durham are developed on glacial deposits filling the valley of the pre-glacial 'Tees', and without their protection a considerable area of low lying land would be liable to inundation.

North of Crimdon Dene Mouth there are two closely defined lines of dunes. They do not appear to suffer greatly from blow outs, and have become well established. A third line of dunes is being formed but it is as yet only a foot or so high and has the form of a low bank of sand with only occasional patches of marram.

Immediately south of Crimdon Dene Mouth the single line of old dunes is suffering serious erosion, and the rate of recession is increased by maltreatment. Further south there are two or even three lines of dunes with a small bank of sand in front. Such conditions extend southwards to Hartlepool.

4. Between Seaton Carew and Seaton Snook is an extremely wide area of sand hills, most of which have become stable and well colonised by vegetation. They protect a very broad area of marshland from tidal inundation and are a most

important feature of the Durham coast. During the past few years they have been increasing in size and provide better protection from the sea.

One of the most important effects of glaciation in East Durham has been the deposition of a layer of superficial deposits over the limestone plateau and the filling up of the pre-glacial valleys. It is from this glacial overburden that much of the beach material is derived, and the cliff profile itself is dependent upon the thickness of these superficial deposits. The complex nature of the drifts results, naturally enough, in a complex beach material, and this has posed many problems in the study of beach processes and wave effects (Chapter 5). On the whole, the glacial material outcropping in cliff sections is extremely heterogeneous, but locally, as at Tunstall Hope, the beds are of gravel with no admixture of sand and clay. Attempts to classify the deposits have proved unsatisfactory, though there is a tendency for the deposits south of Castle Eden Dene to be red, whereas those to the north are brown. The erratics are haphazardly distributed throughout, and there is no way of locating the source of beach material found along the coast. The four areas of sand dunes are all associated with pre-glacial valleys and are of sufficient size to form an important feature of the Durham coast.

Chapter 4. Evidence of Recent Changes

East Durham has experienced changes in the relative height of land and sea, and these must be taken into consideration when attempting to explain the present coastal features. The evidence suggesting such changes is reviewed below.

Examination of the sub-drift surface by means of borings (see Figs. 10, 11 and 12) has shown that the pre-glacial drainage of East Durham was adjusted to a sea level many feet lower than that of today. The time elapsing between this period of relatively low sea level and the Ice Age is not known, but it may have been sufficiently long to accommodate a rise in sea level to bring the sea to somewhere near its present height immediately before the onset of glaciation. Lamplugh believed the buried Chalk cliff and associated deposits at Sewerby proved that the pre-glacial sea level was very similar to that of today, as they occur only about ten feet above Ordnance Datum, but the age of those features has been disputed and they may be much later than pre-glacial. There is little evidence of the relative heights of land and sea during the Ice Age, though a band of gravel along the Durham coast at about 80 feet above O.D. has been described as a remnant of an interglacial beach.

It seems reasonable to suppose that towards the close of the Ice Age the land stood even higher in relation to sea level than before the onset of glaciation, so that the development of post-glacial river valleys was checked to a certain extent by a rising post-glacial sea level. There is evidence in Durham that this sea level may have reached a height of about 150 feet.

Evidence for a Sea Level at 150 feet

Over the past one hundred years evidence has been gradually collected of apparent sea caves, sea cliffs and patches of marine gravel occurring at about 150 feet O.D. on Fulwell, Cleadon and Tunstall Hills. Much of this evidence has become hidden by colliery material, quarried away or carried away by the sea.

Gravels are found all round Cleadon Hill at between 100 and 150 feet O.D., and the village itself rests on a gravel spread. The partially bedded gravel rests on water-worn rock in places, and is often underlain by several feet of fine, current-bedded sand. Woolacott considered that these gravels were of marine origin, but they may well be fluvio-glacial deposits such as are found further south in the Cheviot Drift. Professor Lebour believed them to be typical raised beach deposits, and they were mapped thus by H.M. Geological Survey. Lamplugh and Wright were both rather sceptical, and were not satisfied that similar deposits ought not to be expected in Yorkshire. A section of a supposed 'old sea cliff' and some 'sea caves' were found by Woolacott[1] and Howse[2] respectively on Cleadon Hill, and a deposit of sand and gravel with boulder clay washings was found leading up to an old sea-cliff at 150 feet in Fulwell Quarries. This type of evidence suggesting a higher sea level is extremely useful but as yet is not conclusive.

There is widespread flattening of the land surface around the mouth of the River Tyne at this same height, and the meandering streams in this area contrast markedly with the steeply falling rivers elsewhere within the county. The streams leave this flattish area of re-assorted drift by deeply entrenched courses to the sea. Anderson[3] has recognised numerous platforms and shelf features at 140 feet in the lower Tyne valley and elsewhere throughout the country, and believes the feature is too widespread to be associated with anything smaller than a sea level surface. The evidence which he has collected is extremely detailed, but it often consists of minute areas of land which appear to be more easily explicable if one supposes lateral corrasion by meandering streams flowing to a possibly higher base level than today. Not dissimilar areas of planation are also apparent at about 190 feet (Fig.14)

1. Woolacott, D. Proc. Univ. Durham Phil. Soc., Vol. 2, 1906, p. 243.
2. Howse, R. Old Sea-Caves and a Sea-Beach at Whitburn. Nat. Hist. Trans. Northumberland and Durham. Vol. 7, 1880, p. 361.
3. Anderson, W. Possible Late-Glacial Sea Levels at 190 and 140 feet O.D. in the British Isles. Geol. Mag. Vol. 76 1939, pp. 317-321.

Evidence for a Sea Level at 80 feet O.D.

One of the most interesting pieces of evidence suggesting a change of sea level along the Durham coast is on the flanks of Beacon Hill, immediately north of Easington Colliery, where a band of gravel reaching a maximum thickness of 15 feet extends over about 50 feet of the cliff face at 70 to 80 feet O.D. (Plate VII). This gravel has been critically examined by Woolacott, Lamplugh, Trechmann and Merrick and all agreed that it was a marine deposit, though they disagreed over its age. The gravels rest on a platform of Middle Limestone which has been bored by marine organisms, and contain bored pebbles. Both whole and broken marine shells have been found in the gravels which include water-worn pebbles of Cheviot andesites and most of the other constituents of the Durham boulder clay, showing that the deposits must be post-glacial or at the very earliest late-glacial. There is nothing in these deposits to show that the climate differed in any way from that of today.

The lower, shell-bearing gravels are often loose but frequently layers are calcreted, and the degree of calcretion increases upwards to a hard almost calcreted gravel overlain by partially calcreted boulder clay. The upper calcreted gravels contain fewer shells and bored rocks, and in this way are very similar to the calcreted drifts found at a similar height both to the north and south of Beacon Hill.

The exposures of calcreted gravel between Ryhope and Castle Eden Dene contain few marine shells,[1] but it seems possible that these may be connected with the Easington marine gravels. The finding of marine shells is not at all conclusive, as they have been found in gravelly portions of the Cheviot Drift at all heights up to 420 feet and two to four miles inland Woolacott was convinced that these calcreted gravels were marine, and attributed their absence from the Northumberland and Yorkshire coasts to the supposition that Northumberland was covered by ice when the beach was being formed in Durham and that there has been complete removal of the beach from Yorkshire by coastal erosion.

The occurrence of a fairly continuous band of gravel at about 20 feet below the cliff top may appear difficult to explain if one cannot accept it as a marine deposit, and it has been suggested that the gravels are comparable with those along the Northumberland coast which Smythe considered were fluvio-glacial deposits. This is unlikely, however, as the Durham gravels do not occur in the typical mounds and swellings of such deposits, nor are the beds sufficiently irregular. It seems more reasonable to suggest that the gravel band is associated with the sorting action of running waters which have washed away the finer particles from the boulder clay, leaving the pebbles and small stones to accumulate.

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1. Mr. D. Smith, H.M. Geological Survey, has recently found the first shells in these gravels, near Hawthorn Dene, 1955.

The relationship between the height of the water table and the position of the calcreted drift may be significant. There are many local instances in Durham of calcareous conglomerates being formed by the percolation of lime-charged water through gravelly portions of sea beaches, and it seems reasonable to suppose that such a process could occur when water flows over and through a gravelly calcareous glacial deposit.

The suggestion that calcreted gravel results from percolation of chemically charged water requires that there should be little development of this feature where there is a decrease in the amount of Magnesian Limestone present in the drift, and such is the case south of the River Tees estuary and north of the River Tyne. The relationship between this calcreted gravel band and the Durham Magnesian Limestone is indeed quite close.

Immediately south of the entrance to Hawthorn Dene a small dry valley leads out to the present sea cliff and the embouchure is at a similar height to the exposure of cal-creted gravel on the south side of Hawthorn Hive, in which some broken marine shells have been found. Presumably this small valley could have been carved by a stream whose base level was at the calcreted drift height. After recession of this higher lake/sea level, the stream became diverted slightly to the north, and cut the deep gorge of Hawthorn

Dene, which has remained the permanent channel of Hawthorn Burn. This suggests that the formation of the calcreted drift gravels preceded the development of the denes. Woolacott was in favour of this order of dating, as he was unable to find sufficient outcrops of calcreted drift along the dene sides to enable him to suggest that the higher sea level could have extended into those valleys.

Even Woolacott had to admit that there was a great difference between the gravels on Beacon Hill and those to the north and south,[1] but he ascribed this to differences of exposure to the waves. Woolacott believed that the calcreted layer sloped downwards from the north and assumed that it may have been a southern continuation of the marine sands and gravels at 150 feet around Cleadon and Fulwell Hills.[2] He considered it may have passed south to the 10-foot raised beach at Sewerby. Such evidence was used to support his contention that East Durham had been subject to post-glacial differential uplift and warping, but the writer has been unable to trace the supposed gradual reduction in the height of the raised gravels southwards along the Durham coast.

Sections of a strip of sand and gravel beginning immediately west of West Hartlepool and extending north for two miles at about 80 feet have been examined by Professor

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1. Woolacott, D. On an exposure of Sands and Gravels containing Marine Shells at Easington, Co. Durham. Geol. Mag. Vol. 57, 1920, pp. 307-311.

   Woolacott, D. On the 60-ft. Raised Beach at Easington, Co. Durham. Geol. Mag. Vol. 59, 1922, pp. 64-74.

2. Proc. Geol. Assoc. Vol. 24, 1913, pp. 87-107.

Fearnsides and W. Anderson, who considered it to be a typical beach deposit notched on boulder clay, with well-rounded boulders at the western edge, grading into sand at the eastern edge. These deposits may be equivalent to those of the Easington 'raised beach', in which case there can have been no differential movement between the two areas.

The development of the gravel band at about 80 feet assumes great significance when it is remembered that a large part of Boldon Flats occurs at about 75 feet, and this is covered by redeposited boulder clay (see Fig. 14). The upper prismatic clay derived from the stony boulder clay may be seen in brickfields around Sunderland and along the line of the 'Cleadon' Valley. Woolacott was convinced of the very strong connection between these clays and the Cleadon and Fulwell raised beaches, but much of the available evidence has been destroyed and until fresh exposures are found, it is not possible to determine whether in fact they were formed on a sea level surface.

Other Gravels

Trechmann[1] has described gravels at Blackhall Rocks at about 8 feet above high water mark as beach gravels. The exposure is one foot thick, extends over four feet and is strongly calcreted. It is about 30 feet below the rock top

1. Proc. Yorks. Geol. Soc. Vol. 28, 1952, pp. 164-179.

and this is overlain by some 30-40 feet of boulder clay. Trechmann supposes this remnant to have been washed down a fissure from the level of the rock surface and to be a remnant of a 40-foot raised beach. This gravel contains marine shells similar to those at Easington, but from what has been said above they cannot be used as conclusive evidence of sea level changes. Gravels in similar positions have been noted in the bay south of Chourdon Point though no shells were found.

It is unnecessary to demand a change of sea level to account for the presence of these gravels, as it is believed that the processes acting at present could in time lead to similar occurrences of gravel. Between Frenchman's Bay and Velvet Beds the cover of superficial deposits is thin and has been denuded from a large part of the cliff top, leaving the underlying limestone jutting out as a flat platform. After heavy falls of rain this flat surface is often covered by down-washed boulder clay and pebbles and if cracks or fissures exist in the limestone they are filled by this free superficial material, which falls as a heterogeneous mass of mud and stone. The fine material may be washed out of the fissure eventually, but the stones remain and become calcreted by the evaporation of percolating water. The height at which these gravels rest is completely arbitrary, and the exposure is necessarily limited both in space and in time, as their exposure is dependent upon coast erosion.

Marine shells are not indicative of marine conditions, as such shells have been found at all heights and in numerous gravels throughout East Durham. It is quite possible that these gravels, with included marine shells, were swept up from the North Sea by an advancing ice sheet and spread over the eastern part of the county. Denudation and weathering would have swept these shells into the rivers, and if the drainage became impounded into a glacial lake or glacial sea, the shells may well have been washed ashore by small waves to form a gravel with included marine shells. The types of shell found in such a deposit of re-assorted and washed up beach material may be out of all proportion to the size of the actual impounded water surface.

Can such reasoning be used to explain the presence of clays, gravels and re-assorted boulder clays at about 80 feet along some 15 miles of the Durham coast?

It has generally been accepted that Scandinavian ice formed an offshore barrier to British ice sheets during the Glacial Period, and there is evidence that it actually came up on to the Durham coast at some period. The formation of the 'Wear Lake' has been ascribed to the ponding of melt water from the Pennines by the combined barrier of the Magnesian Limestone escarpment and Cheviot ice covering the northern end of the Durham Permian country. Little is known of the relative rates of decay of this lobe of Cheviot ice and the Scandinavian ice, but the possibility of ice damming offshore should not be overlooked.

During an early stage of ice retreat, when the 'Wear Lake' was in course of formation, the Scandinavian ice may have been in juxtaposition with the Cheviot ice lobe except for a small area in the vicinity of Sunderland. Melt waters from both ice sheets could accumulate there and form a high-level lake, the surface of which may have remained at about 150 feet O.D. sufficiently long to enable the water to wash away the clay particles from the boulder clay, leaving the included stones as a gravel deposit. Continued recession of the Cheviot ice lobe was probably accompanied by the easterly retreat of the Scandinavian ice which allowed the pent-up water to escape to a somewhat larger lake, probably stretching south from the Cleadon Hills to the North Yorkshire coast. The waters may have found a level at about 80 feet O.D. during which time shore deposits were laid down, and the gravel band along the coast south of Sunderland may have been formed. Percolation and evaporation of lime laden water has resulted in calcretion of these pebbles into a hard mass of gravel. Continued easterly retreat of the Scandinavian ice allowed this 80-feet water level to fall as the water escaped southwards along the coast. Laminated clays at the mouth of the River Tees may also have been formed during this period of higher base level. The difference in the type of marginal deposit may be attributable to the different degrees of exposure to waves and winds of the open coast and the sheltered Tees Bay, but it may also be accounted for by considering the amount of coastal denudation which has occurred since the deposition of such deposits. The coast between Sunderland and Crimdon Dene has suffered much cliff top recession in historical times, and it is probable that the marginal deposits have now been almost completely removed. In the Tees Bay area the deposits have not experienced the same amount of denudation, and it is obvious that lateral variations should be expected in the coarseness and bedding of the marginal deposits.

During this period of generally impounded drainage in East Durham, melt water from the west of the county became locally impounded and cut itself an outlet between Tunstall and Newport Hills. The escaping waters may then have flowed into the impounded lake, or sea, off the east coast of Durham, at which point the load of the flowing stream was deposited in the form of a large gravel delta which now forms the gravel cliffs off Tunstall Hope. Alternatively, these deltaic-like deposits may result from seasonal variations in stream flow in the Tunstall overflow channel. The gravel workings immediately inland from the cliff edge at Tunstall show the following general sequence of deposits:

1. Up to 12 feet of bedded beach-like sands and gravels containing fragments of Littorina and Cyprina.

2. Sandy laminated clay locally developed to two feet.

3. Contorted clays.

4. Coarse boulders of limestone as noted on the coast.

Following the easterly retreat of the Scandinavian ice, the waters of the East Durham lake escaped and the rivers were greatly rejuvenated. The recession in the level of the sea or local base level was sufficiently great to allow the rivers to cut their valleys to depths of at least 90 feet below O.D. some distance from the present coastline; and, allowing for the subsequent decrease in length of the rivers as a result of more recent marine denudation, the sea level may have been as much as 150 feet below O.D. The gradual rise of sea level as the ice melted resulted in a considerable reduction in the downcutting power of the streams, and sediments accumulated in the lower reaches of the valleys. These deposits consisted largely of gravel and sands up to about -60 feet O.D., and grey sands and silts up to about -16 feet O.D. During the succeeding period of still-stand, peats accumulated a few feet below O.D. to a thickness of about 6 feet.[1]

Peat Beds

The size of exposures varies from time to time, but there are two quite considerable areas where peats may be seen occasionally, one in Whitburn Bay and the other near Hartlepool. The exposure of peat in Whitburn Bay appears to

1. See Barrow, G. The Geology of North Cleveland. Mem. Geol. Surv. 1888, p. 71.

extend for about one mile northwards from where the Concretionary Limestone dips down beneath the sands north of Roker to where that rock rises again on the north side of the bay. The exposure is often seen at the mouth of Cut Throat Dene near the centre of Whitburn Sands, where oak tree stumps are found in situ below or near high water mark. The peat exposures are patchy, rest on boulder clay, and sometimes contain the antlers of Red Deer as well as numerous rodent-chewed hazel nuts.

Exposures of peat have been found over a distance of about three miles extending N.W.-S.E. to the north of Long Scar.[1] In 1936 a two-foot thick continuation of this 'Forest Bed' was found beneath eight feet of shore deposits to the north of Hartlepool. No exposure of peat has been found south of Long Scar, but this may result from the thick accumulation of blown sand. Some of the better exposures have revealed up to eight feet of peat resting on a boulder clay, which is compacted and contains striated erratic boulders from Northumberland. Finds of mollusca within the deposits of peat suggest very damp conditions with a climate somewhat warmer than that of today, and these peats are probably of 'Atlantic' age (6000-7000 B.C.). Remains of Mammoth, Red Deer, Irish Elk and the Bos longifrons have all been found beneath the peat in blue clay. Though Woolacott[2]

1. Trechmann, C.T. The Submerged Forest Beds of the Durham Coast. Proc. Yorks. Geol. Soc. Vol. 27, 1947-49, pp. 23-32.

2. Woolacott, D. The Interglacial Problem. Geol. Mag. Vol. 58. 1921, p. 66.

has suggested that their present relation to sea level may have resulted from the settling down of the superficial deposits in the valleys in which they occur, it is now generally accepted that the peats are indicative of base level changes. Inundation of these peat and forest beds occurred during a rise of sea level to about 30 feet O.D., which is now represented by both erosional and depositional marine features.[1] Inundation was both intermittent and irregular and marine silts alternate with peat beds and thin soils which supported tree growth.

The intermittent character of the inundation is shown by the following sequence of deposits in the valley of the 'Tyne'.

Soil
Yellow Clay (weathers into short columns)
Brown Clay (stiff, with boulders)
Loam Sand
Common Clay (roughly bedded boulder clay)
Leafy Clay
Black Clay
Leafy Blue Clay
Boulder Clay
Sand

The alternation of sand, silt, gravel and clay is a strongly developed feature, but the bands are at very differing heights (Figs. 15 and 16). The leafy clays may be associated with estuarine conditions of the raised beach period, though they are usually considered as glacier lake deposits.

1. Agar. R. The Glacial and Post-Glacial Geology of Middlesbrough and the Tees Valley. Proc. Yorks. Geol. Soc. Vol. 29, 1953, pp. 237-253.

The Rivers of East Durham

The effects of base level changes should be apparent in the profiles of the present coastal streams, and this interesting topic has been fully investigated by Mr. Hopkinson. It is not possible to treat this subject adequately without seriously encroaching upon his studies, and this has been avoided. The following remarks are suggestions, therefore, rather than conclusions based on a detailed analysis of field observations.

Before the onset of the last Glacial Period there was well-established west to east drainage in East Durham down the dip slope of the East Durham Plateau, and the cross profiles of these early valleys may be seen in the sea cliffs of today. During the Ice Age there was a considerable scouring of the limestone plateau surface, but deposition was probably of greater significance than glacial erosion, and the pre-glacial valleys were filled with boulder clay.

Upon the retreat of the ice sheets melt water accumulated in small depressions and pockets in the uneven clay surface. These small depressions eventually overflowed and post-glacial streams developed. Depressions were more likely to develop on thick drift where included pieces of ice melted, than on areas of thin drift, and the post-glacial streams tended to flow along the drift-filled courses of the old valleys in the first instance, resulting in superimposition of drainage. As the volume of water increased by continued melting, the streams cut through the boulder clay and into the underlying fissured and fractured limestone and gorges were initiated which have maintained their positions throughout the post-glacial period (Fig. 17).

The streams in these deeply incised coastal valleys fall three or four hundred feet to the sea coast in the course of a few miles, and often have average gradients as high as 70 feet per mile (see Fig. 18). An ideal dene has four parts: (1) an upper area of headwaters flowing on boulder clay in meandering valleys towards (2) an upper flood plain upstream of (3) a gorge section cut through limestone, which opens out lower down the valley to (4) the main flood plain. The development of these four parts varies from dene to dene, but there is always a tendency for them to be present. In Castle Eden Dene both the upper and lower flood plains have a width of 100 to 200 feet, and in these sections the stream has a gradient of about 8 in 1,000. Throughout the intervening limestone gorge the river has a gradient of about 12 in 1,000, making an 'average' gradient of 13 in 1,000 for the whole of the burn. Tributaries of the main consequent streams seldom have flood plains developed along their courses and their average gradient is often as great as 32 in 1,000, or 170 feet per mile(see Fig. 19).

Swiftly flowing streams can readily undermine the river banks and lessen the stability of clay valley sides, and slumping and sliding occurs (Fig. 20). The stability of the clay slopes in Castle Eden Dene is of great interest to the Peterlee Development Corporation, and a study has been made by Skempton.[1]

The denes are best developed between Ryhope and Crimdon Dene. South of Crimdon Dene the height of the land surface falls towards the lowlands of the River Tees estuary, and the limestone becomes buried under a thick cover of superficial deposits. Under such conditions it has been impossible for typical denes to develop, as they depend essentially upon a steep fall from a source some 300 to 400 feet above sea level and a limestone bed rock.

North of Ryhope the decreasing width of the Permian Magnesian Limestone outcrop and the associated diminishing size of the catchment area of the streams has resulted in an inadequate volume of water to cut the denes down to sea level. There are two small dene-forms north of Ryhope which cut the rock to a depth of about 10 feet and form small hanging valleys and waterfalls fifteen to twenty feet high on the shore. Both are used as pathways and sewer courses, and must be considered as representing an intermediate stage between the deep gorges to the south and the coast between

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1. Skempton, A.W. Final Report on the Geological and Engineering Problems associated with the Denes at Peterlee. 1949.

Sunderland and the River Tyne to the north where there are no rocky gorges, except for the small ravine at Roker Park. The former waters in the more southerly of these two partially developed denes drained through the present dry valley of Tunstall Hope, and it is apparent that the water supply failed before it could be cut deeper.

Castle Eden Burn has been accurately levelled over its lower six miles (Fig. 18), and the profile shows breaks of slope along the stream which cannot be correlated with geological horizons. Having earlier considered the significance of marine-like features at 80 feet, 150 feet and 190 feet, it is interesting to note that a small nick point occurs at 85 feet, and small waterfalls at 150 feet and 190 feet. Similar features have been observed in some of the tributaries flowing to Greatham Creek, which were levelled by the writer during the winter of 1954-55, and it will be interesting to know if Mr. Hopkinson has found these features to be typical of all the East Durham rivers.

The writer has also found that river terraces are quite common towards the mouths of some of the denes, especially Dawdon and Ryhope Dene, and whilst some of these are about 15 to 20 feet above the present flood plain, there are occasional high level terraces about 80 feet above that level.

There is considerable and varied evidence that the base level of the rivers of East Durham has not remained steady since the Glacial Period, and erosional and depositional features at many heights have been attributed to marine conditions. It is suggested that insufficient importance has been attached to the effects of ice ponding during the retreat stages.

The occurrence of rounded gravels at about 80 feet along the present cliff-line, together with marine shells and nick-points, may be considered sufficient evidence to prove a former base level at that height, but many of these suggestive features have alternative explanations. The evidence for sea levels at 150 and 190 feet O.D. is even less conclusive and the subject could well be investigated anew. The effects of a lower base level are clearly seen in the forms of the deeply entrenched river valleys and the 'submerged forests'.

In conclusion, it is apparent that there are many controversial problems concerning the late-glacial and post-glacial evolution of the Durham coastline, and it seems clear that they cannot be satisfactorily solved until additional evidence becomes available.

Chapter 5. The Development and Movement of Beach Material

Beach material largely results from cliff denudation and its abundance is closely associated with the rate of coastal erosion. Lithology, structure and exposure all help to determine the rate at which the cliff line recedes under marine attack, and very differing rates are recorded in Co. Durham.

The Durham Cliffs

Much of the coast is capped by superficial deposits which offer little resistance to denudation, and cliff-top recession is almost continuous (Plate VIII). Where pre-glacial valleys cut through to the present coastline, the cliffs consist almost entirely of such unresistant deposits, and erosion is rapid (Plates IX and X). Along the greater part of the Durham coast, however, the cliff foot is formed of more resistant limestone, which considerably affects the denudation of the overlying glacial material. Where the limestone outcrop is present to a height of more than a few feet above high water mark, the development of the overlying clay is largely dependent upon its cohesion (Plate XI).

Although the Durham Magnesian Limestone was not greatly affected by the faulting and folding which disturbed the underlying Coal Measures, it has nevertheless a well-developed series of joints and bedding planes, which have affected the development of the main trends of the promontories and bays along the coast, as well as the fashioning of details. The presence of E-W fractures has frequently permitted the sea to cut deep gullies in the cliffs, and these have often been widened to form caverns and caves leading inland from the cliff face. It is often possible to detect a direct continuation of these fractures through the caves, across the foreshore rock and beside the headlands, suggesting that the forms of the headlands themselves have been structurally guided to some degree. Usually the E-W fracturing is associated with fractures running N-S, and the headlands tend to be broken into squarish blocks as erosion proceeds along these lines of weakness (Plate XII). The seaward ends of the headlands are subsequently cut off by a complete breakthrough by the sea, resulting in the formation of smallish stacks.

In addition to structural weakness, the limestone shows extreme lithological variability, and extraordinarily diverse erosional forms result.

"Where hard and soft, crystalline and earthy, calcareous rock are co-mingled in a kind of omniform mosaic, it is not surprising to find caverns, ravines, stacks, promontories of all kinds to be the rule, and all such features are imminently characteristic of the coast of Durham."[1]

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1. Lebour, G.A. Geology Section, in Victoria County History (Durham), 1905.

Chemical erosion of the limestone is not unimportant. Frequently the water draining from the cliffs is so charged with carbonate of lime that tufa is deposited on the cliffs, and powdered carbonate is left on the beach sands after the water has percolated through and beneath the surface. This direct loss of material in solution results in a serious decrease in the cohesion of the rock, so that mechanical disintegration is easier. Indeed, mechanical destruction of the cliffs is most important, and at the appropriate seasons splitting and disintegration caused by extremes of temperature can be seen and heard.

It is generally unwise to make any broad generalisations when dealing with such a varying rock mass as the Durham Magnesian Limestone, but it seems fairly clear that there is a very close connection between the positions of resistant headlands and the brecciation which has occurred. In almost all cases along this coast the headlands are formed of hard breccia (Plate XIII), which has offered greater resistance to erosion than has the unbrecciated limestone and soft white lime silts and sands which have been eroded to form bays.

Where the limestone has been brecciated a number of times, as at Seaham Harbour (where the rock has suffered slump, fault and internal brecciation), the rock has become especially resistant to erosion.

One of the few places along the Durham coast where the promontory is not composed of brecciated limestone occurs to the south of Hendon, at Salterfen Point, where the headland has a base of well-bedded, yellow limestone which resists the action of the sea quite strongly (Plate XIV).

South of the sand hills filling the old valley of the 'Tyne' there are exposures of bedded breccia extending from Trow Point in the north to beyond Marsden Point (Fig. 21). The brecciated Middle Limestones are separated from the folded and fractured Lower Bedded Limestones by an intervening thin band of mylonised rock, which led Woolacott to suggest that there had been horizontal thrusting along the junction. This rather softer band has been notched by the sea and forms a distinctive feature of the cliffs around Frenchman's Bay (Plate XV). The higher parts of the Lower Limestone have often become veined by calcite and brecciated, and tend to merge into the Middle Limestone where the intervening mylonite rock is not developed. Frenchman's Bay itself has been developed in a fractured and fissured anticline, which offered special opportunities for attacking waves. The Lower Limestone dips beneath sea level some way north of Man Haven, and almost the complete cliff face is of Concretionary Limestone.

Near Marsden Bay, the grey, cellular, amorphous masses of irregular concretionary structure and many knotty protuberances are gradually replaced by beds of yellow-brown limestone with slaty and finely foliated structure. The foliations often alternate with soft earthy laminae, giving the weathered rock a grooved appearance. Brecciation occurs at intervals in the gently undulating beds, and south of the Grotto the flexible limestone has in many places been broken up and joined into a dolomitic paste. At the northern end of the bay the breccias are often found in the form of V-shaped gashes. Towards the southern end of the bay the brecciated structure is no longer visible and the cliffs are formed of foliated, slaty, cellular and earthy beds alternating with thick compacted grey beds.

Between Marsden and Whitburn occur the concretionary forms of limestone so well described by Sedgwick. The fairly low cliffs consist for the most part of slaty beds passing into and alternating with irregular masses of great and small concretions.

South of Whitburn Village the whole cliff is composed of concretions, which are replaced by a regularly bedded yellowish-white limestone of earthy texture on the south side of the 'Fulwell Valley'.

South of the clay cliffs at Hendon, the cliffs are quite broken, and consist of bedded breccias. A synclinal structure results in the low cliff line at Nanny Rains' Springs, and a low-angled reverse fault north of Salterfen Point has brought the Middle Limestone over Concretionary Upper Limestone.

South of Salterfen Point there are some well-developed stacks, of which Jane Jiveson's Rock is the most remarkable. This stack consists of Middle Limestone breccia hardened by impregnation with chert. Collapse of the surrounding soft, bedded, dolomitic rock has resulted in slickensided planes on both faces of the dyke-like mass. There is no apparent cause for this local alteration and segregation. Calcification and silification begin along joints in the massive Middle Dolomite and in the space of a few yards the calcareous layers and ribs become thicker and replace the dolomite.

Seaham Harbour has been artificially cut in multiple-brecciated limestone, and south of the harbour the cliffs are of fractured cellular limestone. The metasomatic segregation producing the cellular breccia affects especially the bedded Middle Limestone on the flanks of the Reef. Bedded breccias occur along almost the whole of the coast between Hendon and Hawthorn Dene.

At Chourdon Point is a small anticline of brown, bedded dolomite overlain by the more typical Middle Cellular breccia which Trechmann has shown to be a bedded extension of the Shell Reef. On either side of the anticline the fossiliferous rock tends to develop calcarous veins and merges into the overlying calcareous breccia with powdery dolomite.

Between Castle Eden Dene and Crimdon Dene the structure is complicated, with brecciated beds and globular concretions alternating and passing into each other. The contortions are violent, and the breccias are subordinate to the regular brown, slaty or foliated beds associated with cellular, amorphous, concretionary masses. At Blackhall Rocks the cliffs consist of inter-bedded conglomerates of Reef Limestone with small-grained crystalline dolomitic layers around them. The mass is probably a reef talus rounded by wave action on the eastern side of the reef.

On the eastern side of Hartlepool promontory are several beds of perfectly oolitic, concretionary structure associated with hard, cellular, concretionary and earthy beds. The spherules are partly hollow and of earthy texture. The earthy beds are easily washed out of the rock surface, giving the weathered rock a honeycombed appearance. Large globular 'cannon-ball' concretions are often present at Hartlepool and are associated with the laminated limestone.

The Present Disposition of Beach Material

The eroded cliff material in Durham falls either as rock fragments or pebbles and clay, so that the foreshores are of very variable consistencies. The present disposition of beach material is represented diagrammatically in Fig. 22(C), in which measurements of the distances in feet between the cliff foot and high water mark and low water mark at each of the northing grid lines on the O.S. 1 : 25,000 maps have been plotted.

The well-developed beach south of South Shields at 567N. peters out between Trow Point and Velvet Beds, where the cliffs are hard and rocky, but is again developed in Marsden Bay at 565N. Immediately south of Lizard Point the development is less, but from thence south to Sunderland Harbour the beach becomes progressively wider and better developed. The Roker Pier retains drifting beach material and helps to build up the beach.

Between Sunderland and Seaham Harbour the tidal beach is not overdeveloped, and there is little upper beach between high water mark and the cliff foot. The cliff line therefore very liable to marine denudation.

South of Seaham Harbour the tidal beach is narrow, though bay head beaches occasionally introduce broader areas into the graphs. These alternate with rocky headlands where the sea comes up to the cliff foot at every high tide. Such conditions extend south to about Blackhall Rocks, whence the foreshore gradually increases to a maximum width north of Hartlepool Headland. But throughout almost the whole of this stretch of coast there is a fairly broad upper beach protecting the cliffs from direct marine attack.

South of Hartlepool Harbour the foreshore is broad, and high water mark does not reach the foot of the low sand hills.

Although there are no major shingle banks along the Durham coast, there is a quite considerable accumulation of sand and shingle immediately north of Souter Point, which has been built up into such a wide platform that the sea cliffs are no longer attacked by even the greatest storm waves (Plate XVI). Much of the shingle is above H.W.M.O.S.T. (Fig. 23), and this has led to the belief that there has been a change of sea level. There are many real objections to such an explanation.[1] If this area of shingle has really resulted from a change of sea level and is, in fact, a raised beach, there should be other areas of shingle representative of this former higher sea level. Examination of the Durham coast has revealed none.

It may be argued that one should not expect to find more than very limited traces of a higher sea level along a coast which is being eroded at the rate of ten feet per annum. This view must be accepted, but, on the other hand, it seems unwise and unsafe to deduce widespread sea level changes from the merest patch of evidence. If additional similar evidence can be found stretching at intervals along a considerable stretch of coast, then the case for sea level change becomes stronger.

There seems to be a more simple explanation of the shingle area at Souter Point, which does not demand anything more than local change.

A survey of the Souter Point shingle bank shows two features which may supply the key to the problem. Immediately to the north of the bay is a small headland with some offshore stacks, now but little above high water. At very low tides it is possible to detect across the foreshore the continuation of the headland out to these stacks and further beyond. It is therefore almost certain that the present

1. Ting has found storm gravels up to 30 feet above sea level and warns against accepting patches of high shingle as evidence of sea level changes. Beach Ridges of the S.W. Jura. Scot. Geog. Mag. 1936, pp. 182-187.

headland bounding this small bay to the north once extended considerably further to the east. Similarly, the headland of Souter Point probably once extended further eastwards.

Initially, the coast may have been fairly straight in this area. Erosion would proceed at a greater rate in the soft white limestone than in the harder breccias and a small bay would be formed. Eventually a balance would be attained between the erosion of the harder, resistant but exposed brecciated headlands and the softer but more protected lime silts.

When the temporary state of balance had been attained, it is probable that although storm waves dashed against the headlands with increased force their greatest effect was to throw shingle up upon the well-sheltered bay head beach at elevations well above normal high water.

Meanwhile, the headlands had been ceaselessly attacked by the waves and were broken through, the more exposed northern headland being eroded more speedily. Once the protecting headlands had been broken, the bay was exposed to more severe wave attack, from a new angle, and the bay head beach became adjusted to meet the changed conditions.

The breaking of the northern headland at Souter Point need not have been of great antiquity, as the rate of erosion of the headlands, once they have become partially breached, is very rapid.

Whilst no accurate measurements are available to prove it, it appears that the beach of shingle at Souter Point is now being eroded by the sea, and it is quite likely that within a few years most of the shingle will have been washed away, and the sea cliffs once again subjected to wave attack. Before this can be so, however, further erosion of Souter Point must occur to reduce the groyne-like effect of this long low headland projecting eastwards, which holds up the southerly drift of beach material. That this effect is not negligible is shown by the lack of beach material south of the point and the resulting severe erosion of the cliffs there.

This seems to be an adequate, logical explanation of a perfectly natural coastal feature, which no doubt has many counterparts elsewhere.

In the words of Professor Steers,[1] "it is in the everyday events of coastal evolution that we can trace some of the great changes in parts of our coast".

A further bank of shingle occurs immediately south of Nose's Point, and consists largely of shales and sandstones derived from Dawdon Colliery. Many thousands of tons of Coal Measure rocks have been added to the naturally occurring beach material, and the resulting super-abundance of material for the waves to work on has led to the throwing up of a

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1. Steers, J.A. The Coastline of England and Wales, 2nd Edition, 1948, p. 1.

huge bank of rubble in front of the cliffs, which has restricted cliff recession to the effects of sub-aerial weathering. Similar conditions exist at almost every place where collieries are depositing their waste material into the sea, but more will be said of this later.

A third shingle area exists at the mouth of Castle Eden Dene, where the accumulation of beach material consists of a mixture of normal beach shingle and colliery waste derived from Horden Colliery to the north and Blackhall Colliery to the south. Again the abundance of beach material has allowed the waves to construct a bank of shingle so large that the sea cliffs are now safe from wave attack.

The general coastal trend is NNW-SSE in its northern section, and from NW-SE in the south, i.e. almost at right angles to the direction of maximum fetch (Fig. 24). The maximum development of shingle embankments is perpendicular to the direction of the largest waves, though this is not necessarily the direction of the dominant wind, as inshore and coastal irregularities produce local complications.

The relationship between beach development and exposure is indicated in Fig. 22. In the construction of A (The Orientation of Beaches) mid-point normals have been drawn to lines representing the mean directions of the cliff foot between successive national grid northing lines. The orientations of the normals from grid north are indicated.

The plotted normals show quite clearly the gradual curve of the coast from Tynemouth towards Seaburn, by way of Lizard Point and Souter Point, broken only by the broad bay formed as a result of the relatively rapid erosion of the rocks between Velvet Beds and Lizard Point.

With the exceptioh of the beach immediately south of Sunderland Harbour and south of Shippersea Point, the coast between Hendon and Blackhall Rocks faces the north-easterly winds, and south from Blackhall Rocks the coast curves to face those winds even more squarely. Immediately south of Hartlepool Headland is a lee shore, but from Seaton Carew southwards the normals are again approximately SW-NE.

Part (B), Fig. 22, indicates the exposure of the Durham coast to the generally dominant winds from N.30°E. An exposure of 0° indicates that the shore is parallel to the dominant winds, and one of 90° indicates that the shore is perpendicular to that direction. Where the exposure rating is to the left of the 0° line the beach is a lee shore. From this diagram of exposure ratings, the sheltering effects of Marsden and Whitburn Bays are clearly seen and put in perspective, and the gradual variation in the direction of the coastal trend is apparent, until a maximum exposure is recorded at Hartlepool Headland. The lee shore immediately to the south quickly gives way still further south to a shore with 45° exposure.

<u>The Movement of Foreshore Material</u>

Local conditions of wind, wave and tide determine the direction and speed of beach drifting. Along the Durham coast the 'normal' direction of movement of beach material is from north to south, as would be expected with dominant north-east winds.

The extreme diversity of beach material makes the choice of a distinctive indicator rock for beach drifting experiments difficult. Field trials carried out with broken bricks suggest that obtaining distinctive rocks from outside sources for use as indicators would not necessarily be successful, as the rate of 'loss' of marked beach material to the waves is quite considerable.

The use of radio-active methods to mark and locate indicator rocks was not practicable for several reasons. It was considered undesirable that radio-active rocks be present on well-frequented beaches, and the problem of geiger-counter location was not small. The range of the instrument would necessarily be seriously limited, owing to the small charge of material which could be inserted into the rocks to ensure reasonable safety against accidental contamination, and the difficulty of penetrating beach material thrown above the marked pebble. But leaving aside all the problems of location and safety, there remains the fundamental problem of the risk that all the marked pebbles may well be washed out to sea after only a few waves, and become lost for all practicable purposes.[1]

During the brief time that marked material was visible on the Blackhall beach the lateral movement was extremely rapid, and even with waves approaching normally to the beach the movement was in the order of twenty yards in ten minutes. Movement during periods of north-easterly winds and waves was often five yards per wave.

Many types of beach material have been marked and the differing rates of movement noted. The Coal Measure shales have a lower specific gravity than has Magnesian Limestone, but the flat shale pebbles travel more slowly along the beach, showing that in this instance the shape is of more consequence than the density in affecting the rate of beach drifting. The slow lateral movement of the shale seems to result from the lack of movement during the backwash, as a consequence of its inability to roll down the beach under its own weight.

The occurrence of Coal Measure material on the beaches at Horden and Blackhall Collieries prompted a further series of observations. Iron pyrites is occasionally met with in the Horden Colliery workings, and this exceedingly dense material tends to accumulate in a distinctive band to the south of the colliery dump. As this beach material was derived from a point-source, it seemed to offer an opportunity for studying the beach drifting of heavy minerals.

1. This method of study was later used by D.S.I.R. in experiments to determine the movement of mud banks in the Thames estuary. It is also being used by The Nature Conservancy to trace the movement of beach material at Scolt Head Island, Norfolk.

A number of sand samples were analysed by grain size and by heavy mineral content, but before a sufficiently long series of samples had been taken a second source of pyrites was uncovered at Blackhall Colliery. The local favourable conditions for this type of work were thereby lost.

Samples taken from the pyrites band south of Horden Colliery stone dump showed that 80% of the beach material was heavy mineral. It is interesting to note that during the 1939-45 war attempts were made to crush such pyrites at the colliery pit-head before transporting it to Billingham for use in sulphuric acid manufacture. The percentage of pyrites was only about 35%.

The presence of such heavy minerals affected the form of the beach profiles, as it was found repeatedly that pyrites was deposited as a flat-topped bank bounded by slopes of quartz sand.

The rapid break-up of Coal Measure beach material is an important characteristic, because the continued movement of such grimy and oily material southwards from Easington, Horden and Blackhall Collieries towards the Yorkshire coast would have constituted a serious problem for sea-bathers and holiday-makers. A few observations at Blackhall showed that the Coal Measure shales and coals were abraded far more speedily than the sandstones and Magnesian Limestone. Coal tends to become rounded by the sea, and perfect spheres are not difficult to find (Fig. 25). The coal is progressively worn away by the grinding action of quartz sands and pebbles and is usually too small to be detected as far south as Crimdon Dene mouth. During northerly gales, however, coals are swept up on to the north sands at Hartlepool and at Seaton Carew.

The break-up of coal shales is very different from that of coal. As a result of well-developed bedding planes, coal shales are easily split into flattish slabs, and these are broken into even smaller flattish plates by the waves. Repeated breaking seems to be of greater significance than ordinary abrasion, and the shales are less persistent along the beaches to the south than are the pebbles of coal.

The Magnesian Limestones and Carboniferous Sandstones appear to become progressively more rounded and smaller by repeated grinding and wearing in the same manner as do the coals (Fig. 25), but, being more resistant, are found persisting further to the south along the coast.

The Relationship between Wind and Wave Incidence and Beach Changes

In order to determine the degree of correspondence between weather conditions and beach changes along the Durham coast a number of beach profiles have been repeatedly surveyed and compared with the appropriate wind and wave conditions.[1] The resulting evidence tends to support the conclusion that offshore winds assist constructive waves

1. See Introduction for details of methods of work adopted.

to build up beaches, whereas onshore winds assist destructive waves to comb them down, though the evidence is not, in itself, conclusive.

Field estimates of wind directions and strengths prevailing at the time of profile measurements have been compared with the anemometer recordings of Tynemouth Weather Station and found to be satisfactory. The anemometer at Tynemouth is not ideally situated as it records a 'funnelling' of winds along the Tyne Corridor and is sited too close to the roof of the Coastguard Station to record north winds accurately. Nevertheless, it does provide a good record of wind conditions over the past few years, and the wind statistics have been plotted in a number of ways (Figs. 26-31 inclusive). A summary of the onshore and offshore winds is shown in Fig. 32. The records show that gales are mostly from the west, though there is a considerable number from the north-east in winter and spring.

Observations of wave height and wave frequency were made whenever beach profiles were surveyed. The direction of approach of waves offshore, the direction of movement of beach material, and the general nature of the waves were recorded.

Beach drifting cannot be attributed to tidal currents. Although they flow as much as five knots at certain states of the tide off the Durham coast, they are usually much slower and incapable of moving much material unless it has been thrown into suspension by wave action. The tidal current flows south near the time of high water, and north near low water, so that the greater part of the foreshore comes under the influence of south-flowing tidal currents. The average rise of spring tides along the open coast is 14-15 feet, and of neaps 6-8 feet. WNW-ENE winds cause the highest tides and check the ebb, whereas SSE-SSW winds depress high water and produce the maximum ebbs.

Abundant beach material protects the cliffs between Horden and Blackhall Collieries from marine denudation (Fig. 33). The profiles of these cliffs have been softened by slumping and slipping of the overlying superficial deposits, but the fallen material is not removed by the sea, so that little of the foreshore material is derived from the denudation of the local cliffs. Rock outcrops are not numerous along this beach, and very little land water comes from the small gills opening on to the beach. The beach is fully exposed to the north-east winds, and is well situated to show the different effects of dominant onshore and prevailing offshore winds.

Ideally, beach observations should be taken at every low tide, but several series of daily observations over periods of a week to ten days have been taken. Often profiles have been measured less frequently, but they are valuable nevertheless. From these profiles it is possible to detect accurately the changes in the surface level of the beach, and the superimposition of two successive beach profiles allows the amount of change accomplished by waves to be recorded.

At the end of January 1953 the Durham coast was subjected to severe pounding from storm waves, which completely altered the appearance and profile of the beaches. The gradual development of the 'post-storm' profile towards the 'pre-storm' profile has been of overriding importance in the recent evolution of this particular coastline.

The essential effects of that storm may be seen clearly in Fig. 34, by comparing the profiles recorded on 31st January and 3rd February 1953. The height of the beach at the cliff foot was increased 12 to 18 inches by an accumulation of quite fine sands, which have later settled down and compacted to expose boulders of Coal Measure shales and sandstones and Magnesian Limestone. This sandy zone was quite flat, and ended seawards in an abrupt slope of coarser sand and fine shingle which had been scooped out by the waves, in some instances as much as 3 ft. 6 ins. below the 'pre-storm' profile. The scooped-out beach material was deposited on the lower part of the beach profile and the storm had the effect of redistributing the beach material rather than increasing or decreasing its abundance. Since February 1953, the hollowed central area in the profile has been progressively filled in, though not without temporary setbacks when material has been swept away by destructive waves. Even after a full year the upper beach had not fully recovered its former height.

Planimetric measurements of differences between successive beach profiles have revealed little clear connection between wind and wave incidence and beach changes. During a period of thirty-six observations there were only eight occasions when a gain in the upper beach was accompanied by a loss in the lower beach, or vice versa (Fig. 35(A)). On six of those occasions, a period of offshore winds had coincided with a loss in the upper beach and a gain in the lower beach, and on one occasion offshore winds coincided with a gain in the upper beach and a loss in the lower beach. On the only other occasion of any well-marked change in the mean slope of the whole beach onshore winds had coincided with a gain in the upper beach and a loss in the lower beach. On only five occasions were the volumetric changes in the upper and lower beach of equal size and opposite sign.

Immediately south of Horden Colliery stone dump major changes in the beach profiles can be attributed to the great storm. The whole of the upper beach was cut away by as much as three feet in some places and by at least 1½ feet almost everywhere above mean water level (Fig. 36). Immediately below that level there had been some slight building up of beach material, but this was of limited seaward extent, and the lower beach had suffered serious erosion. Throughout the succeeding year the beach gradually accumulated again, and rocks at about low water mark ceased to protrude through the sands.

About one-third of the profile observations showed a gain in the upper beach accompanied by a loss in the lower beach, or vice versa, but there was no apparent connection between winds and beach changes. During a period of onshore winds the down combing of the beach was most noticeable. (Fig. 35).

Between Horden Colliery stone dump and the centre of the bay at Castle Eden Dene mouth, the abundance of beach material results in a very flat lower beach profile, and in nearly half the profiles recorded a redistribution of material between upper and lower beaches was noted (see Figs. 35 and 37).

Further south towards the centre of the bay, redistribution of material between upper and lower beaches occurred in two-thirds of the recorded profiles, but on the only occasion of onshore winds there was great accumulation of beach material (see Figs. 35 and 38).

The field evidence shows that the relationship between wind direction and beach changes is not a simple one and is by no means close.

A comparison of beach changes and wave type yields more positive results. On each occasion that high frequency waves were observed, down combing of the whole stretch of beach occurred, being greater towards Blackhall Colliery when beach movement was northwards, and greater at Horden Colliery when movement was from the north.

Towards the south of the county, the promontory of Hartlepool delays the southerly movement of beach and off-shore material, and gently sloping sandy foreshores are characteristic.

Between 5th May and 25th May, 1954, sixteen profiles were surveyed near Crimdon Dene mouth, covering a period of two spring tides and two neap tides (Fig. 39). During the early part of the month strong westerly winds prevailed, and much sand was blown from the upper beach. Some of this material seems to have been thrown up by the advancing sea into a small sand bank at about mean tide level, and this persisted until the wind direction changed. After backing from west to north, the wind blew steadily from the north, and there was a great accumulation of blown sand on the upper beach and in front of the sand dunes. A considerable sand ridge was developed at high water mark, and this was pushed more and more landwards as the tides increased in height and the northerly winds persisted.

It may be seen from Fig. 35 that onshore winds prevailed throughout almost the whole of the period of profile measurements. On each occasion of vertical redistribution of beach material the waves were the dominant factor, and wave type was always of more significance in fashioning beach details than was wind direction.

Along the Durham coast generally, a combination of large waves from north-east and onshore winds brought about the greatest beach changes. Such winds are more common in Spring than at any other period of the year, and consequently greatest longshore drifting should be expected between April and May.

<u>Summary</u>

The Durham coast is exposed to the dominant north-east waves along almost its whole length, and cliff denudation is often rapid. Very little of the cliff line is protected from direct marine attack by rock platforms, and there are few rocks close inshore (Fig. 40). In the south of the county the rock has been covered by sand and fine shingle, but towards the north, where beach material is less plentiful, rocky ledges are more noticeable on the foreshores. Geological structure is an important consideration, and the relationship between structure and coastal morphology is often exceedingly close. The directions and forms of many brecciated headlands are structurally guided, and intervening bays of lime silts and sands often contain smaller bays eroded in anticlinal structures.

The almost universal slope-over-wall cliff profile results from the presence of superficial deposits above the Magnesian Limestone, and these add to the complexity of the beach material. As a result of its character, the fallen cliff material is speedily broken up by the incessant pounding experienced on the foreshore, and spreads of naturally formed gravel are very limited in extent. Fine shingle and sand is more widely found on the beaches, though gravels resulting from the dumping of colliery waste are quite common in the south of the county.

The foreshore material is moved great distances during northerly storms, but observations have tended to show that the slow net southerly movement results from more tranquil conditions. Changes in foreshore gradients appear to be more closely connected with wave type than wind or wave direction, and this is in accordance with expectations.

The significance of the natural groynes formed by the Cleveland Hills and Hartlepool Peninsula in the development of the Durham coast cannot be over-emphasised. With a net southerly drift of beach material, these two features have encouraged the accumulation of abundant material in South-East Durham, which has been built up into sand bars and sand dunes and has completely buried the former mouth of the River Tees to the north of

Hartlepool. The tendency is for the amount of beach material to increase southwards, with local exceptions, and this is consistent with gradual erosion in North Durham and steady accretion in the south.

PART II

THE INFLUENCE OF HUMAN ACTIVITY

The coastline of an industrial area rarely escapes being spoiled by Man, and Durham is no exception. The presence of a coalfield extending almost completely across the county and under the sea has brought great prosperity, but it has also led to the almost complete spoiling of a great deal of the countryside in East Durham, and has ruined some of the finest beaches in the North of England. The basic reason for the spoiling of the Durham coast is the exploitation of coal, but it has taken place in two main ways:

(a) Spoiling attributable to the collieries themselves, and

(b) Spoiling attributable to the associated shipping and trading activities.

Chapter 6. The Development of Collieries

The development of coal mining in North-East England has been from the exposed Coal Measure rocks outcropping in West Durham towards the concealed Coal Measures in the east. It was at one time believed that coal would not be found in any economic quantity below the Permian rocks of East Durham, and this, combined with the difficulty of penetrating the water-laden Yellow Sands at the base of those rocks, discouraged seventeenth and eighteenth century exploitation of the concealed part of the coalfield. The Coal Measure Vale was then being exploited, and the coal obtained was shipped down the Rivers Tyne and Wear. These early days of coal mining are of little significance to this discussion, and the difficulties of transport and navigation along the rivers will be left to a later chapter.

The development of boring and mining techniques and the growth of geological knowledge led to the exploitation of the eastern part of the coalfield, and it was from this time onwards that the coal industry began to affect increasingly the development of the Durham coast.

One of the earliest effects of coal mining was the extraction of millions of gallons of water from the Yellow Sands during the boring and shaft sinking, and during the subsequent working of the colliery. Most of the East

Durham collieries pump this water into the local denes, so that both the winter and summer levels of the affected streams are now much higher, downcutting is more effective, and the removal of gravel and boulders more easily and speedily effected than was formerly the case. Not all the tributaries of the main streams are affected, however, and it is interesting to note the break of slope resulting at the junction of two tributaries not equally affected by colliery water. Where the stream flow has not been increased in this way, the streams do not appear to carry as much water as formerly. Even after heavy rains the heights of the streams do not rise to those witnessed forty or fifty years ago. This suggests that there has been a general lowering of the water table as a result of the pumping out of colliery water and the activities of the local Water Companies. Examination of water bore records has confirmed that this tends to occur.

The colliery water pumped into the denes is seldom clean, as it has usually been passed through the coal 'washery', and the effects of this black, oily, coal-dust laden water on fish and plant life is not difficult to imagine.[1] Much of the coal dust settles along the stream bed in the lower reaches, but there is usually a sufficient quantity still

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1. Throughout the whole of the two years of this research, no fish was seen in any stream affected by colliery 'washery' water.

left in suspension for the river water to stain the sea black and leave broad black bands of coal dust across the sands.

East Durham is liberally dotted with colliery tip heaps (e.g. in the Wingate, Trimdon, Wheatley Hill area), and it is not uncommon for part of a tip to slide bodily into a nearby stream valley, thereby effectively blocking it and impeding drainage. Many of the upper tributaries of Castle Eden Burn are cut off in this way from the main stream. For example, the colliery tip heap and railway embankment at Thornley Colliery have effectively blocked the drainage from the headwaters of Gore Burn, and marshland results.

The drainage waters in the denes have been decreased by such artificial 'beheading', and have been increased by collieries pumping from underground sources. As the streams blocked up are seldom the same ones as receive the colliery waste water, the effects of the collieries tend to be more noticeable.

Subsidence associated with coal mining has not seriously affected the coast of Durham. This results from the depth at which coal is worked (1,000 feet below O.D. at Blackhall and Easington, and 1,500 feet below O.D. at Seaham Harbour - see Fig. 7), and from careful planning of coal extraction. There are, of course, local instances of quite appreciable subsidence, which has broken open houses, walls, gas mains, etc., but on the whole such occurrences are rare.[1] A subsidence fracture in Hawthorn Dene has been sufficiently great to act as a 'swallow hole', and the stream no longer finds its way to the beach except in times of flood.

Subsidence has been quoted as one, if not the only, reason for erosion occurring at Featherbed Rocks. It has been stated that there was little local erosion before the opening of the colliery at Seaham, that a colliery leads to subsidence, subsidence means a lower land surface, and hence the sea has been able to attack the land more powerfully. The fact that thousands of tons of beach material have been removed from the protecting shingle banks on the foreshore immediately in front of the area of greatest erosion has been completely ignored in such arguments, but more will be said of this later.

There can be little doubt that the most important way in which the collieries have affected the coast has been by the deposition of waste material over the cliff edge on to the foreshore. This is a twentieth century practice, and has become significant only within the last twenty-five years. There are now no fewer than ten collieries tipping large amounts of material on to the beaches. The most important

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1. Subsidence at Horden has been sufficient to split open the post-war prefabricated houses, and a carefully planned building programme has been prepared for the new town of Peterlee, to avoid needless repairs and maintenance.

of these are, from north to south, Dawdon, Easington, Horden and Blackhall.[1]

In the mid-nineteenth century only the thick coal seams were being worked so that the amount of stone extracted was small. The amounts gradually increased throughout the nineteenth century as production increased and thinner seams had to be exploited. With increasing mechanisation, a great increase in stone dumping has occurred, and the present annual tonnage to be disposed of is an embarrassment. The sea coast has provided an easy answer to the problem.

The Seaham Harbour Dock Company dumps approximately 550,000 tons of colliery waste per annum immediately south of the harbour. This material is derived mainly from Dawdon, Vane Tempest, Seaham, South Hetton and Murton Collieries, but from time to time small quantities are dumped from Ryhope and Silksworth Collieries, when bad weather makes shipment at Lambton Drops impossible. The greater part of this colliery waste was formerly dumped by shutes on to the cliff edge, whence it slumped on to the beach, to be removed by waves at high water. Much of this colliery refuse was swept south into the bay between Dawdon and Chourdon Point, and has been piled up by storm waves into a quite considerable storm beach, sufficiently broad to

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1. I am indebted to the Managers of these collieries and their staffs for some interesting information concerning these cliff-top stone dumps.

protect the cliffs from further sea erosion. Smaller amounts of refuse dumped on to the storm beach have largely remained there (Plate XVII). Further material is currently being added to that already forming the cliffs north of Nose's Point towards Liddle Stack. Reference to various editions of Ordnance Survey plans shows that there has been an advance of the cliff face eastwards, and this is entirely attributable to the addition of colliery waste. Exposures of limestone along this stretch of cliff are extremely rare and ephemeral, depending upon the rate of deposition and the rate of slumping and rain wash of the bare Coal Measure faces.

The cumulative effect of many years of such deposition over a stretch of the cliff face has led to the recession of high water mark eastwards, and the protection of a considerable stretch of coast from further wave attack, except under exceptional conditions.

From the opening of Easington Colliery in 1911 until 1931 colliery refuse was led in wagons and tipped on the cliff edge. The actual amount of refuse dumped during that period is not known, but it was probably between 150,000 and 250,000 tons per annum. Part of this refuse was washed away by the sea, but much remains still, and extends the original cliff line seawards.

There has been a gradual colonisation of the slumped refuse by grasses and flowers, so that the whole presents a rather less unsightly appearance than is usual along the parts of the coast affected by colliery tipping. The ash content of these older tips has often become cemented into a hard mass which resists the scouring of rain water and stands well. Occasionally large fragments break away and stand out on the beach as incongruous red and white 'stacks' amid a mass of black and grey Coal Measure shales and sandstones.

In August 1931, an aerial ropeway was installed to a terminal on the low water line just north of Loom Point, so that from that date all refuse has actually been dumped into the sea. The amounts are as follows:

Year ending	Tons	Year ending	Tons
August 1932	190,395	August 1944	128,783
" 1933	199,172	" 1945	140,605
" 1934	110,040	" 1946	144,988
" 1935	110,293	" 1947	155,673
" 1936	90,931	" 1948	168,273
" 1937	119,558	" 1949	158,441
" 1938	192,495	" 1950	181,380
" 1939	227,612	" 1951	190,637
" 1940	209,300	" 1952	203,859
" 1941	162,658	" 1953	227,502
" 1942	151,346	" 1954	194,372
" 1943	158,785	To June 1955	271,416

As a result of dumping into deeper water much of the waste material is covered by the sea even at low tide, but there is a most noticeable shoaling of the water near the aerial flight support. The addition of refuse to the normal beach material is leading to the development of a triangular platform of colliery waste around Loom Point, much of the upper part of this area being above the reach of all but the highest waves. As may be expected, the cliffs both to north and south of Loom Point are protected from sea attack, and there has been an easterly retreat of high water.

Horden Colliery was in full production by 1906. At first the refuse was dumped in the small ravine leading to the sea coast, and on waste land inland from the winding shaft, but as production increased, the amount of refuse became an embarrassment. An aerial flight was started up in 1922, and deposition of material on to the foreshore has continued since that date. No extended aerial flight was built to carry the material out to sea before dumping, and it was merely dumped direct on to the beach. Much of the loose material was removed during gales, but the heap gradually grew in size until the whole cliff face was covered. Colliery waste water was directed on to the heap to wash some of it down to the sea, and this method has been used since then, though with varying degrees of success.

Possibly as a result of compaction under its own weight, the tip heap on the beach began to offer greater resistance to the waves, and only small parts were eroded at each gale instead of the abundant quantities needed to keep pace with the rate of dumping. The heavy seas of January-February 1953 were able to remove only about ten feet of the seaward end of the tip, and despite sea erosion and the rushing of colliery water over it, the tip has continued to grow. Bulldozers have been used to push some of the material into the sea. The actual amount of material discharged in 1954 was 184,522 tons.

This huge bank of colliery refuse has contributed much material to the surrounding beaches, and these have tended to become higher, and so more effectively protect the cliffs from sea attack. The cliffs are now retreating by only sub-aerial denudation.

At Blackhall Colliery no fewer than three supporting towers have been built on the foreshore to continue the aerial flight out to low water mark, and a large triangular area of coal waste has been developed. The cliffs are quite safe from wave attack during even the largest gales, though this does not mean that the cliffs are secure from cliff foot erosion. Large lakes of impounded water are always present at the cliff foot, and are unable to escape seawards on account of the banks of colliery waste. Small waves develop on these lakes, and, washing continually against the cliff foot, they have succeeded in wasting the cliff to a certain extent. The estimated yearly tipping for the next five years at Blackhall is 300,000 tons.

There is little doubt that the dumping of colliery material into the sea has had a most beneficial effect as far as the checking of coastal erosion is concerned. But for the presence of colliery waste on the foreshore, there would be serious erosion in the lee of the harbour breakwater at Seaham, just as has occurred to the south of the Sunderland breakwaters. In place of this expected erosion there is, in fact, an area of growing or thriving beaches extending beyond Chourdon Point into Hawthorn Hive (Plate XVIII) and beyond Beacon Point into Shippersea Bay.

Southwards from Easington Colliery the coast is almost completely protected by colliery refuse as far south as Blackhall Rocks, with only occasional areas of active sea erosion around the headlands. The whole question of marine denudation along the Durham coast is considered in Chapter 9, and it has been thought wiser to include local details in that chapter.

Recent geological work has established that the workable seams of the Durham coalfield extend far out to sea, so there is little likelihood of the amount of colliery stone becoming appreciably less during the next few decades. The utilisation of more mechanised methods of coal cutting and conveying may well lead to an increased amount of stone being brought to the pit head for disposal, so that the present annual tonnage of dumped material (over 1,300,000 tons) may be exceeded in future years.

During the past twenty-five years some fifteen million tons of waste material have been dumped on the Durham beaches, and this amount has been sufficient to alter radically the natural development of that coast.

Chapter 7. The Development of Associated Activities

The activities associated with coal mining have had far reaching effects on the later evolution of the Durham coastline. The inter-relation and inter-dependence of these activities is so great that it has been exceedingly difficult to prevent some repetition, but where it has occurred it is justified by the importance and significance of the point.

The growth of both the major and minor harbours along the North-East coast has been greatly influenced by the presence of coal. In order to understand fully the present character of the Durham coast it is necessary to consider briefly the development of each of the five harbours and the effects which that development has had on the evolution of the coast, both locally and in general.

Much of what follows has been based upon reports and early maps drawn by engineers of the River and Harbour Boards, and the accuracy of portrayal of some coastal features may vary. This should be remembered during the reading of this whole chapter. Only the most reliable sources have been used, and this partly accounts for the apparent lack of balance in the numbers of illustrations for each port.

Tyne Harbour

There is evidence that the River Tyne once had three mouths; a northern channel followed the depression between Tynemouth and Collingwood's Monument and discharged at Prior's Haven (Fig.41); a second channel flowed through the present stream course, and a third channel diverged from the main stream at Mill Dam, followed the plainly discernible depression south of St. Hilda's Church, and entered the sea south of Shields Lawe. Under those circumstances, Shields Lawe would have been an island, separated from the mainland by the southern channel. The earliest existing map of the mouth of the Tyne,[1] of the time of Henry VIII, does in fact show the Lawe as an island. Confirmatory evidence of the former triple mouth was the finding of the blackened remains of a vessel in sea sand and shells, in about 1840, at a considerable depth in this old southern channel.[2]

The eastern end of the old southern channel appears to have been gradually choked and converted into a morrass, but in Fryer's map of 1773 (Fig. 42) the tide is shown flowing up the gut from the Mill Dam as high as the Sunderland Road (the present Fowler Street)[3].

There is very little information available concerning the state of the River Tyne before the close of the seventeenth

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1. Preserved among the Cottonian MSS in the British Museum.
2. Hodgson, G.B. South Shields, 1905.
3. In view of the great reduction of the original map for inclusion in this thesis, it has not been possible to show this feature.

century, but it may reasonably be assumed that navigation was not easy between shifting sand banks and shoals. There was no protective breakwater at the river's mouth, and each gale would presumably move thousands of tons of sand and shingle from off the bar into the harbour.

Collin's map of the Tyne (Fig. 43) is the earliest reliable map recording depths of water both within the river and also on the bar at the river's mouth. There were then only seven feet of water on the bar at low water spring tides, and in many places towards Newcastle even less. Being fully exposed to the sea, the bar was of very variable depth, and occasionally was impassable.

The shifting sandbanks along the river channel were probably attributable to four causes:

(1) The deposition of silt brought down by the river.

(2) The falling of ballast into the river from cobles and barges, and from the riverside ballast hills.

(3) The sweeping of marine sand into the river by the sea.

(4) Landslides, especially from the northern banks of the river, where bank recession was over 100 feet in a fifty year period.[1]

A comparison of Fryer's map of the lower Tyne (Fig. 42) with the earlier one of Collins suggests that during the

1. Macgregor, J. Observations on the River Tyne, 1832.

eighty years between these two surveys the river navigation was not appreciably improved. Fryer shows a channel through the bar, but it seems likely that this was extremely variable. Comparison of Fryer's soundings with those of Collins can be no more than extremely general, but the low water depth off the Black Middens may actually have been reduced by two feet, and between Mill Dam and In-sand the shoaling was as great as six feet in some areas. Towards Jarrow Slake there was a slight increase in depth, but on the whole the river and its approaches appeared to have deteriorated. Much of this resulted from unwise dumping of ballast, and could have been avoided.

Rennie's chart of the river[1] showed only six feet of water on the bar at low water spring tides in 1816, and a minimum depth of four feet in the sailing channel to Newcastle. Numerous sandbanks, eddies, shoals, and projecting points obstructed the tides and shipping, and the river was in a worse condition than at the date of Collins' survey.

By the middle of the nineteenth century, ships were often aground for several days waiting for a high spring tide to cross the bar, where there was still only about six feet of water (Fig. 44). The shoals between South Shields and Newcastle were increasing and extending, and the tortuous,

1. Rennie, J. The Mouth of the River Tyne, 1816.

shallow stream impeded the flow of the tide so much that even at Newcastle the river was fordable at low tide.

In 1850 the management of the river was vested in the Tyne Improvement Commission, and the passing of the Tyne Improvement Act in 1852 allowed a tonnage levy to be imposed on shipping for the construction of protective piers. A Royal Commission, appointed to enquire into the condition of the river, showed that during the last two or three centuries the navigable state of the river had not greatly altered, and in 1860 the river was then in its worst condition (Figs. 45 and 46). Conditions were so bad that larger vessels deserted the River Tyne for the River Wear, which was then in quite good condition. The three-fold problem was:

(1) The lack of water at the bar.

(2) The narrow and tortuous navigation at the Narrows, caused by the existence of rocks and sand banks.

(3) The lack of water and abrupt bends between South Shields and Newcastle.

J.F. Ure started work on both the North and South Piers (Fig. 47), both as a protection against the prevalent and destructive gales from between north-east and south-east, and to facilitate the removal of the bar. He carried out extensive improvements in the river, changing the "narrow, shallow, dangerous river into a broad, deep and noble stream."[1] Whitehill and Bill Points were cut away, and docking

1. Richardson, T.M. Antiquities of Northumberland and Durham, 1881.

facilities became available with the opening of the Northumberland and Tyne Docks in 1857 and 1859, respectively.

The building of the piers was not easy. Being fully exposed, they were occasionally badly damaged by storms and were partly undermined, but by 1862, it was considered that they had been extended far enough seawards to allow dredging to be done on the bar itself. The results were spectacular, and in 1866 over five million tons were dredged out, so that the bar had substantially disappeared. There were then 15 to 16 feet at low water, in place of 6 to 7 feet in 1850, and dredging was gradually extended further and further upstream.

The improvement at the river entrance as a result of dredging may be seen in Figs. 46 and 48. Until 1860 there had been a decrease in the depth of water at the bar, as is shown by comparing the 9-foot sounding line of 1849 with that of 1860 (Fig. 47). By 1871 the dredging had been so efficient that the 9-foot sounding line indicated a channel considerably broader than the low water area of eleven years earlier, and by 1875 there was 18 feet at low water in places which had been dry sand in 1860. The depth on the bar was increased from 6 ft. 8 ins. in 1849 at low water, to 15 feet at low water in 1865, and to 27 feet in 1872.

The piers have been lengthened steadily since that date and the navigable channel dredged deeper. By 1930 the North and South Piers were 2,950 feet and 5,150 feet long, respectively, and there were over 30 feet of water on the former bar at even the lowest tides. A certain amount of dredging is still undertaken by the Tyne Improvement Commission, but dredging at the river entrance is no longer so necessary. The piers extend out to deep water where the waves are unable to move the bottom material into the harbour, and most of the material now being dredged has been brought down-river by floods.

Before considering the effects of these harbour developments on the local beaches, two other important points should be mentioned concerning the development of the Tyne estuary: (1) the disposal of ballast, and (2) the development of Jarrow Slake.

The Disposal of Ballast and Waste Material

Salt manufacture was an extremely ancient craft along both banks of the River Tyne, but especially at South Shields. By the mid-seventeenth century 121 pans were assessed in the Chapel-warden's book, and the number seems to have increased steadily to 200 by 1730. The number of pans remained stable for a few years but by the early nineteenth century there was a marked decline, only two pans being assessed in 1834. This decline was, of course, associated with the use of coal for shipbuilding and, increasingly, for export instead of being used in salt making.

In the eighteenth century, when the industry was thriving, the associated fires and smoke were making South Shields almost uninhabitable, and "all or most parte of the grasse within twenty score yards of the said panns is altogether burnt up and waisted."[1]

These facts convey some idea of the size of the salt industry, and of the amount of waste material which must have arisen. The disposal of this waste was a difficult problem, and a great deal of it was dumped upon the line of sand dunes extending south from the river mouth and Shields Lawe, and spread along the course of the southern channel of the former River Tyne towards Mill Dam. By these means the contours of the whole landscape surrounding South Shields were altered.

The greatest changes in the contours around South Shields result from the deposition of ballast, however, and these changes are truly remarkable. Many of the colliers coming north began dumping flints and cobbles northwards from Frenchman's Bay if the weather conditions were favourable, but frequently vessels were compelled to retain their ballast until the harbour entrance had been reached. It was then unloaded at the quayside and piled into huge mounds. The importance of the coal exporting trade from the River Tyne was so great, and the number of ships employed so large, that at the beginning of the nineteenth century at

1. Victoria County History, Durham. Vol. II, p. 298.

least two million tons of ballast were annually brought into the river.[1] Such enormous amounts of material could not be dumped close to the river indefinitely, and much fell into the river, thereby shallowing the water alongside the quays. In order to dispose of further ballast, the fine bay or inlet of Mill Dam, at the western extremity of South Shields, was filled in, despite its affording an admirable site for wet docks, which were then completely absent at Shields.

The eighteenth century encroachment of ballast hills southwards from Shields continued during the nineteenth century, completely filling up the former southern course of the Tyne towards Trow Rocks. The once luxuriant sand hills were almost entirely covered with ballast, or suffered blow-outs as a result of human interference.

As a result of the dumping of rubbish from the salt pans and of vast quantities of sand and gravel, brought in from the south of England and the Continent, the contours around South Shields are now largely artificial.

The Development of Jarrow Slake

One of the most interesting cases of silting in North Durham has been the gradual infilling of Jarrow Slake. The River Don and Hedworth Brook flow through the Slake to the Tyne, and it is thought that both streams were originally much larger before the feeders were drained off by neighbouring collieries.[2] The Don was certainly of sufficient size to have

1. Rennie, J. Report to Newcastle Corporation, 1816.
2. Hutchinson, W. History of Durham, 1794, p. 477.

been navigable to Boldon, three miles from its mouth, where the remains of an ancient ship were found in 1894.[1]

The Saxon King Egfrid is reputed to have anchored his fleet of one thousand ships on the Slake, and even as late as 1834 it may have covered an area of 460 acres.[2] Demands to use it as a ballast dump during the seventeenth century were not successful until 1698, when the Corporation of Newcastle gave permission for a ballast quay to be built. In the early nineteenth century, the Slake was half-filled by deposits of sand and soil, but was still covered by the sea at high water.

There was much controversy concerning the usefulness of the Slake. Some thought that the inrush of the flood tide into the Slake increased the flood tide rate over the bar by nearly a quarter of a knot, this increase being of considerable importance to shipping, particularly in an adverse wind. Others thought the flow of the tides up the river would be so increased as a result of the embanking of the Slake, that on the ebb "the formidable sands and mudbanks, which now render the navigation up to the town of Newcastle so dangerous for ships of very moderate burden, would, in consequence, be materially diminished."[3]

Meanwhile, the Slake continued to become smaller and shallower. Part of it was eventually used as the site of

1. Hodgson, G.B. South Shields, 1905.
2. Mackenzie, E., and Ross, M. The County Palatine of Co. Durham.
3. Mackenzie and Ross, 1834.

the present Tyne Dock, and the rest has been converted into timber ponds.

Effects of Tyne Harbour

The construction of the harbour breakwaters and dredging of the bar to great depths has obviously imposed a completely new set of conditions at the mouth of the Tyne, and it is now intended to assess the degree to which these artificial features have influenced the later evolution of the coasts in the immediate locality.

In 1849 the sounding lines at the Tyne Entrance before the construction of the piers were roughly parallel to the coast, from Sharpness Point in the north to Frenchman's Point in the south (Fig. 44). The effects of the piers may be seen by comparing the 1849 soundings with those of 1952 (Fig. 44). (Soundings in 1860 and in 1879 are shown in Figs. 46 and 48, but it should be noted that the datum line of soundings in these two latter figures is fourteen feet above that used in Fig. 44.) The shape of the sounding lines in 1952 is exactly as expected, the sand and gravel accumulating near the barrier of the North Pier, resulting in a reduction of about six feet in the depth of water. Immediately in the lee of the South Pier some inshore sand appears to have been eroded during the past one hundred years, and this tendency extends south to at least as far as Frenchman's Bay. Low water mark in 1952 was considerably further east than in 1849, showing accumulation of material on the beach between tide marks, and a steepening of the offshore gradient out to 18 feet at low water spring tides. The old cliff line of 1849, indicated on Fig. 44, has been extended seawards by means of the marine gardens and parks, the coast promenade and railway, and the sea wall. Much of the park and garden land consists of levelled-off ballast material.

Reference to Fig. 49 shows a more detailed examination of the foreshore at South Shields. Great development of the sand dunes appears to have occurred between 1832 and 1838, but the quantities and movements involved are so great in so few years as to throw doubt upon the accuracy of mapping of high water mark on either the Tyne Improvement Commission Plan, or on that of Commander Slater. The T.I.C. Plan dates from the time when control of the river was in the hands of the Corporation of Newcastle, and is probably not reliable. Between 1838 and 1855 high water advanced along the Shields beaches, but there was a slight retreat of the sea in the south towards Trow Point. Meanwhile, Herd Sand had been growing in size and, as noted earlier, occasionally completely blocked the river's mouth.

Between the publication of the 1855 and 1895 editions of the Ordnance Survey Six Inch Maps, the harbour piers were started and dredging operations carried out. High water mark retreated eastwards between the South Groyne and the

South Pier, and this was probably a consequence of the reduction in the size of waves able to break on this remnant of the former expanse of Herd Sand. The almost complete removal of Herd Sand resulted from a combination of dredging and scouring along the northern face of the South Pier. A steepening of the beach occurred here between 1895 and 1921, and this continued up to at least 1951, when there had been a considerable advance of low water mark and a slight advance of high water towards the land.

South of the pier widespread and important advance of the sea has occurred during the past thirty years. This has been progressively greater from the lee of the pier southwards to Trow Point. Low water mark immediately south of the pier has continually retreated eastwards between 1838 and 1951, though at a decreasing rate. Towards Trow Point, the change in the position of low water has been in the reverse direction, indicating that the beach is gradually re-orientating itself to meet the changed conditions resulting from the presence of the South Pier to the north. This pier has reduced, or even eliminated, the effect of waves and winds from the north-east, and the beach is adjusting itself to dominant waves from between ESE and SE. That this position has almost been attained is indicated by the continual slowing down of the recorded movement.

During the first quarter of the present century high spring tides were encroaching on the small marram-covered dunes, and the practice of removing sand from just south of the pier was therefore discontinued. This did not have the desired effect, and from a consideration of the orientation of the beaches, it is evident that it could not do so until such time as the beach had readjusted itself. During the past thirty years, there has been no significant change in the beaches at South Shields (Fig. 50), and it is obvious that the readjustment of the beaches has been completed. The removal of sand and shingle for constructional purposes is widespread along the Durham coast, and will be fully discussed later.

Wear Harbour

The mouth of the River Wear,[1] like that of the River Tyne, has been developed from a shallow tortuous stream, almost dry at low water, into an important harbour, with extensive docks, piers and breakwaters.

Little is known of the early history of the port, but considerable evidence is available showing that the promontory on the south of the river was occupied by the Romans.[2] Hutchinson[3] believed the port to have had some importance in the eleventh century, though never much, as at the time of Hatfield's Survey fishing nets were still being cast in the harbour. In these early times the haven was probably of great importance to coastal shipping, and its proximity to

1. The Vedra of Ptolemy, and Wyrus of Bede.
2. Potts, T. Sunderland, 1892.
3. Hutchinson, W. Durham, Vol. II, p. 503.

the monastery probably increased its trade.

One of the earliest maps of the mouth of the Wear upon which any reliance may be placed is the chart drawn by Greenville Collins in 1693 (Fig. 51), and this shows several features of importance to this discussion.

For instance, Monkwearmouth Church was then within 150 yards of high water mark, and the navigable channel ran between extensive sands at the river's mouth and crossed a bar thrown up by sea waves at a position ENE of that church. Collins recorded a depth of 12 feet of water on the bar at high water spring tides, but only 2 feet at low water. The bar consisted of sand and gravel,[1] and had a variable depth depending on the state of the winds, tides, and floods, and other local circumstances.

Although Sunderland was of some importance as a port at the end of the seventeenth century, having its own Customs House (see Fig. 51), there were no piers at the time of Collins' survey, and the harbour was fully exposed. Six years later, however, in 1699, Charles II granted letters patent to Edward Andrew, Esq., to erect a pier, but no trace of that pier can be found.

The River Wear Commissioners were constituted in 1717, and in 1719 James Fawcett published a plan showing the

1. T. Meik in his 1851 report to the River Wear Commissioners stated that dredgers had nowhere found rock in the channel (between the piers) at less than 11 ft. 4 ins. below low water, and that only at one spot.

harbour before the Commissioners had made any improvements (Fig. 52).

High limestone cliffs trending south and south-west formed the river's mouth on the north, though parts of the limestone near Monkwearmouth Church had been covered by ballast. The limestone reappeared along the river bank further to the west, however, and ended in a bold rocky cliff at the Sheepfolds (see Fig. 53).

The promontory on the south side consisted of an irregular mass of sand, gravels and boulders about ten feet deep, resting upon a bed of stiff clay or marl interspersed with boulders and fragments, the whole resting upon a soft and porous limestone. Towards the west, the topping of clay was replaced by the limestone ridge running to Rector's Gill (now Galley's Gill).

Fawcett's plan shows very clearly the essential features of the river mouth. Both the North and South Rocks were exposed as extensive ledges at low water, and afforded some protection from gales to the river mouth. Between these two rocky areas flowed the main stream of the river in a general north-easterly direction. The channel was not simple, and there were numerous sandbanks and shoals which sub-divided the river at low water into countless creeks and channels. Outcrops of rock extending into the river from both banks constituted further hazards to shipping.

In 1719 there were two main channels. The position of the northern channel, known as The Stell[1], was associated with the presence of rocks off the north-west corner of the Town Moor, which deflected the main ebb stream of the river towards the north, until it was deflected eastwards again by Dame Dolly's Rock on the northern bank of the river mouth. This channel was characterised by a line of shifting sandbanks in its south-north section. The narrower, southern channel, known as The Sledway, also had its line of shoals, and was seldom used by shipping. Between these two channels was the Stell Canch, a bed of gravel and sand with some larger beach stones, which effectively blocked the river mouth for vessels at most states of the tide. East of The Stell Canch the bar of sand and shingle stretched completely across the mouth of the river between the North and South Rocks. Ships were often unable to cross the bar and lighters were necessary to convey cargo to vessels waiting offshore.

A South Pier was started from the most northerly point of the Town Moor in 1723, to direct the current of the river against the bar and the shifting sands. By 1737, the pier was 1,000 feet long (Fig. 54), and Potts believed that it was from that seaward end that all subsequent improvements have radiated, "according to the prevailing ideas of the then engineer". The pier base was on limestone near the Town Moor, but piles became necessary as the pier was extended into deeper water and the sandy shoals.

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1. A word describing a deep gut in which water is always to be found.

The immediate effect was to direct the southern channel alongside the pier for the whole of its length, and the extension of The Sledway across the Stell Canch greatly diminished the size of that sandbank. The northern channel, however, remained the main shipping channel, and its course was approximately the same as in 1719. Burleigh's and Thompson's soundings in feet at low water show clearly the presence of shoals and sandbanks, many of them being attributable to the careless disposal of ballast. At the western end of the pier there was a low water depth of only four feet in the channel, which became even more shallow over the bar, where less than one foot of water was available at low tide.

It is not easy to assess the extent to which the pier affected the longshore movement of beach material, but from a comparison of the two plans of 1719 and 1737 it is obvious that in the later map a greater width of sand existed between the cliff-line and the rocks, and low water mark had almost certainly retreated eastwards.[1] These features are explicable if one supposes an increase in beach material, resulting in a higher beach and a lower beach gradient. This could well have occurred as a result of the retaining of beach material by the South Pier.

1. It should be noted that during the copying of the original maps only a generalised shape was given to the rock outcrops.

By 1750 (Fig. 55) a sand bank had developed on the lee side of the pier and this protected the Town Moor from sea attack. The accumulation of sand was so great that the low water exposure of the South Rocks had been reduced by half. This considerable accumulation was considered to be the result of an eddy current swinging round the pier head, but it is worth noting that the pier was built parallel to the direction of dominant waves and the stretch of coast where the sand bank had accumulated was at right angles to that direction. At Jockey Dike Nook the coastline trend became NE - SW, and there was no further development of the sand bank to the south.

The condition of the north river channel was seldom satisfactory during the first half of the eighteenth century, and in 1752 it was artificially blocked, the southern channel becoming the main navigable waterway for the first time. In 1756 the old north channel became entirely filled with sand, and the scouring power of the ebb tide in a single channel was so greatly increased that the southern channel was deepened considerably, and the seaward end of the pier itself undermined.

The re-alignment of the old South Pier, the commencement of work on a South Mole, and the cutting away of a considerable amount of rock from the navigable channel during the latter half of the eighteenth century, had great beneficial effects upon the harbour. By 1774 a regular, open channel had been formed near the pier, allowing ships to go out of the harbour without the difficulty and danger formerly experienced.

Constant extension of the pier (Fig. 56) seems to have trapped southward-moving beach material, which was washed into the harbour during storms, and in 1787 work was started on the North Pier (Fig. 57).

Much sand and gravel accumulated north of the new pier, and within the first nine years high water mark retreated more than a quarter of a mile seawards, leaving a broad expanse of dune grassland at the foot of the former cliff line. This area of sandy grassland was quickly claimed for building purposes, and shipyards were established on what was formerly the sea beach.

After the erection of the North Pier, the sand bank south of the South Pier tended to become smaller, and high water mark tended to advance. This is the first indication that the beaches south of the harbour were being starved of beach material.

During the early years of the nineteenth century the piers were continually extended and re-aligned to improve the harbour, (Figs. 58, 59 and 60). Beach material continued to accumulate in the north, but in the south a sea wall had to be built to prevent further washing away of the accumulated sands from the lee of the South Pier. Removal of the sands had been so great that the Town Moor was becoming exposed again to wave attack and was "rapidly wasting away".[1]

Despite the protection of large blocks of stone, much of the landward end of the South Pier itself was undermined, and 800 feet of it were removed and set back in a circular direction so as to make a receptacle similar to that of Potato Garth (Fig. 61), on which the surge could break during easterly storms (see Fig. 62). At low water, Potato Garth dried out for about twenty acres, and at low spring ebbs it extended almost completely across the river and left only a narrow channel close to the southern shore. The Garth was considered of great importance to the harbour "as a receptacle for tide-water for scouring the bar, and for tranquillizing the swell of the sea in the storms from the eastward".[2]

The increasing amount of shipping using the harbour in the mid-nineteenth century prompted the Commissioners to make further attempts to improve the harbour. The navigable channel was straightened and deepened by dredging and blasting, and by 1845 the bar had been cut away to give four feet of water at L.W.O.S.T. and 18½ feet at H.W.O.S.T.[3]

Docking facilities became available at Sunderland when

1. Jessop. W. Report to the River Wear Commissioners, 1807.
2. Rennie, G. Evidence before the Tidal Harbour Commission, 1845.
3. Murray, J. Evidence before Tidal Harbour Commission, 1845 p. 606.

the North Docks were opened in 1837 (Fig. 62). These docks were built on the site of the former north channel, and the soil and marl excavated was dumped on the rocks and cliffs at Roker. Material excavated from south of the river during the construction of the South Docks was deposited on the local beaches, where groynes were necessary to collect and retain beach material. The South Outlet was opened in 1856, and the Hendon Dock in 1868 (Fig. 63).

In 1884, work was started on the Roker Pier (Fig. 63) which was to be extended 900 yards south-east, having a curve of 760 yards radius. It was believed that its most beneficial effect would be to stop the movement of sand along the shore which collected behind the North Pier during the summer, and which was swept round its extremity on to the bar during winter gales (Fig. 64). By 1890 over 700 yards of the Roker Pier had been built, and it was proposed to build a new 960-yards long South Breakwater some 500 yards south of the existing South Pier. (Fig. 63).

In addition to sheltering further the harbour entrance, the South Breakwater would prevent further scouring of the beach south of the South Pier, which was largely attributable to the upsetting of the original 'balance of forces' acting on the local foreshore by the building of the Roker Pier. Although the foreshore between Roker and the South Outlet was protected against seas from north-east, it was still exposed to seas from the south-east which moved beach material northwards. The width of the foreshore between the harbour and Roker Pier had in fact increased from 70 to 100 yards between May 1890 and April 1891, and only by dredging and scouring had the material been prevented from accumulating in the river's mouth.

With the construction of the New South Pier, Sunderland Harbour assumed its present character.

Disposal of Ballast

Much effort has been expended in dumping ballast material satisfactorily. Even as early as the mid-seventeenth century the quantity of ballast being dumped around Sunderland was a matter of some concern, and ballast tipping near the harbour mouth was prohibited. Much of the ballast was put overboard by the colliers as they came north along the coast in a light southerly wind, or discharged when they anchored in Hendon Bay. With stronger winds the ballast was kept until the harbour had been reached and then discharged into keels or at the wharves, quays or beaches.

On the North Sands ballast from colliers was taken by carts to the cliff top and dumped around Monkwearmouth Church and the Poorhouse. The Church was originally about 150 yards from high water mark, and stood on a hillock, but the quantity of ballast dumped was so great that eventually the Church appeared in a hollow, and the neighbouring

Poorhouse was removed, the hollow being levelled off with additional ballast. This huge mass of ballast continually encroached upon the Ham Sands, and eventually they were completely covered. Parts of these ballast hills frequently fell or were washed into the river, and the Act which established the River Wear Commissioners in 1717 noted the shoaling in the harbour and river caused by the improper throwing out of ballast in the harbour.

The contours of the land east of Church Street were entirely changed by ballast dumping, and numerous ballast hills were built at Southwick, North Hylton and Deptford. Many valleys were filled in and the Gill Cemetery is the site of a filled in ravine.

Effects of the Harbour at Sunderland

The development of Sunderland Harbour has considerably disturbed the natural disposition of beach material, and throughout its history the harbour works have been repeatedly redesigned and rebuilt to encourage as favourable a disposition as possible. Many of the difficulties resulted from river engineers attaching too much importance to eddy and tidal currents, and the present form of Sunderland Harbour is largely the result of trial and error.

In general terms, the effects of the piers have been simple. Beach material has accumulated to the north of the river's mouth since the date of the first pier, and as the piers have become larger their efficiency as barriers to beach drifting has increased. The resulting abundant beach material north of the harbour was thrown up by waves into shingle ridges, and these were covered by marram grass to form the Grass Bents. This land was almost immediately utilised for building purposes, and by 1830 there were extensive shipbuilding yards where formerly was the sea.

The North Rocks were progressively covered by beach material, and Figs. 65 and 66 indicate that the accumulation of such material has continued. Depths of six feet are now recorded where formerly twelve feet existed, and shoaling north of Roker is apparent almost everywhere.

The beaches south of the harbour have been deprived of much beach material as a result of the prevention of longshore drifting, and without doubt the rate of erosion of Sunderland Town Moor has been increased with the building of the piers and the removal of offshore protecting rocks.

From written and cartographic evidence, it seems clear that the clay promontory on the south side of the mouth of the Wear formerly extended much further to the east and north-east, but has suffered much coastal erosion. In 1346 ships were built in Hendon Bay,[1] and considerably

1. Summers, J.W. History and Antiquities of Sunderland, 1858, p. 41.

extended promontory would have provided the necessary shelter. Ships rode at anchor in Hendon Dene in 1350, when the sea "probably flowed much higher than at present up some of the deep gullies".[1] If cliff recession proceeded faster than valley formation, the denes along the clay promontory would be reduced to mere notches, 'hanging' at their mouths. As this took place, there would be an apparent reduction in the height of high water at the dene mouths, and this appears to have occurred.

There is ample evidence that the Town Moor has been washed away at no small rate. The site of a former 'spaw well' on the Town Moor some 70 yards from the cliff edge in 1737 was seen during the making of the South Outlet. The distance between the Town Moor edge and the South Outlet, plus 70 yards, indicates the amount of coastal erosion between 1737 and the passing of the Sunderland Dock Act in 1846. This amounts to 270 yards in 109 years.

Detailed measurements suggest that there was an increase in the rate of erosion from one yard per annum between 1737 and 1800, to four yards per annum between 1800 and 1850. During the latter half of the eighteenth century the Town Moor was protected by the sand bank in the lee of the South Pier, but towards the close of the century this sand bank was being washed away and afforded less and

1. Potts, T. p. 119.

protection to the clay cliffs behind, which were then becoming subjected to the full force of the sea.

There is another relevant point to consider. In 1767, when work was started on the South Mole, most of the stone was quarried locally from the foreshore in front of the Town Moor, thus removing the natural protection for the clay cliff. As soon as the sea began to encroach upon the land it was able to act directly on the clay with a force undiminished by offshore and foreshore rocks, with the expected results.

Potts[1] described the action of the sea thus:

"On calm days the sea washed away the marl from between the rock and the clay, and in storms the whole bank was pounded by sea water. The erosion was assisted in no small way by the almost continual oozing out of water from the top of the clay, trickling over the clay face and making it a soft, puddle bank, so that being undercut by the sea it was quite ready to fall under the action of storm or frost. No matter what amount of clay fell, it was all eventually washed away by the sea, with the exception of the blue stones which fell embedded in the clay, so that the beach was none the more able to resist the waves. These blue stones themselves were gathered from off the beach by the Commissioners of the Town to pave the streets, and thus helped to make this an area of beach material deficiency."

1. Potts, T. Sunderland, 1892.

In 1845, evidence was given before the Royal Commission on Tidal Harbours that the bank of the Town Moor had been eroded about 80 feet within the last nine years. Numerous batteries and gun sites were washed away in the late eighteenth and early nineteenth centuries, and an old storehouse and lime kiln were also destroyed.

From both cartographic and written evidence there seems to be much truth in Summers' statement[1] that "the action of the sea upon the coast has been considerably increased by the extension of the piers at the harbour entrance."

Seaham Harbour

About five and a half miles south of the River Wear is one of the two minor harbours of the Durham coast. The classification of 'minor' and 'major' harbours, as used in this context, is not based upon tonnage of shipping nor revenues, but upon the size of the harbour defence works and their importance in retaining beach material. In such a classification Seaham Harbour is a 'minor' harbour, as is the combined harbour of Hartlepool and West Hartlepool.

The harbour at Seaham is an extremely recent haven, dating only from 1828. Before the nineteenth century the old village of Seaham, in the neighbourhood of the present Seaham Hall, together with a manor house in the dene, called Daldon Towers, and three farmsteads, made up the total

1. Summers, J.W. 1858.

population of the locality. These settlements are very old, but little is known of the early history. In about 1678 the manors of Seaham and Dalden were both sold to Sir Mark Millbanke with whose descendents the property remained until purchased by the Londonderry family in 1821.[1]

Before 1828 the space now forming the harbour at Seaham was a mass of solid rock. The third Marquess of Londonderry began building Seaham Harbour "with the humble and confident hope of facilitating the exportation of produce of mines and of augmenting the commercial interests of the county of Durham".[2] Seaham had no river mouth which could be improved to make a haven, and everything that was done to make it a harbour was artificial. The barren, rocky coast had huge isolated fragments projecting out to sea, and these afforded some shelter to the many small coves and inlets. These inlets were artificially enlarged during 1828 to form the harbour (Fig. 67). The rock excavated was used for building the piers and the foreshore on the north, which was defended by a sloping pavement and a parapet. The first coal exported was by sailing ship in July 1831, and the docks then remained almost unchanged for about seventy years, except for a modest extension in 1845.

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1. Seaham Urban District Council, Seaham Harbour, 1950.
2. Contemporary Biographies, No. 17, 1906. Durham. Edit. W.T. Pike.

During the first decade of the harbour's existence considerable shoaling occurred, most of the material being swept into the harbour by the sea during easterly gales. Some material had fallen from the colliers during loading, and periodic falls of limestone and glacial material from the steep bounding cliffs of the harbour were also contributory sources of material.

In 1842, the Outer Harbour, or receiving basin, could only be entered at high water, there being only 15 to 18 inches of water in the channel between the pier heads at low tide.[1] The approaches to the harbour were not completely satisfactory, the surrounding shores being rocky, and there were numerous off-shore rocks. Liddle Scar was a large detached mass of rocks extending south for about half a mile from the South Pier, outside of which were numerous smaller rock masses above which the water depth varied from three to eighteen feet at low water ordinary spring tides. North Scar, Outer Rock, South Scar, and Tangle Rock were all dry at low water.

The increasing importance of the coal trade resulted in many improvements being carried out at Seaham, and in 1898 the Seaham Harbour Dock Company was formed to provide additional docking accommodation. No fewer than ten acres of additional dock area were completed by 1905, and new

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1. Lt. Kortwright, R.N. The East Coast. 1842, H.O. Ref. O.D. 313.

piers run from both north and south of the rocks enclosed a further twenty-eight acres. Enlargement of the harbour again took place in 1923, when the Castlereagh Extension was completed.

Effects of Seaham Harbour

Since Seaham Harbour is a completely artificial harbour with no river outlet and little history, it is not easy to determine the effect which the harbour has had on the surrounding coasts. The local limestone is of extremely varied character and had been cut by the sea into numerous well-developed bays. Initially, the effect of Seaham Harbour was merely to emphasize the bays and promontories, but with the gradual nineteenth century development of piers there was an accumulation of beach material to the north. The increasing amount of beach material north of Red Acre Point resulted in the beaches becoming flat sandy areas favoured by boatmen, and the rock outcrops were gradually buried beneath sand and shingle. The cliffs became more and more protected from wave attack and conditions appeared to be quite stable.

As would be expected, a shortage of beach material became noticeable south of the harbour mouth, and a sea wall was extended southwards to prevent further undercutting of the cliffs. The construction of the sea wall did nothing to solve the fundamental problem of insufficient beach material being present for the beaches to remain thriving, and the amount of shingle became progressively less. Wave attack became more pronounced, and erosion of the cliff-line was already quite rapid when colliery refuse was dumped on to the foreshore south of the harbour by Seaham Harbour Dock Company. The exact date of the beginning of this practice is unknown, but the quantities dumped were probably not great until the present century. Many collieries now make use of the dumping facilities offered by the local Harbour Company, and the amount of beach material has increased to become more than sufficient to act as a successful barrier between the cliffs and the sea.

As a result of the presence of this additional beach material, the effects of the harbour works at Seaham do not extend far to the south.

Recent evidence has proved that the accumulated beach material north of the harbour was not an inexhaustible source of building material, and the removal of this sand and gravel for constructional purposes lowered the level of the foreshore to such an extent that the sea was able to attack the soft limestone cliffs with great force. Erosion became a source of great anxiety, as the main road north from Seaham Harbour was in danger of being washed away, and a massive sea wall has recently been completed to help to protect the cliffs from further wave attack. This topic will be discussed at greater length in a later chapter, but sufficient has been said to show the folly of removing unlimited supplies of beach material without keeping careful check of resulting changes in beach profiles.

Hartlepools Harbour

The combined harbour of Hartlepool and West Hartlepool is a minor one in the classification of harbours adopted in this text, as there are no breakwaters of sufficient size to affect seriously the longshore movement of beach material.

Hartlepool

The peninsula of Hartlepool consists of a 500-yard wide neck of sand connecting Hartlepool Rock to the mainland, and it seems probable that the rock was once a tidal island. Rennie[1] attributed the sand neck to the neutralising of the northern inshore current by the opposing Tees current, the alluvial matter held in suspension being deposited at their junction or neutral line. But the tombolo at Hartlepool has obviously been formed by wave action throwing sand and shingle up into a sand bank. Once the sand bank had been built up to above sea level by waves, the height

1. Rennie, Sir John. The Theory, Formation and Construction of Harbours, 1854.

of the bank was increased by wind blown sand from the dried-out foreshore at low water. The bank has increased in width by the gradual accumulation of southward moving beach material.

Some of the sandshave been thrown up into dunes to both the north and south of this connecting ridge and these have impeded land drainage, thereby allowing lagoons to form and silt up into the present marshlands protected from the sea by thriving dunes.

The height of the land increases gradually from the connecting sands to the rocky east and south coasts of Hartlepool Rock, which are defended by 30 to 40-foot cliffs, and by rocks extending a considerable distance out to sea.

About one and a half miles south of Hartlepool peninsula a ledge of rocks, the Scar, projected about 1,200 yards into the bay at right angles to the shore, and formed a natural protection to Hartlepool Headland from any swell driven in from the south.

The peninsula forms the eastern side of a large shallow bay, the Slake, extending inland in a north-westerly direction. The Slake was formerly underlain by a large mass of anhydrite in the Magnesian Limestone, but this has been partly dissolved away and the land has been submerged by the sea to form a shallow brackish lake.

The precise date of the building of the first port of Hartlepool is unknown. Some authors believe it to have been a Roman settlement, but this is questionable, as there is neither historical nor archaeological record to support this opinion.

Hartlepool monastery was founded in 640 A.D. by Hieu on the thickly forested and probably uninhabited peninsula.[1] Settlement around the seventh century monastery was obviously of some consequence by 1153, when pirates carried off ships and goods,[2] and in 1200 King John granted a charter to Hartlepool, making its inhabitants free burgesses. During the thirteenth century the town walls were built, but by the early fourteenth century the port had been plundered at least twice by the Scots.

The south-east facing harbour on the landward side of Hartlepool Rock (Fig. 68) had a sandy shore, and from earliest times acted as a refuge, though its depth at high water before the nineteenth century was not more than eight to ten feet. A smaller but deeper natural harbour was formed by a promontory jutting westwards from the end of the peninsula.

The outer harbour on the south of the promontory was formed in the fifteenth century by means of a pier, built

1. The name Hartlepool is supposedly derived from the peninsula being the haunt of the hart (Bede and Huntington). Sir Cuthbert Sharp. History of Hartlepool, 1816.

2. Johnstone. Antiqu. Celto. Scandicae. 268.

under licence from Bishop Booth. This pier was to defend the harbour from storm waves, and to protect the south side of the town walls from erosion. It was built due west from the Crofton Heugh headland, and although loose stones were periodically added to repair the pier, it was in a ruinous condition by 1565, and during southerly and easterly gales a heavy swell swept into the bay.

Sixteenth and seventeenth century attempts to repair the pier were unsuccessful, and Hartlepool declined in importance as a port. In the eighteenth century the whole harbour fell into disrepair, and from 1808 to 1813 the Slake was actually enclosed for agricultural purposes, and a crop of corn grown on the dry bed of the Slake.[1] The pier was then completely broken by the sea, and the town itself appeared to be threatened with destruction during southerly gales. Public subscriptions and a toll levied on all shipping using the port in 1813 provided money for the repair of the seaward end of the pier. The Slake was returned to the harbour during that same year, and thereby saved the harbour from ruin, as it would probably have been completely silted up without the scouring action produced by the sweep of the backwater from the Slake.

Further silting up of the harbour occurred, even though the Slake had been opened to flood waters again, and by 1830 nowhere had more than eight feet of water at high tide, and

1. Sharp, Sir Cuthbert. History of Hartlepool, 1816.

at low water carriages, horses and even foot passengers could cross the mouth of the Slake channel with safety.[1] Hartlepool was then merely a small declining fishing village of 1,000 people. After an Act of Parliament in 1832, a tidal harbour was formed in the outer part of the Slake, defended by the old pier on the east and the rubble jetty on the west.

During the construction of a dock and the draining of the Slake, a bed of peat containing tree roots, some trunks of oak and elm trees, and antlers and teeth of deer were found a few feet below the surface of the inner harbour. The deposit varied from twelve to fifteen feet in thickness, and several anchors, mooring stones, etc., were found twelve feet below the surface of the Slake.[2] From these facts it may be inferred that the shore near Hartlepool has experienced oscillations of sea level, and from the well preserved nature of the fossils it may also be inferred that these oscillations took place at a comparatively recent period.[3]

The dock was opened to shipping in 1835, and to deepen the channel more effectively than by dredging, a pier or jetty was built on the Stranton side, which became

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1. Fordyce, W. The History and Antiquities of the Co. Palatine of Durham. Vol. II, 1857, p. 273.
2. Fordyce, W. Vol. II, p. 273.
3. Even at the beginning of the thirteenth century the 'wood' of Hartlepool still existed. Guisbro Chartul. (Surt. Soc.) ii, 324.

strengthened by the natural accumulation of sand and shingle. A second dock was opened in 1840 (Fig. 69).

Much of the stone for the docks was quarried from the local cliffs below high water mark, and boulders were taken away also for lime making. Although there was no further quarrying off Hartlepool Headland after the completion of the Victoria Dock in 1840, except for the removal of some further stone for lime making for a few years, the effects of the earlier removal of material were quite apparent. In 1851 it was necessary to build a breakwater south-east from the Heugh to protect the Heugh itself from the encroachments of the sea. The broken stone required for the concrete was supplied from the reef on which the new structure was being projected, thereby increasing the likelihood of serious erosion.

Whereas Hartlepool is a port of some antiquity, both the town and port of West Hartlepool are extremely modern, dating only from 1845.

The harbour was formed of stone piers projecting from the land and enclosing thirteen acres. The initial eight-acre dock was excavated from the meadows south of the Slake, and additional docks have been constructed periodically as trade increased.

Acts of Parliament in the latter half of the nineteenth century provided for an outer harbour of refuge south of Hartlepool Headland, with two piers projecting from the shore and a sea wall, but this project was later abandoned and small scale jetties and walls built in its place. Continued development of the protecting harbour works occurred, but the effects on longshore drifting were not remarkable. In the lee of the peninsula of Hartlepool, there is no well-marked movement of beach material southwards, and the effects of the Harbour are dwarfed by the effects of the Headland to the north and the breakwaters at the mouth of the River Tees.

Effects of Hartlepools Harbour

The old harbour of Hartlepool is on the south-west side of the limestone promontory of Hartlepool Rock, and any piers or harbour works have had little effect on the development of the coast. Southward drifting beach material has tended to accumulate on the northern side of the peninsula, making the beaches quite extensive, and providing material for sand dunes. Accumulation of such material has continued at a steady rate, and during both stormy and calm weather some of this material is swept around the headland into the shelter of the rock, but not in sufficient quantity to produce an abundance of beach material. The piers at Hartlepool have been built on a steep foreshore, where beach material was not overabundant and have been built to cut off sea swell rather than to improve the entrance channel of the port.

Whenever small groynes or piers were built at Hartlepool it was some time before any beach material accumulated near them, and even then the amount of sand and shingle was not great. Even the building of large piers has had no appreciable effect on the local foreshore, and this results from the harbour being situated in the lee of a large natural groyne.

As a result of the natural disposition of beach material, erosion of the northern and eastern faces of Hartlepool promontory has been less than the erosion of the southern cliffs. The erosion of the original borough which led to the construction of a protecting sea wall on the east was brought about largely by the undercutting action of the sea. This action was increased by the removal of rocks from the foreshore for the construction of piers and harbour works.

It was reported that the rate of erosion was increasing at the beginning of the present century, and this would suggest that the shortage of beach material had become increasingly noticeable since the mid-nineteenth century. Alternatively, the proximity of the cliffs to the houses along the cliff top may have given the cliff falls greater significance than formerly, and even small cliff falls were noted with concern. Great erosion was recorded opposite Albion Terrace and South Crescent, where the sea was within ten feet of the gardens of the houses by 1905, but no measurements have been made of the rate of erosion. Erosion was also especially great along the north-eastern side of the headland where there was greater exposure to the dominant north-east gales. South of the headland, erosion was not great despite the absence of abundant beach material, as the largest waves came in from the south-east, bringing with them some beach material from the River Tees mouth, which was deposited as a sand bar just off the entrance to the harbour. The harbour was kept open to shipping by the sluicing action of water escaping from the Slake, which removed great quantities of sand and silt.

Further away from the shelter of Hartlepool promontory beach material was more abundant, but not sufficient to prevent coastal erosion occurring at a fairly rapid rate, as the beaches became exposed to north-east gales. The construction of small piers at West Hartlepool in 1845 delayed the movement of beach sands to some extent and caused slightly increased erosion at Seaton Carew, but within fifteen years work was started on breakwaters at the mouth of the Tees, and sands began to accumulate in this area.

Before the construction of a harbour at Hartlepool there was abundant beach material north of the promontory and some shortage to the south. Such a distribution of material exists today, showing that the effect of Hartlepool Harbour on coastal development has been exceedingly small.

The River Tees and Tees Estuary

The extreme south of the coast of Co. Durham is formed by a line of sand dunes backed by an extensive area of lowland and tidal flats, extending inland to beyond Stockton (Fig. 70). This area has been considerably altered during even the last one hundred years, and it is worth recalling its earlier state.

A broad estuary once extended to Stockton, making both that town and Yarm flourishing sea ports, but with the gradual silting up of the estuary these ports have fallen into disrepair, and marshland grazings have extended across the former tidal flats. Professor Steers[1] has attributed the deposition of material to the combined effects of the southerly drift of beach and offshore material, and the sluggish nature of the Tees.

Stockton was first noted as a port in 1228[2] and was again mentioned in 1543, but twenty years later the River Tees was being foresaken by seamen as Stockton was ten miles from the open sea and the river channel was far from satisfactory. The decline of Hartlepool towards the close of the seventeenth century[3] encouraged the trade of Stockton,

1. Steers, J.A. The Coastline of England and Wales, 1948.
2. Feod. Prior. Durham (Surt. Soc.) 241.
3. The piers were broken down and the harbour unprotected from gales.

and in 1731 De Foe[1] referred to Stockton as "the chief place in all those parts for the shipping of lead, corn, and butter, for London".

The winding course of the Tees east from Stockton still caused a good deal of inconvenience to shipping. These were the days of sailing ships and tides were frequently lost in navigating the crooked channel, for a favourable wind from the sea to Portrack became contrary from Portrack towards Stockton. Laden vessels could seldom get higher up river than Portrack on the same tide and their cargo had to be taken to Stockton by river barges, which themselves often stuck on the sands for six to eight days.[2]

Near the sea, the river expanded into a large estuary, about three miles across and five miles long, which was narrowed somewhat at the coast by the tongue of Seaton Snook. From this Snook the North Gare Sand stretched south and east, and almost opposite it was South Gare, a peninsula shoal extending from the Bran Sand, which occupied the south side of the harbour mouth.

To increase the fall of the river and shorten the river navigation, a 220-yard 'cut' was made at Portrack in 1810, cutting off two and a quarter miles of meander (Fig. 70). The tonnage of shipping using the port almost doubled, and

1. Daniel De Foe, "Tour through Great Britain", 1731.
2. Hutchinson, W. Durham. Vol. 3, 1794, p. 134.

a further cut was made near Newport in 1821. The increased flow of the river scoured away many sandbanks, and improved the river channel over the bar.

During excavations for the 'New Cut', a buried forest of fruit and other trees was found, whose roots were lower than the deepest part of the river. Acorns, nuts and a metal buckle, a stag's horn and a bullock's head were also found.[1]

The navigation of the River Tees was entrusted to the Tees Conservancy Commissioners, but their comprehensive programme of improvements was delayed for seven years by lack of funds. In 1858 an Act of Parliament gave the Commissioners powers to sell the land reclaimed by the training walls built near the mouth of the river, and the money was used for further dredging and deepening of the river channel. Heavysides[2] (p. 53) stated that as a result of this over twelve miles of training walls had been completed by 1865, 160 acres of silted up foreshore between Haverton Hill and Port Clarence had been reclaimed, and all the foreshore between Middlesbrough and Newport, similarly silted up, had been sold for the erection of wharves, etc.

As in the case of nearly all rivers with sandy outlets where no artificial works exist to ensure permanence,

1. Fordyce. Vol. II, p. 187.

2. Heavysides, H. The Annals of Stockton-on-Tees, 1865.

the entrance was subject to every disturbing cause, and was continually varying in direction and depth. In the mid-eighteenth century the general direction of the channel over Tees bar was east-west, and the depth of water was nine feet at low tide. By the early nineteenth century the depth was ten to twelve feet at low water spring tides, depending upon circumstances, and by the mid-nineteenth century the direction of the channel varied between NE by N and N by W, with a low water depth of nine feet.

The variable depth and direction of the shipping channel resulted in efforts being made to stabilise the channel and Hutchinson[1] noted the presence of several moles and earth breast-works on Seaton Moor near the Snook. Hutchinson remarked that they had not previously been recorded by local historians, as they were then considered unnoteworthy. He presumed that they were the remains of temporary works built to defend the entrance of the Tees, and Walcott[2] imagined them to have been built about 1667.

In 1863 the depth of water on the bar at the river mouth was only 3½ feet at low water, and in that year work was started on building a large South Gare Breakwater. The completed South Gare Breakwater was over two and a half miles long in 1887, and at the beginning of the twentieth

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1. Hutchinson, W. Vol. 3. p. 43 (1794).

2. Walcott, M.E.C. Guide to the coasts of Durham and Northumberland, 1861.

century the North Gare Breakwater was about 3,000 feet long.

It had been calculated that a hundred million tons of water would pass between the pier heads at every ebb and flow of the tide, and this was considered sufficient to scour the sand from the bar, leaving a depth of at least 14 feet at low water, or an average depth of 28 feet at high water, with 20 feet up to Middlesbrough and 18 feet as far upstream as Stockton.

By 1906 there were 20 feet of water on the bar at low water and 37 feet at high water. For some miles upstream the rocks and sandbanks had been removed and miles of training walls had been built to about five feet above low water mark. Further improvements have continued and a broad deep waterway has been developed in the River Tees.

Effects of Tees Mouth Harbour

With the development of the Gare Breakwaters the erosion problem at Seaton Carew began to be solved. These harbour works have most effectively prevented the continued southerly movement of beach material, and large sand dunes have been formed on the landward side of broad flat sandy beaches. These dunes are increasing in height and width, and the hinterland of low-lying grassland is quite secure from marine inundation arising from waves overtopping the dunes.

The harbour works are small compared with the huge out-jutting promontory of Redcar and the Cleveland Hills, and the effects are very much smaller than those attributable to the larger feature.

There are still many sandbanks in the Tees estuary, but their size and shape is controlled by dredging, and the problem remains one of over-abundant beach material. In this way, Tees Harbour contrasts markedly with Hartlepool Harbour, where shortage of beach material is usually experienced.

<u>Summary</u>

The greatest development of harbour works along the Durham coast occurred during the latter half of the nineteenth century and during the present century, and little further development is planned. Evidence has been obtained which shows that the effects of the harbour works on beach processes and developments does not depend solely upon the magnitude of the works but also upon the local siting of the harbour on the coastline.

The effects of Sunderland Harbour are greater than those attributable to either the Tyne or Tees Harbours, despite its breakwaters being appreciably smaller in size. This results from the nature of the coastal area around the harbour. At Sunderland, there is not a naturally occurring abundance of beach material and the cliffs immediately to the south of the river entrance are of soft boulder clay. With such local conditions the development of the North and South Piers has been accompanied by an accumulation of beach material to the north of the harbour, and serious erosion to the south.

At Tynemouth, the river entrance is partially sheltered by Tynemouth Headland, and between the river and Trow Point sand dunes have established themselves behind a beach of fine sand. The construction of harbour breakwaters has had relatively little effect on local conditions, beyond tending to change the alignment of the beach to the south, as a result of the sheltering effect afforded by the piers from north-easterly winds. This is an area where beach and foreshore material naturally tends to accumulate, and there appears to be no shortage of such material, despite the prevention of longshore movement from the Northumberland coast.

At the mouth of the River Tees the effects of the breakwaters are dwarfed by those attributable to the easterly extension of the North Yorkshire coast, and the harbour works merely effect local disturbances in the broad sandy tracts accumulating at the river mouth. At Hartlepool the harbour has been built in the lee of the peninsula and no spectacular results can be attributed to the artificial features. At Seaham the harbour works are quite small, and although accumulations of beach material have occurred to the north of the breakwaters, the expected erosion to the south has been prevented by colliery dumping.

Chapter 8. Other Coastal Works

In addition to colliery and harbour developments, the coast has experienced great changes resulting from the general industrial character of East Durham.

Almost all the denes have been used as courses for sewer outfalls, which have been carried out to beyond low water mark. Each of these outfalls acts as a groyne, and the local effects are often quite remarkable, the difference in beach height amounting to three or four feet (Plate XIX). Some of the largest outfalls occur south of Sunderland, where there is a shortage of beach material, and they have been responsible for local accumulations of sand and shingle, which have protected the soft clay cliffs to some extent from wave attack, and small promontories have tended to remain as the sea eroded the remainder of the cliff.

The combined effects of harbour breakwaters and sewer outfalls have imposed completely artificial conditions upon beach material, and movement is very much restricted and guided. In Fig. 71(A), the siting and perpendicular lengths of all artificial obstructions to beach drifting have been plotted, based on 1 : 25,000 O.S. maps and field work. A full list showing the type of obstruction is given in Appendix C.

Local accumulations of sand and shingle, resulting from natural or artificial causes, have been exploited, and in some cases the amount of beach material carted away has been sufficient to impair seriously the effectiveness of the beach in protecting the cliffs from direct wave attack (Plate XX). The places from which beach material is exploited are shown in Fig. 71 (B) on the left of the diagrammatic coastline, and the short lines are drawn proportional to the amount of material annually removed. Local details regarding amounts and type of beach material removed are given in Appendix D. It is sufficient to note that the quantities removed are never great, amounting to only 31,000 tons annually at South Shields, the largest source of beach gravel. This is a very small quantity when compared with the quantities of colliery material dumped on to the beaches. The positions of the four main colliery tips are shown on the seaward side of the diagrammatic coastline (Fig. 71(B)).

The essential feature of human interference with the amount of beach material is that exploitation is greater in the north of Durham, where erosion is occurring, and dumping of material is greater in south Durham, where accretion is usual.

Human activities have been partially, if not completely, responsible for many instances of severe coast erosion, but perhaps the most important instance occurred north of

Seaham Harbour, where a sea wall has been constructed recently to prevent the undermining and carrying away of the main road to Sunderland. The local cliffs are of soft friable limestone, with harder calcitic veins, and these have been undercut and eroded, bringing the landward edge of the slope of glacial overburden to within a few feet of that road in some places.

Immediately north of Red Acre Point, and again north of Featherbed Rocks, the cliff-line turns at a right-angle, and under the usually accepted conditions of southerly movement of beach material, these should have been areas of accumulated beach material instead of areas of cliff recession. Photographs in Seaham Library show that fifty years ago there was a very large accumulation of beach material which provided protection for the cliffs. Removal of this material occurred on a large scale during the later, and presumably the initial, construction of Seaham Harbour, and was continued until as recently as 1949. The partial removal of the protecting barrier of shingle allowed the sea to attack the cliffs across a steep foreshore, and large waves brought about the serious cliff erosion noted above. Residential and commercial development of the cliff-top area necessitated the building of a wall to retain the cliff line in its present position, and this has been accomplished. A series of groynes is to be built out from the sea wall to retain drifting beach material and help to protect the wall itself. An experimental groyne built in 1952 showed that despite periodic reversals the net movement of beach material is southwards.

A most significant way in which the coast has been affected by human interference is the development of field drainage associated with agriculture. The channelling of rain water into subterranean pipes means that a stream of water issues from a point source in the clay slope at the cliff top and, running over clay, washes a good deal away so that erosion of a bay of clay becomes merely a question of time.

In the course of time the downcutting stream slices through the underlying limestone, and a deep incision extends from cliff top to cliff bottom. Such an occurrence is most common where the glacial overburden is thick and the limestone soft and friable, and the best instances of this type of feature occur in the vicinity of Jane Jiveson's Rock (Plate XXI).

Over-enthusiasm on the part of farmers ploughing to the very cliff edge results in some cliff-top crumbling of the clay under the weight of agricultural implements, but this is of secondary importance.

Wartime constructions have had an important effect upon the most recent development of the sand dune areas of south-east Durham. Numerous concrete pill-boxes and blocks have favoured the development of eddy currents, which have swirled sand away from the sides of some of these defence fortifications and buried others. Often the buried pill-boxes have formed the solid basis of growing and thriving dunes. Such fortifications provide evidence of continual changes in the positions of dune sands, as many pill boxes are now completely surrounded by high dunes.

The sand dunes, especially to the north of Hartlepool, have been used as a source of building sand, and in order to maintain the sea defences brick and ash rubble has been dumped in its place, thereby presenting a more solid barrier to the sea, but completely spoiling the seaside as a holiday amenity.

The importance of these human activities is small compared with those mentioned in the two previous chapters, but they do contribute something to an understanding of the present coastal features of Co. Durham and should not be ignored.

PART III

THE RESULTING PATTERN OF PRESENT DAY EVOLUTION

Chapter 9.

Co. Durham has a coastline resulting from a combination of natural geological complexity and an ever increasing amount of human activity. The gradual development of harbours has been considered, and local effects attributable to their construction have been studied. The development of the eastern concealed part of the Durham coalfield during the present century and the subsequent deposition of colliery spoil on the beaches have also been mentioned. It is now necessary to consider the more recent development of that coastline.

Not much reliance can be put on maps of the whole county before the Admiralty survey of 1831. Attempts have been made to compare earlier maps of the seventeeth and eighteenth centuries, but the distortion and inaccuracies are too great for any valid results to be obtained. Latitude and longitude graticules cannot be superimposed with any accuracy and even points of detail, though clearly and definitely mapped, have entirely different respective positions, one to another. Much of the mapped coastline is merely a wavy line, and no attempt has been made to map coastal features, the amount of copying from earlier maps being quite remarkable. It seems extremely unwise, therefore, to base any estimate of coastal changes on these old maps, and they have been largely ignored. Some large scale plans of estates or towns have been used, however, since on the larger scales the errors of surveying are relatively much less and inaccuracies are reasonably resolved.

The only conclusions which will be advanced, based on these sixteenth and seventeenth century maps, is the tendency for the sand spit joining Hartlepool headland to the mainland to become wider, and the tendency for the estuary of the Tees to become progressively silted up, leaving Yarm and Stockton as river ports of little consequence at the close of the seventeenth century.

The original 1831 Admiralty survey of the Durham coast shows the coastal features with great fidelity,[1] and since that date there have been four editions of the Ordnance Survey 25-Inch Plans (about 1856, 1898, 1919 and 1938), covering the same area.

Much thought has been given to the problem of illustrating graphically the changes along the Durham coast,

1. The original plan has been consulted at the Hydrographic Department of the Admiralty, by kind permission of the Hydrographer of the Navy, Admiral Day, 1955.

which may be deduced from an examination of the large-scale plans.[1] A direct superimposition of successive coastlines is extremely informative, but it has not been found possible to reproduce successfully black and white maps showing all the coastal changes over a period exceeding one hundred years. In order to avoid a multiplicity of maps and diagrams only selected features have been indicated on the series of maps based on O.S. 25-Inch Plans (Figs. 72-82). In all these reproduced maps, the line mapped as the cliff line is the point where the gently sloping coastal plain meets the boulder clay slope leading down to the verticle face of limestone. Almost all the cliff profiles of Co. Durham reflect the relative thicknesses of limestone and overlying boulder clay, and the line chosen as the cliff line in this discussion may be looked upon as the inner limit of the cliff. Unfortunately, the position of this line does not take into account either the thickness of boulder clay or its slope; neither does it indicate the presence or absence of a limestone facing at the foot of the cliff. On some of the first edition O.S. maps this line has not been mapped completely and interpolation has been necessary.

1. The majority of these have been examined at the Ordnance Survey Headquarters, Chessington, by kind permission of the Director General, 1953. Others have been examined at the British Museum, and at local Council Offices in Co. Durham.

A direct comparison of cliff-top lines from successive O.S. Plans is possible, but in itself it does not give a true picture of coastal changes. Measurement of cliff-top recession does not indicate the true rate of erosion, since no account is taken of the amount of the cliff foot material which has to be removed by the waves before further cliff recession is possible; nor, to take the opposite case, does it take account of the undermining and weakening of strata which has not yet resulted in actual falls. The results obtained by the superimposition of all four editions of the O.S. 25-Inch Plans are shown in Figs. 72 to 83, which cover almost all the Durham coast. The distortion of the original plan paper and tracing cloths, and interpolation on the first edition results in slight inaccuracies, but this is nevertheless an extremely useful method of illustrating coastal changes.

Before proceeding to the main discussion, it seems advisable to point out some general characteristics of the photographic reductions. On the whole, Co. Durham has not been subjected to serious coastal erosion, and the differences in the coastline as deduced from a comparison of the O.S. Six Inch Plans are often so small as to be almost impossible to map. For this reason the 25-Inch Plans have been traced and even after photographic reduction the scales are larger than six inches to the mile.

It is not intended to deal systematically nor fully with Figs. 72 to 83, since the results are quite apparent from the illustrations themselves. In this discussion I shall attempt to indicate the reasons and causes behind the changes rather than to describe the changes themselves.

South Shields - Sunderland

There has been little erosion between South Shields and Sunderland during the past one hundred years (Figs. 72 to 76), the cliff recession nowhere amounting to 100 feet. This results from a number of factors.

Between Trow Point (567 N.) and Velvet Beds (565 N.) the cliffs consist of Lower Bedded Limestone overlain by unbedded, fossiliferous Middle Limestone (Fig. 21). Plate XXII shows very clearly the contrasting features of these two divisions of the Magnesian Limestone. Along Marsden Bay the cliffs are of yellow, bedded Middle Limestone being replaced by cliffs of Upper Concretionary Limestone extending from 564 N. to Whitburn Bay at 562 N. Between Whitburn Bay and 560 N. the cliffs consist of thick boulder clay extending to below low water mark. Southwards from 560 N. the cliffs consist of Upper Concretionary Limestone and Upper Roker Dolomites extending south to the mouth of the Wear. With the exception of the Whitburn Bay area of thick boulder clay the cliffs between the Tyne and the Wear are covered by only a thin mantle of glacial material, and this has had an appreciable effect on the evolution of the cliff line. Fig. 22 shows the decline in height of the high cliffs in the Marsden Bay area south to Whitburn Bay. Reference to Fig. 2 shows clearly the narrow drainage area behind the cliff face in North-East Durham. The general absence of surface drainage should also be noted. Both these features are direct results of the narrowing northwards of the Permian series of rocks and the usually thin covering of superficial deposits.

The absence of surface drainage means that the coastal plain is unbroken by stream valleys, and there is therefore no easy natural descent to the beach. The removal of shingle and beach sand for building purposes is therefore exceedingly difficult and has not been attempted.

As a result of the thin covering of superficial deposits over the limestone and the lack of surface water, there is little necessity for artificial field drainage in this stretch of coast. Often the soils developed on the coastal plain are so thin and rubbly as to be quite dry even after showers of rain. This means that there are none of the deep notches developed at the mouths of drainage pipes coming out of the cliff face, such as are found in abundance to the south of Sunderland, where the superficial clays are thicker.

The development of the harbour at the mouth of the Tyne did not occur until the second half of the nineteenth century, and it has been possible to note the resulting changes from both written and cartographic evidence. The effects appear to be limited to the area north of Trow Point, where a re-orientation of the beach has taken place. There seems to be no evidence for suggesting that the presence of the Tynemouth pier has had a detrimental effect on the Durham coast, as there appears to have been no noticeable increase in the rate of erosion during the past one hundred years.

As a result of the high cliffs, the thin covering of boulder clay, the gentle seaward slope of the coastal plain, the absence of canalised drainage and the absence of marked human interference, this is an almost unspoiled stretch of coast, suffering but little sea erosion.

Many exceptions to such generalisations are found, however, when considering this stretch of coast in detail.

Local details of coastal changes between Trow Point and Man Haven are shown in Fig. 72. North of Trow Point there has been a recent advance of high water mark, and this is in accordance with the view that the beach south of

South Shields has been adapting itself to the changed conditions resulting from the construction of the piers. Since the commencement of work on those piers, the Commissioners' Quarry has been continually extended southwards, leaving Trow Point and an area of rock around Jacob's Well as isolated masses of limestone rising from the flat floor of the quarry, which is but little above the level of high water spring tides. Trow Point apparently suffered little cliff recession between 1856 and 1940, and the southern side almost none at all. Plate XXIII shows the southern side of Trow Point, composed of unbedded, fossiliferous Middle Limestone, topped by a variable and often thickish covering of boulder clay. Undermining of the Fossiliferous Limestone has occurred where the Lower Bedded Limestone is found at the cliff foot, and caverns have been cut in the blocky masses of Middle Limestone, but actual cliff recession has been negligible.

South from the limit of the Commissioners' Quarry there has been steady erosion into Frenchman's Bay, where some quite considerable falls have occurred. These result from the undercutting of the yellow, bedded, Lower Limestone. A line of weakness marks the abrupt change from Lower Bedded to Middle Unbedded Limestone, and erosion has there proceeded at a greater rate. The extremely thin covering of the superficial deposits results in a complete lack of surface drainage, and there is very little seepage of ground water from the cliff face.

The southern side of Frenchman's Bay suffered little cliff recession between the 1st and 4th Editions of the O.S. Plans, but there was, nevertheless, some considerable local erosion in the form of undercutting and undermining, and falls have been continuous since about 1945. The cliff edge of the bay is now very unsafe and many yards of the cliff top fencing have been broken away. One large fall from the north-east facing corner of the bay in 1946 still affords a considerable measure of protection to the cliffs behind.

Between Frenchman's Bay and Man Haven the Middle Unbedded Limestone has been carved into quite remarkable features. The boulder clay covering the Middle Limestone has been removed by rain wash and winds so that a wide expanse of grey unbedded limestone slopes gently down towards the Lower Bedded Limestone at the cliff foot. (Plate XXIV). The covering of clay is seldom more than four or five feet thick and it is speedily removed by rain water if a break has been made in the vegetational cover. When this does occur, small-scale slumping is widespread and small vertical faces of bare clay alternate with 'flats' of grassed boulder clay. The washing away of the finer portions of the clay covering leaves a mantle of stones overlying the limestone, and such is the case along almost the whole cliff top between Frenchman's Bay and Man Haven.

Fracturing of the Middle Unbedded Limestone affords lines of weakness which are etched out by the waves, and slumped limestones are often carved into arches and caverns (Plate XXV). Details of the effects of sea attack may be seen in Plate XXVI.

South from Man Haven to Velvet Beds (Fig. 73) there has been no apparent cliff recession, except for isolated instances where the north-east facing cliffs have been washed away. The Velvet Beds themselves have suffered erosion on the north-east facing side and they have probably afforded some measure of protection from dominant wave pounding to the surrounding coasts. South of Velvet Beds, into Marsden Bay, steady erosion occurred between 1919 and 1940. The washing away of soft white limestone has undermined the overlying brown broken limestone and further falls appear likely (Plate XXVII). Marsden Rock seems to shelter the neighbouring cliffs to some extent and no cliff top recession has been mapped. Just south of the Marine Grotto large falls are imminent, but these will not immediately affect the cliff-top position. The varying resistance to erosion of different beds of limestone results in undercutting, and there are periodic small falls when the undercut portion of the cliff crumbles away (Plate XXVIII). Between Smugglers' Cave and Marsden Village erosion has been proceeding at a much greater rate, and there seems little chance of its slackening.

There are several reasons why erosion should be greater at the southern end of the bay. The yellow, bedded, Middle Limestones of the northern end have been replaced by the Upper Concretionary Limestones, which are blocky, broken and extremely unstable, and fall readily when even slightly undermined. Such blocky and slabby broken limestone extends to the cliff top, with only a few inches of overlying clay. Hence, from geological considerations alone, one should expect greater erosion at the south end of the bay between Velvet Beds and Marsden Village.

There is a considerable amount of local evidence to show that the Marsden Village area is subject to subsidence resulting from Colliery workings, and this would allow the sea to attack the cliffs more strongly as the protective influence of the beaches would be reduced if they subside relatively to sea level. The effects of colliery subsidence vary greatly over short distances, with the result that local fracturing and cracking occur, often close to the cliff edge. The importance of these subsidence cracks as future lines of weakness for the sea to open out and expand suggests that erosion will continue at an appreciable rate.

Human activities may be assisting sea erosion in yet another way. Marsden Quarries are quite close to the cliff edge and the daily firing of shots to bring down the quarry face may well be responsible for shaking down some of the already unstable blocks in the sea-cliff face. No direct instances of this were noted in the field, but the shaking down of dry boulder clay and fine powdery limestone at the time of shot-firing has been witnessed by the writer.

The rapid erosion of the cliffs around Marsden Village over the past forty years has caused some concern to the inhabitants and the local authority. There are no records to prove it, but it does seem that the rate of erosion has been increasing. A bounding fence has recently been set up by East Boldon R.D.C. and it will be interesting to see how long it will be before it becomes necessary to build another (Plate XXIX).

There has been considerable recent erosion on both the north-east facing sides of Lizard Point (Fig. 74). The

Upper Concretionary Limestones are intensely broken and fractured, and are quickly broken down by the pounding of the waves. Lizard Point is mapped on the 1940 Edition of the O.S. as a peninsula, and as late as 1947 the point was quite an impressive feature. By July 1954 the point was severely undercut by the sea and breaks appeared imminent. By June 1955 Lizard Point had been broken off from the mainland and a huge gap had been formed (Plate XXX). The remaining area near Lizard Point is by no means stable and further crumbling is to be expected.

Cliff crumbling between Lizard Point and Buyer's Hole has made the cliff-top path very dangerous, and parts of the wooden fence bordering the cliffs have been undermined and removed. This stretch of folded and faulted concretionary limestone is seen in the foreground of Plate XXX. The crenulate cliff line results from the succession of anticlines and synclines, the anticlines being cut into minor bays and the synclines standing as minor headlands.

The headland immediately north of Buyer's Hole, mapped as a peninsula in 1940, has been broken through and the detached mass has been considerably reduced in height and size.

The instability of the undermined broken limestone causes the erosion in Buyer's Hole to be very rapid. The from erosion by the dominant north-east waves. The discontinuance of the practice of dumping colliery material at the cliff edge has allowed the sea to remove much of the earlier dumped material, and in parts the limestone is now being eroded. The cliff height at the southern side of Potter's Hole has occasionally been increased by as much as ten to fifteen feet with colliery waste.

South from Potter's Hole as far as Souter Point there appears to have been little recent erosion. Souter Point is a prominent feature along the Durham coast, and it may have a delaying effect upon the southerly movement of beach material similar to, but not as great as, the effects of Hartlepool peninsula. Many of the cliffs south of Potter's Hole appear to be quite stable, and near Souter Point itself there is an extensive area of shingle which completely protects the sea cliffs from wave attack.

Evidence from Fig. 74 supports the idea that local conditions are adequate to account for the formation of Souter Point beach and no eustatic changes of sea level need be adduced. At the time of the O.S. 2nd Edition the northern headland of Souter Point beach appears to have existed, and a considerable bay head beach had been developed. Twenty years later, the beach had been developed even more, and high water mark had retreated eastwards. There had been a slight advance of high water mark at the north end of the bay, suggesting that erosion of the northern headland was occurring steadily. After a further twenty years this headland was apparently broken through and high water mark advanced westwards (see Fig. 74). Erosion of the bay head beach occurred, particularly in the north, and evidence obtained in the field suggests that erosion is continuing to diminish the size of the shingle 'flat'.

South of Souter Point erosion appears to have been increasing of late (see Fig. 75) and has been quite serious at Whitburn Rifle Range, where the Upper Concretionary Limestone is very broken (Plates XXXII and XXXIII). There has been steady erosion south to Whitburn Bents, at which place the low boulder clay cliffs are often protected slightly by small foredunes. South of White Steel the height of the limestone outcrop decreases steadily.

It will be noted that at Whitburn Bents there has been erosion since 1919, but there has also been a retreat of high water mark. This apparently anomalous situation may result from the earlier erosion at Whitburn being arrested by the steady accumulation of beach material to the north of the Roker Pier, which was started in 1884. It was seen in Chapter 7 that the effects of even a small pier were considerable and extended some way to both north and south, and it may be that steady shallowing of offshore water has reduced the size of wave able to attack the cliffs in Whitburn Bay. Alternatively, the gradual reduction in the amount of shingle removed from the beach at South Bents for building purposes may well have allowed the beach to recover some of its earlier abundance of material, and so to present a better barrier to the attack of waves. Unfortunately, no records have been kept by Boldon Urban District Council of the amount of beach material removed, and it is not possible to show the connection between this removal and the rate of cliff recession. It is generally admitted, however, that appreciably less material than formerly is now removed.

For over a mile north of Roker Pier the cliff foot is protected by a sea wall of varying designs and dimensions, but always adequate to prevent erosion. It may be seen in Fig. 76(A) that cliff recession had been of some importance before the construction of this artificial barrier to the sea. The sea wall was often placed a few yards in advance of the sea cliff and the intervening space filled with refuse, so that an actual advance of the cliff top has occurred locally. The most notable instance of this has taken place at Roker Cliff Park, where Parson's Rock has been protected by a wide pavement and promenade, after the undercut portions of the Rock had been artificially removed. Fig. 76(B) shows the easterly retreat of high water mark resulting from the construction of the Roker Pier, and the reclamation of land from the sea effected by the building of the promenade.

Sunderland - Crimdon Dene

The development of Sunderland Harbour was discussed in Chapter 7, and little further need be said at this stage. South of the river mouth the shortage of beach material became more noticeable as the harbour works increased in size.

The Upper Concretionary Limestones and Roker Dolomites south of the river mouth had been carved by a pre-glacial stream into a broad valley, which later became filled by boulder clay. This results in soft cliffs occurring south of Sunderland Town Moor along the present coast line. The combined effects of Sunderland Harbour piers, together with the broken nature of the Upper Concretionary Limestone and the slight resistance to erosion of the boulder clay filling the 'Hendon' Valley, have all allowed the sea to erode the cliffs at an alarming rate (Fig. 77).

The rather obvious connection between the presence of extensive pier works at Sunderland and serious erosion to the south had been ignored for nearly two hundred years, and even today there are some who attribute the erosion at Hendon to the effect of eddy currents swinging round Souter Point in the north and advancing directly against the cliffs south of the mouth of the River Wear.

The shortage of beach material south of the River Wear is not entirely the result of the prevention of further southerly movement of beach material from the north. Until the early years of the present century shingle was removed from the foreshore and a lowering of the beach level resulted. It is recorded in the Minutes of Evidence of the Royal Commission on Coast Erosion that in the Easington area (some miles south of Hendon) the beach had been lowered some four feet between 1902 and 1907, and at Hendon the beach had been lowered "by upwards of 10 to 12 feet" since the construction of the major harbour defences 25 years before.[1] It was admitted that the removal of beach material had been the cause of much damage and this practice had been almost wholly stopped by 1911. Even after the prohibiting of shingle removal, the low rocky foreshore

1. Royal Commission on Coast Erosion. Vol. 3, Part I, 1911, p. 45, para. 12.

was covered by only a thin mantle of shingle, which was often almost completely removed during north-easterly gales.

The serious erosion of the boulder clay banks at Hendon led to the belief that the coast may have sunk slightly as a consequence of:

(1) Extensive coal mining in the immediate neighbourhood.

(2) The constant pumping of water for the use of the town and district, taking away the support and causing falls in the limestone.

(3) A material shrinking resulting from geological or other causes.[1]

Comparison of the 1st and 2nd Editions of the O.S. plans of the Ryhope area show an annual loss of about one foot per annum during the period 1856 to 1895, but in evidence before the Royal Commission it was stated that the rate of cliff recession had been much greater than that during the first few years of the present century. When it is remembered that the two large breakwaters were being built at Sunderland at the beginning of this century, the significance of this point becomes obvious.

The recent development of the coast south of Sunderland is shown in Fig. 77. The sea defence works shown in the north of (A) have periodically been broken through, and the sea wall extending southwards has on occasion been completely destroyed. Cliff top recession between 1856 and 1896

1. Lebour, G.A. in evidence before the Royal Commission on Coast Erosion.

amounted to over a hundred feet in places north of Blue House Way Foot, but since then the cliffs have been protected, even though not continuously, so that the rate of recession has been reduced.

There has been serious recent erosion over a distance of more than two miles south of Sunderland at a rate some three times greater than in the nineteenth century (Plate XXXIV). The time intervals between successive editions of the O.S. plans have become smaller,[1] but the amount of erosion between the 3rd and 4th Editions often exceeds that which occurred between the 1st and 2nd Editions over a period of more than double the length. Although this primarily reflects the shortage of beach material south of Sunderland breakwater, there are other causes to be taken into account.

South of Hendon the limestones are overlain by quite a thick covering of boulder clay, and artificial field drainage has been considered a necessity. This drainage has usually been directed across the coastal plain towards the cliff face, and, as a result, there are numerous field drains carrying sub-soil water breaking out in the cliff face (Plate XXI). The local cliff-top

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1. Approximate interval between 1st and 2nd Editions = 40 yrs
   " " " 2nd and 3rd " = 24
   " " " 3rd and 4th " = 19

recession resulting from such ill-conceived field drainage is often very considerable, and unless steps are taken to prevent the further development of field drains towards the cliff face there seems a distinct possibility that cliff recession will become increasingly more rapid. It would be more expensive, more difficult and more laborious, but not impossible, to direct field drainage towards the valleys and streams which discharge into the sea.

In addition to cutting off the source of supply of beach material from the north, human activity has allowed the sea to attack the cliffs south of Sunderland with greater force by the removal of the protecting rocks that formerly existed at the foot of Sunderland Town Moor. The effects of this lack of foresight have been remedied, to some extent, by the building of the South Docks in front of the Town Moor, with a sea wall and protecting groynes.

The lack of foreshore material at Hendon and Ryhope has been further aggravated by exploitation of the beach sand and shingle there. A great deal of material was removed during the early years of the present century from south of Sunderland, but such removal was later prohibited. The practice has now been restarted, and about 15,000 tons of beach shingle are removed annually from near Ryhope Way Foot (Plate XX).

The presence of two or three small sewer outfalls immediately south of Sunderland has led to local accumulations of beach material, and there has been some augmenting of beach material, by the deposition of rubble and ashes over the cliff face from factories and industrial plants at Hendon. Much waste material also finds its way on to the beaches south of Sunderland from the docks themselves, but the serious effects of the depletion of the beach may be clearly seen in Fig. 77. Nowhere else along the Durham coast has erosion been so rapid, and there is obviously no easy remedy for the problem of cliff recession south of Sunderland (Plates XXXV and XXXVI). Further to the south, away from the effects of that harbour, cliff recession becomes less and less (Fig. 77, Part C).[1]

Erosion north of Maw Steck has been slight (Fig. 78(A)), but there has been a tendency for the amount of cliff recession to increase between Seaham Dene and Featherbed Rocks. The proximity of the main Seaham Harbour-Sunderland road to the cliff edge has meant that even slight cliff

1. It should be noted that the O.S. 1st Edition Plan, XVI 11 like many other 1st Edition maps, does not have a well defined and clearly mapped cliff top line along all of its length, and some interpolation has been necessary by the writer. This is especially so towards the south of the map where great erosion would appear to have occurred between 1855 and 1897. Much of the difference between the 1st and 2nd Editions may result from the lack of coastal information on the earlier map.

top recession has been of considerable importance. The limestone is here quite soft and friable and offers less resistance to erosion than might be expected. The removal of decayed softer material from between the veins of calcreted harder limestone results in cliff falls which displace the overlying boulder clay so that slumping and sliding occur. The decayed material is rather softer than Chalk, and the advance of the undermining action of the sea is seen at every high tide, when the sea water rebounding from the cliff face and cliff foot is milky-white with small particles of soft white limestone in suspension.

The finer material from within the limestone is taken out to sea and is lost to the beach, but the larger boulders of concretionary and brecciated limestone lie on the beach for some time as coarse shingle. In addition to the harder fragments from within the limestone strata the beach receives a considerable amount of shingle from the overlying boulder clay. This covering of beach material is not a permanent feature of this stretch of coast and the bare rock surface of the platform is frequently exposed by destructive waves. Erosion of this platform then occurs so that when foreshore material again accumulates the platform is slightly lower. It is this slight lowering of the basal platform during periods of little beach material which allows larger waves to attack the cliffs and may lead to the eventual undermining of the sea wall at present under construction.

In addition to direct wave attack, the cliffs suffer from the effects of sub-aerial weathering. During strong easterly gales a considerable amount of fine sand is blown out of the boulder clay capping the limestone cliffs, and an easterly gale accompanied by rain causes great erosion of the clay. Rivulets and rain wash become widespread, and pebbles and boulders in the boulder clay become isolated from the main mass and fall to the beach, accompanied by a few cubic inches of saturated clay from each individual rivulet. The effects of frosts are very considerable, especially in the limestone itself, which is here full of cracks and fissures. The freeze-thaw action results in numerous quite large falls of stone.

As a result of marine undercutting and sub-aerial weathering, the top of the clay slope is within a few feet of the Seaham-Sunderland road for a distance of a quarter of a mile to the north of Featherbed Rocks. Small protective works were of no avail, and the problem could not be tackled successfully until the passing of the Coast Protection Act in 1949.

Early in 1953 a start was made on a sea wall extending from Featherbed Rocks in the south to the Social Service Camp at Seaham Hall in the north. The wall is now almost complete (Plate XXXVII). It is proposed to build thirteen groynes, 150 feet long and 250 feet apart, in front of the sea wall, to hold up the movement of beach material so that the wall is protected from the full force of north-east gales.

Much of the erosion north of Featherbed Rocks has been the result of human interference (Chapter 8), as shingle was continually removed from the beach on a considerable scale until as recently as 1949.

Locally, erosion was at a very great rate, and the siting of the Coastguard Lookout Station near the greatly eroded Featherbed Rocks has resulted in a very full record being kept of the extent and place of cliff recession. Much of the erosion on the north side of Coastguard Point was attributed to waves swinging round between that point and Featherbed Rocks, causing a whirlpool effect and resulting in considerable undercutting of the cliffs. It is recorded in the Coastguard Reports[1] that falls of as much as fifteen feet in depth have occurred,

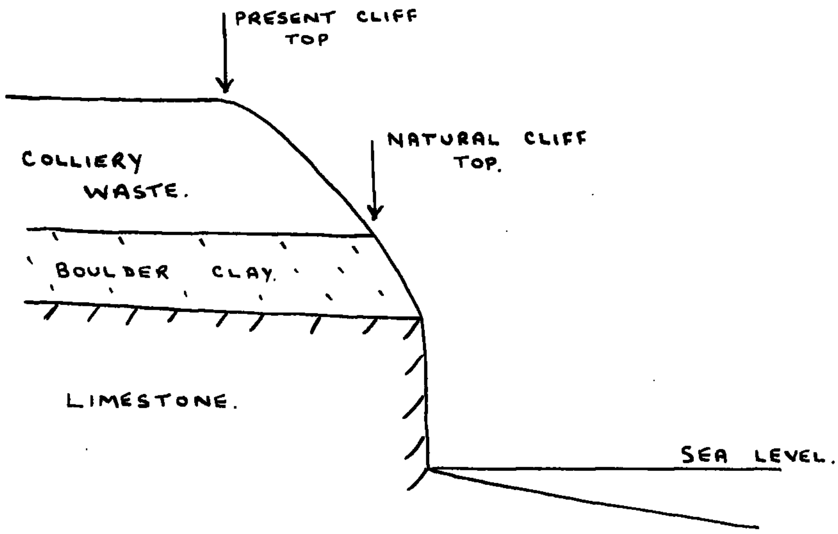
1. Consulted by kind permission of the Minister of Transport and Civil Aviation and the Inspector of the Tynemouth Division, Commander C.A. de. W. Kitcat.

and some sixty feet in depth has been lost in about a year. Eventually the Coastguard Station had to be removed and the very foundations of the site are now threatened by the sea.

South from Featherbed Rocks to Seaham Harbour little recent erosion has occurred, and almost none in the present century, although exceptional storms have broken open the harbour walls and pier base. The harbour has been built on a syncline of Upper Concretionary Limestone which had been eroded to leave numerous promontories and off-shore stacks. The west-east North Breakwater at Seaham Harbour holds up what little beach material is present along the local beach, so that there is a shortage of beach material south of the harbour. This has allowed the sea to attack the cliffs powerfully, and cliff top recession has been considerable.

To prevent further erosion, a sea wall is being extended southwards along the cliff foot and will no doubt be continued until such time as it reaches the point where the cliffs are being covered by colliery waste and so protected from sea erosion. The dumping of waste has been sufficient to advance the cliff seawards, and this has occurred all the way from just south of Liddle Stack (Fig. 78(B)) to just north of Nose's Point (Fig. 79(A).

The significance of the deposition of colliery waste on to the cliff face and beaches has already been discussed, (Chapter 6). It will be seen in Fig. 79(A) that cliff top recession has apparently occurred locally around Nose's Point, but this is not a result of sea attack. The position of the cliff top has been changed by the addition of colliery waste material, as indicated below.



Throughout the whole stretch of coast from Dawdon Colliery to south of Fox Holes (Fig. 79(C)) a marked reduction in the amount of cliff top recession has been noted, and this is evidence of the beneficial effect of abundant beach material.

Steady erosion between Dawdon Colliery and Chourdon Point occurred in the nineteenth century, but by the close of that century material was being dumped on the beaches, and there has been little subsequent erosion. On the whole, there has been a retreat of the sea along this whole stretch of coast, the retreat being usually greater in the bays, such as Shippersea Bay and Busier's Holes. Occasionally the sea has advanced westwards, the most interesting instance being at Loom (Fig. 79(C)). Before the close of the nineteenth century there was an impressive stack off-shore from Loom Point, and evidence suggests that it may have been joined to the mainland only a few years earlier. Once the promontory had been broken, erosion would presumably proceed at a great rate, so that high water mark advanced appreciably. The installation of an aerial ropeway from Easington Colliery to a terminal on the low water line in 1931 allowed colliery refuse to be dumped directly into the sea, and from that date there has been a gradual easterly retreat of high water mark at Loom Point. By 1939 the low water line was still somewhat west of its 1896 position, but it is probable that today it is east of its position at the close of the nineteenth century.

South from Loom Point and Easington Colliery even smaller changes in the position of the cliff top have occurred (Fig. 80). This results from the abundance of beach material, most of which is derived from the local collieries. Some slight cliff top recession results from the slumping and sub-aerial denudation of boulder clay, but perhaps the greatest changes have been recorded at the mouth of Castle Eden Dene.

The course of any small stream over a beach is very susceptible to movement as storms can upset the whole shape of the foreshore, but at Castle Eden the mouth of the burn has been pushed steadily southwards. Castle Eden Burn is quite a small stream during the summer months, and often dries up completely, but during the winter it has quite a strong flow. The winter flow is sufficient to enlarge meanders on the foreshore, and bluffs and slip-off slopes become well developed. The course is progressively filled in by blown sand and wave-swept shingle during the summer, so that a new course has to be cut the following winter.

South of Blackhall Colliery the easterly retreat of high water mark is greater than that recorded on any other colliery beaches, and the cliffs are safe from marine denudation. The Blackhall beach has suffered a great deal from human activities, however, and is completely spoiled.

The amount of water in Blue House Gill is considerably increased by the pumping of colliery water into the stream. The pumped water is heavily charged with coal dust, and this has encouraged some enterprising gentlemen to dam back the water to allow the coal dust to settle out and be collected. The first dam used was a natural one formed by the well-developed storm shingle ridge strengthened by boulder clay. The continued strengthening of this dam resulted in the flooding of several acres of beach between the shingle ridge and the cliff foot. The water was eventually drained off by breaking open the shingle ridge, and the coal dust dug out. A refinement of this practice is now being used. The dam is made in Blue House Gill itself, and there is less contamination of the beaches. It is to be hoped that the results of the earlier flooding of the beach will become buried by wind blown sand in a short time.

There has been some erosion of Blackhall Rocks, but this appears to have resulted largely from rainfall run-off and sub-aerial weathering rather than marine attack. Most of the caves at Blackhall have been partially filled by colliery waste material, and are no longer impressive coastal features.

The series of rather unusual cliff top features in

Fig. 81(B) results from the slumping and washing of quite thick boulder clay into small valley-forms between outcrops of limestone standing out as promontories. There are other instances along the Durham coast where thick layers of boulder clay outcrop, but this is a unique series of features. It may result from land drainage being canalised along gravel spreads, or the forms may have resulted from melting of included ice within the glacial deposits after the retreat of the ice sheets.

Crimdon Dene - River Tees

An abrupt change from limestone cliffs to sand dunes occurs some way north of Crimdon Dene, coinciding with the northern limit of the former 'Tees' Bay. There is no corresponding sudden change in the nature or the abundance of the foreshore material, however, and there is a gradual increase in the quartz grain content of the beach sands.

The sand dunes have experienced great changes in the last century and a half, but a comparison of O.S. maps does not reveal any definite pattern of development (Fig. 82). This probably results from the very nature of sand dunes. On the whole, there has been an increase in the amount of beach and dune sand, and the dunes have advanced seawards slightly. There are places where the dunes have been badly denuded, and perhaps the most noteworthy instance is immediately north of Crimdon Dene mouth. The promontory of clay on the north side of the dene formerly had quite a thick covering of sand, but this has been swept away by winds, and the clay itself has been badly defaced by bulldozers. Other denudation is currently occurring south of the dene, where wartime fortifications have been undermined and wire entanglements and fences hang suspended across great gaps blown out of the cliff top during north-easterly gales.

Denudation along almost the whole length of the dune fringed coast is attributable to a great extent to the trampling down and breaking of marram grass by holiday-makers during the summer months, and it is interesting to note that the dunes which have a good vegetational cover still have barbed wire entanglements upon them. Small foredunes have been developed along much of this coast, but their continued growth depends largely upon the amount of summer damage which they can endure. A holiday camp built at Crimdon Park has increased the popularity of the area, and further blow outs and denuded dunes are to be expected.

Exploitation of the dune sands is occurring immediately north of Hartlepool, and broken rubble and building stone is being dumped in its place. This presents a more formidable barrier to the sea, but means that holiday-makers are moving further north towards the more easily eroded small foredunes.

The abundance of beach sand is also being exploited, but care should be taken not to tax the recuperative powers of the beach too severely, as there are already signs that waves are reaching closer towards the sand hills.

Hartlepool Headland is now almost completely protected from marine denudation by a sea wall and promenade along most of its length. Some erosion occurs north of the Throston area of Hartlepool, but the dumpihg of waste rubble on the cliff-edge is reducing the rate of cliff top recession.

Erosion at Seaton Carew, which was attributed to the effects of the harbour at West Hartlepool, has been effectively stopped by the construction of a sea wall. Coastal erosion was not a new phenomenon at Seaton Carew, however, and historical records refer to the washing away by the sea of the eastern side of the old village green. Many writers believed that houses formerly stood on all sides of the village square, including the seaward.

Between Seaton Carew and the mouth of the River Tees accretion is currently occurring, and foredunes of some size have been developed immediately north of the North Gare Breakwater. A line of concrete coastal defences has guided the development of the sand dunes to a certain extent. Many of the blocks have been buried by sand, but in many cases they have encouraged the development of swirling eddy currents which have scoured out the sand. This area is rather more isolated than that to the north of Hartlepool, so that holidaymakers are fewer and the dunes do not suffer so greatly. Many of the dunes are covered by coarse marram, and appear quite stable.

The beaches between Seaton Carew and North Gare are seldom spoiled by colliery material, though pieces of coal may be found there after north-easterly storms. A laboratory analysis of beach sand would probably disclose an abundance of colliery material, but its grain size is too small to be detected in the field by general observation.

SUMMARY AND CONCLUSION

The extreme variability of the limestone coast of Co. Durham in its resistance to the sea results in the dominant north-easterly storms wasting the cliff-line at very unequal rates. The geological complexity results from the inherent character of the deposits which have been recrystallised and chemically changed since deposition. Where movement and brecciation has occurred the resistance of the rock to denudation has been increased, and the rate of removal by the sea depends more upon the resistance of the matrix. Where the matrix is quite resistant or where it makes up only a small percentage of the rock, the limestone presents a most resistant surface to the sea and the breccia tends to stand out as a headland. Where the matrix is soft and powdery or forms a large percentage of the rock mass, the harder fragments of rock may be easily removed by undercutting and undermining of the softer matrix, and bays are formed. Almost without exception the major Durham headland and bay features result from such geological differences. Minor bays and headlands resulting from local variations in lithology and structure are frequently seen along the Durham coast, and these add greatly to the complexity of coastal forms.

The limestone of East Durham is not everywhere exposed, and the overburden of glacial material may reach thicknesses of up to 200 feet, though the average thickness is very much less. The overburden surface has a tendency to be sub-parallel to the limestone surface in certain areas, but this is by no means universal, and borings are needed to determine drift thicknesses. Difficulties of boring have prevented their over-frequent sinking, but sufficient have been sunk to allow one to reconstruct a tentative sub-drift drainage pattern, in at least part of East Durham. This reconstruction shows that the drainage was adjusted to a sea level many feet below that of today, and the closeness and complexity of the drainage pattern suggests that East Durham was formerly a headwater gathering ground of rivers flowing across what is now the North Sea. The contours of this pre-glacial limestone surface were not completely obliterated by the plastering of boulder clay, and the present drainage has tended to follow the course of pre-glacial streams in many instances. Almost all the short, deeply-incised streams in East Durham have cut through the boulder clay filling of old river valleys. Most have tended to flow in a more direct course towards the sea than the older rivers, and hence have cut through some limestone spurs and bluffs.

The outcropping of pre-glacial valleys extending to below present sea level along the present coastline is a factor of some consequence in the present evolution of the coast. Wherever the limestone cliff-face is broken by a drift-filled pre-glacial valley, an area of potentially rapid cliff-recession is formed. Major breaks in the limestone cliffs attributable to a former drainage pattern occur immediately south of South Shields, at Whitburn, at Hendon, at Castle Eden Dene, between Crimdon Dene and Hartlepool, and south of Hartlepool into Tees Bay.

At South Shields, Whitburn and around Hartlepool sand dunes have been thrown up in front of low-lying marshland, and erosion has been stayed by the accumulation of wind-blown sand. Over a long term these features have all proved unstable along the Durham coast and erosion of the dunes has frequently been alluded to in historical writings.

At Hendon and Castle Eden Dene no records of sand dunes have been found, and the sea has been able to attack the infilling of boulder clay and sands and gravels. As a result of its lower resistance to denudation the glacial material has been washed away at a faster rate than the limestone, and bays have tended to be formed. But the points at which greatest erosion occurs no longer depend upon solely geological conditions. Many artificial features and conditions have been imposed upon the coast of Durham and the simple, naturally-occurring pattern of brecciated headlands and intervening bays in softer material is no longer typical.

Much material on the Durham beaches has not been derived from normal cliff denudation, but has come from artificial tips of waste material. The greater part of this waste is dumped on the beaches southwards from Seaham Harbour, to the great advantage of the beaches south of that point. As the rate of cliff recession depends largely upon the rate at which the sea can remove the spoils of previous denudation, the addition of large masses of material has delayed the advance of the sea. In some places, indeed, dumping has been sufficiently great to lead to a seaward advance of the coast. This is certainly so at Castle Eden Dene mouth, where the drift-filled pre-glacial valley has been protected from marine attack by an ever growing beach of Coal Measure sandstones and shales derived from Horden and Blackhall Collieries.

The steady southward movement of beach material under the influence of dominant north-east winds is interrupted by many groynes and harbour breakwaters along the Durham coast, and local excesses and deficiencies of beach material result. Almost all the major accumulations of beach sand and gravel have been exploited, in some instances unwisely so (as at Featherbed Rocks and Seaham Harbour, where coast erosion has occurred). To the north of Hartlepool, such huge amounts of material have been removed as to cause some concern for the permanence of the local sand hills.

The shortage of beach material south of groynes and other obstructions to beach drifting has been aggravated in some instances by exploitation. The worst instance is at Ryhope, south of Sunderland, where despite rapid cliff recession and an obvious shortage of beach material, mechanical excavators daily remove many tons of foreshore material.

There is one most noticeable exception to the generalisation that foreshore material is not abundant south of beach obstructions along the Durham coast. This occurs south of Seaham Harbour, where there is indeed a shortage of naturally occurring beach material, but an abundance of material derived from local collieries. This is sufficient to protect the cliffs, and the effects of abundant beach material extend far to the south.

It is not difficult to divide the Durham coast very broadly into two stretches (a) north of Seaham Harbour, where coastal morphology depends upon geological and physical conditions rather than human activities, and (b) south of Seaham Harbour, where the reverse tends to be true. But a finer division will be attempted, in the light of more detailed information.

1. Immediately south of the River Tyne The south-east trending coast between Tyne Harbour and Trow Point consists for the most part of blown sand overlying boulder clay, which fills an old mouth of the River Tyne. The older dunes have been considerably altered by ballast dumping, and excavations and levelling associated with the development of typical seaside amenities at South Shields. A promenade and sea wall have been built along the whole of the northern half of this section, and, since the beach has become quite re-orientated as a consequence of the presence of the Tyne breakwaters to the north, this section of the coast should be considered artificial.

2. Between Trow Point and Whitburn Bents A platform of limestone with only a thin covering of superficial deposits slopes gently seawards to end in vertical cliffs. These cliffs have been intricately carved by the sea into fantastic shapes. Stacks and offshore rocks abound, and as there are few artificial features this is possibly the most natural piece of coastline in the whole county.

3. <u>Between Whitburn Bents and Hendon</u> At Whitburn Bents the low cliffs are of boulder clay protected by small sand dunes. Southwards towards Sunderland the cliffs increase in height and the limestone reappears. A sea wall increasing both in height and width southwards from the Bents to Roker Pier has been built along almost the whole length of the coast. This has been used as a promenade and it is sited many yards in front of the old sea cliffs at Roker. The promenade and sea wall have stabilised the great mass of sand and gravel which accumulated on the north side of the Roker Pier. This is an entirely artificial coast, and even the lower reaches of the meandering Cut Throat Burn have been converted into a boating and bathing pool.

4. <u>Hendon to Seaham Harbour</u> The artificial mouth of the River Wear at Sunderland Harbour is protected by extensive moles and walls. South of the harbour are the boulder clay cliffs formed of the superficial deposits filling the pre-glacial 'Hendon Valley'. These give way southwards to limestone cliffs topped by quite thick deposits of sands and gravels which have been etched into deep notches and denes by post-glacial drainage. The varied lithological character of the cliffs results in

multiple bays and promontories, but the development of the cliffs under marine attack has been affected in no small way by the presence of the Sunderland piers to the north and the effects of badly designed land drainage.

5. Seaham Harbour to Crimdon Park At four separate points along this stretch of coast large quantities of waste material are being added to the naturally occurring beach material. The resulting abundance offsets the effects of Seaham Harbour and the beaches afford adequate protection from marine denudation to the cliffs. The cliffs suffer sub-aerial denudation and are slowly developing into grassed slopes leading gently down to the beach.

6. Crimdon Park to Tees Mouth The sand dunes seldom attain a height of more than 70 feet, but extend almost continuously along this southern stretch of coast. The dunes have been altered in some measure by tipping and excavation, but on the whole this has not affected the essentially natural character of the coast. The dunes result from the piling up of wind blown sand from broad sandy beaches, which themselves have been formed by essentially natural processes.

The Durham coast is not one of grandeur or great beauty, but is of great interest in detail. Even the finest cliffs are only 100 feet high, and there are no well developed coves or bays. Some quite striking scenery results from the presence of the incised denes, but the general impression is one of monotony and 'sameness'. The sand dunes in the south afford a welcome change from this monotony.

The exploitation of sand and gravel resources has not always been wisely undertaken in Durham, and this has resulted in serious problems of coast defence. Such problems would have been even greater were it not for the tipping of colliery material on to the foreshores, which has been of the greatest benefit to the beaches. It is probable that the beneficial effects of dumping have exceeded the adverse effects of harbour development and foreshore exploitation. It hardly needs stressing that the effects are 'beneficial' only in the sense that erosion is prevented. The nature of the beach is deplorably worsened, and few can take pleasure in beaches so blackened by colliery spoil.

ACKNOWLEDGMENTS

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I am deeply indebted to Mr. C.W. Holmes, Resident Tutor, St. Cuthbert's Society, Durham, for commenting upon the manuscript.

APPENDIX A

NATIONAL GRID REFERENCES OF ALL PLACE NAMES MENTIONED IN THE TEXT

Aycliffe	285.225
Ayre's Quay	390.577
Batter Law	405.460
Beacon Hill	440.454
Beacon Point	444.455
Bent's House	373.668
Billingham	460.229
Blackhall Colliery	455.395
Blackhall Rocks	472.390
Black Midden Rocks	371.688
Blue House Gill	475.383
Blue House Way Foot	411.555
Boldon	363.613
Boldon Flats	340.620
Boldon Hills	350.602
Bowburn	308.378
Bradbury	315.285
Bran Sand	560.250
Brierton	475.300
Building Hill	400.565
Burnmore	310.517
Busier's Hole	444.440
Byer's Hole	411.639
Castle Eden Dene	455.407
Chester-le-Street	275.512
Chourdon Point	443.465
Church Street	400.580
Claxheugh	348.563
Cleadon Hills	395.638
Cleadon Village	380.620
Coastguard Point	388.665
Cold Hesledon	415.466
Collingwood's Monument	373.692
Crimdon Beck	485.366
Crimdon Park	479.372
Crofton Heugh Headland	528.336
Cullercoats	363.715
Cut Throat Dene	406.602

Daldon Towers	421.487
Dalton-le-Dale	409.481
Darlington	290.145
Dawdon Colliery	435.482
Dawdon Dene	430.499
Deptford	383.577
Durham City	273.425
Easington Colliery	435.439
Easington Village	416.435
East Boldon	363.613
Elwick	455.322
Featherbed Rocks	430.499
Ferryhill	290.326
Flinton Hill	342.546
Fox Hole	446.437
Frenchman's Bay	390.661
Fulwell	400.596
Fulwell Hill	385.598
Fulwell Valley	375.620
Galley's Gill	392.574
Gateshead	250.620
Gore Burn	365.390
Greatham	491.277
Greatham Creek	530.265
Grindon	396.252
Grindon Kame	359.546
Harbour Quarry	411.637
Hart Railway Station	483.363
Hartlepool	526.340
Hartlepool Cemetery	510.350
Hartlepool Slake	522.340
Harton	380.650
Hastings Hill	352.545
Haswell	375.432
Haverton Hill	500.228
Hawthorn Dene	440.459
Hawthorn Village	419.456

Hedworth Brook	336.630
Hendon	409.555
Hendon Bay	411.555
Herd Sand	375.677
Hesledon	415.466
Hetton-le-Hole	354.477
Heugh Hall	320.385
High Barnes	373.558
High Haining	356.509
High Newport	383.539
Holey Rock	408.593
Horden Colliery	443.410
Houghton-le-Spring	342.502
Howdon	330.664
Humbledon Hill	380.552
Hurworth Burn	408.338
Hylton	353.567
Jacob's Well	387.665
Jane Jiveson's Rock	415.536
Jarrow	330.654
Jarrow Slake	345.654
Kelloe Beck	364.384
Lambton Drops	394.573
Liddle Stack	436.486
Limekiln Gill	448.418
Lizard Point	410.642
Long Scar	530.314
Loom Point	444.444
Lot's Wife	401.648
Mandale	465.182
Man Haven	395.659
Marine Parks Road	370.672
Marsden Bay	398.650
Marsden Grotto	400.647
Marsden Quarries	399.641
Marsden Village	402.642

Maw Stack	423.512
Middlesbrough	490.200
Mill Dam	360.670
Monkwearmouth Church	401.585
Moorsley	338.455
Mordon	328.265
Murton Colliery	395.470
Nanny Rain's Springs	414.544
Newbottle	337.515
Newcastle	250.640
New Herrington	335.526
Newport	484.195
North Gare Sand	540.275
North Hylton	350.570
Northumberland Dock	340.663
Nose's Point	438.480
Old Cassop	336.395
Parson's Rock	407.597
Penshaw	330.538
Penshaw Hill	335.545
Peterlee	425.410
Piercebridge	210.156
Pittington	325.448
Port Clarence	501.216
Portrack	462.198
Potter's Hole	413.636
Prior's Haven	375.693
Quarrington Hill	335.375
Raisby	349.359
Raisby Hill	350.353
Red Acre Point	432.496
Redcar	595.250
River Browney	272.384
Deerness	254.409
Don	340.652
Gaunless	213.307

River Skerne	290.100
Stockley	240.359
Team	233.625
Twizell	279.516
Tyne	370.685
Wansbeck	300.855
Wear	410.580
Roker	400.590
Roker Pier	409.588
Ryhope Colliery	405.532
Ryhope Dene	421.519
Ryhope Way Foot	417.532
Salterfen Rocks	415.541
Seaburn	405.596
Seaham Dene	425.505
Seaham Hall	419.506
Seaham Harbour	429.495
Seaham Village	420.505
Seaton Carew	524.299
Seaton Snook	530.280
Sedgefield	355.289
Sharpness Point	371.699
Sheepfolds	395.575
Sheraton	440.350
Sherburn Hill	334.421
Shields Lawe	365.676
Shippersea Bay	443.453
Shippersea Point	444.450
Silksworth	375.527
Smuggler's Cave	401.648
Souter Point	415.626
South Farringdon	368.522
South Gare Sand	555.265
South Hetton	376.453
South Shields	365.665
St. Hilda's Church	360.671
Stockton	442.188
Sunderland	395.575
Sunderland Town Moor	412.572
Team Valley	233.625
Tees Bay	550.270
Thornley Colliery	370.396
Thornley Village	362.395

Throston	492.332
Trimdon Colliery	380.358
Trimdon Grange	368.357
Trimdon Village	370.342
Trow Point	385.667
Tunstall	391.534
Tunstall Hill	392.544
Tunstall Hope	415.530
Tyne Dock	353.653
Tynemouth Weather Stn.	374.694
Tynemouth	360.685
Vane Tempest Colliery	426.501
Velvet Beds	398.656
Warden Law	370.505
Warren House Gill	447.423
Warren Point	446.427
Washington	310.565
West Hartlepool	510.325
Whangdon Hill	440.340
Wheatley Hill	377.392
Whitburn Bay	406.603
Whitburn Bents	408.611
Whitburn Rifle Range	412.625
Whitburn Village	408.619
Whitehill Point	352.665
Whitehouse	425.229
White Steel	413.620
Wingate	440.369
Wingate Grange	393.369
Wingate Hill	380.370
Witton-le-Wear	146.312
Wreath Quay	391.579
Yarm	419.128

APPENDIX B

Statistical Analysis of East Durham

Four common statistical methods of analysis have been used, viz.:

1. Altimetric Frequency Curves.
2. Generalised Contours.
3. Superimposed Profiles.
4. Planimetric measurement of contours.

Throughout the statistical examination the present topography has been considered, and no allowance has been made for the thickness of superficial deposits covering the bed-rock. The greater part of the Permian of Durham is covered by only a thin deposit of superficial material, and the results obtained do not become invalid on this account. Where post-glacial surfaces have been developed, they are clearly indicated by the statistical methods adopted.

1. Altimetric Frequency Curves

Altimetric frequency curve statistics for the Permian area of East Durham have been compiled from O.S. One Inch maps.

Curves A and D (Fig. 3) show maxima at 110 feet, 210 feet, 310 feet, etc., and at 50 feet, 150 feet, 250 feet, etc. Minima occur at 90, 190 and 290 feet, etc., and 130, 230, 330 feet, etc. This suggests a personal error of inspection and estimation in opposite directions on either side of the mapped contours of the O.S. One Inch

Series. This personal inspection error has been found to be a common characteristic,[1] and it is essential, therefore, to adopt a wider class grouping than 20 feet for statistical analysis of O.S. One Inch maps.

Curves B and C are sub-parallel, despite the different class groupings, and greater reliance may be placed upon them. In curves B, C, F and H absolute maxima occur between 150 and 180 feet. These maxima result from the occurrence of the post-glacial 190-feet surface, which is so prominent a feature in the River Tees Valley below Darlington.

Curves A, B, C, D and F all show a maxima just above 300 feet, and most of the 'highest points' at that height result from the broad area of ill-drained bog between 270 and 350 feet, so well developed in the Bradbury-Sedgefield area south of the Ferryhill overflow channel.

The maxima above 400 feet indicate the plateau surface of East Durham occupying a considerable area between 400 and 500 feet.

There is a small but important series of maxima at 620 feet representing the high hillocks rising above the plateau surface at its western side. These have often been considered to be monadnocks.

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1. Hollingworth, S.E. The Recognition and Correlation of High-Level Erosion Surfaces in Britain: A Statistical Study. Quart. Jour. Geol. Soc. Vol. 94, 1938, pp. 55-84.
Hollingworth found that preferential omissions had been made by O.S. draughtsmen of summit levels near the contoured heights, which accounted for minima he had detected on the O.S. Popular Edition.

2. Generalised Contours

The statistical data obtained in the preparation of the altimetric frequency curves has been used in the preparation of generalised contours (Fig. 4).

The land over 600 feet is restricted to the south-western corner of the Permian country, with the exception of a conical hill at G.R. 4370, 5505, the gravel hill of Warden Law. South of National Grid Line 534N, the land slopes gently south-east towards the River Tees, with a very broad expanse of country between 300 and 400 feet O.D. in the Bradbury-Mordon Carrs area. North of Grid Line 534N the slope of the country is towards the east and east-north-east, with the trend of the contours swinging round towards the N.W. and W. in the northern half of the county.

The land over 500 feet O.D. at 444.534 results from glacial deposition; the limestone in the Sheraton area is covered by quite well-developed kames which have distorted the run of the generalised contours. If these superficial deposits are ignored, the extent of the 400-500 feet plateau is even greater.

3. Superimposed Profiles

Superimposed profiles based on O.S. One Inch maps were unsatisfactory, both on account of the small relief of the area under consideration, and the large contour interval. The 1 : 25,000 Provisional Edition maps were used, and the results are shown in Fig. 5. No attempt has been made to orientate the profiles along either the dip or strike of the Permian beds; the National Grid Lines have been used throughout.

West-East Profiles

The west-east profiles show very clearly the sloping nature of the limestone plateau between 400 and 500 feet O.D. The general absence of profile bunching results from the westward retreat and increasing elevation of the limestone escarpment, and the associated gradual lengthening and rising of the profiles as they are superimposed from north to south. A line drawn on the figure from 550 feet at 430 E. to 150 feet in the east passes through areas of greatest bunching and may be looked upon as an ideal profile. It is worth pointing out the kame at Whangdon Hill (444.E), rising to 512 feet as a conical peak above the general plateau level.

Great bunching of the profiles occurs at 150-350 feet between 430.E and 435.E. The upper bunching (200-350 feet) results from the Bradbury-Mordon Carr area sloping towards the River Skern. The lower bunching (140-200 feet) results from the easterly slope of the River Tees marshlands eastwards of Darlington, and also the easterly slope of the marshland of the River Don towards Boldon. The only other area of bunching from 448.E. to 453.E., results from the superimposition of the profiles of the Lower Tees marshlands.

The general pattern of profile lines between 100 feet and 400 feet is not simple, and the crossing of profiles is largely attributable to the gradual northerly reduction in the width of the Permian strata to an apex just south of the River Tyne outlet, and the deeply incised nature of the Durham Denes.

South-North Profiles

As a result of the triangular form of the Permian country the number of profiles extending the full distance between 520.N. and 568.N., in the area under consideration, is not numerous. The value of the superimposition, therefore, tends to become less towards the north of the county.

The profiles show quite clearly the gradual decrease in elevation of the hill tops from 700 feet in the south to 250 feet in the extreme north. The most notable hill projecting above this plane is Warden Law (551.N.) rising to 646 feet O.D.

There is very little plateau surface bunching between 400 and 500 feet, the regional slope being towards the east and each successive profile being lower than the one immediately to the west. This results in a series of sub-parallel profiles rather than bunched profiles.

Southwards from 535.N. there is a remarkably well-developed bunching of profiles, falling from 450 feet O.D. in the north to 250 feet at 525.N. in the south. This is the Bradbury-Mordon Carrs area, which has been so well displayed in almost all the statistical examinations.

Between 520.N. and 535.N. the Tees lowlands are responsible for further bunching of profiles at about 50 feet O.D., and there is a secondary bunching of profiles at about 190 feet between 520.N. and 524.N.

The only instance of bunching in the northern sections occurs between 561.N. and 566.N., where the Boldon Flats result in bunching at about 100 feet O.D.

The south-north profiles show very clearly the deeply incised streams and in certain instances, e.g. at 537.N., it is almost possible to trace the winding course of the dene through successive profiles.

4. Planimetric Measurements

During the winter of 1952, Miss E.M. Shaw[1] made a planimetric measurement of East Durham, measuring the area mapped out by each 50-foot contour on the relevant O.S. One Inch maps. The limits chosen by Miss Shaw in her work correspond to the One Inch sheet boundaries, National Grid Lines, or purely arbitrary boundaries, as this is merely part of her planimetric measurement of the whole Alston Block. Miss Shaw has measured East Durham in four areas (see Fig. 6), and an area-height curve has been drawn for each, so that direct comparison is possible.

In the north, area C includes the very flat area around Boldon and Jarrow Slake, which just reaches a height of 140

1. Department of Geography, Durham Colleges.

2. I am indebted to Miss Shaw for allowing me to use the statistical data she obtained, and also to Dr. Maling for drawing up the area-height curves for East Durham.

feet, and this is very well illustrated in the appropriate area-height curve. In area C the Permian country occupies only a relatively small area, and the 400-500 feet plateau surface is indicated by no more than a slight flattening of the curve at 450-500 feet.

Area F is probably the most representative area of East Durham, showing the true Permian surface with only a thin covering of superficial deposits and almost none of the post-glacial surfaces resulting from base level changes or lake surfaces. The plateau nature of the Permian country between 400 and 500 feet is definitely its most significant feature, though in curve F there is a slight development of the 320 feet surface, which tends to detract from its significance.

Area J is complicated by the presence of the 320 feet post-glacial surface in the Wear Valley to the west of the Permian escarpment, and by the extensive post-glacial surface of Bradbury and Mordon Carrs south-east from the Ferryhill Gap. Between them, these post-glacial surfaces are responsible for the lower of the two peaks in the area-height curve of area J, so that the plateau surface appears to be of secondary importance. It will be noted that the Permian rises to considerably greater heights as it approaches the Pennines than it does further to the north-east in area C.

The curve for area K again shows the plateau surface at 400 to 500 feet, and there is also a considerable amount of land between 300 and 400 feet. Area K extends sufficiently far south to show part of the important physiographical unit of the Tees-Hartlepool Lowlands at about 30 feet.

The combined curves show clearly three significant platforms already noted: namely, the plateau surface between 400 and 500 feet, the post-glacial lake surface at 320 feet, and the 140 feet surface around Boldon.

The results of the statistical examination may be summarised by means of a table showing the heights at which maxima occur, using the methods of analysis.

Height	Highest Points per square K.M.			Highest Points per $\frac{1}{4}$ sq. K.M.			Highest Points per 4 sq. K.M.		Generalised Contours		Area Height Curve	Super-imposed Profiles	
	Grouping			Grouping			Grouping		4 sq. Kms.	16 sq. Kms.	Total area	N-S	E-W
	20	40	60	20	40	60	20	40					
700													
			630	630	630	630							
600	610	620		610			620						
				570									
							540						
500	510	500	510	510				510	500	500			500
	470								↕	↕			↕
			450	450		450			↕	↕			↕
400	410	420		410	420		420		400	400	420		400
	350			350					↕	↕		350	
			320			330			↕	↕	320	↕	340
300	310	300		310					300	300		↕	↕
					280							↕	↕
	270			250			260					250	250
200	210			210									
	170	180		170	180		180					190	190
			150			150		150	150	150			↕
100	110			110							120		100
	50				60		60		50	50		80 50	
				30									
0													

33. West Hartlepool Pier.

34. and 35. Sewage Pipe.

36. Pier, West Hartlepool.

37. Sewage Pipe.

38. North Gare Breakwater, Tees Mouth.

<u>Sea Walls along the Durham Coast</u>

<u>See Fig. 71 Part (A)</u>

A. South Shields promenade.

B. Short length of sea wall in Byer's Hole.

C. Sunderland and Seaburn sea walls.

D. New sea wall, Seaham Harbour.

E. South sea wall, Seaham Harbour.

F. Hartlepool and Seaton Carew promenades.

THE FORESHORES OF CO. DURHAM

See Fig. 71 (B)

A. Foreshore at South Shields

The annual tonnage of sand removed fluctuates somewhat, since in some years it is impossible to remove substantial quantities of sand without detriment to the beaches as a holiday amenity. The tonnage removed in the year 1953-54 was 22,500 tons and in 1954-55 31,000 tons. In 1955-56, however, accretion was much less than usual and the tonnage removed will be much less. Occasionally some sand is removed from the North Foreshore, but the majority is taken from the South Foreshore. There is no usable quantity of beach gravel.

B. Foreshore at Whitburn

Although there is not an abundance of beach material, some sand and shingle is removed for building purposes though no records have been kept of the annual tonnages. Beach material at Seaburn is removed at a rate of about 2,000 tons per annum, and at Roker the rate has been 8,000 tons per annum, though this is to be reduced considerably.

C. Foreshore at Ryhope

Despite the lack of beach material, gravel is removed from the foreshore at Ryhope at the mouth of the Tunstall Hope overflow channel. Ease of access to the beach by a concreted ramp has allowed mechanised excavation to remove approximately 15,000 tons per annum, though the wisdom of such activity is very much in doubt as coast erosion is very severe. The beach material consists mostly of angular shingle fallen from the adjacent cliffs.

D. F. and G. Foreshore at Dawdon, Easington, Horden and Blackhall

The mechanical sorting and hand grading of mechanically cut and loaded coal is not 100 per cent efficient, and much coal is dumped on to the foreshores with the stone. The collection and sale of this 'sea coal' has provided a source of employment and income for over 30 lorry owners who are to be seen on the foreshores at each low water. Ease of access means that greater numbers are to be seen on the Horden-Blackhall beach than elsewhere. Although no records are available, it is believed that some fifteen to twenty thousand tons of coal are removed annually in this way from the foreshores.

1, 2, 3 and 4 are the points of dumping.

H. Foreshore at Hartlepool

About 2,000 tons of beach sand are removed annually from the foreshore at Crimdon, and some wind-blown sand is removed from dunes above high water mark. The North Sands at Hartlepool have provided many thousands of tons of beach sand for building purposes, and it is believed that the quantities removed during the summer of 1954 and 1955 were sufficient to lower the beach profile some feet, so that at high water the waves came up to the foot of the sand dunes. The recuperative powers of the beach may be sufficiently great to overcome such activity if not continuous.

About 14,000 tons of sea sand are removed annually from immediately south of West Hartlepool where there is little likelihood of its affecting the slope of the beach profile.

APPENDIX E

THE RECENT DEVELOPMENT OF THE DURHAM COAST

See Fig. 71 Part (C)

The development of the Durham coast is greatly influenced by human activities, and Fig. , Part (c) summarises the more recent development.

A, D, H, J, L, and X indicate areas where sea walls make coastal erosion unimportant.

At M, O, Q, S, and U the beaches have been increasing in size largely as a result of colliery dumping. At Y. increasing amounts of foreshore material result from the groyne effects of the Nore Gare Breakwater at Tees Mouth.

Elsewhere along the coast there has been coastal erosion, being greatest where the thick black line is farthest to the left of the axis. The great erosion at I is attributable to the presence of the Sunderland Harbour breakwaters immediately north of boulder clay cliffs.

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