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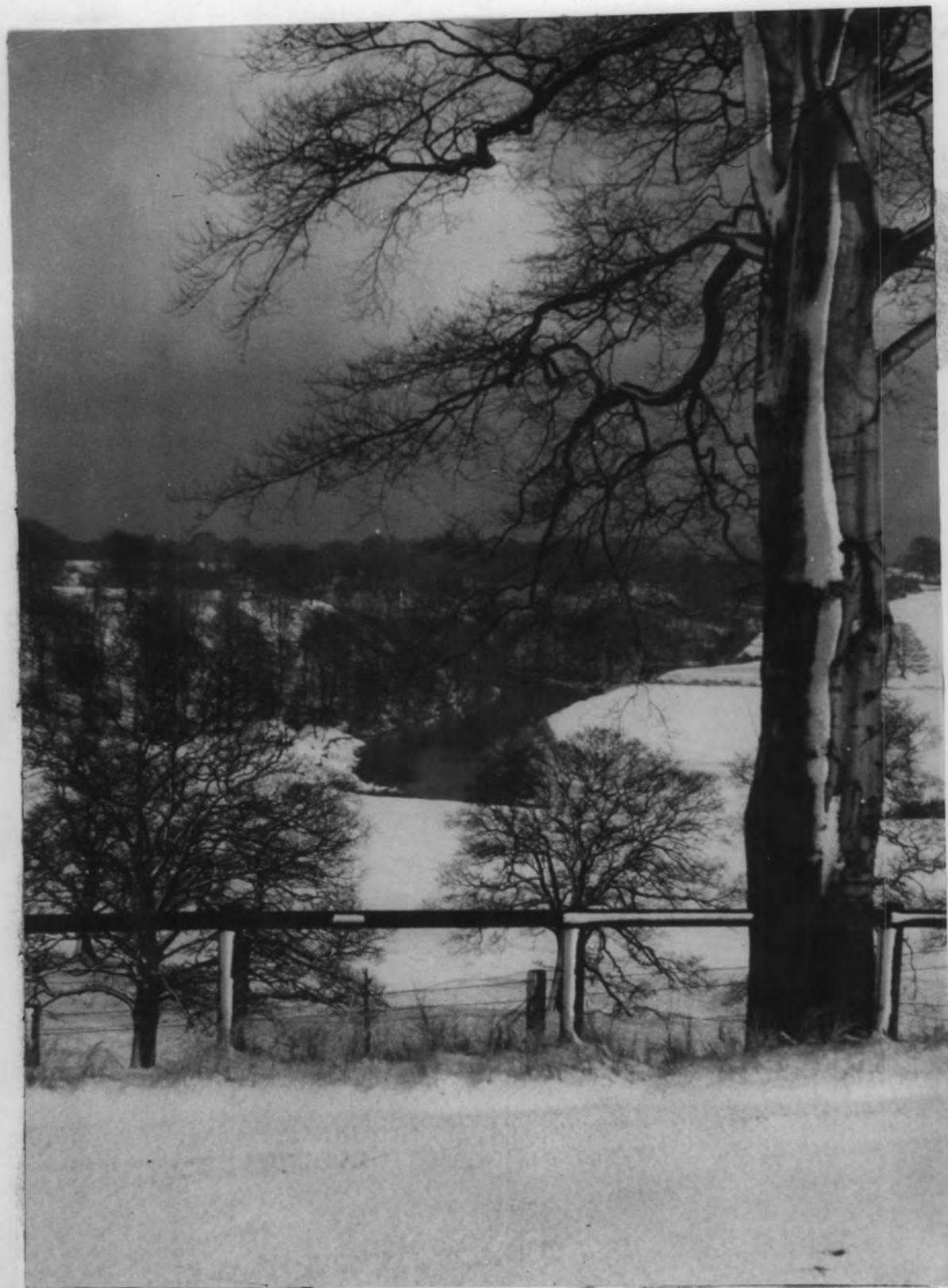
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THE GEOMORPHOLOGY OF THE WEAR VALLEY.

by D.H. Maling.

Thesis submitted for examination for the degree of Doctor of Philosophy, Durham University, October, 1955. Based upon research carried out from the Department of Geography, Durham Colleges, under the supervision of L. Slater Esq., M.A. and with the aid of a Nature Conservancy Research Studentship 1952-1955.





The River Wear. Incised meander near Cocken

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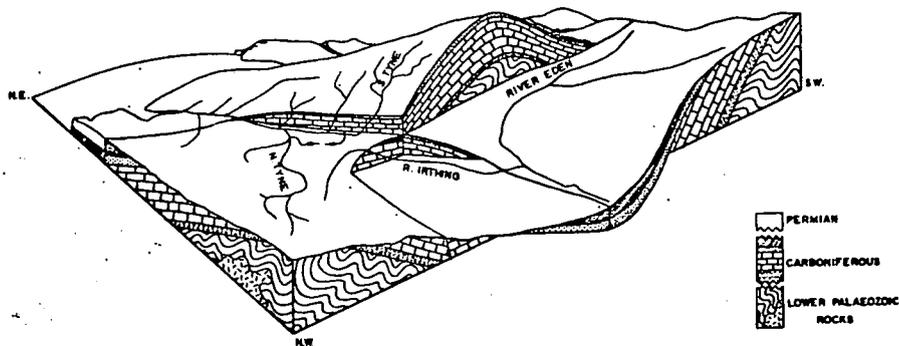
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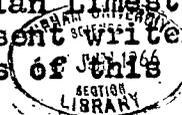
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INTRODUCTION.

This thesis has been written to summarize the results of three year's research. It is a detailed study of many aspects of the morphology of a single river system, in a part of Britain which is remote from those areas exhaustively studied by three generations of geomorphologists. Consequently, the evolutionary record appears, at present, to be most incomplete. When correlation with adjoining areas can be made, when the results of contemporary work elsewhere in Northern England are available, the significance of certain landscape features may be recognised. At present, the writer cannot provide a full account of the evolution of the River Wear or its associated land forms. This thesis describes and discusses certain specific problems which have arisen in consequence of the general survey. The texture of this thesis is loosely knit, for, within its scope are many aspects of the morphological evolution of the area. No single thread of evidence can be followed far enough to give any measure of continuity ~~to~~ ^{between} the different chapters.

The country examined during the course of field-work lies almost entirely within the present confines of the Wear drainage system. This has an area of roughly 500 square miles. It has not been possible to study the whole of the area with equal attention to detail, nor is this desirable in a tract of such varied relief. Field-work was curtailed during two summers, in 1952, by outbreaks of foot-and-mouth disease, in 1954, by persistently bad weather. Consequently, the extreme south of the area, the tributary valleys of the River Gaunlegs and Linburn, have only received superficial examination in comparison with the remainder. Plans for much additional work were abandoned owing to lack of time. For example, it has not been possible to complete the height determination for the longitudinal profiles of certain tributary valleys.

The programme and area of field study was modified, from time to time, to take account of the investigations of other geomorphologists who were working in adjacent areas or concerned with similar problems. The evolution of the Durham coast has been studied by W.A. Westgate from this Department. In order to avoid duplication of labour, we have divided the work of examining borehole records for the coastal fringe of North East Durham, the Magnesian Limestone Plateau and the Wear Estuary. During the same time, R. Hopkinson, of the Geography Department, Birmingham University, has been making a study of the morphology of the Magnesian Limestone Plateau as a whole. For this reason, the present writer has avoided detailed field-work on the uplands of this tract, although



it is almost certain that there has been an overlap in our respective studies. Similarly, R.L.Wright, of the Geography Department, Sheffield University has been studying the upland surfaces of the Alston Block for an M.Sc. degree. For this reason, the present writer intended to limit the discussion of early Tertiary evolution to an examination of conclusions already published and to that statistical work which was completed before Wright began his work. Since, the author disagrees with certain conclusions of Wright, it has been necessary to amplify the introductory chapters to take account of this recent work. During 1954, P.L.Bowes, of Leeds University, studied the morphology of Weardale for his undergraduate dissertation. The present writer was able to suggest suitable topics for investigation and wishes to acknowledge the great assistance given by Bowes during his period in the field.

In this thesis, the introductory chapters on the geological structure and Tertiary evolution of the whole Alston Block form a necessary preliminary to the detailed study of the Wear Valley. The author must emphasize that he has not worked elsewhere in the Northorn Pennines. The area studied for this thesis is only one-third of the whole Alston Block defined in Chapter 1. With the exception of certain statistical studies which have been made of the whole Alston Block (Chapter 3), the author can contribute little to detailed knowledge of the remaining two-thirds of this morphological unit. However, the statistical approach has suggested certain lines of evidence which have been followed within the area of field study. In order to avoid an overlap of work with Wright, investigations of the upland surfaces of the Alston Block were discontinued, and the writer has concentrated upon a detailed examination of the West Durham Sandstone Plateau to look for multiple platform surfaces which may represent successive stages of the late-Tertiary evolution of the landscape. Related to this problem is that of the significance of the high-level terraces of the Carboniferous Limestone tract of Weardale, some of which may be graded to the levels of these platforms. These prominent shelves on the valley sides have hitherto been regarded as features caused by differences in the lithology of the Carboniferous succession. In this thesis, the author has attempted to discover whether these shelves are, indeed, entirely dependent upon lithological variations in resistance to normal erosion or whether certain of them reflect early cyclical development of the valleys.

The next line of evidence is supplied by the buried drainage system which may be pre-glacial in origin. The author believes that this enquiry into the sub-drift topography of the Durham coalfield has provided some of the most important conclusions contained in this thesis. It has

been possible to determine the pre-glacial drainage pattern with some degree of reliability and it has been possible to show the shape and nature of the valley in certain important areas. Although the present evidence is remarkably detailed and it is probable that no other part of Britain has been so exhaustively examined by boring, there are still important breaks in the evidence. Until the continuity of the buried valleys can be proved throughout their length, it will not be possible safely to draw far-reaching conclusions about their age and origin. It is possible that the buried valleys may have been formed in part by glacial erosion, in part by stream action during interglacial periods. In order to assess the extent and periodicity of Quaternary glaciation, it has been necessary to study the Pleistocene deposits of the area. It has long been known that the Wear Valley was, in a sense, anomalous, for Weardale supported its own local glaciers independent of the great ice streams through Stainmore and the Tyne Gap. This research has confirmed earlier conclusions that no ice reached any part of Weardale. Examination of the glacial drifts of the Middle and Lower Wear has provided additional confirmation of Carruthers' view that there is evidence in the drift stratigraphy itself to support a multi-glacial hypothesis, but a detailed morphological study of many overflow channels along the flanks of the Wear-Durham Plateau suggests that these show signs of occupation by meltwater on at least two occasions. With the exception of terminal moraines, which appear to be almost entirely absent from the Aston Block as recognisable morphological features, the great deposits represented in the Middle Wear valley are particularly impressive and it has been possible to give additional evidence to support the conclusions of earlier writers.

Finally, the post-glacial evolution of the river has been studied. Detailed measurement of the longitudinal profile of the River Wear and certain of its tributaries, has made possible the correlation of river terraces and incised meanders. The extent of post-glacial diversion of drainage has been proved and some attempt has been made to reconstruct the sequence of sea-level changes which followed the final retreat of the Pleistocene ice-sheets.

This survey of the order in which the problems are discussed in the text of this thesis is almost the exact reverse of the order in which they have been studied in the field. It has been necessary to establish the terrace sequence in order to show the nature and origin of certain post-glacial surfaces which are exposed along the lower parts of the valley. It has been necessary to study drift thicknesses, proved by boring, before it has been possible to judge the significance of certain platform surfaces. No valid conclusions about the pre-glacial evolution of drainage could be attempted before the pattern

of buried valleys was proved. Thus, although this work begins with a consideration of the earlier evolution of the landscape, this part of the work has only become feasible and justifiable towards the end of the period of research and it has not been possible to devote the same time to the field-study of Tertiary evolution as has been spent on Quarternary problems. In a sense, therefore, this is not an orthodox geomorphological study, but, in Northern England, little orthodox research can be attempted before the effects of glacial erosion and deposition have been estimated. This research has cleared the way for a further more detailed attack upon the more fundamental problems of Tertiary evolution.

It has been possible to study certain topics in considerable detail, but, in order to achieve some balance in the final synthesis, this detail must be omitted and it is only possible to enunciate general conclusions. In order to restrict the length of the completed text, the author has tried to confine descriptive writing to a minimum and to incorporate some of the detailed results through the medium of the detailed topographical and geological maps which accompany this work. For the same reason, detailed summaries of published work, especially those which are readily accessible, are excluded from the text.

The chapters on drift thickness and the extent of buried valleys provide the clearest example of this omission of detail. In order to obtain the general conclusions given in Chapter 5, the records of some 25,000 borings have been examined and many mine plans have been studied. In addition, detailed mapping of stream sections, with height determination by levelling or aneroid, has proved the height of the rock floor in a large number of places. Much of the initial work was done on 1:2,500 plans and all preliminary compilation of rock floor contours was made on a scale of six inches to one mile. In order to provide a general account of the buried valleys, the details of this compilation must be omitted from both the text of this thesis and from any map whose scale is small enough to show the whole drainage pattern of the coalfield. It is not yet possible to draw an accurate map of rock-floor contours for the whole area. The detailed work has shown that the rock floor can be most irregular and, for this reason, it would be misleading to link the areas where detailed contours can be plotted with interpolated rock floor contours. It is possible to describe the evidence in detail for small areas. This was done by both Hindson and Hopkins (1946) and the present writer (1954). However this method of exposition is too unwieldy for the whole coalfield and not appropriate to this thesis, in

which the problem of evolution of the buried valleys represents only a part of the whole work. Thus the chapter on buried valleys is confined to an analysis of the results and these are illustrated by the indication of the middle line of each valley on the appropriate maps and by a series of sections drawn where the evidence is most reliable.

The text of this thesis consists of an analysis of the pertinent geomorphological problems. In order to maintain continuity of the text and to avoid needless digression, technical and methodological details of field-work, compilation and statistical work are confined to appendices.

ACKNOWLEDGEMENTS.

The author has pleasure in expressing his gratitude to the many people who have helped during the course of this work. In particular, the author wishes to thank W. Anderson, M.Sc., District Geologist of H.M. Geological Survey; G. Armstrong, B.Sc., Divisional Geologist to the National Coal Board and M. Barefoot, M.A., formerly Area Prospecting Officer of the Opencast Executive, all of whom have provided access to valuable manuscript data and who have devoted much time to the discussion of different aspects of this research. The author has received much assistance and encouragement from Professor K.C. Dunham and Dr W. Hopkins of the Geology Department, Durham Colleges.

In the course of levelling the flood-plain of the river, the author received assistance from many members of the Geography Department, Durham Colleges. M. Richardson, S.A. Taylor and J. Marsh have been especially active in their help and, between them, helped to survey more than two-thirds of the total distance. Many of the instruments were kindly lent by Cdr. D.H. Fryer, Reader in Surveying, King's College.

Finally, but most important of all, the author wishes to thank his supervisor, L. Slater, M.A., for advice, assistance and encouragement throughout the whole period of research and to thank The Nature Conservancy, whose financial aid made it possible to carry out detailed field-work over such a large area.

A NOTE ON PLACE NAMES AND NOMENCLATURE.

It is always difficult to provide the reader who is not conversant with an area with adequate aids to orientate himself. This difficulty is especially important in a detailed regional study such as this thesis, for many of the place names which are used are only shown on the six-inch Ordnance Survey maps. For this reason, most of the more obscure place names which are used in the text are recorded on the detailed topographical maps in the Map Folder.

The National Grid References of all place names, with the exception of the large cities (Newcastle-upon-Tyne, Gateshead, Sunderland, Durham etc.) are listed in Appendix III at the end of this thesis.

The general terms describing the Wear valley may be defined as follows:-

"Weardale" is that part of the valley which lies upstream (West) of Witton Park Railway Viaduct. (NZ/170,308).

"The Middle Wear" is that part of the valley which lies between Witton Park and Chester-le-Street.

"The Lower Wear" is the tidal portion of the river which extends from Chester-le-Street to the present mouth of the river.

The following One-inch Ordnance Survey maps provide complete coverage of the Alston Block:-

Sheet 76	Carlisle
"	77	..	Hexham
"	78	..	Newcastle-upon-Tyne
"	83	..	Penrith
"	84	..	Teesdale
"	85	..	Durham

Sheets 78, 84 and 85 cover the whole of the Wear drainage system.

CHAPTER 1.

THE STRATIGRAPHY AND STRUCTURE OF THE ALSTON BLOCK.

We may define the Alston Block as that part of Northern England which lies east of the Pennine Escarpment, south of the Tyne Gap and north of the Stainmore Depression. The boundaries of the Block are structural discontinuities which have had a persistent effect on its topography since Lower Palaeozoic times. The northern edge of the Block is determined by the Stublick and Ninety-Fathom fault system, which is arranged en échelon along the southern side of the Tyne syncline. The western boundary of the Block is the great fault-scarp - the Pennine Escarpment - which extends from Brampton to Brough and which overlooks the Vale of Eden. The southern limit of the Alston Block is, in part the linked series of faults from the Swindale Beck on the Escarpment to Thrislington in East Durham; in part the broad syncline of Stainmore which separates the Alston Block from its southern counterpart. The eastern boundary of the Block is not clearly defined. In East Durham there is no known structural discontinuity which is comparable with the other three boundaries. For the purposes of this discussion, the eastern limit of the Alston Block is taken as the present coastline of Durham.

The Alston Block is a gently warped mass of Carboniferous rocks, overlain by Permian rocks in the East and Triassic rocks in the south-east. The Lower Palaeozoic floor of the Block, which consists of Ordovician and Silurian igneous and metamorphic rocks, emerges in the Cross Fell Inlier, on the western margin and in Upper Teesdale. It has been proved by boring as far east as Crook. It is now supposed, from geophysical evidence, that these rocks are underlain by a considerable granitic intrusion. This approaches nearest the surface, in the centre of the Block, in Upper Weardale.

THE SEDIMENTARY ROCKS.

The rock succession in the Alston Block has been summarized in figure 1. The nomenclature adopted in this thesis for the various horizons ~~are~~^{is} indicated in this table. All reference to Pleistocene and Recent deposits is deferred to later chapters (Chapter 6 et seq.)

Owing to the great economic importance of the Coal Measures and Carboniferous Limestone series, the stratigraphy and structure of parts of the Block have been recorded in great detail. The Millstone Grit and Permian rocks are less well-known, but only in contrast to the abundant information available from both coal- and lead-mining districts. A very considerable number of

borings have been sunk in the coalfield and the significance of these will be recorded in later chapters. For the present discussion we may note three deep borings which are important because they have been continued below the Lower Coal Measures and have penetrated the Millstone Grit and rocks of the Lower Carboniferous Limestone Series.

- 1) The well-known boring at Roddymoor (NZ/152363), near Crook, has been described by Woolacott (1923). This boring proved the entire Carboniferous succession below the Middle Coal Measures and penetrated Lower Palaeozoic slates at great depth.
- 2) The boring at Lintzford (NZ/150572), near Chopwell, proved the Carboniferous succession from the Lower Coal Measures down to the Four Fathom Limestone.
- 3) The boring at Littleton Colliery (NZ/339433) penetrated the whole Coal Measure sequence from the Five-Quarter Coal, passed through the Millstone Grit and reached a thin limestone which may possibly be identified as the Upper Felltop Limestone. (1)

The total thickness of Carboniferous rocks is small compared with the troughs of Carboniferous sedimentation which lie north and south of the Block. Dunham (1948) has suggested that both the Alston and Askrigg Blocks constituted a shelf-area during Carboniferous times. The sedimentary succession on both Blocks is divisible into well-defined cyclothemic units which represent the rhythmic rise and fall of the shelf. The sedimentary cover is consequently variable in thickness and lithology. With the exception of the Lower Carboniferous rocks of the extreme south-west, few beds of the Alston Block exceed one hundred feet without marked lithological change. In consequence, there is generally a rapid alternation of rocks of different degrees of hardness and resistance to weathering and erosion.

(1) The records of this boring, with a letter written by Professor Lebour, are preserved in the files of the National Coal Board, Bowburn. Lebour considered that the limestone proved at a depth of 1131 feet below Ordnance Datum represents the Felltop Limestone. This is the conclusion adopted in this thesis, but it must be acknowledged that this limestone may represent a marine band within the "Millstone Grit" sequence.

of which only a few correspond with major faults or disturbances. The Whin Sill forms the most resistant horizon of all the country rocks and thermal metamorphism has tended to toughen adjacent Carboniferous sediments for as much as one hundred feet beyond the dolerite contact. Where the Whin Sill is thick and exposed over a large area, as in Upper Teesdale, it forms well-defined shelves, gashed by steep, narrow gorges. Both the major breaks in the longitudinal profile of the River Tees are associated with large waterfalls at the dolerite outcrop. Associated with the Whin Sill are a number of dykes which trend between N.E. and E.N.E. The Hett, Ludworth, Wackerfield, Biddick and Muck dykes may be considered to be representative of this suite. It is almost certain that the Whin Sill and its dykes are pre-Permian in age, for the dykes, which have been proved frequently within the concealed coalfield have not been seen to penetrate Permian rocks.

The Tertiary igneous episode is represented by several members of the échelon of dykes, collectively known as the Cleveland-Armathwaite Dyke. The general trend of the Dyke is E.S.E. and it is now exposed in the valleys of the South Tyne and Tees. Stratigraphical and geochemical evidence shows that the Dyke is certainly post-Liassic in age and there is little doubt about the Tertiary age of the intrusion.

STRUCTURE.

By definition, the Alston Block is surrounded on three sides by complex faults. Within these structural boundaries, the Block has remained essentially a morphological unit since the deposition of the Carboniferous sediments. During the subsequent history of the Block, there has been much faulting and a little gentle folding.

The Marginal Structures:-

The Pennine Fault-system, forming the western margin of the Block, contains three principal groups of faults of different age (Shotton, 1935; Dunham, 1948):-

- i) The N.N.W. Inner Pennine Fault, downthrowing eastwards.
- ii) A series of thrust faults, along which overthrusting was directed towards the E.N.E.
- iii) The Outer Pennine Fault, a great N.N.W. fault-system which throws westwards. The size of this fracture cannot be determined, but it must be several thousand feet for it brings the New Red Sandstone of the Vale of Eden against the Lower

Palaeozoic rocks of the Cross Fell Inlier.

The first two faults are assigned to Hercynian earth movements, the latter to the Tertiary.

The échelon series of the Stublick Fault-system and the Ninety-Fathom Fault form the northern edge of the Block. The Stublick system comprises a belt of East-West or E.N.E. faults which now throw northwards. These extend from the neighbourhood of Castle Carrock eastwards to Thornborough near Corbridge. Six miles south of Corbridge, the Ninety-Fathom Fault continues the E.N.E. trend to the Northumbrian coast near Tynemouth. Dunham (1948) has shown that the faults of the Stublick system show two phases of movement :-

- (i) Some of the faults are clearly Hercynian since dykes of the Whin Sill suite are associated with them. Trotter and Hollingworth (1928) were able to show that, at the time of the intrusion of the Whin, the downthrow of the Stublick Fault was southwards.
- (ii) The main movement of the Stublick and Ninety-Fathom faults is, however, a downthrow northwards of 500-1750 feet. Since both faults affect Permian and Triassic strata, the age of the main movement is taken to be Tertiary. Hickling (1949) has shown that the Ninety-Fathom fault diminishes in throw as it approaches the coast. At Cullercoats, the displacement of the Coal Measures is about 360 feet, but that of the overlying Permian appears to be only about 100 feet. Upon this evidence we must conclude that the Ninety-Fathom fault, itself, has thrown in one direction only, part during the Hercynian, part during the Tertiary earth movements.

To the south of the River Tyne, a third great fracture, the St. Hilda Fault has been proved by mining between Jarrow and South Shields. This throws southwards as much as 700 feet. The seaward extension of the fault is not yet known, and, owing to the removal of their Permian by erosion, it cannot be dated. However, Armstrong and Price (1953) have shown that it is associated with folds which are possibly Hercynian in age. It is possible, therefore, that the St. Hilda Fault comprises an important Hercynian element of the Stublick/Ninety-Fathom system.

Along the northern side of the Stainmore syncline, there is a linked series of E.N.E. faults. Of these, the Swindale Beck Fault throws northwards. The line of weakness along this fault is clearly pre-Carboniferous in age. For Dunham (1948) has shown that it acted as the

hinge-line whence Lower Carboniferous rocks thicken southwards to the Stainmore syncline. The Lunedale faults throw southwards, but Dunham (1948) has shown that there is evidence for a former downthrow towards the north. Dunham has shown that, like the Stublick system, movement occurred along the Lunedale faults before and after the intrusion of the Whin Sill. The Wigglesworth and Butterknowle faults both throw southwards. The throw of the latter exceeds 800 feet in the Coal Measures near Bishop Auckland and has been shown by Anderson (1945) and Hickling (1949) that the fault affects both Carboniferous and Permian strata. East of Thrislington, the Butterknowle fault turns eastwards and rapidly dwindles. It has not been proved to reach the Durham coast. South of the Butterknowle fault, the Coal Measures have been folded into a series of elongated domes and basins, the axes of which lie parallel with the fault. The overlying Permian rocks are folded along the same axes, but according to the contour reconstruction of Hickling (1949), the amplitude of folding in the Permian appears to be smaller than those in the Coal Measure Strata. Anderson has expressed doubt in the validity of this interpretation. (See page 15).

The Stainmore syncline forms a structural and topographical depression between the Alston Block and the Askrigg Block. It is a gently sloping synclinal trough with a maximum amplitude of about 1600 feet (Dunham, 1948). The axis of the syncline can be traced as far east as Houghton-le-Side, where the Lower Magnesian Limestone overlies rocks of the Carboniferous Limestone series.

The Structure of the Alston Block:-

Within the confines of the marginal faults, the Lower Palaeozoic rocks appear to be intensely folded along the typical Caledonoid axis. In the western and central parts of the Block, the Carboniferous Limestone series have been arched upwards to form a gentle asymmetric dome which is truncated by the Pennine Faults. This is illustrated in an exaggerated form in figure 3. This feature has been called the Cross Fell Anticline (Merrick 1915), the Teesdale Anticline (Versey, 1927, and Trotter, 1929) and the Teesdale Dome (Dunham 1948). The last name is used throughout this text. In the extreme north east of the Durham coalfield, the Coal Measures have been folded. It has hitherto been accepted that most of this folding occurred before the deposition of the Permian sediments.

We owe to Dunham (1948) and Hickling (1949) a most complete picture of the structure of these folds. Dunham has drawn structural contours for the base of the

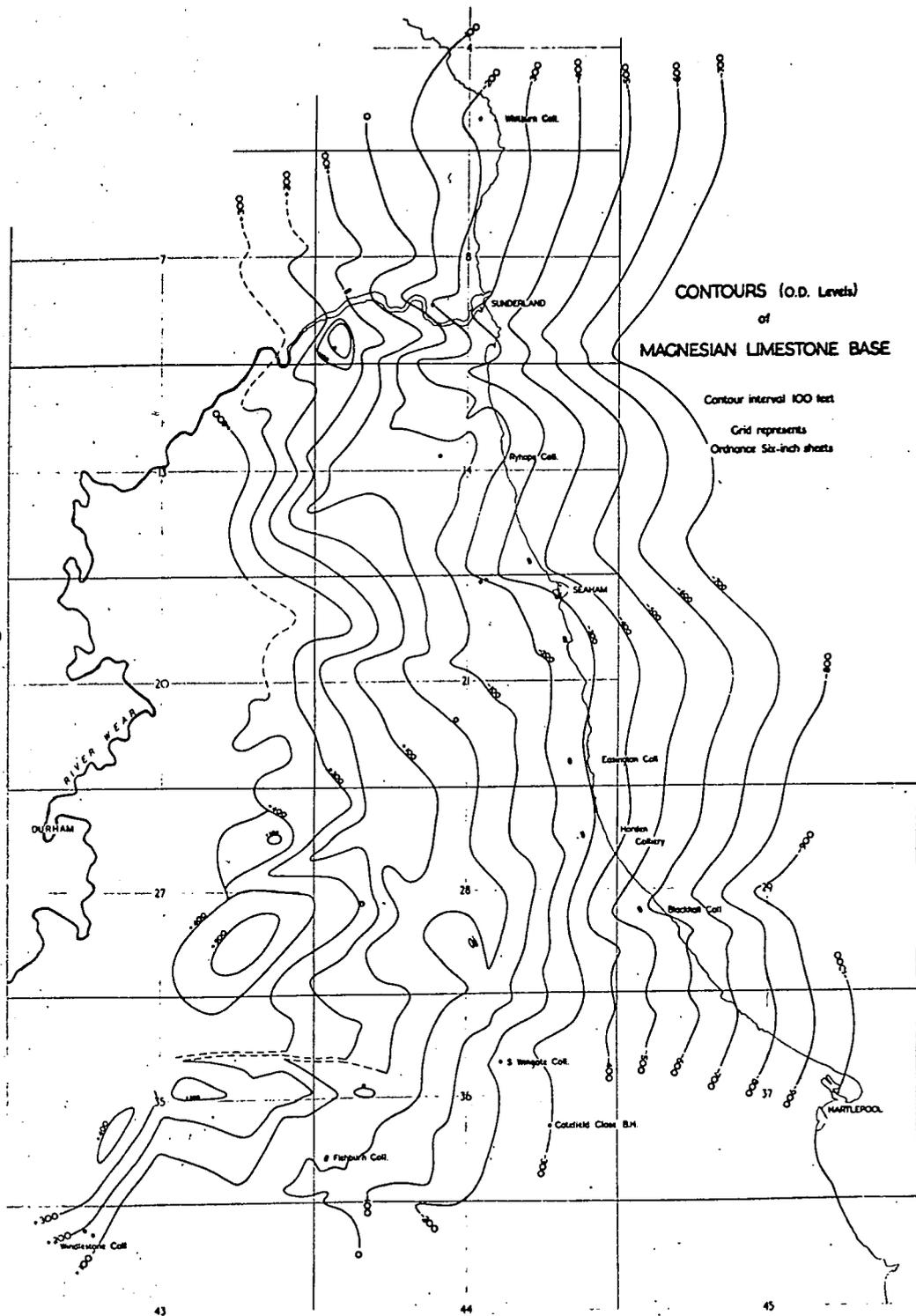


Figure 3. (After Hickling, 1949).

Great Limestone as far east as the borings at Roddymoor and Chopwell. Hickling constructed contours for both the Hutton Seam and the base of the Magnesian Limestone. (Figure 3). Alternative contours for the Magnesian Limestone have also been published by Anderson (1945).

Plate 3 (map folder) has been compiled from this published work. The Great Limestone contours show that the flat top of the Teesdale Dome is situated beneath the headwaters of the Tees and Maizebeck, between Great Dun Fell, Mickle Fell and Cronkley Fell, with the key horizon at 2400 - 2500 feet above Ordnance Datum. To the north and east, the beds dip away at an average of 130 feet per mile, the key horizon reaching -500 feet beneath the western edge of the coalfield. Further evidence of the eastward continuation of the Carboniferous Limestone Series is provided by the confirmation by the author of a deep boring at Littleton Colliery. It is suggested, from the record of this boring, and comparison with the succession at Roddymoor and Chopwell, that the Great Limestone may here lie as low as -1750 feet (2). To the south of the Teesdale Dome, the beds dip rapidly into the Stainmore Syncline. As the Pennine Faults are approached, especially West of Cross Fell, the beds rise rapidly, the key horizon reaching 3000 feet above Ordnance Datum. Dunham (1948) suggests that this feature is derived from the former easterly downthrow along the Inner Pennine Fault.

In the central part of the Block, a major disturbance extends from north to south, from East Allendale to Lunedale. This is known as the Burtreeford Disturbance. It has the form of an east-facing monocline which has a downthrow of 250 feet where it crosses the Killhope Burn near Cowhill. Southwards, the throw of the monocline increases to 500 feet or more. The age of this fold is almost certainly Hercynian.

The Coal Measures dip towards the east and, despite minor irregularities introduced by faulting,

(2) Recent deep borings at Billingham (I.C.I.) are reputed to have proved the entire Trias-Carboniferous succession. Details of the record have not been released, but it is understood that the Lower Carboniferous succession is different from that proved further West. It is possible that the shelf facies of Carboniferous rocks gives way to basin facies in South-East Durham.

the regional dip is remarkably constant. In the north-east, however, a series of folds have been proved by mining in the concealed coalfield beneath the Permian. The most important structure is the deep broken syncline which runs with a south-easterly axis through Jarrow to Hylton. It can be traced for about a mile south of the Wear, where it merges into the broad flat of low-lying Coal Measures south of Sunderland. The Hutton Seam here lies about -1500 feet below Ordnance Datum. Hickling (1949) considers that a shallow syncline may continue south-eastwards from Ryhope, although, at the date of his analysis, the coal workings below the North Sea had barely penetrated beyond the axis of this feature. East of the Jarrow-Hylton Syncline, there is a shallow upfold known as the Tynemouth-Marsden Anticline. This has been described by Armstrong and Price (1953), who further suggest that a second syncline may occur about 2 miles east of Whitburn.

Associated with these structures are numerous faults, illustrated in Plate 4 (map folder). Few are large enough to be traced in the field beyond the limits of mining. Many of the coalfield faults have a throw of ten feet or less and would not be seen in the field. Indeed, the number of faults shown on the maps of the primary Geological Survey are a mere fraction of those recorded in the post-war revision of this area. In the Carboniferous Limestone series, the trend of minor faults is often better known than that of some of the larger fractures. Dunham (1948) has shown that mineralization is rare in faults throwing more than forty feet and that many vein fissures may be traced for long distances through the displacement may be very small or very variable. The hiatus within the areas of Millstone Grit and Lower Coal Measures is thus possibly more apparent than real. The lack of evidence of small faults emphasizes the contrast between the abundance of detailed mining information east and west of this zone and of the difficulty of proving minor fractures in the field.

The whole of the Alston Block is dominated by an apparently conjugate series of faults which trend east-north-east and north-north-west. Both Dunham (1948) and Hickling (1949,) have shown that the persistence of individual fracture lines bear no relation to the amount of displacement along the line.

The principal structural trends may be tabulated as follows :-

Table 1. DIRECTIONAL TRENDS OF FAULTS, VEIN-FISSURES AND JOINTS IN THE ALSTON BLOCK.

	Carboniferous Limestone (Dunham, 1948)	Coal Measures (Rickling, 1949)
North	A few faults	A few faults
South		
NNE	-	- SSW
NE ENE	Dominant direction of vein fissures; secondary maximum of jointing; Feeble faulting.	Dominant direction of faulting SW WSW
East	Secondary maximum of faulting; 'Quarter-Point' veins	Occasionally West important faults
ESE	-	- WNW
SE SSE	Dominant direction of faulting; Cross veins; Dominant joint direction.	Variable conjugate NW series of faults. NNW

History of Earth Movements in the Alston Block :-

The principal movements which are of significance to the discussion in the next chapter are :-

- 1) The evidence suggesting depression of the Block by Hercynian fault block movements, so that the Alston Block remained depressed throughout the Mesozoic Era.
- 2) The nature of the Tertiary uplift of the Block, for, if this was intermittent and differential, it may have influenced both drainage pattern and existing platforms.

Table 2. PRINCIPAL EARTH MOVEMENTS OF THE NORTHERN PENNINE OREFIELD.

PERIOD OR OFCENY.	MOVEMENTS IN NORTHERN PENNINE OREFIELD.	PROBABLE REGIONAL STRESS OR MOVEMENT.
Caledonian	ENE folding of Lower Palaeozoic rocks. Development of ENE & WNW cleavage.	NW-SE compression.
Early Carbon- iferous.	Initiation of marginal hinge-lines, defining Alston Block.	Progressive relative down- warping of adjacent areas to north, west and south.
Inter-Carbon- iferous.	Gentle Warping of Block. 1) Formation of Master Joints N 20-25oW, N 60-70oE and E-W folds. 2) NNW and E-W normal faults along margins, depressing Alston Block relative to surrounding areas. 3) NNW thrusts and folding. Intrusion of Whin Sill. Intrusion of Whin Dykes in ENE tension fissures. 4) NE folding in Hunstanworth area.	N-S Compression : folding Bewcastle anticline and possibly Stainmore syncline. Fault block movements. ENE Compression.
? Late Hercynian.	Formation of conjugate vein-fissures. NNW, ENE and E-W to WNW, contemporaneous with gentle doming.	Rotation of block relative to adjacent areas; tear-faulting in Brampton district.
Tertiary.	1) Intrusion of E-W dykes in linear echelon, trending WNW. 2) NNW and E-W normal faulting along margins, elevating block and tilting to east. 3) Slickensides in mineral veins due to small sideways movements.	Differential side-ways movement. Fault block uplift.

- 3) It is necessary to discuss, in detail, the possible age of folding which formed the Teesdale Dome, for this folding may have affected both drainage pattern and upland surfaces also.

We must, at once, admit that the problem cannot be solved beyond argument with the evidence which is available at present. The only outcrop which is demonstrably Tertiary in age is the solitary Cleveland Dyke. Those structures and earth movements which can be dated by this dyke are of relatively little consequence in determining the age of the major structures of the Block. The only sedimentary strata which are post-Hercynian in age are the Permian and Trias. Consequently we are forced to conclude that those movements which affected Carboniferous rocks only date from the Hercynian; those which affect Trias, Permian and Carboniferous are Tertiary.

We owe to Dunham (1948) the most complete summary of the sequence of earth movements which produced the structures which have been recorded. These have been tabulated in Table 2.

Hickling (1949) has shown that, in the Coal Measures, the development of the fracture pattern antedated the major movements and that practically all folding of the Coal Measures occurred before the deposition of the Permian. In the Coalfield, major Tertiary displacement is apparently confined to the Ninety-Fathom and Butterknowle Faults. Hickling (1949) has argued that since the general dip of both Coal Measures and Permian are similar throughout much of East Durham, the principal Tertiary movement here was a gentle tilting. This was apparently associated with the fault block uplift further west. It was long argued, from the lithology of the Permian Brockrams of the Vale of Eden, that this coarse conglomerate had been deposited by torrential streams flowing down the steep Pennine Escarpment (e.g. Kendall and Wreot, 1924). The discovery of pebbles of Whin Sill in both Upper and Lower Brockram by Holmes and by Dunham (1932) appeared to confirm the presence of high land to the east, although Dunham did not admit this to be conclusive evidence. The difference between the Permian facies which are exposed east and west of the Pennines have frequently been attributed to the presence of a land barrier between two cuvettes. Arkell (1933) has shown that variations in Jurassic lithology in Yorkshire may be accounted for by the presence of land to the west. The early work of Versey (1927) on the structure of the Northumbrian Fault Block, favoured the conclusion that the Alston Block was initially raised by Hercynian fault block movements. These conclusions have been summarized in cartographical form by Wills (1951) who has shown a Scottish-Pennine land mass which persisted

throughout almost the whole of the Mesozoic until covered by the Cenomanian transgression.

Turner (1927) provided the first tentative conclusion that the Alston Block had been depressed relative to the Vale of Eden by pre-Permian faulting and this was soon confirmed, in the extreme north of the Block, by the work of Trotter and Hollingworth (1928). It has now been shown by Shotton (1936) and Dunham (1948) that each of the major marginal fault systems has a Hercynian component which throws towards the Alston Block itself. In consequence, it may be accepted that the first fault block movement was downwards. The Brockram evidence is inconclusive, for only two pebbles of dolerite have been found in these deposits in thirty years. It is reasonable to suppose that a torrential deposit derived from the Northern Pennines would contain many more specimens of an intrusion as widespread as the Whin Sill.

It is necessary to emphasize the conclusion that the Alston Block was depressed during the Hercynian and that there is no evidence to suppose that the relative position of the Block altered during any period of the Mesozoic era. The notion of uplifted Carboniferous rocks still persists and any consideration of the extent of Mesozoic sedimentation must take into account this depression of the Block.

Trotter (1929) envisaged two periods of Tertiary movement separated by a long period of erosion. The first uplift tilted the initial surface eastwards. During the period of still-stand, which followed this initial uplift, the surface of the Alston Block was reduced to the peneplain which may be represented by the present hill-top surface. At a later period during the Tertiary, Trotter believed that the Alston Block was further lifted by fault block movements. This was accompanied by the gentle arching of the Teesdale Dome, which, as will be seen, folded Trotter's peneplain and initiated a sequence of river captures.

The only evidence for the early uplift of the Block is that the surface of the peneplain passes without disturbance over the southern branch of the Stublick fault system and the northward continuation of the Outer Pennine Fault. Where the two faults meet, near Castle Carrock, the total throw is approximately 1500 feet. The argument appears to be valid if one accepts Trotter's conclusion that this is the only part of the marginal fault zone where the faulting is demonstrably post-Triassic and where no fresh fault-scarp can be recognised. It must be emphasized, however, that Trotter's hypothesis of two periods of movement during the Tertiary is based upon this morphological evidence alone. There is no direct geological evidence which can support this conclusion and, as will be seen later, the

morphological evidence can be interpreted in at least two ways.

Trotter described the surface resulting from the second Tertiary uplift as a "desk structure" with a major fault-scarp along the line of the Outer Pennine Fault, minor fault-scarps associated with the northern Stublick and Lunedale faults and a general dip-slope towards the east-north-east. This dip-slope was gently arched by a simultaneous fold movement which, according to Trotter, formed both the Teesdale Dome and the Stainmore syncline.

Since folding is fundamental to Trotter's hypothesis of the subsequent development of drainage, it is necessary to show in detail whether this movement can be positively dated as Late Tertiary. It is clear that the Stainmore syncline dates from a much earlier period than the Tertiary and Dunham (1948) has suggested that it was formed early in the Hercynian orogeny so that it is contemporaneous with the Bewcastle anticline. In the east, the axis of the syncline passes under the Magnesian Limestone near Houghton-le-Side, without, apparently affecting the overlying Permian rocks. For this reason, no later age than Hercynian can be entertained for the origin of the Stainmore syncline.

Dunham (1948) has favoured a late Hercynian age for the folding of the Teesdale Dome (Table 2,) and has shown that folding and mineralization may be closely associated.

"It is a proven fact that productive fissures become progressively narrower as they are followed downwards.... such conditions can be accounted for by assuming the contemporaneity of doming and mineralization." Dunham (1933).

Dunham (1948, p119) has brilliantly summarized knowledge regarding the age of the deposits and has shown that the local evidence is in part ambiguous, in part contradictory, in part inconclusive.

"Conclusive evidence as to the exact age of the primary mineralization is lacking. The deposits are definitely later than the Whin Sill, which is proved to have been injected in the interval between the Carboniferous and the Permian....It is here suggested that mineralization was completed before Tertiary erosion brought the deposits within reach of the groundwaters. If therefore the deposits are to be assigned to a major period of deformation and igneous activity, the choice lies between Hercynian and Tertiary. In favour of the former the following arguments have been advanced:-

- (i) The proved Hercynian deposits in Cornwall and elsewhere

in Europe includes types closely similar, geochemically, to those of the Pennines, whereas the British Tertiary igneous province is remarkably lacking in mineral deposits, apart from a few barite veins.

- (ii) Detrital fluorite was found in the Permian Yellow Sands of Yorkshire ... barite was found to be widespread in the Permo-Triassic sandstones of the Vale of Eden ... though only one occurrence of fluorite was found here.
- (iii) There is evidence indicating that the deposits were in place before the injection of the Tertiary Cleveland Dyke. The fact that no occurrences of minerals of the Pennine suite introduced along the walls of the Tertiary dykes have been found, whereas there are several occurrences in association with dykes of the Whin series points to the same conclusion."

"In favour of a Tertiary age the following evidence may be cited.

- (i) The fresh and unbroken appearance of minerals in cavities.
- (ii) The apparent absence of fluorite in the basal sands of the Durham Permian.
- (iii) The widespread presence of fluorite, barite and traces of galena in the Lower Magnesian Limestone of Durham.
- (iv) The lack of association of mineralization with the known major folds of Hercynian times, the Bewcastle and Middleton Tyas anticlines.
- (v) The sericitization of a member of the Cleveland dyke-échelon near Lodgesike Vein in Coldberry Gutter."

"The evidence of the heavy-mineral residues from Permian sandstones cannot be regarded as decisive in either direction, especially in view of the difficulty of being certain that the minerals are detrital and not introduced. The evidence from the Tertiary dykes is also ambiguous for it is well established that alteration to 'white trap' such as the Coldberry Dyke displays can be produced by injection into carbonaceous strata. The structural argument is not conclusive since it has not been proved that the Pennine Dome could not have been initiated in Hercynian times as a complementary structure to the Durham Coalfield basin; the area is known to have been under compression in Hercynian times. If, however, the most probable explanation of the replacements of the Lower Magnesian Limestone by fluorite and barite be accepted, namely that the process was connected with the Pennine mineralization then a post-Lower Permian age must be accepted. Even this does not prove a Tertiary age, for it is quite possible that Hercynian mineralization, the last dying phase of the igneous cycle,

continued into the Permian or even the Triassic periods. There is, however, a possibility that the Permian replacements are associated with the Bitterknowle Fault-system, the continuation of which is mineralized in the Pennines at Closehouse. If this association can be proved, the balance of evidence will perhaps favour a Tertiary age."

In a further comparative study of the age-relations of the epigenetic mineral deposits of Britain, Dunham (1952) has further emphasized his support for late-Hercynian mineralization in the Alston Block.

Primary mineralization may be associated with the intrusion of the Weardale Granite, indeed, both Dunham (1934) and Wells and Kirkaldy (1948) hinted at the presence of this body before its existence was confirmed. Bott and Masson-Smith (1953) have shown that the relation of gravity anomalies to the fluorite zone of the orefield favours this association. Wells and Kirkaldy (1948) support the idea of an American origin of both granite veins. Trotter (1953, 1954), on the other hand, favours the hypothesis of Tertiary mineralization and granite intrusion. Holmes (1953) has objected that the relationship between granite and mineralization is not proven, and, in any case, the age of the granite is more likely to be Caledonian.

Since these conflicting views cannot yet be reconciled, the absolute age of mineralization and therefore probable age of the Teesdale Dome is still unknown. Holmes, (1953) has made the important suggestion that a Tertiary granite would be expected to have an attendant dyke swarm. If it can be proved that intrusion, mineralization and doming are, indeed, related, this negative factor, combined with the absence of mineralization in the Tertiary igneous rocks of Britain, would strongly support the case for Hercynian origin of the Teesdale Dome.

Since direct dating of this fold is not yet possible, an indirect study, from the eastern part of the Alston Block, may contribute the necessary evidence. If the folds of the Coal Measures can be shown to resemble the folds of the Carboniferous Limestone Series and if the Coalfield structures can be dated with certainty, we may draw the tentative conclusion that the Teesdale Dome is of similar age.

Dunham (1948) has suggested that the Teesdale Dome may be related to the downfolded basin of the Coal Measures, which is, apparently, pre-Permian. However, recent examination of this part of the coalfield by Hickling (1949) Armstrong and Price (1953) does not altogether support this idea. The downfolded basin in the vicinity of Sunderland may be much smaller than Dunham believed and it is truncated by the complex structures of the concealed and undersea coalfield between South Shields and Seaham Harbour. In addition,

it is no longer certain that the Permian cover is unaffected by folding.

In 1949, Hickling was able to write :-

"The Permian completely transgresses nearly every Carboniferous structure, here as elsewhere, and thereby leaves no doubt as to the date of the major movements". (Hickling and Robertson, 1949).

It cannot be denied that numerous borings in the vicinity of Sunderland have shown that this part of the Coal Measures basin is overlain by Permian cover which shows no trace of downfolding. Trechmann (1954) has suggested that thrusting of the Magnesian Limestone in this area may be attributed to the decrease in volume of Permian rocks by the removal of evaporite deposits.

Elsewhere, however, evidence is accumulating to show that, in certain parts of East Durham, both Carboniferous and Permian rocks were equally affected by folding and major fault movements. It has already been shown that, in South Durham, south of the Butterknowle Fault, a series of gentle folds occur in Coal Measures and Magnesian Limestone alike. The structure of the Coal Measures is accurately known from the widespread working of the Brockwell Seam in the former Dorman Long Royalties. Evidence about the structure of the Magnesian Limestone depends upon field observation and a few shaft sections and borings. The extent of the field evidence in this area can be gauged from the exposures of solid rock shown in the appropriate drift map, (Middle Wear, Southern Sheet, Drift Deposits and Buried Valleys, Plate 21, Map Folder). As shown on Page 6, Hickling (1949) believed that the amplitude of folding in the Permian was less than that in the Carboniferous rocks. According to W. Anderson, the evidence is quite inadequate to show more than the fact that the Permian cover is folded along the same axes as the Coal Measures and that it is reasonable to suppose that the amplitude of folding in the Magnesian Limestone is similar to that of the underlying structure.

In the Eastern part of the coalfield, there is a major West-East fault disturbance known as the Seaham Fault. This can be traced in all horizons of the Coal Measures from the Wear Valley, near Great Lumley to the limits of exploration under the North Sea, east of Seaham Harbour. According to Anderson (1945), this fault affects the Magnesian Limestone also and this can be proved in the field where the line of faulting crosses the Permian escarpment near Houghton-le-Spring. Hickling (1949), on the other hand, refused to accept this interpretation and has shown the base of the Magnesian Limestone to transgress the Seaham Fault. Recent mappings of coastal sections by officers of H.M. Geological Survey suggests that this fault zone may, indeed, affect the Magnesian Limestone.

Further evidence has come to light following the revision of the six-inch Geological Survey of N.E. Durham. Field-work during 1954 and 1955 by R.H. Price has shown that, in the Magnesian Limestone between South Shields and Boldon, the great bight, which was mapped during the primary survey, does not exist. The Permian unconformity on these drift-covered lowlands appears to lie between one and two miles further west. The discovery of an exposure of Concretionary Limestone (supposedly Upper Magnesian Limestone) in this area strongly suggests that the Permian rocks may be folded in harmony with the underlying Tynemouth-Marsden anticline.

It is not yet possible to assess the full implications of these recent discoveries, for the weight of regional evidence is still in favour of widespread Permian transgression over the Carboniferous structures. It is possible that these are only small flexures which were caused by post-Permian movement, but since it cannot be shown that fold-movements in the eastern part of the Alston Block were confined to the Hercynian orogeny, the dating of the Teesdale Dome must remain an open question.

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CHAPTER 2.

THE TERTIARY UPLIFT AND RESULTANT
DRAINAGE OF THE ALSTON BLOCK.

Towards the end of the Nineteenth Century, several of the first generation of geomorphologists attempted a general explanation of the evolution of land forms of Northern England. Most accepted the hypothesis of more or less continuous Chalk over the Pennines and agreed that, in this part of Northern England, Tertiary uplift tilted the initial surface eastwards. Most of them also agreed that the present hill-top surface represented an early Tertiary peneplain. Davis (1895) appears to have been the first to recognise that a subsequent tributary of the Tyne cut southwards along the outcrop of the soft Permian rocks, to capture the upper Wear near Bishop Auckland. Cowper Reed (1902) showed that a similar capture may have occurred further east, where another north-flowing subsequent stream, roughly parallel to the Middle Wear, cut back along the Triassic outcrop to capture the River Tees near the present coastline.

Since these classic essays, there have been five specific attempts to explain the origin and evolution of the land forms and drainage pattern of parts of the Alston Block. The first was the work of Woolacott (1903, 1907), the second was the curious study of Merrick (1915), the third was a limited investigation of the Middle Tees by Fawcett (1916), the fourth was the important paper of Trotter (1929), to which reference has already been made. The fifth is the unpublished work of Wright (1955), who, as stated in the Introduction, has been working in the Alston Block during the last three years.

Although the broad outlines of the geological structure were known when the primary mapping of H.M. Geological Survey had been completed, the structural history was not clear and, as has been shown in the last chapter, it was commonly thought that high land existed in the western Pennines from the time of the Permo-Carboniferous interval. Thus, neither Woolacott nor Merrick were able to accept the supposition of Jukes Brown, Davis or Reed that a continuous cover of Cretaceous rocks covered the Alston Block. Woolacott envisaged Chalk transgression in the east, but believed that the higher parts of the Alston Block rose above the limits of the Chalk Sea. He supposed that the radial drainage from this island had possibly existed since the Permo-Carboniferous interval. In other words, the highest parts of the Alston Block may be remnants of a surface which forms the Permo-Carboniferous unconformity in East Durham.

Woolacott's interpretation of uplift and the evolution of drainage during the Tertiary agrees with that of his predecessors and contemporaries. It was supposed that Tertiary movement was confined to an eastward tilting of the Alston Block. Consequent streams radiating from the ancient pre-Permian land surface, flowed eastward upon the new surface. As the Cretaceous cover of the lowlands was removed, certain adjustments of drainage occurred. Woolacott accepted Cowper Reed's analysis of first cycle river captures as far as these affected the eastern part of the Alston Block.

The study of the Alston Block by Merrick (1915) was, to say the least, unconventional in its approach. Nevertheless it is an important contribution, for Merrick clearly stated the structural evidence and related this to the evolution of surface and drainage. Certain of his conclusions, erroneous as these might be, were repeated, independently, by Trotter (1929).

The initial assumption from which the whole of Merrick's argument developed was the premise that the hill-top surface of the Block represented an exhumed sub-Triassic peneplain. He recognised the structural importance of both the marginal faults and the Teesdale Dome. He supposed that both Hercynian and post-Triassic movement took place along the lines of faulting and from the evidence of the Brockrams, he supposed that the Alston Block formed high land during the Permo-Carboniferous interval. Merrick was able to demonstrate the post-Triassic age of the Stublick and Pennine faults. From the assumption that the upland surface was arched to the same degree as the Carboniferous rocks, he supposed that the Teesdale Dome had post-Triassic origin also. Merrick recognised the development of a drainage pattern which radiated from the crest of the dome and showed that, further east, the axis of the dome represented the watershed between the Tyne tributaries of the Alston Block and those of the Wear and Tees.

In Stainmore and the valley of the Toes, Fawcett (1916) recognised evidence for two pre-glacial cycles of erosion. He believed that the upland surface of the Pennines represented the surviving remnants of the surface from which it has been formed. During the late-Tertiary, the peneplain was uniformly raised by a second, minor uplift. Fawcett recognised the radial drainage pattern from the Cross Fell dome, but showed that, in Stainmore the consequent drainage was eastwards, though this had been modified by captures in both cycles.

Trotter's paper forms the most detailed and most modern analysis of the evolution of drainage which has been published. For this reason, it is necessary to study Trotter's conclusions in detail. Since the work has been accepted without reservation by certain writers for more than twenty-five years, it is also necessary to review the

conclusions in the light of present knowledge and to show where these are inconsistent with theory and with map and field evidence.

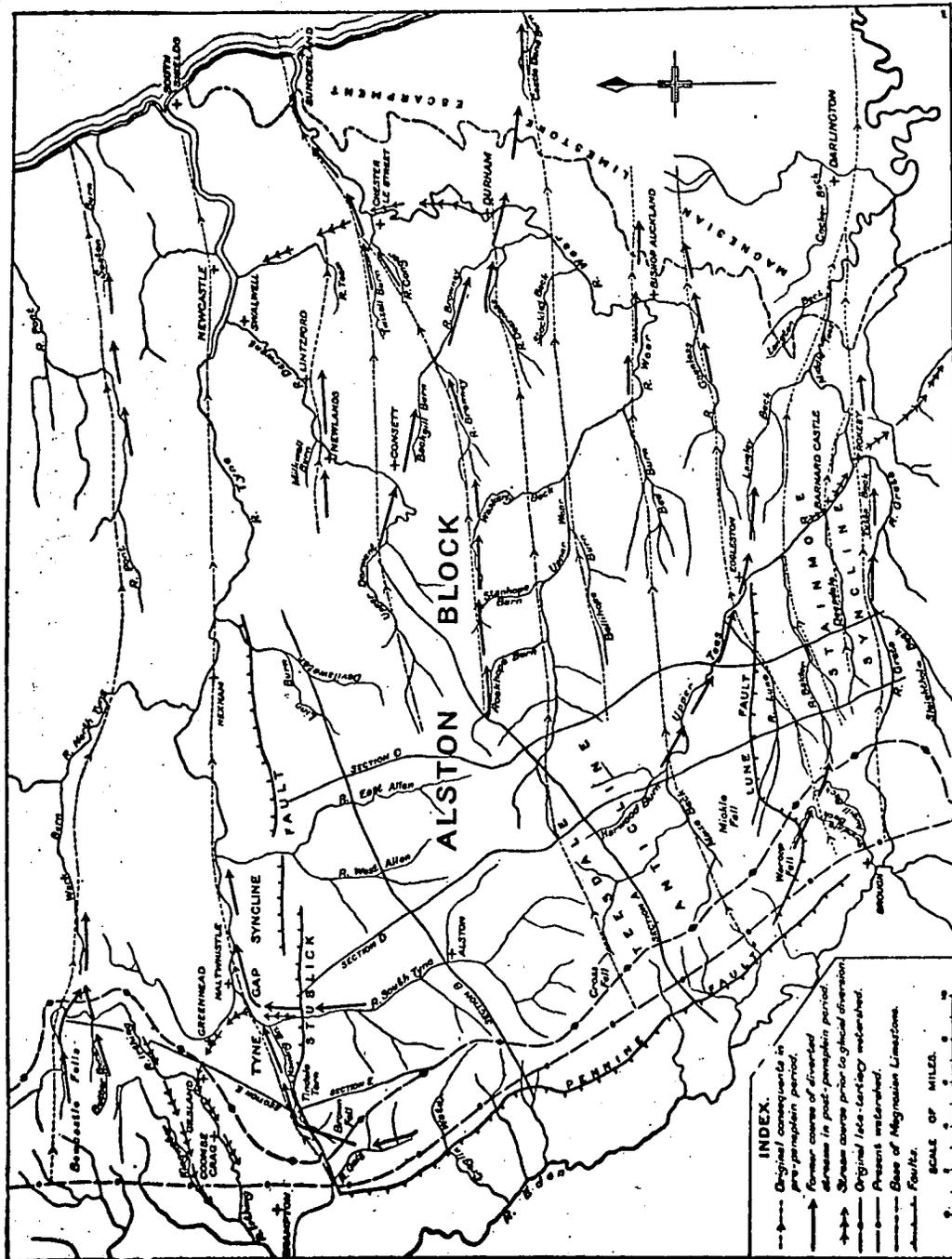
Trotter believed that in consequence of the Hercynian depression of the Block, a continuous thick cover of Triassic, Jurassic and Cretaceous rocks was laid down during the Mesozoic Era.

During the Tertiary, Trotter postulated two periods of uplift. During the initial uplift along the marginal faults, the north-western corner of the Block was raised as much as 1500 feet and the whole tract was tilted eastwards. Trotter and Hollingworth were able to show, from their revision of Sheet 18 (Brampton) of the one-inch Geological Survey, that the Outer Pennine Fault continues northwards across the Irthing valley and along the western edge of the Bewcastle Fells. Trotter therefore concludes that this initial uplift similarly tilted the country north of the Stublick fault.

It is presumed that the initial surface was composed entirely of Cretaceous rocks. Upon this surface, east-flowing consequent drainage was initiated. (Fig. 4). Trotter showed that a number of adjustments of drainage took place during the subsequent evolution of the area. He suggested that there had been a small southerly component in the initial tilt of the Block, which allowed some advantage to those subsequent tributaries which flowed towards the south-east. All the captures recognised by him to date from this period operated from south to north.

In due course, the Mesozoic cover was stripped from the surface and the underlying Carboniferous rocks were reduced to a peneplain. Trotter considered that, in the south-east, this well-developed surface was continued by the peneplain of the Yorkshire Wolds which had been recognised by Davis (1895) and Cowper Reed (1902). In the south and west, the surface was represented by the higher summits of the Askrigg Block, the Howgill Fells and the southern part of the Lake District. Trotter further believed that the higher summits of the Alston Block (Cross Fell, Mickle Fell, the Dun Fells and Cold Fell) rose above the peneplain surface as monadnocks.

It is important to notice that, in assuming these distant correlations, Trotter denied the interpretation of the peneplain as an exhumed sub-Permian or sub-Triassic surface. The second uplift, according to Trotter, occurred much later in the Tertiary. Indeed, he hinted that this phase of movement might even date from the Pliocene. Since the peneplain was already in an advanced stage of development, the fold movements along the axis of



Map illustrating the River Development on the Alston Block.

Figure 4. (After Trotter, 1929).

the Teesdale Dome, which Trotter supposed were contemporaneous with this uplift, arched the land surface. Tilting and arching of the peneplain initiated a wave of rejuvenation which affected much of the drainage pattern. Those consequent streams which crossed the fold axis were captured and "cut up" by rejuvenated previously "subsequent" streams which were favourably situated along the flanks of the Dome. During this period, the Wear was captured by a subsequent tributary of the Tyne near Bishop Auckland. The adjustment of drainage to these changes in structure resulted in a pattern which Trotter supposed represented the pre-glacial drainage pattern of the Alston Block.

The following criticism may be directed against these conclusions. There are three different aspects which must be examined :-

- 1) The morphological evidence for two separate periods of movement during the Tertiary.
- 2) The nature of the peneplain and the extent to which topographical arching is parallel to the structural folding.
- 3) Theoretical criticism of Trotter's reconstruction of the earlier drainage patterns.

According to Trotter, the southern branch of the Stublick fault system crosses the surface of the peneplain without disturbing it. In consequence, this fault, which is demonstrably post-Triassic in age, ante-dates the formation of the peneplain.

This part of the Stublick system is situated in the extreme north-western corner of the Alston Block, between Midgeholme and Castle Carrock. It crosses the north-west face of Cold Fell, which Trotter regarded as the most northerly of the monadnocks. On these slopes of Cold Fell, the fault has a northerly downthrow of about 800 feet. North of the fault, there is a broad spur of Cold Fell which is flattened between 1750 and 1800 feet above Ordnance Datum. South of the fault, the slopes of Cold Fell rise to 2000 feet in less than 700 yards. The contours of the north-west face of the hill are almost straight and parallel with the line of the fault for more than one mile. South-west of Cold Fell and south of the fault, there is a group of summits between 1600 and 1700 feet altitude which may be considered to represent fragments of Trotter's peneplain. These hills are situated around the River Gelt and its tributaries. The group is bounded in the west by the fault-scarp of the Outer Pennine Fault which here forms the western slopes of Cardunneth Pike. North of the Stublick fault, which crosses the River Gelt near the confluence of How Gill, the hills seldom rise above 1300 feet. The difference in level



Fig. 5

The Great Limestone. Collapsed cavern 20 feet deep.
Clints Crag, Ireshopeburn. (NY/844,366)



Fig. 6

The Great Whin Sill. Outcrop at the cirque head of High Cup Gill

across the fault between Cold Fell and the northern spur of Tindale Fell is about 250-300 feet and that between Tarnmonath Fell and Brown Fell about 210 feet. It is possible that the north-western slopes of Cold Fell and the northern edge of the Geltsdale Fells represent a degraded fault-scarp associated with the southern branch of the Stublick fault.

An alternative interpretation of the evidence, presumably that of Trotter, is that the higher slopes of Cold Fell may be ignored, because this represents a monadnock, and that the spurs of Tindale Fell and Tarnmonath Fell represent facets of the same surface on each side of the fault. Indeed, Trotter has suggested that the lower hills north of the fault represent the surface across which the Gelt, flowing northwards from the Teesdale Dome, approached the Tyne during the 'post-peneplain' period. Trotter's hypothesis of differential uplift during the early Tertiary depends upon the interpretation of this ambiguous evidence. Since contradictory conclusions may be drawn about this critical area, it is not wise to accept the hypothesis of two phases of fault-block uplift during the Tertiary until more satisfactory evidence is available.

The second criticism may be directed against Trotter's assumption that the fold movements which produced the Teesdale Dome also folded the peneplain to the same extent. It will be remembered that this assumption was made by Merrick also. The sections with which Trotter illustrated this feature show a certain parallelism of topographical and structural arching, but these sections are over-simplified and the evidence is inadequate. It can be shown, from the maps of Generalized Contours (Plate 5, Map Folder) and Structural Contours (Plate 3, Map Folder) that although the contour patterns are similar, the gradient of the structural contours is greater and that the Carboniferous rocks dip more steeply to north, east and south, than the slope of the peneplain in these directions. Similarly, the Projected Profiles (Plate 6, Map Folder) and Geological Section (Plate 3, Map Folder) support this conclusion. The structural implications are obvious and have been clearly stated by Dunham (1948):-

"Since, however, the supposed peneplain at the crest of the dome is cutting across beds belonging to the Middle Limestone Group, while to the north, east and south, it cuts successively across the Upper Limestone Group, the "Millstone Grit" and the Coal Measures, the view that the surface of the peneplain is even approximately parallel to the Great Limestone cannot be supported."

In addition, Dunham (1948) has shown that primary mineralization was complete before Tertiary erosion brought the deposits within reach of the groundwaters (see Page 12). For this reason it is impossible, on geological grounds, to accept

any hypothesis which involves folding of a Tertiary peneplain.

The third criticism of Trotter's hypothesis may be directed against certain features of his reconstruction of the drainage pattern. The distance from the Bewcastle Bells to the Stainmore syncline is roughly forty-five miles. Within this space, which at present is drained by three rivers, Trotter recognised twelve east-flowing original consequent streams. Six of these cross the whole Block from the Pennine Fault to the outcrop of the Magnesian Limestone and are thus at least forty miles long. We do not know how much further eastward these streams extended, but, in their upper forty miles, most of these streams maintain parallel courses. In order to take account of the large number of these consequents, each valley must measure between $3\frac{1}{2}$ and 4 miles from one watershed to the next. This is about the size of the Wear valley at Wearhead or the Tees near Cauldron Snout. It is difficult to understand how such streams could maintain parallel courses for such great distance without rapid integration by capture. That such captures did occur is not denied by Trotter. These are the south-north sequence of captures ascribed by him to the 'pre-peneplain' period. It is, however, unreasonable to suppose that this parallel pattern of consequents on an initial surface several thousand feet above the present, could survive long enough in the original form illustrated by Trotter to leave recognisable traces until today. It is also significant that, in the north-west quadrant of the Alston Block, where the present drainage pattern is predominantly northwards, no original consequent stream is represented. The northerly trend here is attributed by Trotter to the drainage from the northern limb of the Teesdale Dome. This pattern was therefore developed after the formation of the peneplain. Since the peneplain is well represented here as elsewhere, it is reasonable to suppose that some trace of the drainage pattern which formed the surface ought to remain in this area also. In consequence of these fundamental objections, the conclusions of Trotter cannot be accepted.

As stated in the introduction, some of the fieldwork and later analysis of the upland surfaces was abandoned by the present writer in order to avoid overlap with the contemporary work of R.L.Wright. The conclusions of Wright (1955) are of extreme importance to this discussion for Wright's studies were largely confined to Teesdale and Stainmore, whereas the present writer worked wholly in the Wear valley. He has independently confirmed the presence of certain surfaces along the southern margin of the Block which appear to have similar significance north and west of the River Wear. In the ultimate interpretation of the denudation chronology, however, the present writer cannot agree with certain of Wright's conclusions and, for this reason, it is convenient to examine them before those of the author.

EROSION SURFACES IN NORTHERN ENGLAND: SUMMARY OF OTHER WORK.

UNDIFFERENTIATED

MARINE

SUB-MARINE

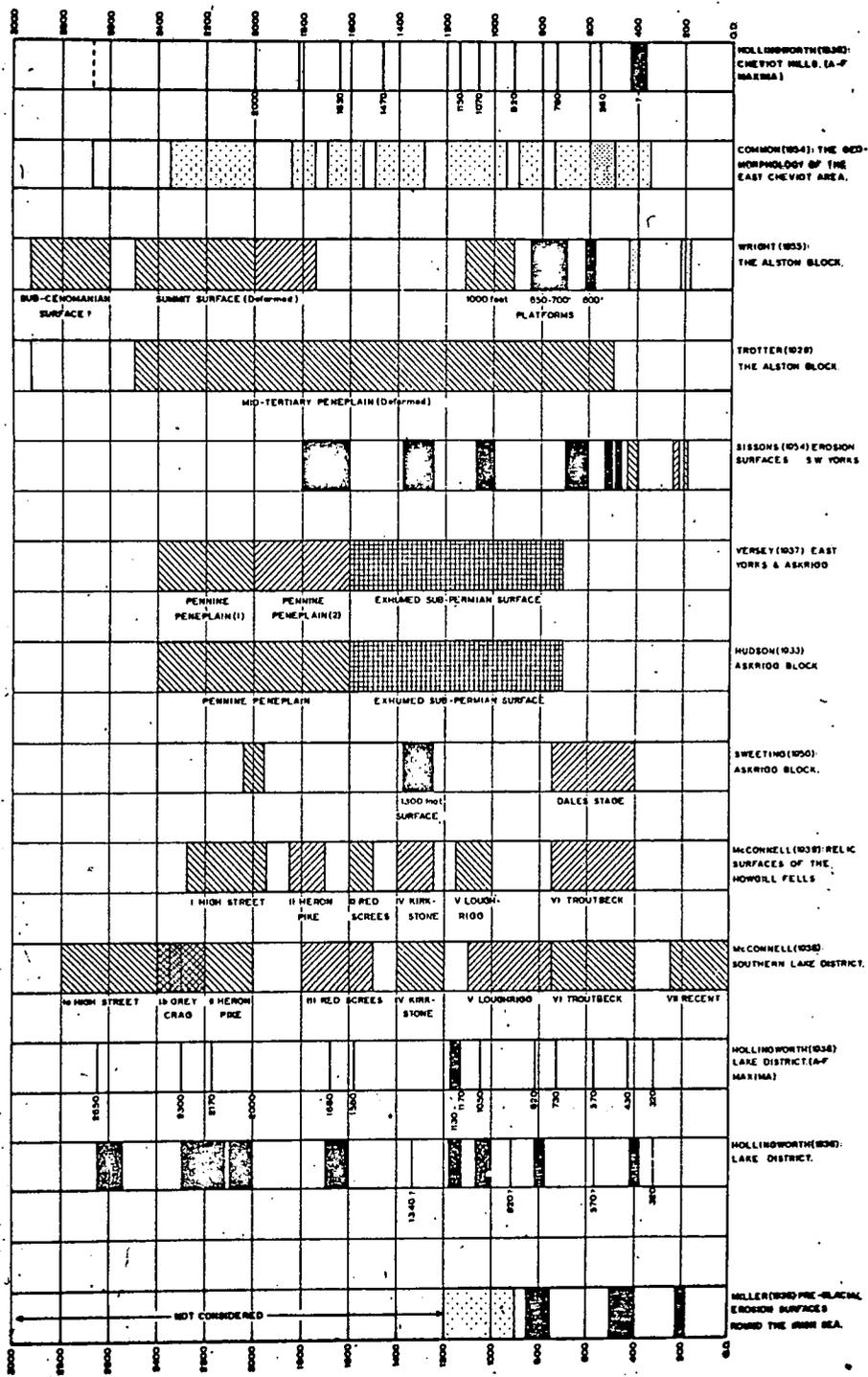


Figure 8.

Wright has recognised the following erosion surfaces within the area which he studied :- (Fig.8).

- 1) The Summit Surface, whose main development is above 2000 feet, but which may extend as low as 1750 feet. The higher summits of Cross Fell, the Dun Fells, Knock Fell and Mickle Fell are probably monadnocks. Their flat summits may represent remnants of an old lowered land surface from which the summit surface was produced. (Sub-aerial)
- 2) A Platform at 1000 feet above Ordnance Datum (Sub-aerial)
- 3) " " between 700-850 feet above " " (Marine).
- 4) " " at 600 feet above Ordnance Datum (Marine).
- 5) " " between 400-450 feet above Ordnance Datum(?).
- 6) " " at 200 feet above Ordnance Datum (?).

Wright has supposed that the Alston Block was covered by Chalk and, possibly, earlier Mesozoic sediments. However, Wright has followed Linton (1951) in his conclusion that the monadnock summits may be considered to represent fragments of the sub-Cenomanian surface. Clearly, therefore, Wright does not accept the thick ~~Mesozoic~~ cover described by Trotter.
with the full succession of Mesozoic rocks

Wright has suggested that there were two periods of Tertiary uplift. The first is correlated with the pre-Eocene phase of Alpine orogeny and Wright has shown that this view is consistent with modern tectonic and morphological theory. It is not clear whether he accepted Trotter's evidence for differential fault block uplift during this early phase of movement, or whether he believed that the Alston Block was only lifted and tilted by movements which affected practically the whole of Britain.

In contrast to the interpretation of Trotter, Wright has recognised four east-flowing consequent streams which originated upon the initial surface of Cretaceous rocks :-

- 1) The Tyne.
- 2) The Upper Wear, with any upper Tees-Bollilhope tributary.
- 3) The Maize Beck - Bedburn - Bishop Auckland consequent described by Trotter.
- 4) The Greta-Tutta-Clow consequent stream, recognised by Fawcett in Stainmore.

Wright has suggested that the first and fourth were significantly more important than the two central consequent streams.

During the late Oligocene-Miocene period of earth movements, the Alston Block was raised by fault block uplift. This was accompanied by folding along the axis of the Teesdale Dome which may have been, in part, posthumous. Wright agreed with Trotter that those subsequent streams which were favourably located round the periphery of the dome were rejuvenated by this folding.

During Miocene and, perhaps, early Pliocene times, large parts of the early Tertiary peneplain were destroyed by these rivers eroding to a lower base level. To the east of the warped surface, a lower, sub-aerial peneplain was produced. This platform lies at about 1000 feet. Wright believes that this is the equivalent of the mid-Tertiary peneplain which has been recognised in other parts of Britain.

He has noted the presence of at least three lower surfaces in the eastern part of the Block, which he supposed may be representative of Pliocene marine transgression. He has suggested that the maximum extent of the sea was about the present 800-foot contour and that a wave-cut platform may be recognised just below this level. During the retreat of the sea, there was a distinct period of still-stand, at about 600 feet above Ordnance Datum, during which a further platform was cut. Wright has noted the possibility of further surfaces at lower levels (about 400 and 200 feet above Ordnance Datum) but he did not study these in detail.

The present writer cannot agree with Wright's conclusion that the Summit Surface was arched by folding along the axis of the Teesdale Dome. The hypothesis which demands folding of an early-Tertiary peneplain cannot satisfy the conditions under which mineralization took place. Dunham (1932, 1948) has shown that folding and mineralization were probably contemporaneous and that primary mineralization was complete before the deposits were exposed to Tertiary groundwater. It might be argued that if two phases of folding occurred along the axis of the Teesdale Dome, it is possible that mineralization was confined to the first period of movement. This argument cannot take account of the "fossil" hydrothermal solutions described by Dunham (1948, 1952) which would be liberated during any posthumous movement.

Wright based his evidence for mid-Tertiary folding upon two morphological conclusions; first that the Summit Surface is downwarped round the periphery of the Dome and secondly that the course of the consequent Upper Wear is discordant with the underlying structure. Wright has supposed, from this discordance, that the Upper Wear was either superimposed upon

- 5) The structure of the western part of the Block shows gentle doming, but the general gradient of the hill-top surface is less than the structural fold.
- 6) The drainage pattern has been recognised as either radial, centred upon the crest of the dome, or a trellised pattern which has been modified by folding after the development of this pattern.
- 7) Until the contrary can be proved, it must be assumed that the hill-top surface represents the remnants of the peneplain of a single cycle.

The Teesdale Dome is either of Hercynian age, or Tertiary age, or gentle folding occurred along this axis during both periods of fault-block movement. It is certain, from the evidence of primary mineralization, that folding occurred before the formation of a Tertiary peneplain. If the folding occurred entirely during the Hercynian and the surface of the dome had been subsequently covered by Mesozoic rocks, there would be thinning of Permian and later rocks as these approached the crest of the dome. After the Tertiary uplift had raised and tilted the initial surface, consequent drainage would have developed upon a Chalk cover which sloped uniformly eastwards. It may be presumed that a trellised drainage pattern would evolve as different outcrops of the Mesozoic cover were exposed. The significant difference between this and the observed drainage pattern is that, when the Mesozoic cover was removed from the Block, there would presumably be superimposition of the trellised pattern on the Carboniferous structures. Merrick (1915) showed that there was sufficient evidence of the adjustment of drainage to Carboniferous structure to rule out the possibility of superimposition. The present writer accepts this conclusion, and cannot agree with the alternative suggestion of Wright (1955).

If the folding of the Teesdale Dome occurred at the same time as the Tertiary uplift, the overlying Mesozoic cover would be folded to the same extent as the Carboniferous rocks. The initial surface would be arched and the drainage pattern would, presumably, evolve as the radial drainage of transverse consequents from the flanks of the dome. This simple radial pattern might develop annular subsequent streams as the different Mesozoic outcrops were uncovered. If the area was not reduced to a peneplain, some trace of the inward-facing escarpments should persist. None of these can be recognised. If the stage of peneplanation was attained, there should be no central dome.

The present hill-top surface must, therefore, represent a single surface which has been arched since its formation by posthumous movement along the axis of

the Teesdale Dome or it may represent fragments of several surfaces which lie round the periphery of the central core of highland. The former conclusion has been shown to be untenable. It is therefore necessary to examine the platform surfaces of the Alston Block in greater detail, to ascertain whether other remnant surfaces can be recognised.

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CHAPTER 3.

STATISTICAL INVESTIGATIONS OF THE UPLAND SURFACES OF THE ALSTON BLOCK.

Apart from a few sections across the Alston Block, Trotter (1929) provides no statistical or cartographical evidence to substantiate his claim that "the peneplain displays a remarkable degree of perfection". This chapter attempts to amplify this statement and attempts to provide the statistical evidence which can help to show whether multiple surfaces are present in the area. The latter cannot be proved by statistical methods alone, but the results of this enquiry may indicate further lines of investigation.

Four different methods of measurement, sampling and reconstruction have been used. These include the different methods of :-

- 1) Drawing multiple profiles.
- 2) Reconstruction of former surfaces by means of generalized contours and altimetric distribution mapping.
- 3) Planimeter measurements of selected contours.
- 4) Altimetric frequency analyses.

All these techniques are well-known forms of analysis but a number of new methods of sampling and illustration have been tried. A detailed critique of the methods, together with certain experimental developments of this work, are given in Appendix II.

GENERALIZED CONTOURS AND MULTIPLE PROFILES.

For the purpose of this analysis, two sets of profiles are illustrated. Three projected profiles (Plate 6, Map Folder) have been constructed for the greater part of the Alston Block along the orientation of the National Grid. The two east-west profiles were constructed by the author, the north-south profile of the western part of the Block has been compiled by P.L.Bowes. Two series of superimposed profiles for East Durham have been compiled and drawn by W.A. Eastgate (Fig. 3). The Generalized Contours (Plate 5, Map Folder) represent only one version of several different patterns which have been compiled by the author and by students under his supervision. Both these methods of representation and reconstruction of upland surfaces are somewhat crude and subjective. It is necessary to examine both contours and profiles together, for positive evidence from one may help to elucidate ambiguities in the other. Owing to the subjective element in representation, any conclusions must be considered tentative.

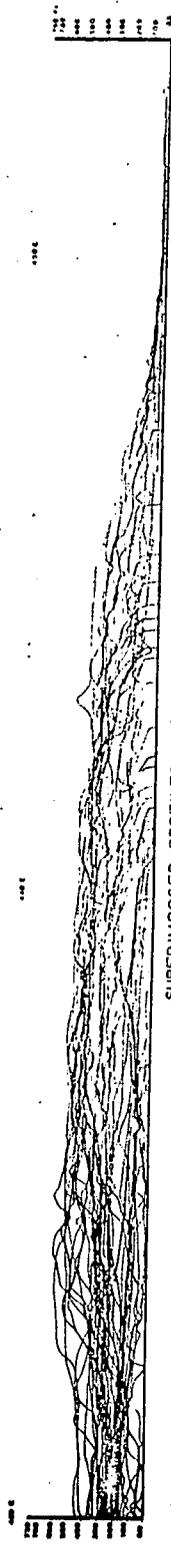
The features shown by the projected profiles must depend upon both the orientation of the axis of projection and upon conscious rejection of profiles which would obscure background detail. For example, all variations between the profile patterns of (1) and (2) (Plate 6, Map Folder), may be obtained by altering the plane of projection through ninety degrees. In profile (3), the choice of the northern boundary, which is the 550 Km.N, National Grid Line, was determined by the presence of high ground in the northern part of the West Durham Plateau (between Pontop Fell and Wrekenton) which would obscure the profiles of Charlaw Moor, Findon Hill and Pithouse Fell.

In the map of Generalized Contours, the principal ambiguity of construction occurs towards the higher contours. Above 2000 feet, the higher summits become isolated in groups which are widely separated by the indefinite moorland country of the Upper Tees and South Tyne. The problem inherent in the construction of the higher contours is the degree to which the generalized contours round one group of hills can be linked to those which lie several miles away. In Plate 5, the group of high moors, which form the watershed of Upper Weardale from Killhope Law to Outberry Plain have been shown as an isolated group which is separated by Upper Teesdale from the main bulk of high ground centred on Cross Fell and Mickel Fell. The generalized contours above 2100 feet could be drawn, with equal validity, to show this as a continuous tract of high land which slopes eastwards from 2500 to 2100 feet. This second interpretation can be justified from the projected profiles. The line A - A on profiles (2) and (3) represent the linear reconstruction of this surface from 2600 to 2100 feet. It will be seen that, excluding so-called monadnocks, the majority of the high summits of the Alston Block lie close to this line.

The less subjective method of Altimetric Distribution mapping, proposed by Balchin (1952) cannot be applied to this tract with satisfaction. Owing to the relatively small number of summits with enclosed contours and the high proportion of gently sloping spurs, mechanical drawing of isopleths, based solely upon the summits, produces a pattern which is completely misleading. The reconstruction which takes account of the principal spurs, may have a pattern which is indistinguishable from one of the many versions of generalized contours and it will contain the same ambiguities.

Within the height range where the generalized contours are reliable, flattening may be recognised at the following heights :-

1700	-	1900	feet above Ordnance Datum.
1000	-	1500	" " " "
700	-	900	" " " "



SUPERIMPOSED PROFILES ACROSS EAST DURHAM

Profiles taken from O.S. 1:25000 Provisional Edition measured West to East along National Grid Lines between 570N & 525N inclusive, eastwards from 430E to the sea.



SUPERIMPOSED PROFILES ACROSS EAST DURHAM

Profiles taken from O.S. 1:25000 Provisional Edition measured South to North along National Grid Lines between 420E & 432E inclusive, northwards from 520 N to the River Wear, the River Tyne and to the sea coast

Figure 9.

There are clearly large areas below 600 feet where accordance of summits and spurs may be recognised, but owing to the uncertainty of reconstruction, no conclusions can be drawn from the generalized contours, themselves, at these altitudes. The marked steepening of the generalized contours between 1500 and 1700 feet is particularly prominent, and, in many places, this slope may extend as low as 1300 feet.

The multiple profiles confirm these levels of accordance. The main summit surface, between 2100 and 2600 feet is shown by line A-A on the projected profiles. The accordance of summits between 1700 and 1900 feet appear to be separated from the upper surface both in altitude and by angle of inclination. The marked break below 1700 feet is clearly visible. From 1300 feet to 500 feet, the slopes of the West Durham Plateau are gently inclined and the principal summits are roughly accordant with the eastward extension of this surface to the crest of the Magnesian Limestone Escarpment. However, this accordance is not linear. Between the extensive area at about 1000 feet in the vicinity of Tow Law and the crest of the Permian Hills at about 650 feet near Cassop, the plateau surface generally occurs below the linear surface B-B. This may possibly be attributed to the presence of multiple platforms below 1000 feet, which is suggested by the steps in certain profiles. An alternative interpretation is that linear extrapolation is not justified and the ridge crests of the West Durham Plateau are accordant to a curved surface.

The Superimposed Profiles of East Durham (Fig.9) show about six levels which may represent platform features. The highest, which lies about 600 feet is only represented by a few summits. Between 500 and 550 feet there is a certain measure of accordance. It will be seen, from the generalized contours that this represents the principal hill-top surface of the Magnesian Limestone Plateau. Below this surface, there are three or more platforms the occurrence of which is widespread. The upper platform lies between 400 and 450 feet. The middle surface, which is particularly well-developed along the western margin of the E-W profiles, occurs between 300 and 350 feet. The lowest surface lies at or slightly below 200 feet. It can be seen, however, that it is also possible to interpret these features as sloping surfaces. Thus, in the E-W profile, the main hill-top surface appears to slope eastwards from about 550 feet to about 400 feet, so that sub-division into two significant levels may be incorrect. In the N-S profile there is a general inclination southwards from the highest summits, above 600 feet, to 200 feet or lower. Two further platforms, of limited extent, can be recognised below 200 feet. The first lies between 140-150 feet and is best shown by the profiles of the northern part of the area. The second lies at or slightly below 100 feet. This occurs most frequently a little behind the cliff edge of the present coast.

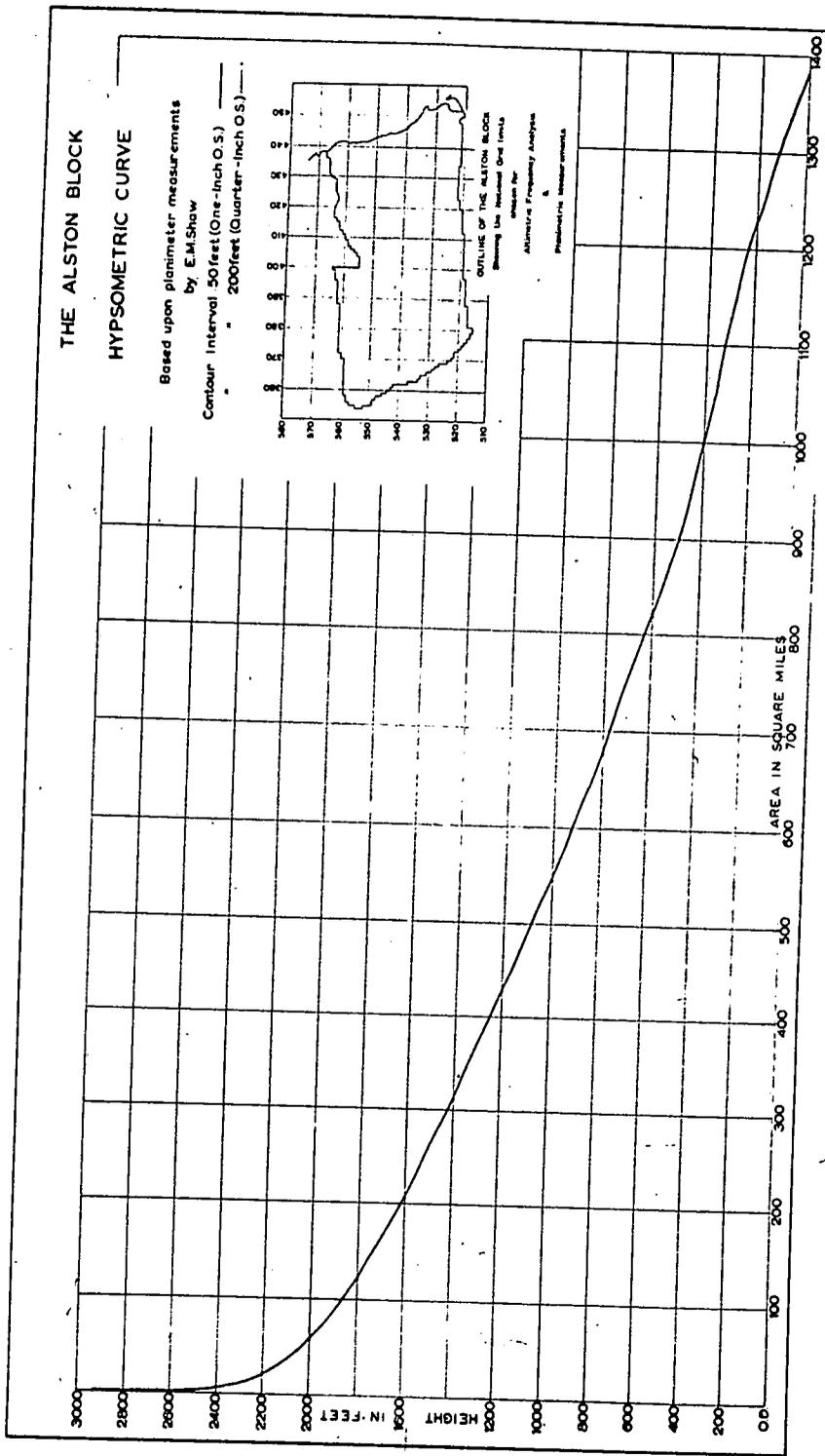


Figure 10.

AREA-HEIGHT AND ALTIMETRIC FREQUENCY INVESTIGATIONS.

The present writer is deeply indebted to Miss E.M. Shaw for a full planimetric measurement of the Alston Block. This laborious work occupied her from October 1952 until March 1953, and, without her help, it would not have been possible to produce such an accurate hypsometric figure for the whole tract. The work was carried out in two parts. First, Miss Shaw measured the areas enclosed by the 200-foot contours on the $\frac{1}{4}$ -inch Ordnance Survey maps; later she measured the area enclosed by every 50-foot contour on a scale of one inch to one mile. The area of each contour measured on the $\frac{1}{4}$ -inch O.S. differs from the equivalent 1-inch figure by less than 0.3% of the total area. The large vertical interval of the $\frac{1}{4}$ -inch O.S. permits only a very general representation of the hypsometric curve, but this preliminary work provided a useful check on later figures which were computed from parts of seven different sheets. The resultant hypsometric curve is shown in Figure 10. The hypsometric curve is not the most satisfactory method by which the data can be illustrated, for it is seldom possible to identify departures from the smooth curve. In consequence, the area-height curve has been computed from the data. This is shown in Figure 11. The area-height curve, which is based upon the difference in area between successive contours, is of greater value than the hypsometric curve because the principal irregularities are immediately apparent and because, in this form, the curve is more readily compared with the altimetric frequency curves.

The three methods of altimetric frequency sampling are discussed in detail in Appendix II. It is only necessary to note that two principal methods have been employed. The first, based upon the original studies of Baulig (1935) samples the highest point per unit area. In this work, unit area has been chosen as one square kilometre of the National Grid. During this analysis, in order to assess the degree of dissection at different altitudes, the lowest point per unit area was sampled also. The second method is derived from the work of Hollingworth (1938), who has restricted sampling to listing, in order of altitude, those summits shown on the one-inch map. The altimetric frequency curve based upon the "Baulig Method" is shown in Figure 11, the two altimetric frequency curves, based upon these methods, are represented in Figure 15.

In general, the four curves, based upon three dissimilar techniques of measurement, sampling and representation, show certain general similarities. The hypsometric curve shows marked regularity in outline from 2900 to 350 feet. Below this height, the curve is predominantly convex. The significance of this feature is emphasized by the area-height curve and by both forms of altimetric frequency curve. The peak at 320-330 feet represents the absolute maximum of all except the "Hollingworth Method" of altimetric sampling. A peak of smaller significance occurs at 125 feet in the area-height curve and at 165 feet on the

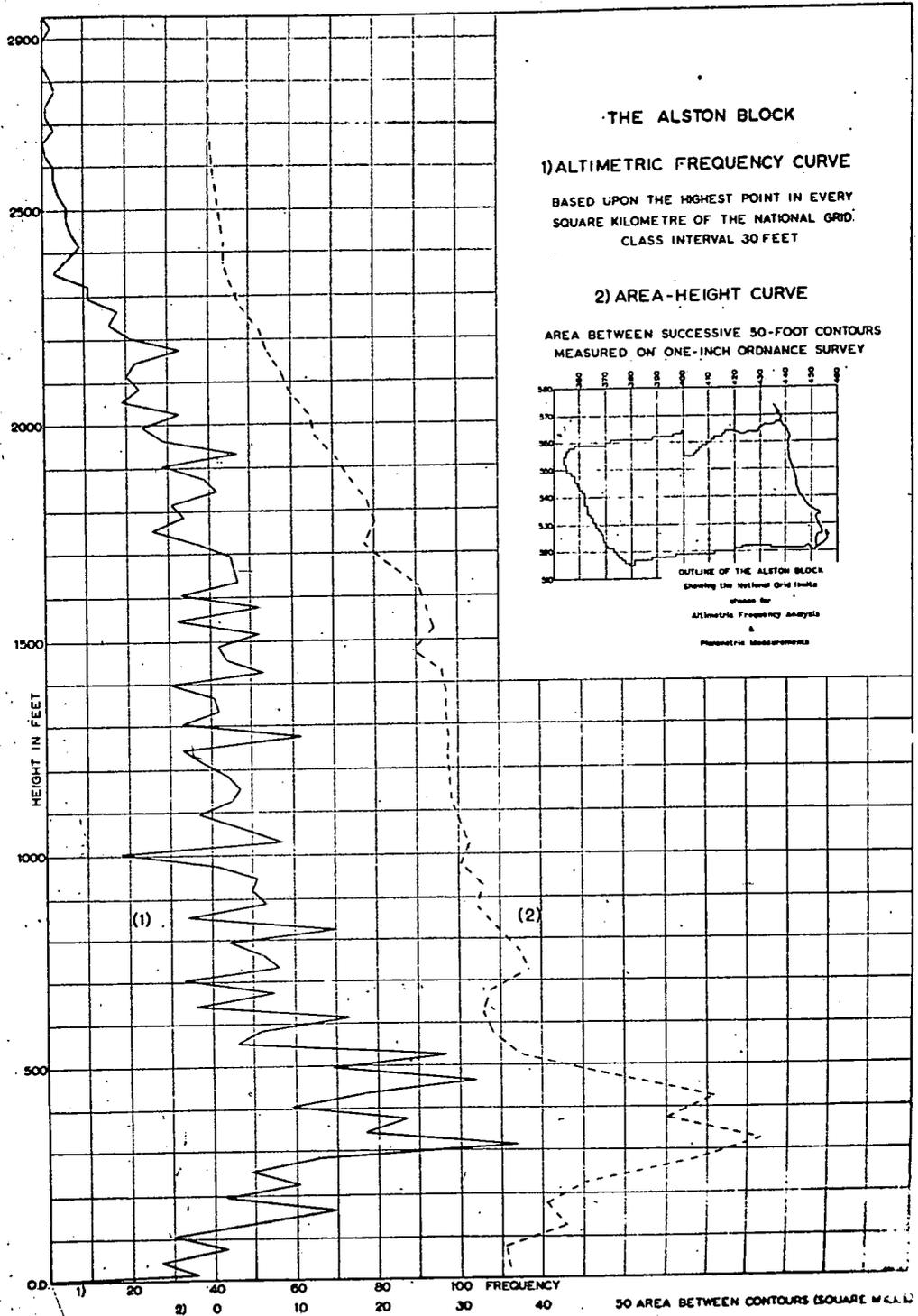
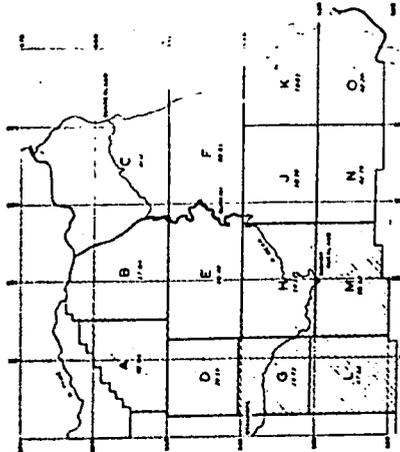
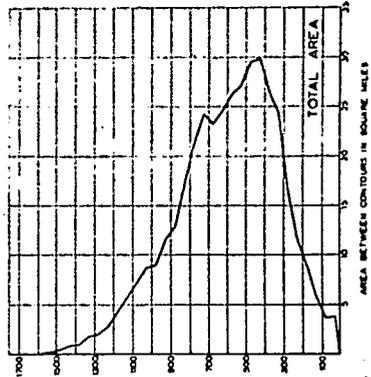
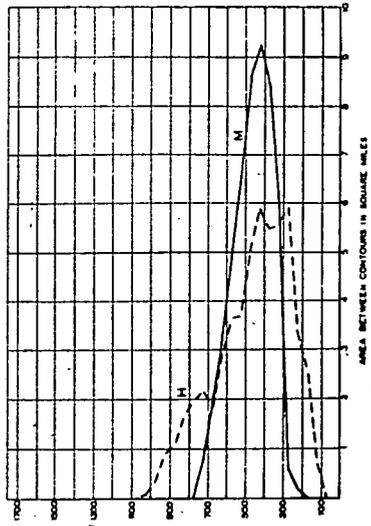
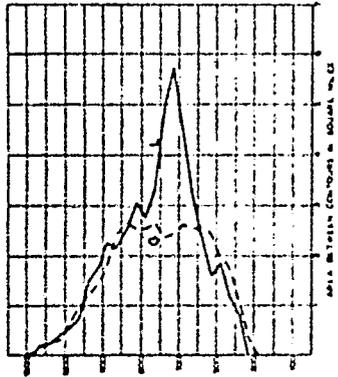
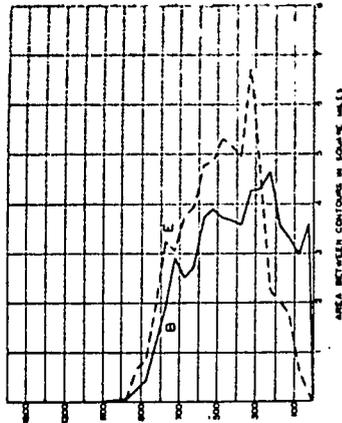
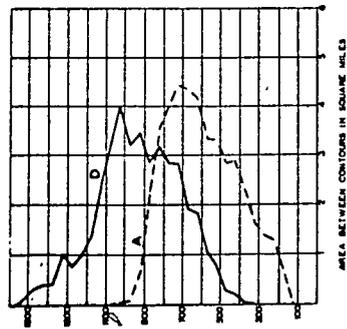


Figure 11.

Table 3. MAXIMA AND MINIMA OF THE ALTIMETRIC
FREQUENCY & AREA-HEIGHT CURVES OF THE ALSTON BLOCK.

Shown by Projected
Superimposed Profiles
& by Generalized Contours.

	<u>Maxima.</u>	<u>Minima.</u>
400-450	425	375-400
500 ?	525	475-500
600 ?	625	550-575
700-900	820	850-875
	1020-40	975-1005
1000-1500	1280	1125
		1240
		1325
1700-1800	1525-1650	
	1775-1850	

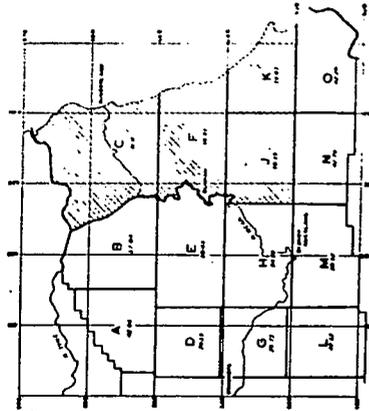
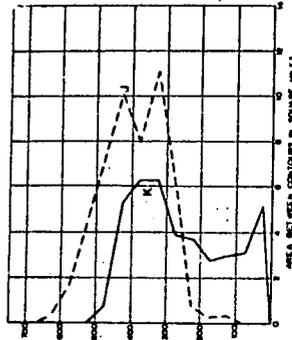
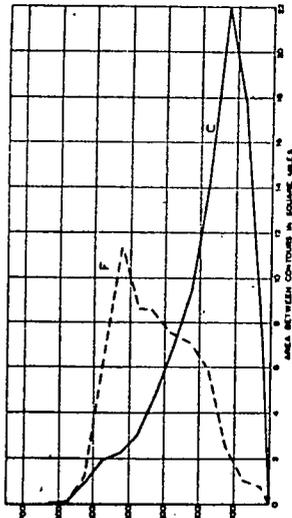


AREA-HEIGHT CURVES OF WEST DURHAM

KEY TO AREAS MEASURED WITH AREAS IN SQUARE MILES

0144770

Figure 12.



AREA-HEIGHT CURVES OF EAST DURHAM
EXCLUDING THE TEES LOWLANDS

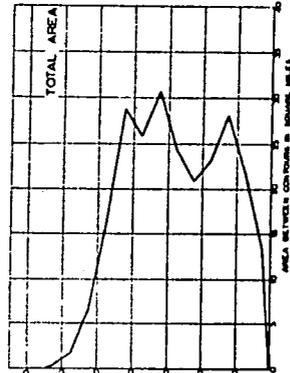


Figure 13.

ALTIMETRIC FREQUENCY CURVES. EAST DURHAM

- BASED ON THE HIGHEST POINTS PER SQUARE KM
 (A) 20 foot Grouping
 (B) 40 foot Grouping
 (C) 60 foot Grouping
- BASED ON THE HIGHEST POINTS PER 1/4 SQUARE KM
 (D) 20 foot Grouping
 (E) 40 foot Grouping
 (F) 60 foot Grouping
- BASED ON THE HIGHEST POINTS PER 4 SQUARE KMS.
 (G) 20 foot Grouping
 (H) 40 foot Grouping

BASED ON OS ONE INCH MAPS, NEW POPULAN EDITION

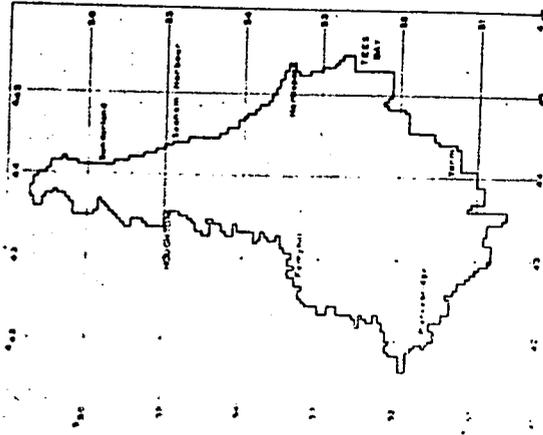


Figure 14.

Thus, if the surface sloped uniformly, such zones would initially have similar area and the altimetric frequency curve would be a straight line. If the area-height and altimetric frequency analyses showed any departures from the straight line, these would be a record of the degree of dissection at different levels. A well-preserved part of the surface would be represented by a maxima on each curve, which would stand out in comparison to more deeply dissected zones above or below. Since these forms of analysis are primarily concerned with the recognition of different surfaces rather than their relative states of preservation, it is necessary to account for this factor of regional slope.

There are two ways of correcting this factor. The first is by making analyses relative to an inclined surface rather than to Ordnance Datum. Certain experimental work in this direction was carried out. This is described in Appendix II. Owing to the formidable difficulties of computation, no results are available. The simpler alternative is to sub-divide the tract and compute the appropriate curves for each subdivision. For this work, parts of East Durham and the West Durham Plateau have been studied separately. The area-height curves for these subdivisions of the Block are illustrated in Figures 12 and 13. It was decided that the relevant altimetric frequency figures were inadequate for comparison, because, using the National Grid kilometre square as unit area, the total number of units was small for any subdivision.. In order to counteract the effects of random errors, it would be necessary to increase the class interval until such an analysis was valueless. In the course of his study of the Magnesian Limestone Plateau and the Durham coast, W.A. Westgate carried out an altimetric frequency analysis using $\frac{1}{4}$ -square kilometre as unit area and was able to show the greater sensitivity of this method for sampling a limited area.

Since the area-height curves are dependent upon the planimetric measurements, the boundaries of the subdivisions are those chosen by Miss Shaw. These areas are determined by the edges of the One-inch sheet edges, suitable grid lines and other arbitrary boundaries. Most of these subdivisions are between 40 and 60 square miles in area. In Figures 12 and 13, the sub-divisions are arranged in adjacent north-south pairs, so that direct comparison may be made of the area-height distribution along meridional belts.

The results of these investigations may be tabulated as follows :-

ice.

Table 4. PLATFORM SURFACES IN WEST DURHAM,
BASED UPON AREA-HEIGHT CURVES (FIG. 12).

Total Area	A	D	G	L	B	E	H	M
		1325						
				1075				
1025		1025						
			975					
925?		925		925		925?		
		825	825					
						775		
725	725	725		725	725		725	
			675					
		625						
	525		575					
				475		475		525
425	425?	425	425?				425	425

The figures for "G" are not representative because much of this sub-division is occupied by the lower part of Weardale.

Table 5. PLATFORM SURFACES IN EAST DURHAM,
BASED UPON AREA-HEIGHT CURVES (FIG. 13).

Total Area	C	F	J	K
425	450?	425	425	450

The figures and tables show that there is a marked persistence of the 400-450 foot platform throughout each area. In West Durham, there is evidence for further surfaces at 500-550 feet and at 700-750 feet. The evidence for platforms at greater altitudes is unsatisfactory because the majority of this tract lies below 1000 feet. In the extreme west of the area, there is, however, evidence for surfaces between 900 and 950 feet and between 1000 and 1050 feet. The maximum at 1025 feet in area 'D' is particularly prominent.

In East Durham, the only surface which is represented above the three post-glacial levels is that which occurs between 400 and 450 feet. This emphasizes the conclusions already obtained from the superimposed profiles of this area.

In the present form, the method is clearly inadequate for summarizing the evidence for planation at the upper limit of the altitude range in any sub-division. However, this approach has confirmed certain tentative conclusions which

have been drawn from the other statistical methods which have been adopted. It has confirmed that the altimetric frequency maxima between 400-500 feet, 700-850 feet and 1000-1050 feet may have considerable local significance.

It is now possible to summarize the conclusions of this statistical work and compare the results with the similar work carried out by Wright (1955). As should be expected, the results are very similar.

Table 6. SUMMARY OF STATISTICAL RESULTS.

Projected Profiles, Superimposed " Generalized contours.	Area-height & altimetric frequency curves.	Area-height curve of W. & E. Durham.	Suggested Level of Significance.
2100-2400	2170-2200		2100-2400
	2025		
	1930		
1700-1800	1775		1700-1800
	1525		
1000-1500	1280	1325	1250-1320
	1030	1025	1000-1050
		925	
700-900	820	825	720-900
600-650	730	725	
500-550	620		600-620
400-450	520	525	520-550
	425	425	400-450
320	320	325	320-330
190	180		190
140		125	140
100	80		100

COMPARISON OF ALTIMETRIC FREQUENCY CURVES OF NORTHERN ENGLAND

- (1) THE ALSTON BLOCK "Hobingworth Method" 50-foot class-interval
- (2) THE ALSTON BLOCK "Bawling Method" 30-foot class-interval
- (3) CLEVELAND After Wisby 40-foot grouping
- (4) THE LAKE DISTRICT After Hobingworth 50-foot grouping
- (5) THE CHEVROT HILLS After Hobingworth 50-foot grouping

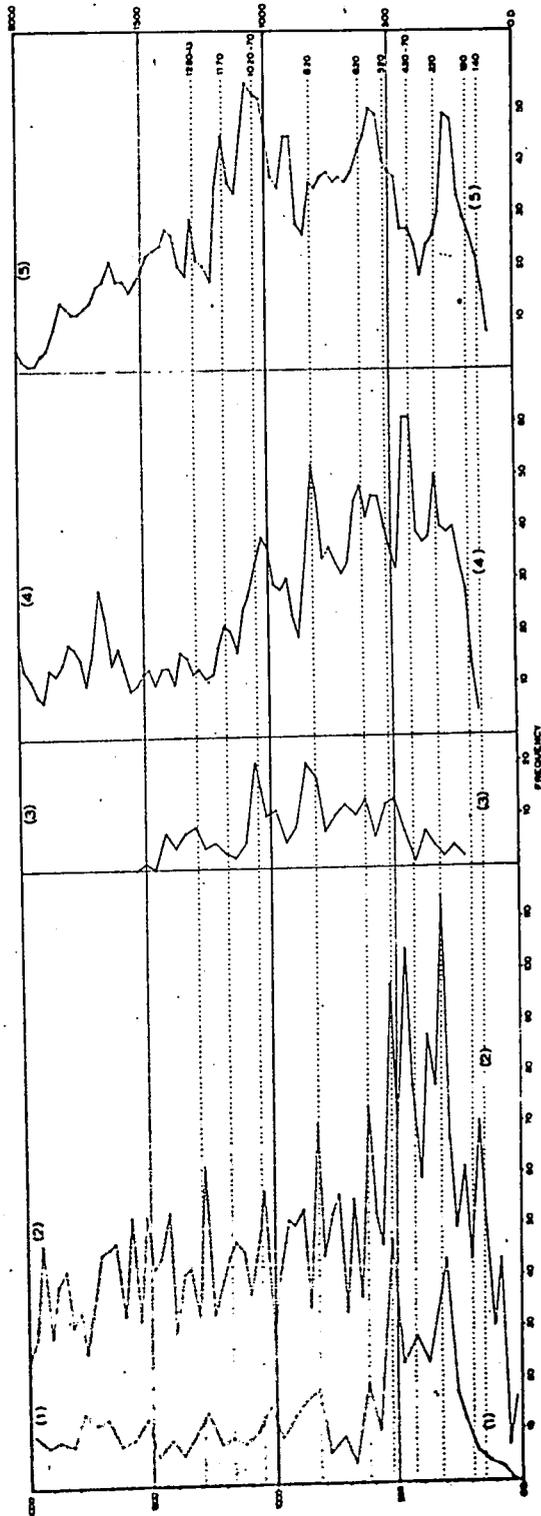


Figure 15.

Table 7. COMPARISON OF STATISTICAL CONCLUSIONS.

	Maling (1955) (Table 6, col.4)	Wright (1955) "Most significant surfaces"
	-	2700
	-	2400-2600
	2100-2600	2000
	1700-1800	1750-2000
		1500
x	1250-1320	1200-1400
x	1000-1050	1000
x	720-900	700-850
x	600-620	550-650
x	520-550	
x	400-450	400-450
x	320-330	250-350
	190	
	140	
	100	

(The altitudes marked 'x' represent those heights at which significant maxima were recognised by Hollingworth (1938) in his analysis of the Lake District and Cheviot Hills. See Fig. 8 and Fig.15).

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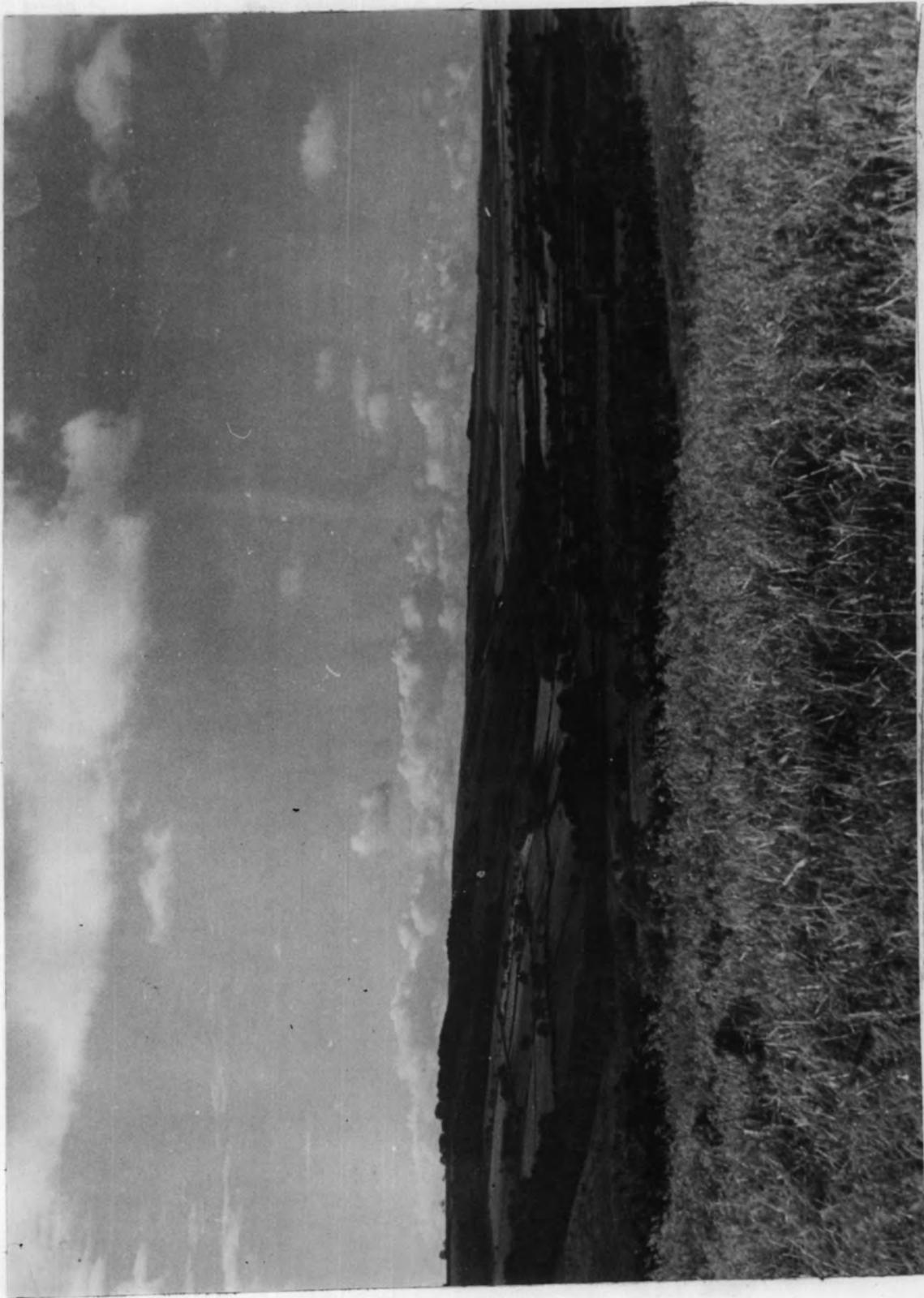


Fig. 16

The 1,000 foot platform. View West from Wilk's Hill (NZ/170,439) of the Hedleyhope Burn and Hedley Edge. Tow Law is on the skyline.

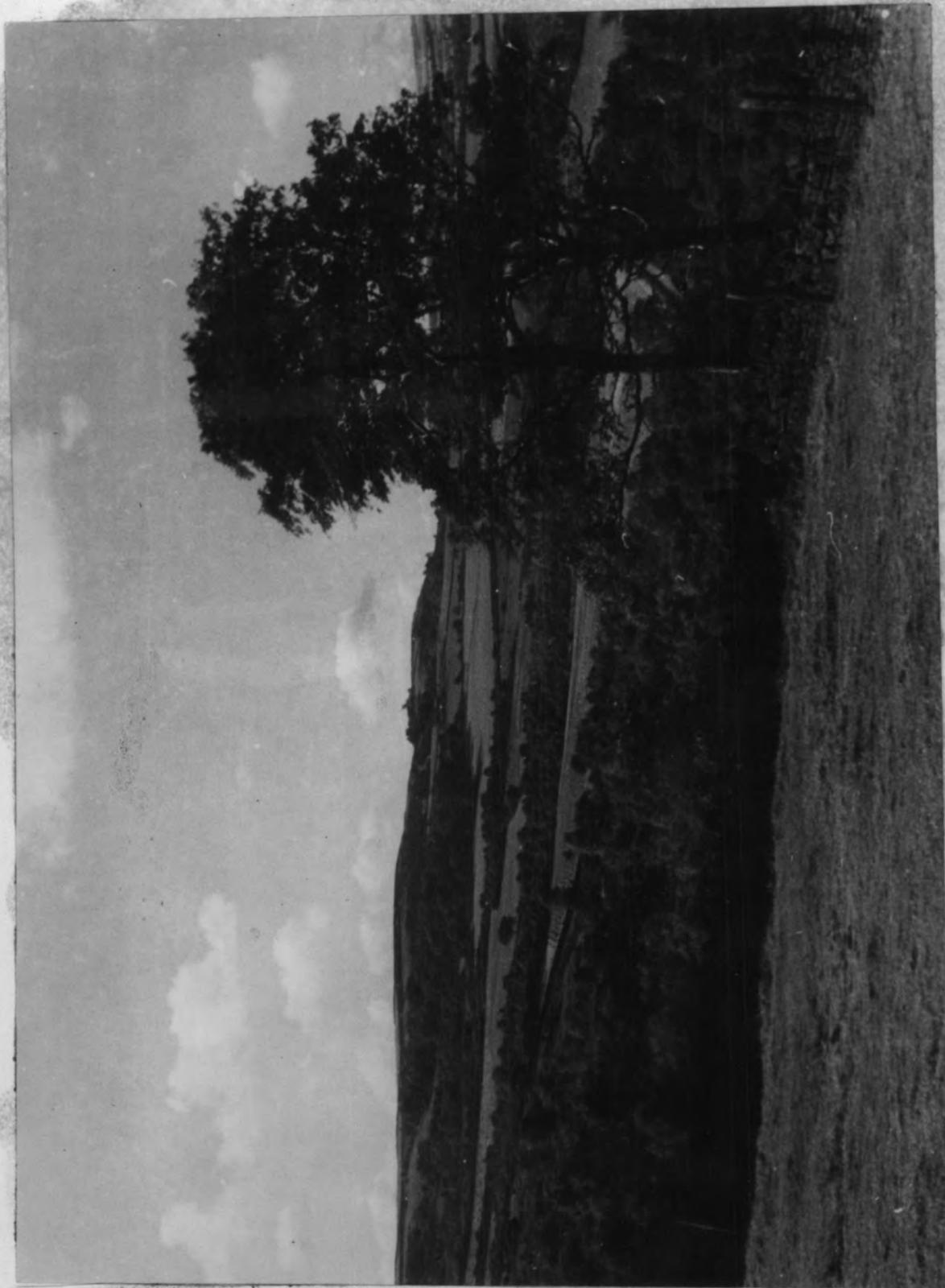


Fig. 17

The West Durham Plateau. View West along the Browney-Deerness
Interfluve from Lead Hill (NZ/163,454)

Trotter, F.M. 1929.

The Tertiary Uplift and Resultant
Drainage of the Alston Block and
Adjacent Areas. Proc. Yorks. Geol.
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Wright, R.L.

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Weardale. Unpublished M.S.c. thesis.
University of Sheffield, June 1955.

CHAPTER 4.

THE INTERMEDIATE PLATFORMS OF THE WEAR VALLEY.

The first three chapters of this thesis have been concerned with the Alston Block as a whole. It is now necessary to study the Wear valley in greater detail and to take account of the field-work which was carried out during this research.

It was stated in the Introduction that the present writer discontinued work on the upland surfaces of the Alston Block when it was known that these were also the subject of study by R.L.Wright. Some of the higher moors were studied in the field during the first season in upper Weardale before it was realized that there was an overlap in our respective studies. The extent of this work has been insufficient to provide an alternative version of the early denudation chronology which can take account of the objections to mid-Tertiary folding which were stated in Chapter 2. For this reason, it is necessary to accept, without prejudice, those arguments which support the recognition of a sub-aerial peneplain above 2000 feet. It has been shown, from the statistical investigations, that it may be possible to recognise additional surfaces between 1700 and 1800 feet and between 1250 and 1320 feet, but it is not possible to confirm these impressions with field evidence.

The term 'Intermediate Platforms' describes those shelf and spur features which lie below the watershed of the Wear drainage system and which occur above the level of the 320-foot post-glacial surface of the Middle Wear. In this chapter, two related problems are examined. It is necessary to study the evidence for multiple erosion surfaces on the lower interfluves at and below the prominent platform at 1000 feet and to account for their origin. It is also desirable to investigate the significance of the higher terraces or shelf features along the sides of Weardale to show whether these are graded to any particular erosion surface, or to confirm that these are purely lithological features whose distribution is independent of the denudation chronology.

THE PLATFORMS OF THE WEST DURHAM PLATEAU.

The West Durham Plateau comprises the mass of high ground which lies between the valley of the Middle Wear and the approximate line of the 1250-foot generalized contour. The upper part consists of an undulating, little dissected plateau which lies between 930 and 1160 feet, but which is best developed between 1000 and 1050 feet in the vicinity of Tow Law. This surface forms the even skyline of the Plateau throughout the whole of the western horizon (Fig.16). This feature has been

recognised and described by Wright (1955), who called this the '1000-foot Platform'. He has shown that it is well-developed above Teesdale, on the hills between Barnard Castle and Eggleston. The work of the present writer, confirms the continuity of this surface, north of the Wear into South Northumberland.

From this platform, a series of fingers of high ground radiate eastwards, gradually losing height until they are abruptly terminated, at heights between 400 and 600 feet, as spurs along the western edge of the Wear valley. The remarkable preservation of the plateau surface along these interfluves is strongly contrasted to the steep-sided valleys of the east-flowing streams which drain the plateau (Fig.17). These essential topographical features of the Plateau are represented in the detailed topographical maps of the Browney-Deerness Interfluve (Plates 16 and 17, Map Folder). Parts of the Plateau are also represented in Plates 11,12 and 13 (Map Folder). The drainage of the Plateau differs from that of the western part of the Alston Block. There are only three streams which penetrate the entire width of the Plateau. These are the major rivers, the Tees, Wear and Derwent. All those streams which drain the Plateau itself, rise on or near the 1000-foot Platform.

The courses of these Plateau streams, as shown by the pre-glacial drainage pattern (Fig.26, and Plate 5, Map Folder) appear to be radial from two centres. The northern centre is Pontop Fell, which rises to more than 1000 feet in North-west Durham; the southern centre is near Tow Law. From each of these centres, valleys radiate in directions which vary from north-west to south-east. The River Browney, which lies midway between them, receives headwaters from each centre. (Fig.18).

The Projected Profiles (Plate 6, Map Folder) show that there is a marked topographical break between the 1000-foot Platform and the higher hills of the Alston Block. As a first approximation it may be suggested that the West Durham Plateau represents a single dissected surface which slopes eastwards from 1150 feet to about 600 feet at an angle which is slightly steeper than the line B-B on Nos. 2 and 3 of the Projected Profiles. A further example of this linear accordance is shown by the low summits of the Browney-Deerness Interfluve, (Fig.19), which are aligned along an almost straight line of similar gradient between 980 and 780 feet.

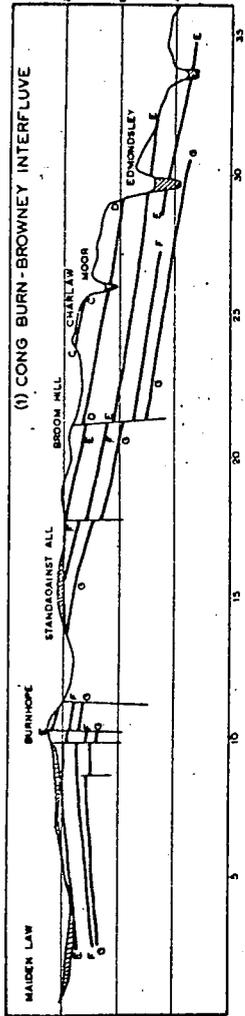
It may be supposed, therefore, that this even surface represents the eastward continuation of the 1000-foot Platform and had similar origin. It may represent the structural dip-slope of the Carboniferous strata; it may represent an exhumed sub-Permian surface such as was recognised further south by Hudson (1933) and Versey (1937) (Fig.8), or it may be a sub-aerial



Fig. 18

The West Durham Plateau. View West up the Browney Valley
from Lead Hill (NZ/163,454)

INTERFLUVE PROFILES OF THE WEST DURHAM PLATEAU



Vertical Exaggeration x5.
Seam Letters according to
N.C.B. Classification.

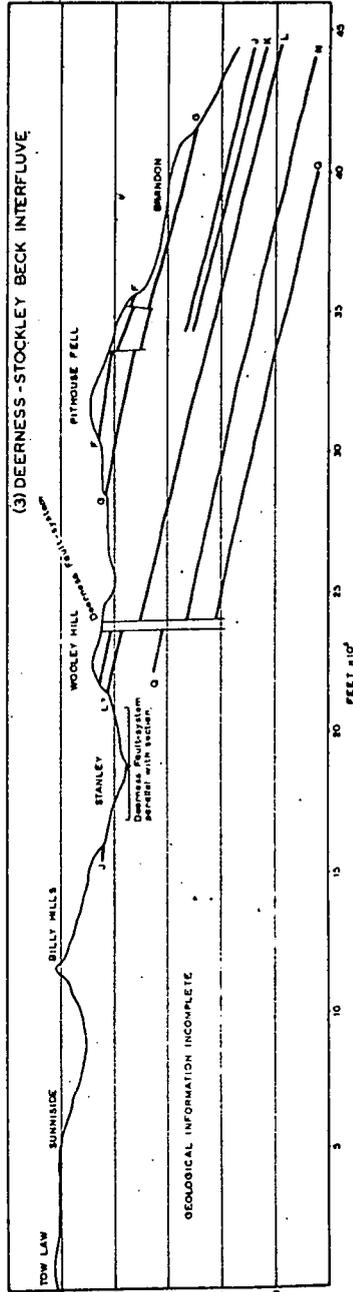
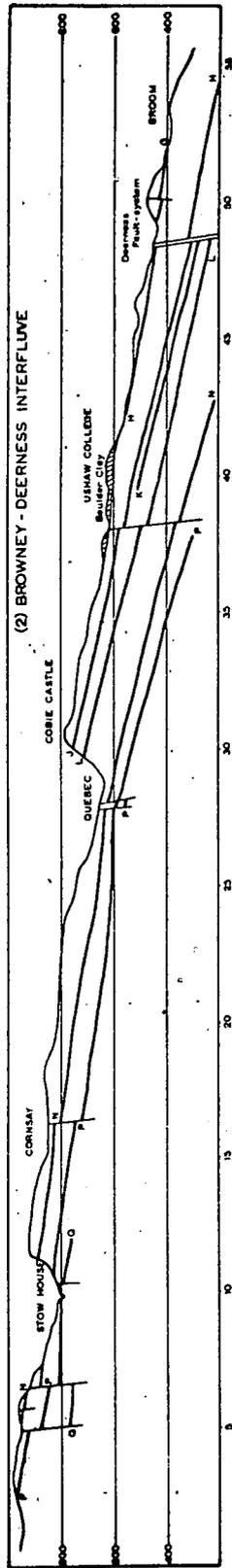


Figure 19.

surface of later age than the Summit Surface of the Alston Block. Alternatively, if the surface of the Plateau can be sub-divided into facets of similar altitude, these may represent marine surfaces of late-Tertiary age. The first of these speculations cannot be supported. Although it is clear that the regional dip of the Carboniferous strata approximates closely to the eastward gradient of the Plateau surface in certain places, the dip of the rocks is slightly steeper, so that successively younger beds are exposed towards the east. Thus, north-west of Tow Law, the 1000-foot Platform transgresses the Millstone Grit, Lower Coal Measures and Middle Coal Measures. Along the interflaves, which are predominantly composed of Middle and Upper Coal Measures, the dip of individual seams is greater than the gradient of the Plateau. It cannot be shown that the surface is disturbed along the lines of major faults. Although a break in the profile may be recognised where the Deerness Fault crosses the Browney-Deerness Interfluve (Fig.19), similar faults do not shift the surface in the other profiles.

If the base of the Permian is extrapolated westwards, assuming that the dip remains constant and that Permian rocks are not disturbed by faulting, the level of the unconformity rises more quickly than the surface of the Plateau. Hickling (1949) has drawn a series of sections through the Durham Coalfield and has shown that, assuming linear extrapolation, the base of the Permian rises to a height of 1700-1800 feet above Ordnance Datum in that area where the 1000-foot Platform is best developed. This reconstruction is justified, for the dip of the Magnesian Limestone has been shown by Hickling (1949) to be remarkably constant (Fig.3, p.7) and, as has been shown in Chapter 1, (page 9), there are few significant faults with north-south trend which could affect the Permian. The extrapolation of the Permian base is shown on No.3 of the Projected Profiles (Plate 6, Map Folder). It is clear that this line has no relation to the present surface of the West Durham Plateau. It is also unlikely that any other topographical feature of the Alston Block can be considered to represent the exhumed sub-Permian surface.

For these reasons it must be concluded that the surface of the West Durham Plateau is either the remnant of a Tertiary peneplain or a marine platform. If the surface had marine origin, it is likely that, in detail, the surface of the Plateau can be resolved into a number of separate facets.

Examination of the area in the field has shown that there are certain well-defined platforms which may be grouped roughly into five altimetric divisions :-

1160-930	feet	above	Ordnance	Datum	'The	1000-foot	Platform
830-780	"	"	"	"	"	"	"
630-610	"	"	"	"	"	"	"
530-510	"	"	"	"	"	"	"
420-400	"	"	"	"	"	"	"

Each of these groups coincides with those altimetric ranges which were tabulated at the end of Chapter 3 as showing some statistical significance.

Moreover, platforms have been recognised at similar altitudes elsewhere in Northern England and they have been regarded by many writers as evidence of marine transgression during the Pliocene (Fig.9 p 25). In this area, Wright (195b) has noted the presence of platforms at 800 feet, 600 feet and lower altitudes, which he believed were marine benches of Pliocene age.

In order to determine the significance and possible origin of these platforms, they were studied in detail with the aid of the large amount of boring and surveying which has resulted from opencast prospecting in the West Durham Plateau.

The first task was to eliminate those summits and facets which were composed of thick drift and, where this was possible, to identify the height of a platform from the height of its rock floor. The second was to obtain accurate heights of each platform fragment, to find whether there was any evidence that these features maintained constant altitudes throughout the area.

From the investigation into the extent and origin of the buried drainage system, which is described in the next chapter and from the examination of opencast site plans for these plateau areas, it was possible to determine the approximate limit of thin drift throughout much of the area. The boundaries of thin drift are shown on Plates 20, 21 and 22 (Map Folder). In general, the drift cover only becomes appreciable below 500 feet. The 400-430 foot surface, which appeared so important in the statistical examination of West Durham, is greatly reduced in extent (Plate 7, Map Folder). This is owing to the large number of hills of fluvio-glacial sand which are associated with the over-flow channels of West Durham and with the initiation of meltwater drainage through Ferryhill Gap. Thus, in Plate 18 (Map Folder), the summits of Pockerley Hills, Pelton Fell and Waldrige Fell, together with minor spurs of the Cong, Twizell and Beamish valleys, all of which rise to this level and all of which are composed of thick drift, must be eliminated from the discussion. In the south, the sand hills associated with Ferryhill Gap and the hill upon which Bishop Auckland is situated (Plate 12, Map Folder) must be ignored because they consist of very thick drift.

At higher levels, there are only a few platforms, such as the crest of the Causey Moraine (Plate 26, Map Folder) at 550-575 feet which must be ignored altogether. There are, however, many sites where the drift thickness is appreciable and it can be shown that the pre-glacial platform lies a little below the level of the present surface. For example, the important facet of the Browney-Deerness Interfluve upon which Ushaw College is situated (Plate 16, Map Folder; Fig.19) rises gently from 600 to 630 feet. This altitude has been shown to be significant in the statistical discussion and this platform occurs at the level of a marine bench recorded by Wright (1955). According to all editions of the Geological Survey, including the recently published revision of six-inch sheet XIX S.E., this part of the Plateau is shown to be drift-free. Nevertheless, a recent opencast boring, which is situated a little west of the College, close to the break in the 620-foot contour (Plate 16) has proved 19 feet of drift.

Similarly, the low summit on the Maiden Law-Charlaw Fell ridge, which rises to 810 feet near the farm known as Standagainst All (Fig.19), was proved by boring to consist of 20 feet of superficial deposits.

Clearly, therefore, it is not possible to accept all the evidence of the topographical maps. Granted the reduction of the heights of certain features by 20 feet does not materially alter the conclusion that platforms have been developed within certain altimetric ranges, but the wholesale elimination of 400-foot summits from the West Durham Plateau has shown that any reconstruction which is based entirely upon the evidence of topographical maps must be suspect. In the compilation of Plate 7 (Map Folder), due consideration of the drift thickness has been taken, where this is known, in the determination of the platform heights.

Within the six-hundred foot height-range of the West Durham Plateau, there is no 10-foot class interval which is not represented by any platform. This does not mean that they are equally distributed throughout the entire height range, for definite concentrations may be recognised within the range 780-830 feet and 530-560 feet. The present writer cannot, however, agree that there is evidence for multiple surfaces at the intervening altitudes, for even if later denudation had modified the higher platforms, the lower platforms ought to be well-preserved. However, the "600-foot Platform" is extremely fragmentary and is only represented on two out of three major interfluves (Fig.19).

It is also difficult to recognise adequate steepening of the slopes between the successive platforms which could be described as degraded cliff-lines. The eastern slopes of Pithouse Fell, where the "600-foot Platform" can be recognised at Brandon, probably represents the best example in the whole area. The Browney-Deerness Interfluve, on the other hand contains no

marked eastward steepening of slope which can correspond with this step or with any other. It can be seen, from the Interfluvial Profiles (Fig.19) and from the distribution of Remnant Surfaces (Plate 7, Map Folder) that the principal breaks between significant surfaces occur as wind gaps through the interfluvies. Nearly everywhere, the 780-830 foot surface is separated from the 1000-foot Platform by a marked wind gap or by a high featureless col.

There are only three places in the whole of the West Durham Plateau where there is any continuous slope which could be regarded as a cliff-line between 930 and 830 feet. One occurs on the southern spur of Pontop Fell, where the surface falls from Loud Hill to Maiden Law, a matter of one hundred feet in three hundred yards. The second occurs at Broom Hill on a northern branch of the Deerness-Stockley Beck Interfluvial, where the surface falls from 949 feet to 830 feet in about $\frac{1}{2}$ mile. The third and most convincing example occurs above the valley of the Upper Browney, near West Birtfield, where the spur between the River Browney and Rippon Burn falls abruptly from 928 feet to 880 feet. Below this there is a featureless platform which falls gently eastwards to 670 feet.

The present writer finds difficulty in accepting that any of these fragments of the West Durham Plateau can represent Pliocene marine surfaces. The lack of clearly defined height limits to the platforms, the lack of intervening 'cliffs' and the departures of the drainage from any simple parallel pattern of extended consequent streams all militate against the belief that these surfaces could have originated during a period of marine transgression. Granted that certain significant altitudes have recurred several times in this discussion and it is inviting to correlate these statistical surfaces with those recognised in south-west Yorkshire, the Lake District and Cheviot Hills (Fig.8, p 25). To suggest direct correlation by altitude alone would, however, deny the possibility of differential earth movements, including isostatic recovery, at all periods after their formation.

In any case, most of these other analyses have been carried out in areas where no correction can be made for the thickness of drift. The extent of correction and elimination of doubtful surfaces by the present writer has shown how inadequate the topographical map can be in the detailed investigation of possible surfaces.

The ultimate objection to the acceptance of the idea of Pliocene transgression is, however, the total lack of acceptable Pliocene deposits within two hundred miles of West Durham. Until these can be proved to have been deposited on the appropriate platforms, the recognition and dating of such features is largely subjective guesswork.

THE MAGNESIAN LIMESTONE ESCARPMENT AND THE MIDDLE WEAR.

Although it is not possible to recognise former surfaces of marine planation from the evidence of the West Durham Plateau alone, some account must also be taken of features at similar altitudes which occur east of the Middle Wear.

It was shown by the statistical investigations that three distinct surfaces may be recognised in East Durham. The highest, at 600-630 feet, which is shown by the multiple profiles (Fig.9 and Plate 6, Map Folder) is confined to the higher summits of the Magnesian Limestone Plateau, most of which are clustered in the neighbourhood of Cassop and Westerton. It should be noted that Warden Law (646 feet) which is the highest summit of the East Durham Plateau, and which lies far to the north of the other high hills, consists of about 150 feet of fluvioglacial sand and gravel. The gravel workings on the south face of Warden Law constitute one of the finest drift sections in the whole of North East England. The rock floor does not, in fact, rise above 500 feet. Similarly, there are a few isolated hills of lower elevation such as Whangdon Hill (512 feet) which are also composed of superficial deposits. Due account has been taken of these in drawing the generalized contours, but certain of these summits are recorded in the superimposed profiles.

The principal summit level of the Magnesian Limestone Plateau is at about 500 feet, though the actual extent of land above this level is limited. By far the most significant surface lies one hundred feet lower, at the altitude of the 400-430 foot platform which was recognised in West Durham. Although the extent of this surface is somewhat limited in the vicinity of the escarpment, elsewhere the undulating surface of the Plateau rises and falls gently about this altitude. There is, however, little evidence of marked break in slope between the surfaces. It is only along the steep western face of the Magnesian Limestone Escarpment that anything approximating to the ideal marine surface can be recognised. Here there are often adequate exposures in the field to show that these platforms have been cut in solid rock, but eastwards there is much doubt about the thickness and extent of the drift cover, for there are relatively few borings in the uplands of the East Durham Plateau.

It has been shown that the 600-foot Platform is too fragmentary in West Durham to justify the assumption that this surface was formed during a period of stillstand of the Pliocene sea. It has also been shown that there is lack of accordance in the linear extrapolation from the 1000-foot Platform of West Durham to the 600-foot summits of East Durham.

A possible explanation which may account for the eastward lowering of the West Durham Plateau may be derived

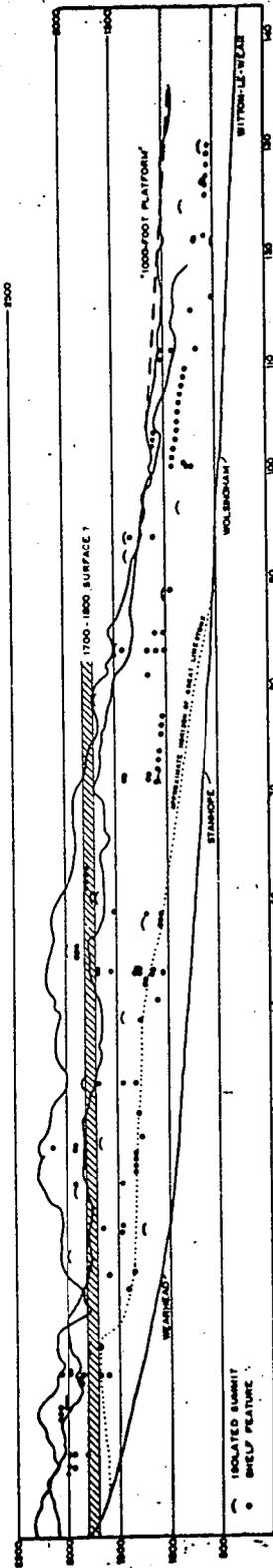
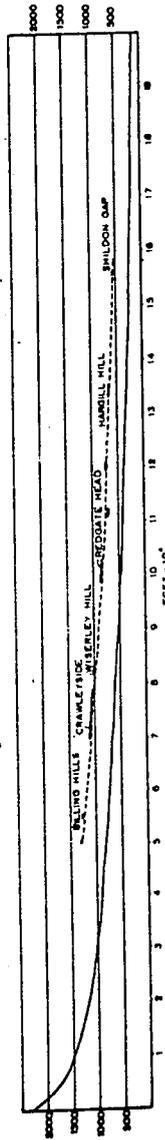
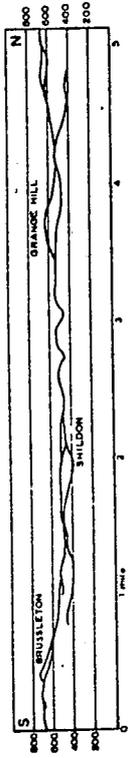


Figure 20.

from a study of the development of the Middle Wear.

Davis (1895) originally showed that a subsequent tributary of the Tyne cut back along the outcrop of softer Permian rocks and eventually captured the Wear near the present site of Bishop Auckland. This has been regarded as one of the classic examples of river capture in Northern England and has been accepted by all later writers. It is, in fact, difficult to account for this diversion of the Wear drainage in any other way.

As will be shown in the next chapter, it is impossible to show that this is an example of glacial diversion, for the middle of the pre-glacial valley can be proved to lie close to the middle of the present valley and shows the northward change in direction at Bishop Auckland. It is difficult to envisage any way in which structural movements could alter the drainage pattern here. Although the elbow of the pre-glacial Wear occurs right at the line of the Butterknowle Fault, the dowthrow of this fault is in the direction of the supposed former course of the Wear.

South and East of Bishop Auckland, lies a break in the even skyline of the plateaux surfaces. This gap occurs between Grange Hill (625 feet) above Coundon, which is capped by fifty feet of Magnesian Limestone and Brussleton Hill (730 feet) which is composed entirely of Middle Coal Measures. Between these two features, there is a low symmetrical col. In detail, this col is now much dissected by the small tributaries of the River Gaunless and the Woodham Burn, but, from a distance, such as the eastward view from Knitsley Fell, the general impression is that the whole represents a continuous broad gap. This is illustrated by the Projected Profile (1) of Fig. 20. Since the mining town of Shildon lies near the middle of this col, the feature will be termed the Shildon Gap.

The low hills which comprise the floor of the Shildon Gap are in part capped by Magnesian Limestone, in part composed of Carboniferous rocks. A few summits are covered with drift, but intensive opencast exploration has shown that most of these summits have only a veneer of superficial deposits. The axes of the folds which lie south of the Butterknowle Fault and which were described in Chapter 1, page 6, lie obliquely across the line of the Shildon Gap. It is clear that the presence of this break in the plateaux surfaces cannot be related to either lithological or structural variations and it is reasonable to suppose that this is the wind-gap which was abandoned when the east-flowing Wear was captured by the tributary of the Tyne. The lowest part of the Gap occurs at 530-540 feet above Ordnance Datum.

North and West of the Shildon Gap, there are extensive platforms at this altitude or slightly higher, and, as will be shown, these can probably be traced into Weardale. North and East of Willington however, there are few platform fragments which can be supposed to represent traces of the subsequent valleys at the time when the capture occurred.

It is reasonable to suppose that the Middle Wear initially developed at a height which is greater than this 500-550 foot surface. It is also reasonable to suppose that during the formation of this valley, there was an eastward retreat of the Magnesian Limestone Escarpment. It has been shown, from Hickling's reconstruction of the base of the Magnesian Limestone (Fig.3), that no part of the West Durham Plateau can represent the exhumed sub-Permian surface. Examination of the contours suggests, however, that the outcrop of the Magnesian Limestone may have lain at a height of 700-800 feet along the approximate line of the pre-glacial Middle Wear. It has been shown that there is a possibility that the 780-830 foot surface may be continuous with the 1000-foot Platform.

It is possible, therefore, that the Middle Wear was initiated upon this surface. During the period while it was cutting south towards Bishop Auckland, it captured the east-flowing streams of the West Durham Plateau and cut downwards towards a height of 500 feet. The numerous small wind gaps of the Plateau such as those at Stow House and Quebec (Fig.19, Plate 8, Map Folder), most of which lies between 800 and 600 feet, were abandoned during minor alterations in the drainage which resulted from the rejuvenation of these streams in response to a lowered base-level. The small platforms which can be recognised on the flanks of the tributary valleys may date from the same period. When the valleys of the Middle Wear had cut down to an altitude which varied between 420 feet in the north and 540 feet in the south, it had cut headwards to Bishop Auckland, where it captured the important Wear Valley.

It is not yet possible to provide a full and closely-reasoned study of these stages in the evolution of the Wear valley. Although this sub-aerial hypothesis runs directly counter to current ideas regarding the extent of Pliocene transgression, this is because the evidence in favour of the latter is wholly inadequate.

As will be seen, there is certain evidence, from the shelf features of Weardale, which support the idea of sub-aerial development at these lower altitudes.

THE SHELF FEATURES OF WEARDALE.

Within the upland dales of the Alston Block, one of the most characteristic features of the landscape is the terraced nature of the valley sides. These terraces are generally best developed two hundred feet or more above the valley floor and, without exception, these features can be shown to correspond closely with one or other of the resistant beds of the Carboniferous succession. The principal resistant horizons have been underlined in Fig.1).

In Weardale, the most important horizon is that of the Great Limestone, but certain sandstones of the Upper Carboniferous Limestone Group also form significant shelves. Here the Whinsill is thin and has limited extent, but where this outcrops, between Stanhope and Eastgate a small but continuous terrace has been formed ~~and~~ which may be traced into the valley of the Rookhope Burn.

During the course of this work, it has been necessary to show whether these step features of Weardale are, indeed, purely lithological in origin or whether they can be shown to represent phases in the development of the valley which have been preserved by the resistance of these beds to later denudation. Since there are so many resistant beds in the Carboniferous Limestone Series and since the regional dip matches the eastward slope of the surface, no objective solution to this problem can be given. Detailed examination of particular shelves has provided evidence which can be interpreted in different ways.

The problem is probably most difficult to solve in the upper part of the dale where certain of the Middle Limestone beds are exposed high on the valley sides. Here the multiplicity of shelves is most remarkable (Fig.20. No.3). Each one, it seems, is related to the outcrop of a limestone or sandstone, and the outcrop of those beds which were mapped for the primary edition of the six-inch Geological Survey are all associated with shelves. However, in the first instance, the outcrops of these beds were mapped according to these features and where thick peat covers the moors and there are few adequate stream sections to prove the structure, this evidence was often considered adequate to show the outcrop of the various beds, so that this correspondence may be apparent and not real. Owing to the lack of continuity of even the best developed shelves where there is thick drift cover or where tributary streams have modified the valley sides, it is not possible to extrapolate the trend of a shelf across a gap without ambiguity.

Eastwards, the Middle Limestone Series dip below the present bed of the Wear and, in the lower part of the

dale there are fewer resistant horizons at which prominent shelves have been formed. In the east, however, there are additional difficulties in the interpretation of the rock succession. There are few satisfactory indicator horizons and the presence of transgressive beds alters the regular rhythmic succession which has been proved further west. Since the primary mapping of H.M. Geological Survey failed to recognise the significance of certain beds and since adequate post-war revision of this area is not complete, it is not always possible to show the true relationship of the different shelves.

In Upper Weardale, the correspondence of detailed topography to lithology is so precise that sometimes, where a resistant horizon has been shifted by faulting, there is a change in the horizon of the topographical feature also. This is well illustrated in the extreme west of the dale, between the Killhope Burn and Wellhope Burn.

The flat-topped ridge which runs westwards between these streams, from the main Wear-Tyne watershed, is terminated above the Killhope Burn at Cowhorse Hill (2036 feet). The summit of Cowhorse Hill lies a little above the horizon of the Firestone Sill and, along the prominent break of slope on the southern side of the ridge, a flaggy sandstone, which may correspond to the Lower Slate Sill, is exposed. Near the south-eastern extremity of the ridge, there are two faults whose trend is approximately NW-SE. Between these faults, the beds are thrown down some 50-60 feet. The prominent edge of Cowhorse Hill here becomes less abrupt and a small well-defined platform is preserved in the flaggy sandstone at a lower altitude. There is a similar break in the continuity of the broad pavement of the Great Limestone which lies lower down the hill. These features are well illustrated by the vertical aerial photographs 541/A/439, 3344 and 3345 (Outline on Plate 8, Map Folder). The correspondence of topography to structure is here so close that it might be imagined, without reference to the structural history, that these faults had shifted the platform after its formation. There is no evidence that these faults, which are mineralized in part, have moved since Hercynian times, though it must be admitted that it is not possible to give a precise date to the movements.

In order to examine the continuity of shelf features across a large disturbance of known age, a detailed study was made of the topography adjacent to the Burtreeford Disturbance. It was shown, in Chapter 1, that this has the form of a monocline which throws 250 feet eastwards at Cowhill. The age is almost certainly Hercynian, so that there can be no question of earlier movements shifting the features after they had formed. Detailed height determination by aneroid and by trigonometric methods has enabled the present writer to draw detailed contours for the spurs which lie on both sides of the

Disturbance. Further survey work has facilitated the drawing of several sections of the valley side where information is inadequate for accurate contours. The results of this work are incorporated in Plates 8 and 25, (Map Folder). The lines of these, and other sections, are shown on Plates 19 and 20 (Map Folder). There are a number of minor shelf features on each spur, but, for the purpose of this discussion, two major shelves may be isolated for examination.

In theory, the height of the shelf, west of the Disturbance ought to be matched by another, at a lower altitude to the east. If the shelves are erosional features, the eastward gradient ought to be less than the total displacement of beds, which amounts to about 250 feet. Alternatively, if the shelves are entirely lithological in origin, a major feature at one horizon west of the monocline ought to be matched by a similar shelf at the same stratigraphical horizon to the east. The latter is evident from both the detailed contours and the sections, for the Great Limestone, Firestone Sill and Lower Slate Sill(?) each show similar platforms on opposite sides of the Burtreeford Disturbance. However, on the spurs which lie nearest to the zone of disturbance, there are at least two shelves which superficially appear to have continuity on either side of the Sedling Burn.

Thus, the small summit of Poppet Hill (1820 feet), (Section 2, Plate 25), which is formed of sandstone which may correspond to the Lower Slate Sill, appears to be matched, to the east of the monocline, by a shelf at 1780-1800 feet, (Section 3, Plate 25). Assuming constant slope, the gradient between these two features is about 1:217. The main shelf to the west of the Sedling Burn is, however that which occurs in the Great Limestone at Greenfield Quarry. (Section 2, Plate 25). The prominent break in slope to the east of the quarry can be followed eastwards towards the zone of disturbance, but the topography along the monocline is much disturbed by ancient mine workings. The main development of the shelf is at 1680-1700 feet above Greenfield Quarry. Examination of the south-western spur of Black Hill (Section 3, Plate 25) shows that there is a similar shelf between 1600 and 1610. This has been proved to occur at the outcrop of a sandstone which is lithologically similar to that exposed on Poppet Hill. The gradient between Greenfield Quarry and this shelf on Black Hill is about 1: 81.

If reconstruction is carried upstream on this side of the valley, the next spur is that represented by Section 6, on Plate 28 (Map Folder). The highest feature, below the watershed is a small outcrop of sandstone called the Moorhen Stone. Below this there is a broad platform of flat moor which is abruptly terminated by a scarp which is known as Clevison Currick. Along this edge, which occurs at 1955 feet, a massive sandstone is exposed. Below the main scarp of Clevison Currick there is a

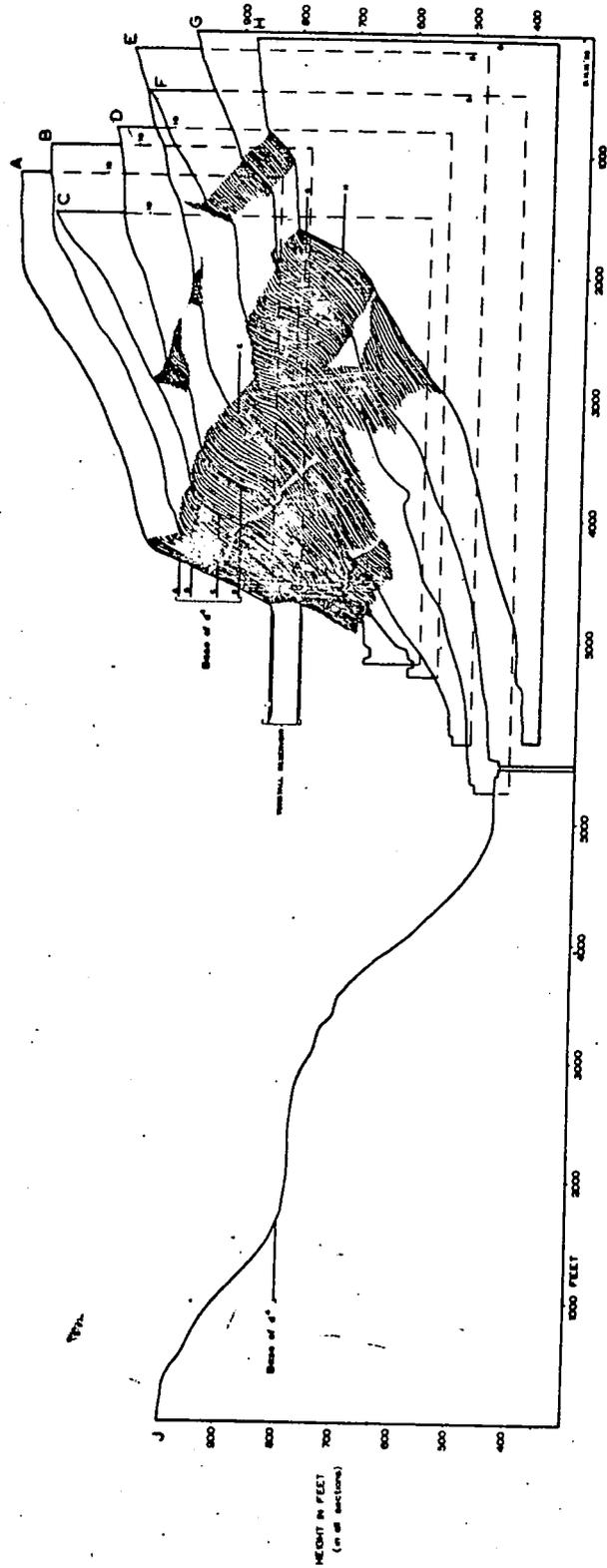
minor shelf which corresponds in altitude with the horizon of the Firestone Sill. At lower levels, the Great Limestone platform is situated at 1680-1700 feet and about seventy feet lower there is a prominent edge, now much destroyed by quarrying, at the outcrop of the Four-fathom Limestone. If Clevison Currick represents the same feature as Poppet Hill, the approximate gradient between them is 1:43. If the minor spur in the Firestone Sill at about 1780 feet is the equivalent of the Greenfield Quarry shelf, the approximate gradient is 1:67. If, on the other hand, the better-developed shelf in the Great Limestone be correlated with the Greenfield Quarry shelf, the gradient is negligible for both are developed between 1680 and 1700 feet. It is clear from these figures that no satisfactory correlation can be made between the terraces which have developed on adjacent spurs. Where there are so many shelves which might be used in any reconstruction of the former valley section, it is difficult to link platforms which occur on opposite sides of the main valley. In order to create any reasonable pattern of high-level erosion surfaces, it appears to be necessary to link a well-defined shelf on one spur with some minor feature on the next. If this can be admitted, it is possible to prove almost anything.

There is certainly no justification in the supposition that these features represent major stages of stillstand during the development of the present valley. It is only possible to conclude that, as erosion proceeded, certain remnants of the valley were preserved where resistant beds happened to occur and thus the relative positions of these shelves are largely determined by structure.

In the eastern part of Weardale there are, however, a series of extensive platforms on the valley sides. Although these, too, appear to be related to resistant beds, it is possible that they are erosional features, for it will be shown that these shelves transgress the various horizons in which they are developed and it is believed that these may be related to a definite stage in the morphological evolution of the valley.

On the north side of Weardale, above Wolsingham, there are a remarkable series of platforms which occur in and below the Millstone Grit. The detailed topography of the valley sides are illustrated in Plate 10 (Map Folder). A series of sections through these platforms are shown in Figure 21. The topography of part of the shelf is shown in Figure 22.

The base of the Millstone Grit has been accepted from the mapping of H.M. Geological Survey, but this cannot be proved continuously along these wooded slopes and the heights tabulated below are less reliable than the figures for the break in slope which have been determined trigonometrically.



THE WEAR VALLEY NEAR WOLSINGHAM: SECTIONS

Vertical exaggeration x 5

Figure 21

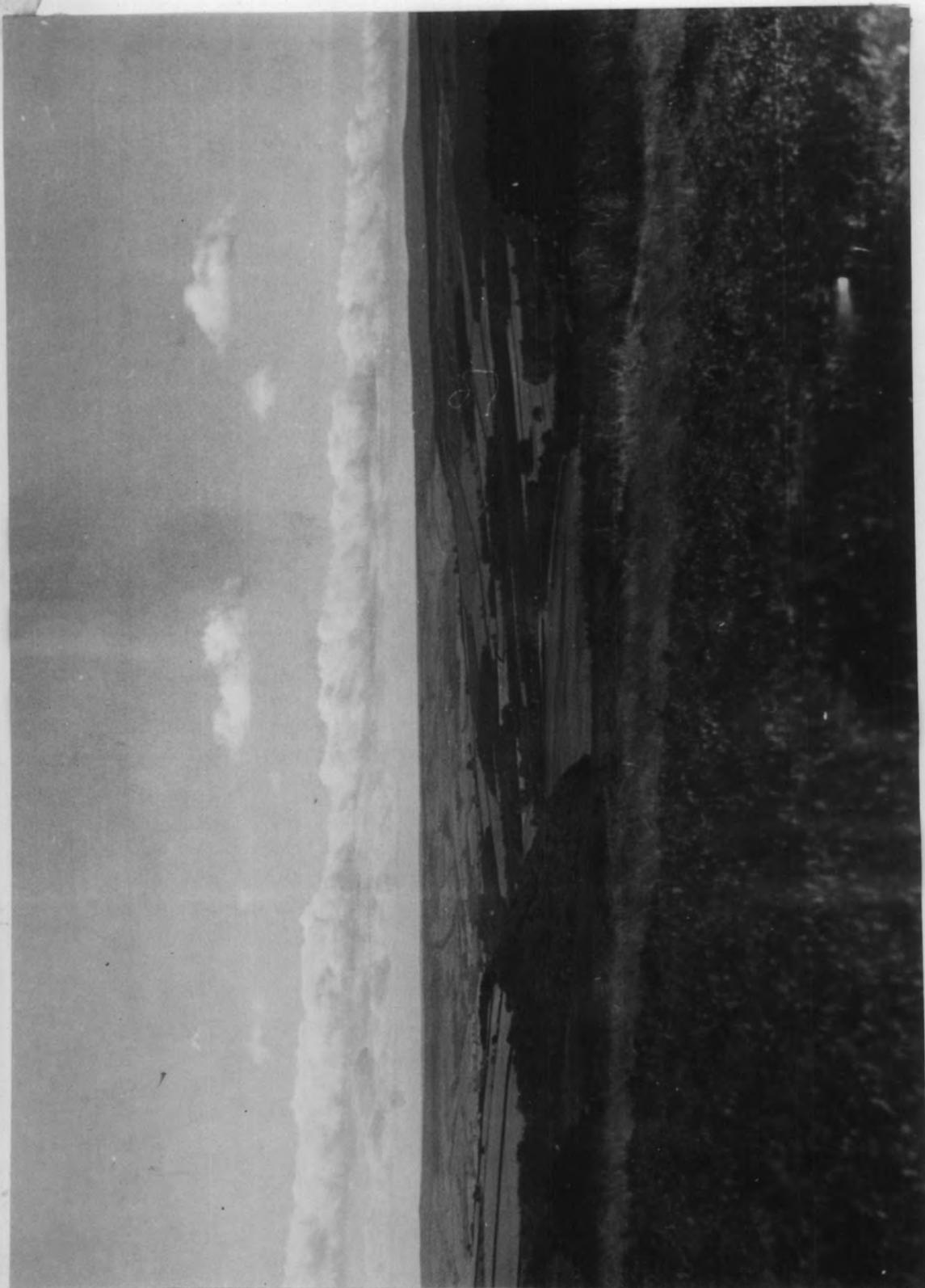


Fig. 22

The northern part of Redgate Head shelf.
View south, down the Waskerley Beck from Saltersgate (NZ/074,427)

Table 8. REDGATE SHELF : HEIGHT OF BREAK IN SLOPE ABOVE THE BASE OF THE MILLSTONE GRIT.

<u>Section.</u>	<u>Break in Slope.</u>	<u>Base of Millstone Grit.</u>	<u>Difference.</u>
A	920	860	60
B	910	865	45
C	912	868	44
D	936	870	66
E	940 (Approx)	885	(55)
F	875	785	90
G	845	780	65
H	840	760	80

Although precise determination is not possible with the present geological evidence to show that the Redgate Head Shelf is sloping less steeply than the dip of the Millstone Grit, it is probable, from the extent of the 840-850 foot facet that this platform may transgress the lower beds of the Millstone Grit. It is possible to match this shelf with the smaller feature at Chatterley on the southern side of the dale. The continuity of these shelves can be seen from the Crock-Wolsingham road where this crosses a spur of the West Durham Plateau near High Woodfield (NZ/140,351). In detail there is a discrepancy of nearly fifty feet in the heights of the opposing shelves, but since these are more than one mile apart, exact correspondence is unlikely. It is important to note that the Chatterley Shelf has developed just below the base of the Millstone Grit, whereas the Redgate Head Shelf is between 50 and 100 feet above this horizon. The resultant Zone of Uncertainty (~~at this point~~) in the reconstruction of a valley section (at this point, occurs between 760 and 780 feet. (Bande d' Indetermination))

The view west from the Chatterley Shelf into Cardale shows the approximate accordance of three groups of platforms. The eastern of these is Wiserley Hill at Rogerley Intake, above Frosterley. This prominent shelf occurs between the heights of 1010 feet and 1030 feet above Ordnance Datum. It has been preserved in the sandstones of the Lower Slate Sill. (Plate 27, Map Folder). In line with Wiserley Hill is the steep-sided edge of Crawley side, above Stanhope and the gently convex summit of Quarry Hill on the south side of the dale. Crawley Edge lies at 1050-1100 feet and the summit of Quarry Hill is 1086 feet above Ordnance Datum.

In detail, a prominent series of platforms, with sharp outer edges, can be traced from Shittlehope Edge (1046 feet), just west of Wiserley Hill, through Crawley Edge and as far up Stanhopeburn as the confluence of Heathery Burn. (Fig.23). The altitude of the outer edge is here about 1120 feet.

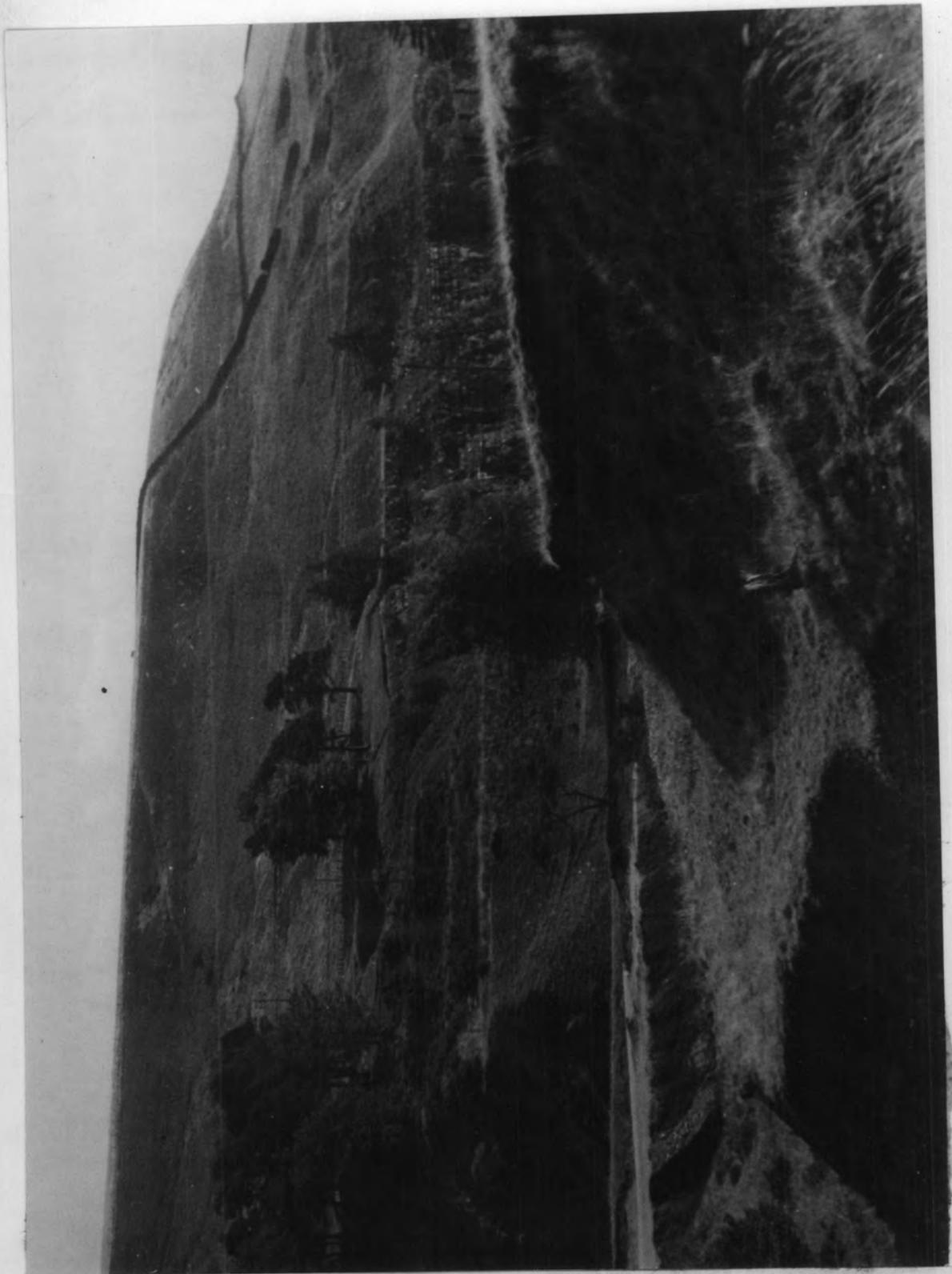


Fig. 23

Prominent shelf in Firestone Sill, Crawley Edge, Stanhopeburn (NY/990,410)
The lower shelf, now quarried, occurs above Great Limestone

Throughout the two miles where this platform can be traced, it occurs slightly above the horizon of the Firestone Sill. Between Rogerley Intake and the Shittlehope Burn, however, coarse grits transgress the horizon of the Firestone Sill and in places it appears to be absent. The detailed lithology of this change in the rock succession has been described by Dunham (1948) who termed this the Rogerley Transgression. Quarry Hill, on the south side of the valley, lies at a slightly lower horizon than the Firestone Sill and thus has a topographical and stratigraphical relationship to the northern platform which is similar to that recognised at Wolsingham.

West of Stanhope, correlation is less satisfactory, for the shelf features become more numerous and individually less continuous. It is suggested however, that a logical continuation of the Crawleyside Platform might be made, on the southern side of the dale with the shelf in the Great Limestone at Horsley Head (1225-1235 feet). It is equally possible, however that the summit of Billing Hills (1269 feet) may represent the appropriate feature. On the northern side of the dale, the surface at Billing Hills is matched by the shelf in the Great Limestone at Heights Pasture (1274 feet). Such correlation must, however, be accepted with extreme caution for the reconstruction west of Stanhope is completely subjective.

Eastwards from Wolsingham, it is possible to suggest the continuity of the Chatterley-Redgate Head Shelf to 710-720 feet on Knitsley Fell (Plate 11. Map Folder) and north of the river near Helme Park. Thence it may be represented at 620-630 feet by the summit of Hargill Hill above Witton-le-Wear and the 540-580 foot platform above Escomb. This, in turn may be related to the height of the Shildon Gap. (Fig. 20. No. 2).

It is here suggested that the sequence of platforms which have been described in Lower Weardale and which may be traced as far west as Eastgate, may represent the height of the valley at the period when the major diversion occurred at Bishop Auckland.

It is possible that higher shelves may be related to the period of erosion possibly associated with the formation of the 1000-foot Platform, but no satisfactory or reliable reconstruction can be made.

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CHAPTER 5.

THE BURIED VALLEYS OF THE WEAR DRAINAGE SYSTEM.

During the course of this research, it has been necessary to study in detail the system of drift-filled valleys which have been proved in the coalfield. The results of these investigations show the extent of glacial diversion and hence the trend of the drainage pattern before these diversions became effective. In this chapter, the salient features of these buried valleys are described and an explanation of the origin of these valleys is attempted.

One of the earliest contributions to the glacial geology of North-East England was the paper of Nicholas Wood and Edward Boyd which was published ninety years ago. In this paper, they described and traced the course of a drift-filled valley southwards from Newcastle to Durham. They were able to show that, at some time, the River Wear flowed northwards, through the present Team valley to the Tyne at Newcastle. This part of the buried valley has been called the "Team Wash". The name is derived from the mining term which describes the "wash-out" of a coal seam where this outcrops against superficial deposits along the side of a buried valley. The general term "Wash" has been used throughout the coalfield to define both the buried Wear and the smaller tributary buried valleys.

Wood and Boyd further hinted at the possible continuation of the "Wash" towards Bishop Auckland and Ferryhill, but, ninety years ago, the evidence was insufficient to show the extent or continuity of any valleys south of Durham.

When Wood and Boyd read their paper to the British Association at Newcastle in 1863, the Glacial Theory was barely accepted. Indeed, in a paper published in the same volume of Transactions of the North of England Institute of Mining Engineers, Howse was unable to accept some of the new ideas regarding the nature and glacial origin of drift. It is therefore, testimony to their careful work and acute observation that the main conclusions of Wood and Boyd are still acceptable. The map which they published is still correct in its broadest details and modern work has done relatively little to alter their conclusions about the horizontal extent of the "Wash" in the part which they studied. Their remarkable analysis of the evidence, weighing the possibility of fluvial and glacial erosion and relating this to the diversion of the River Wear near Chester-le-Street has made this a classic example of diversion of drainage by glacial drift.

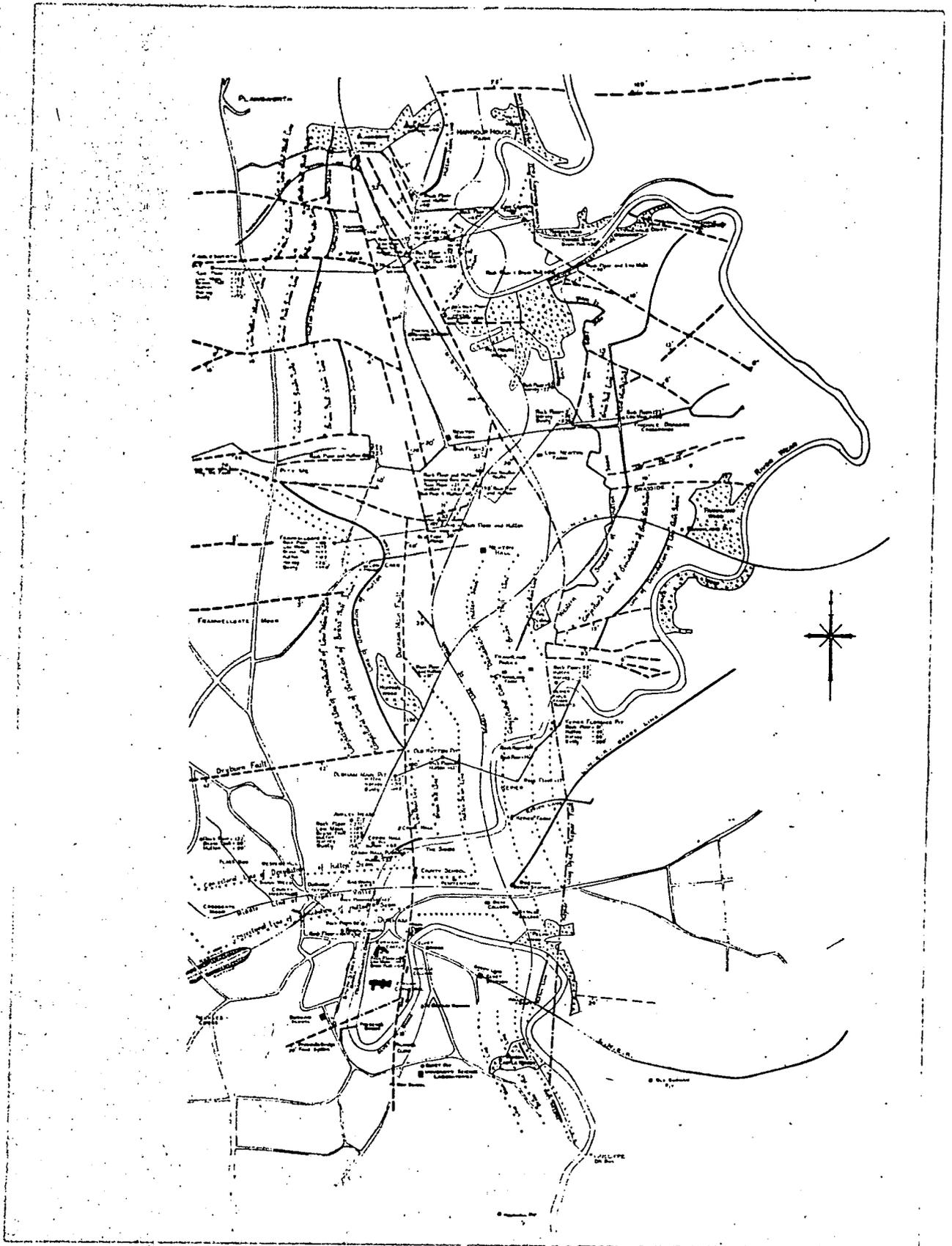
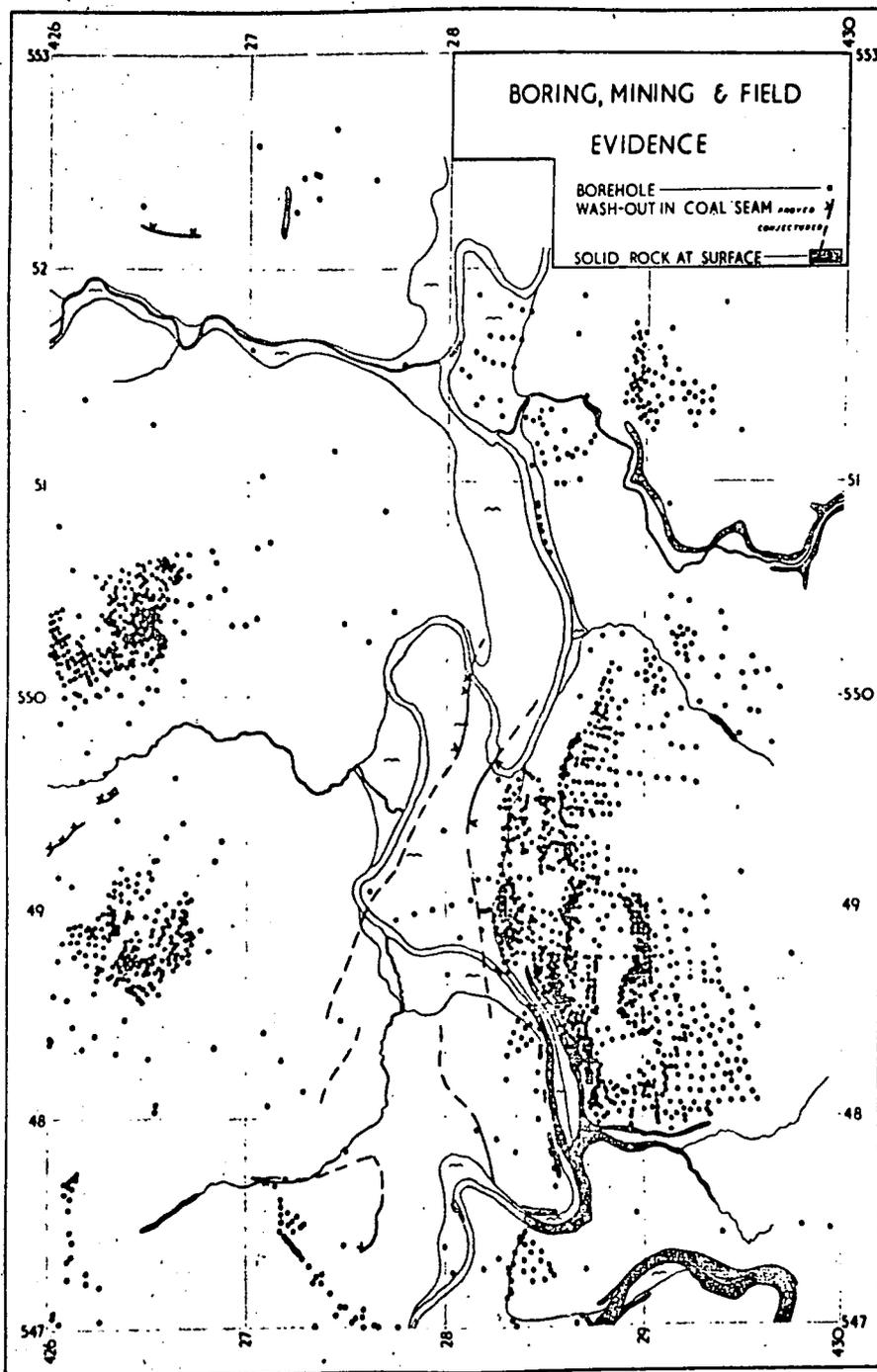


Figure 24 (After Hindson and Hopkins).



THE RIVER WEAR BETWEEN COCKEN & CHESTER-LE-STREET

Figure 25 (After Maling).

Further work on the problem of buried valleys was carried out by Woolacott (1905a, 1905b) who was able to use the several volumes of Borings and Sinkings which were published by the Institute of Mining Engineers after 1878. Woolacott was able to demonstrate that the buried valley existed between Bishop Auckland and Durham, and he showed that smaller buried valleys, corresponding to the River Browney, River Deerness and Stockley Beck, appeared to form tributaries of the "Wash". Holmes (1928) was able to indicate the probable confluence of the Browney buried valley with that of the Wear at Durham. North of the Browney, Woolacott's interpretation of the drift cover was incorrect and it was not until 1940 that Anderson (1940) was able to show that a series of west-east buried valleys, corresponding to the Cong Burn, Twizell Burn and Beamish Burn, lie between Edmondsley and Burnhopefield.

During the last fifteen years, part of the buried drainage system has been re-examined in detail. Shortly before the war, H.M. Geological Survey published the revision, by Anderson, of the Durham six-inch sheet, VI. This includes the Wash between Kibblesworth and the River Tyne at Dunston. In 1946, Hindson and Hopkins (1946) published a detailed account of the "Wash" between Shindliffe and Harbourhouse. The present writer has already described the Wash between the northern limit of the study by Hindson and Hopkins and the diversion at Chester-le-Street (Maling, 1954). Thus, with the exception of two miles between Chester-le-Street and Birtley, the whole tract studied by Wood and Boyd has been described anew. Examination of unpublished data, here and elsewhere, now provides the background to the conclusions given in this chapter.

Most of the evidence is derived from boring and mining and it is only where boring has been intensive that precise conclusions can be drawn. Field evidence, by itself, is seldom satisfactory for the rock-floor is generally only exposed parallel with the trend of the buried valley and, as will be shown, the middle of a buried valley often lies more than one hundred feet below the present flood-plain. Nevertheless, field evidence can be useful to show where no buried valley can occur. In certain parts of the area, this is virtually all the information which is available.

Geophysical evidence is still unreliable. Hospers and Willmore (1953) have described the inadequacy of gravimetric methods for determining the thickness of drift. Habberjam and Whetton (1954a, 1954b) have shown that resistivity methods cannot give precise values of drift thickness unless the drift is homogeneous and its nature is clearly differentiated from that of the rock floor. Recent seismic investigations carried out for the National Coal Board, north of Ferryhill, have shown inconsistent results.

Mining evidence is of value along the sides of the principal buried valleys, especially where recent workings have proved the wash-out of a seam in several places. However, most of the seams which outcrop in the principal buried valleys are relatively accessible from the surface and many of the principal lines of wash-out were proved during the nineteenth century. Consequently the plans do not always indicate the exact line of outcrop, and seam levels are seldom available. It is often uncertain whether the actual outcrop was proved or whether working was abandoned some distance from the "wash" owing to the appearance of excess water or bad coal. There is also confusion between the true glacial washout, where the seam abuts on unconsolidated drift, and the "nip-out", where a barrier of Coal Measures sandstone interrupts the seam. Mining evidence give valuable indication of the direction of a buried valley, but there are few places where coal has been worked to the outcrop in the valley floor so that it is seldom possible to determine the greatest depths of the "wash" from this information alone. On the other hand, where other data are lacking or inconclusive, mine plans of lower seams can give some indication of the maximum depth below which no valley can occur.

The principal evidence for drift thickness is provided by boreholes and shaft sections. Throughout the exposed coalfield, the network of boreholes is generally adequate to show the lateral extent of buried valleys, though few borings appear to have proved the greatest depth of the rock-floor. There must be more than 30,000 borings in that part of the coalfield studied by the present writer. The records of about 25,000 separate borings have been examined. The greater majority of these borings have been made since 1945, more than three-quarters by the Opencast Executive.

The value of the records varies considerably. It must be emphasized that the majority of these borings have been sunk in search of coal. Thus, once the main lines of buried valleys had been identified, relatively few borings were sunk in them. A few wildcat opencast borings have been made in this barren ground in recent years, but frequently the drift was so thick that drilling was discontinued before the rock floor was reached. Since the nationalisation of the coal industry and tightening of safety regulations, the National Coal Board have bored certain critical areas of the "Wash". These records are extremely important and some of the principal conclusions of this work are based upon the evidence of less than one hundred boreholes. The distribution of these important borings is most irregular. This reflects the present state of mining in the Wear valley, for these precautionary borings are only situated where collieries are still working the higher seams. Throughout much of the valley, these seams have been worked out and little further prospecting can be expected. In these areas, the writer has been dependent upon the older borings and shaft sections recorded in the volumes of 'Borings and Sinkings'. The positions of many of these old

borings are not known accurately. Some were recorded to the nearest second of latitude and longitude, but, owing to the marked discrepancies between certain identifiable sites and the published co-ordinates, a double check of position has been required before the location of a boring could be accepted. When confirmatory evidence is lacking, the drift thickness recorded by boring has been taken as correct, but it is clear that many of the records must be treated with reserve. This is partly owing to changes in technique and equipment, partly to the variations in the ability of drilling crews to interpret the geological record. It is particularly important to realise this, for, compared with the detailed stratigraphy of the solid strata, the drift has been recorded in many logs in round figures and without exact differentiation. Even today, cores of the superficial deposits are seldom obtained or examined.

It has been found that, on those opencast sites which have been intensively bored, a certain number of the records appear to be inconsistent with the rest. It is generally found that borings of a particular type are consistent with one another, but not with holes drilled by different techniques. Thus, the obsolete water-flush rig was less reliable than the hand boring and both of these methods are less reliable than the modern diamond drills. Trial pits are sometimes sunk on opencast sites to check the records of doubtful boreholes, but the total number of these is not great and their value in proving buried valleys is negligible.

The information has been compiled by the present writer from various sources. The files of H.M. Geological Survey (4) were used as the primary source of boring data, but this has been amplified by the examination of local records at N.C.B. Group Offices and individual collieries. Where possible, original mine plans have been studied. All the opencast data has been compiled from the original plans and files in the Regional Prospecting Department of the Opencast Executive. An example of the intensity of boring is shown in Fig. 25.

The information has been plotted on a scale of six inches to one mile. In the West Durham Plateau, where opencast prospecting has been particularly active, it was necessary to do the preliminary work on 1: 2,500 plans which were subsequently reduced to the six-inch scale. In certain areas, rock floor contours have been compiled with an interval as close as 10 feet. For the published account of the "Wash" between Cocken and Chester-le-Street (Maling, 1954), the present writer was able to compile

(4) This work was done before the files were classified as confidential. The records of water and mineral borings held by H.M. Geological Survey are no longer available to the public.

twenty-foot rock floor contours for both sides of the buried valley, (Figs. 25 and 30). Elsewhere, however, it is not always possible to draw accurate contours for more than a few hundred yards. Experience has shown that the sub-drift surface may be extremely irregular and that contours which have been interpolated through unknown ground have been later proved to be grossly inaccurate.

It is possible to trace the "Wash" from Witton Park, near the western edge of the productive Coal Measures, along a course which is roughly parallel with the present river, to Durham. Thereafter, the published work, already quoted, has shown that the buried valley lies west of the present river and can be traced to Dunston-upon-Tyne. Similarly, a number of tributary buried valleys can be recognised. In addition to the larger tributaries already mentioned, many minor buried valleys have been proved along both sides of the Wash. The extent of the buried drainage system, so far proved, is illustrated in Fig. 26.

Although it is possible to illustrate the drainage pattern on a small scale, detailed representation of the valleys is less easy. It is generally possible to determine the margins of a buried valley where these coincide with thin superficial deposits, but usually the middle of the Wash cannot be identified with complete certainty, in default of other evidence, it is assumed that the sides of the buried valley are symmetrical and that this line is situated midway between the lowest pair of rock-floor contours which can be proved. The middle lines which are shown on the series of topographical and geological maps (Plates 12-18 inclusive and 21-22; Map Folder) have been constructed in this manner.

The absolute depth of the Wash can be determined in relatively few places for the mining and boring evidence is seldom complete right across the valley. As will be shown, the valley sides are sometimes extremely steep and if a boring is situated a few yards from the middle of the valley, the rock-floor height which is recorded may be anything from ten to fifty feet above that of the lowest point. Since there are so many uncertain factors in the detailed reconstruction of the sub-drift topography, the profiles and sections which form the principal conclusions of this research must be accepted with extreme caution. It has been found that, with the exception of the stretch of the Wash between Durham and Chester-le-Street and certain parts of the tributary valleys, the evidence is very scattered. The longitudinal profile is largely based upon these inferences which can be drawn from the examination of these sections.

The immediate conclusion which can be drawn from Fig. 26. is that the present drainage pattern, on the whole, differs little from the pre-glacial pattern. There are, of

course the major diversions of drainage in the Wear at Chester-le-Street and in the Browney and Deerness near Durham, but apart from these, the deviations are minor and are confined within the broad valley pattern which is defined by the trend of the main interfluves. There is certainly no evidence to suppose that the northward diversion of the Wear and Gaunless at Bishop Auckland are post-glacial features. The boring and mining evidence to the east of Bishop Auckland shows that several minor buried valleys occur, but all of these are inclined westwards towards the Wear valley. In the Brusselton-Coundon gap, where a possible eastwards extension of a pre-glacial Wear or Gaunless would occur, there is no evidence for any drift-filled trough which could correspond in size or altitude with either of these valleys. Moreover, the outline of the buried Gaunless can be proved close to its confluence with the Wear below Bishop Auckland and the buried Wear can be identified with precision for more than one mile north of the town.

The details of deviation between past and present drainage are shown on the various detailed topographical maps. (Plates 12-18, Map Folder). It is clear that, with few exceptions, the buried valley lies close to the present flood-plain. The principal deviation in the main valley is that which lies between Durham and Harbourhouse. This has been described in detail by Hindson and Hopkins (1946) and is illustrated in Fig. 24.

The tributaries of the Wash are sometimes better defined than the main buried channel. The valleys of the West Durham Plateau which correspond with the River Team, Twizell Burn, Cong Burn, River Browney, River Deerness, Stockley Beck, Beechburn and River Gaunless can be followed for the greater part of their course and it is often possible to determine the middle lines of these valleys with great precision. The large amount of opencast prospecting in West Durham has been especially important in determining both extent and depth of these buried valleys. This evidence has also shown that there are many smaller buried valleys, most of which correspond with present streams.

To the east of the river, it is more difficult to determine the extent of buried tributaries. The deep mining information is often inadequate and, with the exception of the sites between Lumley Castle and Cocken Bridge, there has been little opencast prospecting. It is believed that each re-entrant in the Permian Escarpment contains a buried valley for very thick drift occurs almost everywhere at the foot of the steep escarpment slope. There is probably a buried valley in Cassop Vale, certainly one in the valley of the Sherburn Beck, another between Sherburn Hill Colliery and Littleton. Thick drift has been proved near the course of the Pittington Beck and in the scarp valleys between Houghton-le-Spring and Penshaw Hill. It is

possible that the first four coalesce to form a buried tributary which flows south-west along the approximate course of the Sherburn, Pittington and Old Durham Becks (Plate 22, Map Folder). This buried valley may reach the Wash near Shincliffe, but there is no positive evidence to indicate its exact course. Most of these Permian tributaries appear to be terminated upstream by steeper slopes of solid rock. No through valleys can be recognised.

North of Rainton, there is another buried valley which corresponds to the upper part of the Lumley Park Burn and Herrington Burn. This may cross the present course of the Wear between Lambton Castle and Chartershaugh, for thick drift has been proved both north and south of the river. The exact course is, however, indeterminate. The present course of the Lumley Park Burn is entirely post-glacial. Unlike most of the tributaries of the Wear, there is no parallel buried channel which can reach the Wash anywhere between Coochen and Lambton Castle.

Upstream of Witton Park, the continuity of the Wash cannot be proved. The borings shown near the confluence of the Beechburn on Plate 23, (Map Folder) represent the total amount of boring at the western limit of the productive Coal Measures. Although there is abundant mining information on the valley sides for two or three miles further west, the only evidence near the valley floor is the outcrop of solid rock which can be proved intermittently in certain stream sections. In the appropriate maps showing the superficial geology, (Plates 19, 20, 21, and 23, Map Folder), each known outcrop of solid near the valley floor has been plotted. It is clear that, as far west as Wolsingham, the floodplain and river terraces are so broad that, even where glacial drift is absent from the valley sides, there is still adequate room for a deep buried channel beneath the present river. It is not until the confluence of the Bollihope Burn is reached, near Frosterley, that there can be any certainty that there is no buried valley. Between the Bollihope Burn, and Frosterley village, the Great Limestone rises to an accessible altitude, there has been much quarrying on both sides of the dale. Examination of these quarries, and of natural outcrops of solid rock in both Bollihope and Wear valleys, has shown that there is less than one hundred yards of ground near the floor of the dale where solid rock cannot be proved.

Upstream of Frosterley, although the flood-plain and terraces are frequently wide and drift is nearly always present on one side of the valley, there are further places where the absence of the buried valley can be substantiated. The site of the gorge through the Whin Sill at Greenfoot, Stanhope is one example, the section from the Swinhope Burn to Middlehope Burn at Westgate forms another example. For this reason, it must be supposed that if the longitudinal profile of the buried valley

represents a curve of water erosion, this curve is considerably steeper than the profile of the present river, and that, upstream of a certain point, the earlier valley lay higher than the present flood-plain. The hinge-point, where the two profiles intersect, appears to lie a short way downstream of Frosterley.

It is not possible to determine the continuation of the earlier longitudinal profile into upper Weardale. It will be seen from the map of superficial geology (Plate 19, Map Folder) that there is an almost continuous cover of boulder clay along the southern side of the valley. There is a marked contrast between the steep, often rectilinear slopes on the north side of the dale and the hummocky drift topography which is characteristic of the southern side. (Plate 9, Map Folder, Fig. 33.) It is suggested, from the evidence in the coalfield, that the pre-glacial course of the Wear lay through this drift zone, and that the post-Glacial evolution of the river has been along the northern edge of the drift. It is denied that this asymmetrical distribution of drift can be attributed to differential movements of the Weardale glacier. It is clear, from field evidence, that there is a considerable thickness of boulder clay on the south side of the valley, but there are no borings to show the detailed nature of the sub-drift topography. It is not known whether any of the Weardale tributaries contain buried valleys. It is certain that all contain considerable quantities of drift and it can be proved in the field that the Middlehope Burn, Westernhopeburn and the Swinhope Burn all flow over boulder clay in their middle courses. The thickness of drift is not known. In the Rookhope valley, the engine shaft at Boltsburn Mine (B & S 2957) proved 38 feet of drift and a recent adit at stream level near Grove Rake, proved 350 feet of boulder clay on the south side of the valley. Elsewhere in the Alston Block, it has been established that certain upper valleys have their buried counterparts. Dunham (1948) has shown that East Allendale and the Hudeshope Beck (Teesdale) both contain drift-filled valleys which have been proved by mining. Where the southern tributaries of the Wear, Ireshopeburn, the Harthope Burn, Swinhope Burn and several smaller streams enter the hummocky drift, their courses are deflected eastwards and these streams all pass through steep-sided rock gorges. Such tributary courses are characteristic of the southern side of the dale, only where there is a broad belt of glacial drift. Gorges occur in all the north-bank tributaries but there is no marked change in course. These eastward diversions appear to be similar to those of the tributary valleys of Wensleydale which were described by King (1935). The supposed pre-Glacial courses of the southern tributaries are indicated in Plate 19 (Map Folder). In each instance, the direct prolongation of the middle course of the tributary leads into an area of thick drift where no solid rock is exposed. Examination of the rock gorges of these deflected tributaries has shown that as these approach the belt of hummocky drift, there is generally a decrease in the altitude of the rock

LONGITUDINAL PROFILE OF THE WEAR-TEAM BURIED VALLEY

WITH PROFILES OF CERTAIN TRIBUTARIES

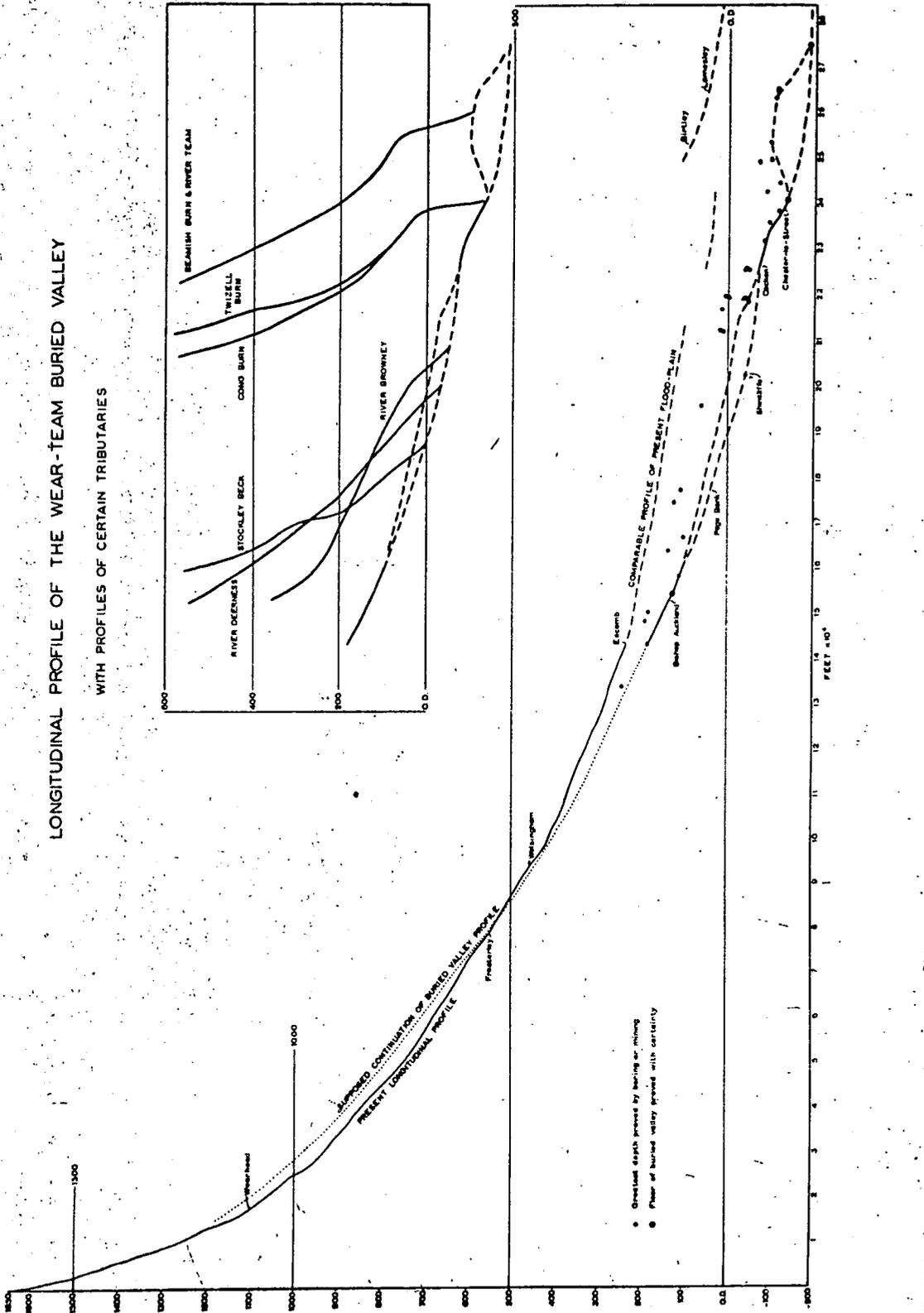


Figure 27

floor. It may be possible to map the approximate outline of the pre-Glacial valley from detailed examination of these natural sections, but, at present, the accumulated evidence cannot warrant such reconstruction.

THE LONGITUDINAL PROFILE & SECTIONS OF THE BURIED VALLEYS.

The longitudinal profile of the buried Wear (Fig. 27) can be drawn from the evidence of some fifteen places in the twenty-six miles of proved Wash. At some of these places, the greatest depth is known accurately within five feet; elsewhere precise information is lacking and it is only possible to estimate the height of the rock floor.

The upper part of the profile can be fixed, with reliability, at four places near Bishop Auckland. The most westerly point is at Escomb, (Section A. Fig. 28), where the Brockwell seam washout was proved at its outcrop in the floor of the Wash by workings in the former Dorman Long Royalties. The altitude of the Wash is here 180 feet (\pm 15 feet). At Bishop Auckland, where the Wash turns northwards from the line of the Butterknowle fault, the buried valley passes below the broad stretch of alluvium and river gravel known as Newton Cap Flatts. (Section B, Fig. 28). Here, the Busty Seam was worked from Newton Cap Colliery without proving any washout at depths between 119 and 130 feet. Recent opencast borings on the alluvium have proved sand and gravel as low as 127 feet above Ordnance Datum without proving the rock floor. At that point where the greatest thickness of drift was proved, there is about 6 feet of untried ground above the roof of the Busty Seam. It is therefore possible to state with confidence that the middle of the Wash lies at 124 or 125 feet above Ordnance Datum. About one mile further north, close to the Sewage Farm below Binchester, a washout was proved in the roof of the Busty Seam at a height of 110 feet. (Section C. Fig. 28). One mile downstream of this point, near Newfield, the Brockwell Seam was worked from Rough Lea Colliery to the Royalty boundary on the west of the present river. Similar workings from Newfield Colliery proved a washout in the Brockwell Seam on the east bank. There is about one hundred yards of unworked ground between these limits where the floor of the buried valley should occur at approximately 100 feet above Ordnance Datum. Thereafter, and as far as Shincliffe, the evidence is insufficient to prove the depth with accuracy. There are a few borings and shaft sections which can determine both the limits of the buried valley and the slopes of the valley sides. The sections at Jubilee Bridge, (E; Fig. 28), Page Bank (F; Fig. 28) and Butterby (G) (Plate 13, Map Folder) are based upon this evidence, but the maximum depth of the rock floor cannot be gauged with accuracy.

At Shincliffe, (Section H, Fig. 29) the Hutton Seam is interrupted by a narrow belt of superficial deposits. According to Wood & Boyd (1864) (Section 7), this wash-out occurs

at approximately Ordnance Datum. This figure was accepted by Woolacott (1905a, 1905b) and later accepted by Hindson and Hopkins (1947). It is, however, uncertain whether this level is correct. The base of the Hutton Seam is recorded in the shaft section of Houghall Colliery (B & S 1189) at a level of -55 feet. One mile north-east, the seam was proved in the shaft section of Old Durham Colliery (B & S 1489) at -47 feet. Between the Old Durham Beck and Shincliffe Bridge, there is a boring which is plotted on the manuscript library copy of the primary six-inch Geological Survey. This borehole was sunk close to the line of the washout on the east side of the buried valley and proved the Hutton Seam at -42 feet. There is no evidence of major faulting here, indeed, Hindson and Hopkins (1947) have shown that the 'Kepier Clay Dyke', the only fault which might affect this area, has negligible throw. It is suggested here that, if the seams recorded in boring and shaft sections are the same as that which has been worked to the washout near Shincliffe Bridge, the middle of the buried valley must lie between -45 and - 50 feet below Ordnance Datum. If, on the other hand, the washout was proved in the Brass Thill Seam, the floor of the Wash may well lie at or near Ordnance Datum. Within the three miles north of Durham, Hindson and Hopkins recorded their estimate of the lowest part of the Wash at three different places. Near Kepier Farm, they suggested that the Wash might lie at -20 feet below Ordnance Datum; near Newton Grange, they recorded a washout in the Hutton Seam at -48 feet and at Cocken Bridge, they believed that the floor of the buried valley might occur at -50 feet. The present writer has already shown (Maling, 1954) that the depth near Cocken Bridge may exceed -70 feet. At Kepier, there is no evidence to suggest that the rock floor does not lie between -50 and -60 feet. (Section J:Fig.29). The washout at Newton Grange can only be considered to represent a minimum value for the depth of the buried valley. (Section K:Fig.29)

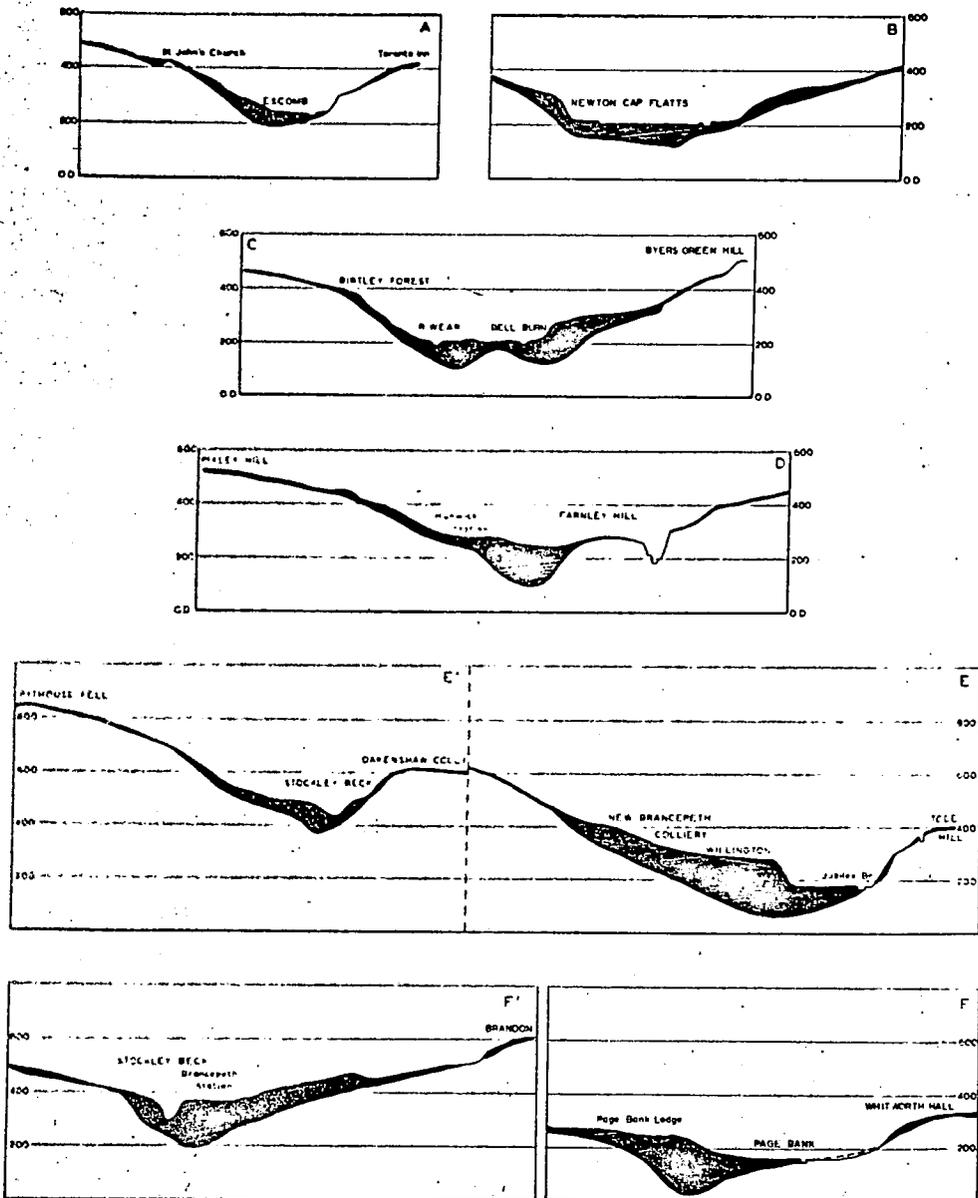
Binchester and Cocken are the two control points upon which this part of the profile can be drawn. Between these two points, two divergent profiles are shown on figure 27. The first is based upon the published evidence and shows a break in profile between Kepier Farm and Newton Grange; the second, based upon the author's interpretation of the Shincliffe washout, follows a steeper, but more continuous curve.

North of Cocken Bridge there is a marked break in profile which has already been described by both Haggerjam and Whetton (1954a) and by the present writer. At the present confluence of the Chester Burn, a minimum depth has been recorded at -138 feet and the borings in this area have shown that the rock floor must lie near - 140 feet in the middle of the Wash (Maling, 1954). (Section N. Fig. 29 and Fig. 30). In the Team Valley Trading Estate, a boring sunk in 1954 proved the rock floor at - 186 feet below Ordnance Datum. (Section Q. Fig.29). This is the greatest depth of rock-floor which has been recorded

one of have

THE MIDDLE WEAR. SECTIONS THROUGH BURIED VALLEYS.

VERTICAL EXAGGERATION x 5



0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000

Figure 28

THE MIDDLE WEAR AND TEAM. SECTIONS THROUGH BURIED VALLEYS.

VERTICAL EXAGGERATION x5.

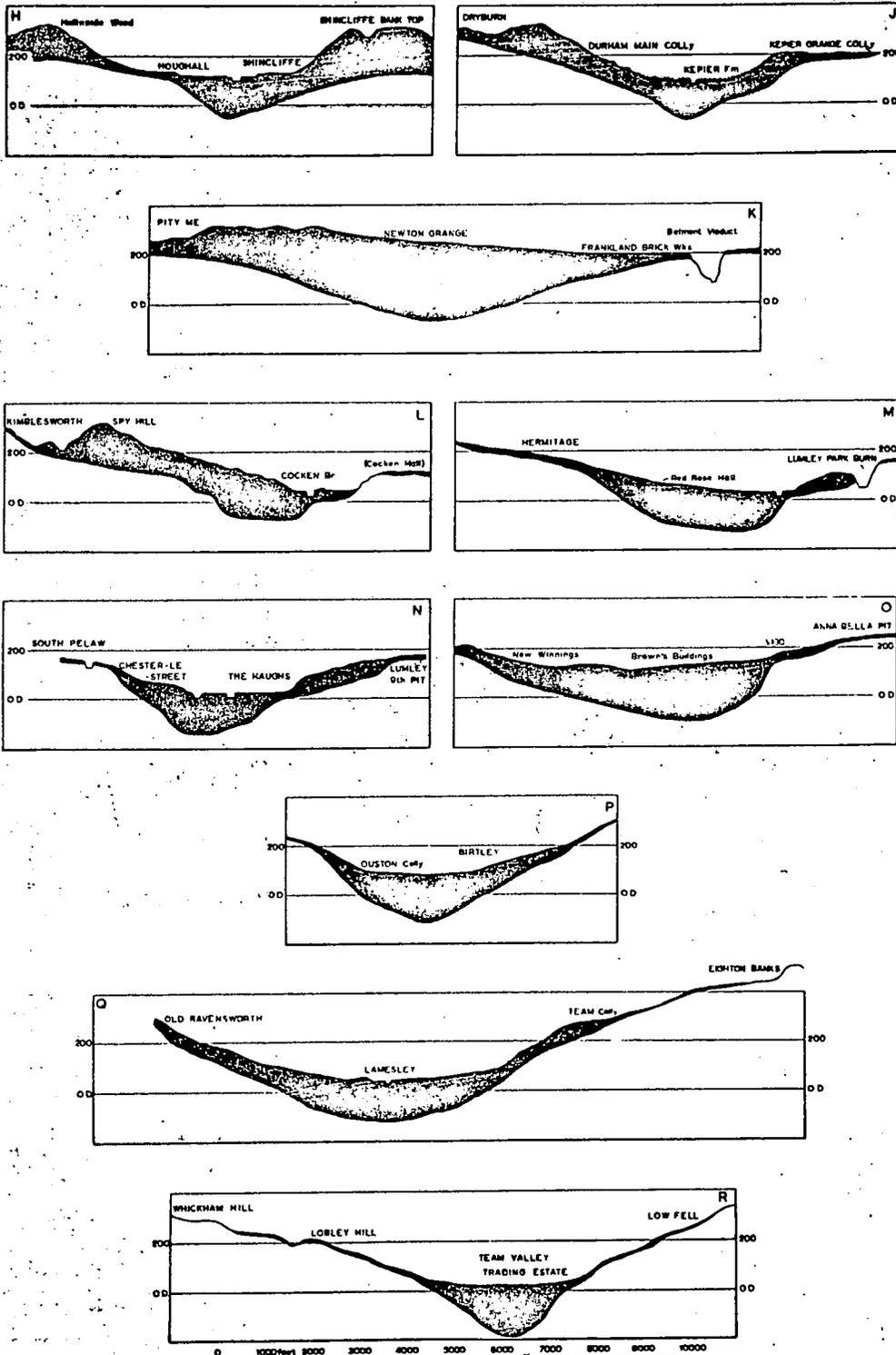


Figure 29.

No. 3 See G. S. Newman
District Court
Glasgow

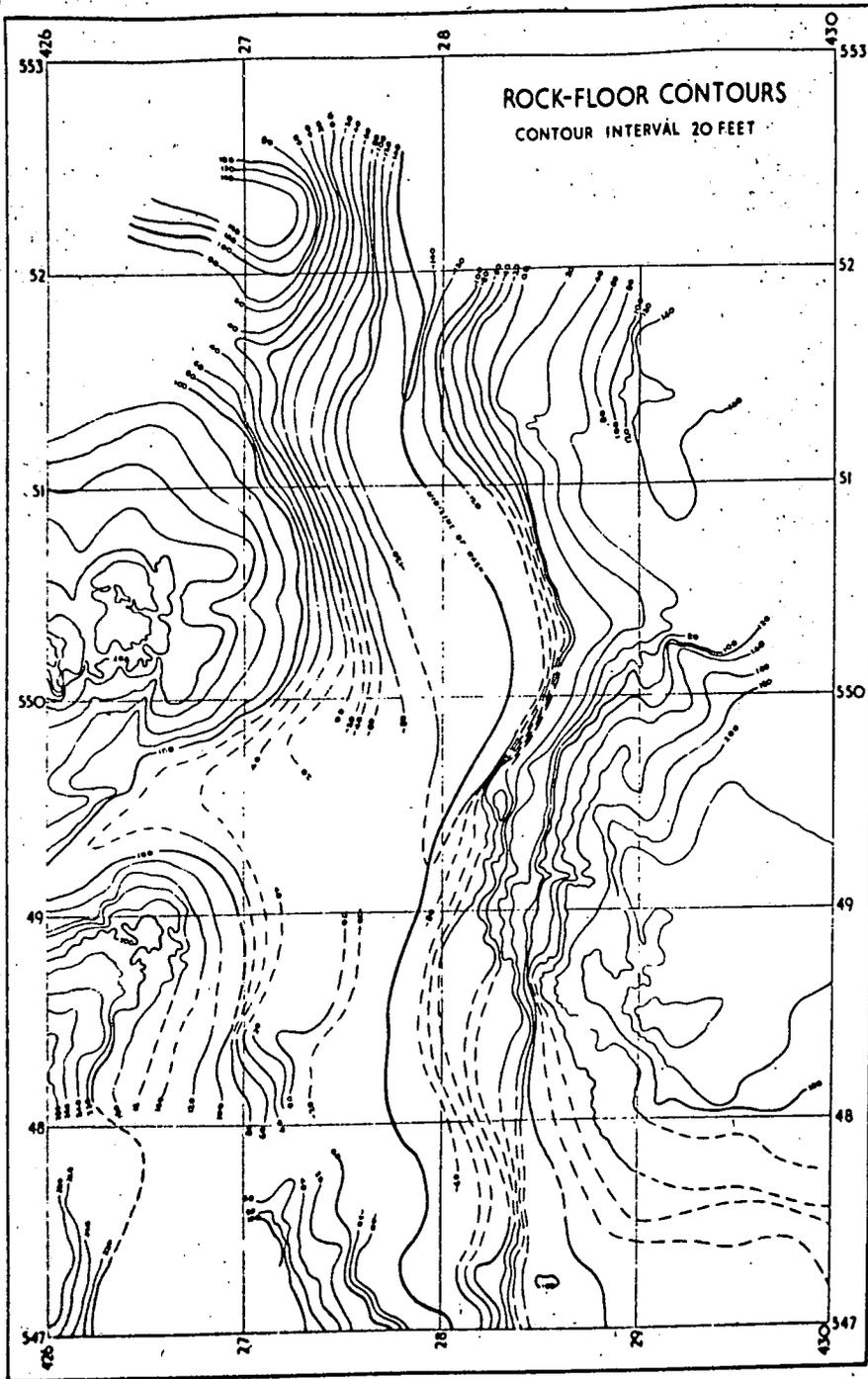
in Britain. Between this point and the Chester Burn borehole, ~~the~~ one version of longitudinal profile has been shown as a smooth curve. Within this stretch of the Team Wash, there is no proof that the rock floor lies as low as those depths recorded at either end. Examination of most of the evidence in this stretch is inconclusive. There are some twenty borings and areas of washout where the rock floor has been proved to lie below Ordnance Datum. Six of these have proved the rock floor to lie at or near - 100 feet. These records are widely spread and it is reasonable to suppose that none of these places are situated along the middle of the buried valley.

At one place, however, there is evidence that the rock floor does not lie as low as the extrapolated profile. Section 4 of Wood and Boyd (1864) shows the middle of the Wash at the horizon of the Hutton Seam, 120 feet below their datum and at about -106 to -110 feet below Ordnance Datum. Wood & Boyd describe, in some detail, how a passage was driven from Team Colliery, through the floor of the wash, to gain the Hutton Seam on the western side. It is stated that thirty yards of boulder clay ^{were} ~~was~~ penetrated in order to pass through the buried valley. It is inconceivable that in this small space, the rock floor could fall another fifty or sixty feet and there is evidence that, for part of the distance, the floor of the Hutton Seam was preserved below the drift. It is certain that this was the main buried valley and not a tributary. For this reason, it must be accepted that, in this section of the valley, the longitudinal profile is hump-backed. From -140 feet at Chester-le-Street, it rises to about -110 near Lamesley. Northwards it falls to -186 feet in the Team Valley Trading Estate. This profile has been plotted in Figure 27. It will be seen that certain other evidence in this stretch of the valley now assumes a new significance for the depths recorded by boreholes near Birtley and Lamesley lie close to the reconstructed profile.

THE ORIGIN OF THE BURIED DRAINAGE SYSTEM.

It has been supposed, in this discussion, that the buried valleys were primarily formed by normal erosion rather than by glacial gouging. That this is so cannot be denied, for the drainage pattern, the continuity of the valleys and the general eastward and northward curve of the longitudinal profile all support this conclusion. It is also doubtful whether the lowland ice-sheets, which are described in the following chapters, could have the capacity for erosion such as would be necessary to excavate these deep valleys. All other evidence suggests that the Pleistocene ice modified the landscape by deposition rather than by erosion.

It has been shown, however, that the longitudinal profile north of Chester-le-Street may be hump-backed



THE RIVER WEAR BETWEEN COCKEN & CHESTER-LE-STREET

and since this cannot be accounted for by normal processes of erosion, it is necessary to enquire whether this is local modification by ice or whether glacial erosion did, in fact, alter the valley forms materially.

Such irregularities in the longitudinal profile have already been noted in the Tyne valley by Woolacott (1905a, 1905b, 1921) and by Hickling and Robertson (1949). A similar irregularity in the buried Mersey, between Widnes and Liverpool has been described by Boswell (1937).

In the Tyne valley, the greatest recorded depths are between -160 and -170 feet at Dunston, at the confluence of the Team Wash. Downstream of this confluence, at the Newcastle bridges, the rock floor rises to -52 feet. Further east, a deep valley has been proved in the vicinity of Burdon Main and Howdon-on-Tyne and this valley appears to reach the present coast at South Shields. Although depths as low as -140 feet have been recorded in this stretch, the buried valley appears to be nowhere as deep as at Dunston.

In the buried Tyne, however, this irregularity of the longitudinal profile has not been fully established. There are large areas of unproved ground near the centre of Newcastle-upon-Tyne where a deep buried valley might occur and, similarly, the boring and mining evidence is often inadequate further east.

Although Woolacott (1921) favoured the explanation that these valleys were formed by normal erosion, he was forced to conclude that some glacial overdeepening might have occurred just upstream of Newcastle. A similar explanation was offered by Hickling and Robertson (1949).

It is possible to postulate reversed flow in certain buried valleys in order to account for a downstream rise in the rock-floor. Reversal of flow was suggested by Boswell (1937) for the buried Mersey and, before the sinking of the Team Valley Trading Estate borehole, it was suggested to the writer by the late Professor Hickling that there might have been a southward diversion of the Tyne into the Team Wash. Hickling supposed that there might have been a second Wear/Tyne diversion north-eastwards from Chester-le-Street towards the buried "Cleaddon" valley of Woolacott (1905a). The boring evidence in the north-east lowlands of Durham favours such an idea and, for this reason, a detailed study was made of the critical section between Harraton Colliery and Washington. In this area, there is much inconclusive evidence, for a series of opencast borings proved more than eighty feet of drift without reaching the rock floor and a few deeper borings have shown that this may occur below Ordnance Datum. It was found, however, that the rock floor can be proved in a stream section some way north of Fatfield and the upper workings of Harraton Colliery are continuous. For these reasons, it is

considered unlikely that there is any buried valley in this area which can correspond in size or depth with the Wash at Chester-le-Street. In the Team Wash, however, there is positive proof that the rock floors rises and falls between Chester-le-Street and Dunston. For this reason it is not possible to support the idea that there has been reversal of drainage.

It is therefore necessary to conclude that there has been glacial overdeepening in certain parts of the main buried valley. Such belief receives additional support from the directional trend of the Wash immediately above its confluence with the Tyne. Here the trend of the Team Wash becomes north-westwards suggesting that the east-flowing ice from the Tyne Gap planed this corner as it entered the Team valley. Further support might be taken from the discordance of the tributary buried valleys, the longitudinal profiles of which are shown in Figure 27. These profiles must, however, be treated with reserve. Although the evidence in the upstream parts is frequently more reliable than that in the buried Wear, there is relatively little information close to the main valley. For this reason, the altitude of the break in profile depends largely upon the height of the tributary at the most easterly place where the floor of the valley can be determined. Further, it will be seen that the profiles of the River Browney and Stockley Beck, which lie far upstream of any overdeepening, show breaks in their profiles also. It is not yet possible to provide any adequate explanation for these, nor to account for the totally different form of the Deerness profile. If glacial erosion be accepted, it would be reasonable to suppose that the over-deepened parts of the valley would be plugged with the boulder clay which formed the basal till of the glacier. This condition is true of the Team Valley, where the boring at the Trading Estate proved 178 feet of boulder clay above the rock floor. At Chester-le-Street, on the other hand, the drift was predominantly sand. Only 20 feet of clay was recorded and this occurred near the middle of the sequence, nearly 50 feet above the rock floor. It is difficult to believe that fifty feet of deposits which are characteristically fluvial could be deposited in a hole unless there was some outlet for the sub-glacial waters.

It is still not possible to give a satisfactory explanation of the origin of the buried valleys. Despite the acknowledged uncertainty in reconstruction, the pattern of these valleys, their longitudinal profiles and sections all support the hypothesis of pre-Glacial or interglacial erosion by running water. The irregularities in the bed point towards a certain amount of glacial overdeepening, but, as has been shown, there are certain objections to the unreserved acceptance of such modification. The present writer has hinted that the break in slope between Cocken and Chester-le-Street may represent the limit of some

phase of pre-Glacial rejuvenation (Melling, 1954), but neither the detailed examination of the longitudinal profile nor the valley sections north of Birtley can support this idea. It is evident, however, from the recorded depths of other buried valleys, that their floor may lie as low as -130 to -140 feet below Ordnance Datum. Radge (1939) has recorded a maximum depth of -138 feet in the buried Tees, Boswell (1937) noted depths of -130 feet in the buried Mersey, and Wills (1929) has recorded a maximum depth of -184 feet in the pre-Glacial Dee. Although these figures, by themselves, do not constitute adequate evidence, they agree sufficiently with one another and with the longitudinal profile of the buried Wear to suggest that, at some period before the final glaciation, these rivers may have been graded to a base level which lay at least 130 feet below the present sea-level.

It has been shown that, despite the large number of additional borings which are now available, the conclusions of the author largely agree with those of earlier writers. However it can now be shown that the buried drainage system is more widespread and more complex than was formerly supposed.

The present writer has shown that the buried valleys, as a whole, are deeper than was hitherto suspected. Neglecting the areas of great depth, which may have been modified by glacial erosion, it is suggested that this valley system was graded, before the onset of glaciation, to a base-level lying at or below -130 feet.

Apart from these considerations of the origin of the buried valleys, two important morphological conclusions can be drawn from this study of the sub-drift topography. The first is that the pre-Glacial drainage pattern did not differ materially from the present trend of drainage. The second is that asymmetrical deposition of drift in a valley does not, as has often been supposed, indicate transverse movement of ice across the line of a valley. It is abundantly shown, throughout the rivers of the coalfield, that the post-Glacial drainage, which was initiated on a surface of drift, excavated new valleys which may or may not correspond with the pre-Glacial valley. For this reason, it must be concluded that where there is continuous cover of drift either in the present floor of the valley or along one side of it, the longitudinal profile of the present stream is almost certainly post-Glacial in origin.

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CHAPTER 6.

THE GLACIATION OF THE ALSTON BLOCK.
SUMMARY OF FORMER WORK.

It is clear, from the study of the buried drainage system, that the pre-Glacial topography was considerably modified by glacial deposition. It is now necessary to study the extent, effects and plurality of Pleistocene glaciation. In order to explain the recent development of the valley and to discover the nature and origin of certain post-Glacial platforms, it is necessary to ascertain, if possible, the duration of the Post-Glacial period.

The analysis must be based upon two lines of evidence. These are, first, the extent, lithology and stratigraphy of the glacial and retreat deposits; secondly, the morphology of the glacial deposits, retreat phenomena and late - or post-Glacial platforms.

Many writers have already discussed the problems of the glaciation of North East England. The interpretation of the drifts and their chronology are the subject of much controversy. There are two widely divergent schools of thought. There are, first, the orthodox writers, who find evidence of several different glacial periods, separated by distinct interglacials. Secondly, there are the few heretics, who, from detailed examination of the drift stratigraphy, refute the orthodox case and who consider that, in Northern England, there is only evidence for one glaciation.

It has long been believed that the Alston Block, was only lightly covered with permanent ice, even during the glacial maxima. Derryhouse (1902) showed, from the distribution of erratics in Northern England (Fig. 31), that the greater part of the uplands of the Alston Block nourished only local glaciers. From the extent of the glacial drifts and the supposed distribution of glacial lakes in the Pennine dales, he supposed that, throughout the Pleistocene, a large area of the Alston Block remained drift-free. Derryhouse believed that the entire Pennine Escarpment, from Warcop Fell in the south to Cold Fell in the north, stood above the great ice sheets of the Eden valley and diverted the major eastward movement of lowland ice through the two gaps in the Pennines; the Tyne Gap and Stainmore. East of this ice-free upland ridge, there were two local glaciers which were nourished by the neve on the eastern slopes of Cross Fell. One glacier flowed northwards through the valley of the South Tyne; the other moved south-eastwards down Teesdale. To the east and north of these glaciers, the high hills surrounding Weardale rose above the limit of permanent ice and prevented any exotic drift from reaching this

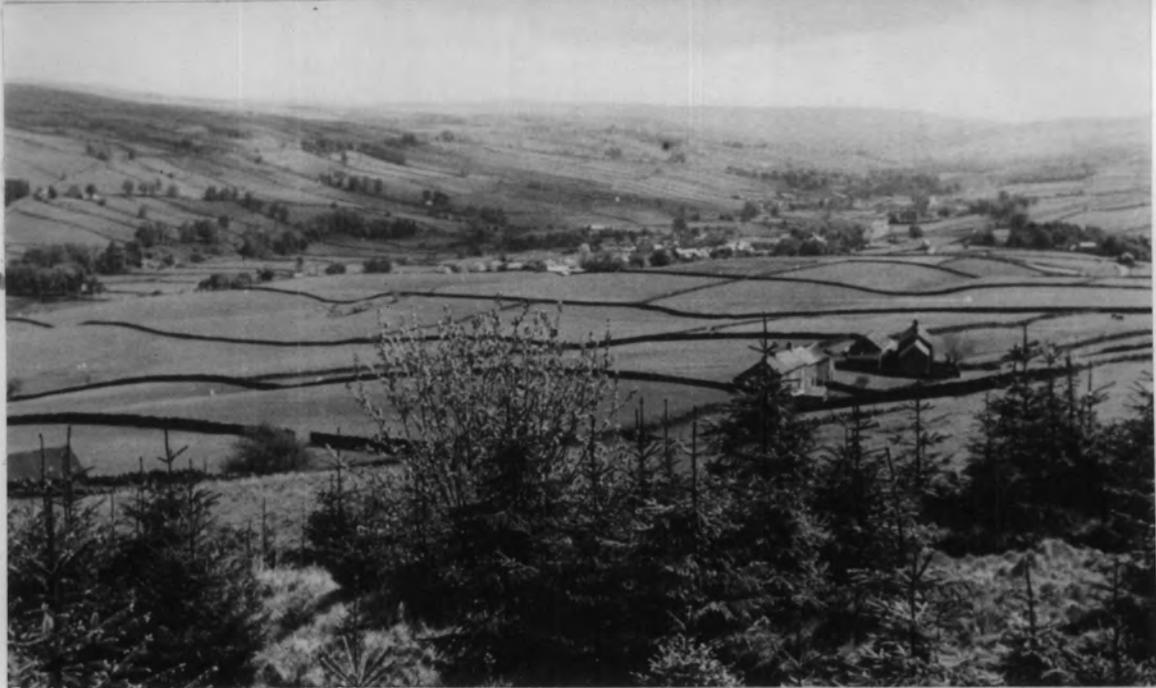


Fig. 33a

Hummocky Drift topography, Weardale
View East from Hawkwell Head (NY/869,377)



Fig. 33b

Hummocky Drift topography, Weardale
View South from East Blackdene (NY/883,386)

valley. To the north of Weardale there was a large ice-free area which extended northwards to the edge of the Tyne Gap ice-sheet on the Hexhamshire moors. These ice-free hills extended eastwards to Tow Law. The tributary valleys of the Allen, Devil's Water and Derwent were occupied by semi-permanent glacial lakes. To the south of Weardale, the Tees-Wear watershed rose above the limits of permanent glaciation as far east as the Bedburn Beck. Ice from Teesdale, which crossed the watershed into the Bedburn valley, brought the only exotic drift which has been recognised in Weardale.

Later work by Trotter (1928) and Raistrick (1931a) has suggested that this interpretation of the extent of ice cover was, in part, erroneous. Trotter (1928) showed that the eastward-moving ice from the Vale of Eden reached an altitude of 2200 feet on Warcop Fell and crossed every col below 2150 feet in the northern part of the Pennine Escarpment to reach the valley of the South Tyne. Raistrick (1931a, 1933) recognised much-weathered drift which occurred at greater altitudes than the boulder clays of the dale floors. He suggested that ~~at the maximum extent of glaciation~~ only the higher summits of the Cross Fell massif and the hills of upper Weardale remained exposed during the maximum glaciation. In West Durham, Raistrick (1931b) noted the absence of drift above 1250 feet.

In the eastern part of the Alston Block, it is certain that the lowlands were entirely overwhelmed by ice. Five ice streams, from different source regions, each left characteristic types of drift and erratics.

These five glaciers are illustrated in Fig. 32 and may be summarized as follows :-

- 1) The Scandinavian-North Sea ice-sheet, which approached the Durham coast from the north-east and extended as far inland as the present coastal fringe.
- 2) The Cheviot-Tweed ice-stream, which moved southwards across central Northumberland. In the Tyne valley, this ice was confluent with :-
- 3) The Lake-District-Tyne Gap ice, which had been derived from the Northern Lake District and Galloway, had collected in the Vale of Eden and had crossed the Pennines through the Tyne Gap. The boundary of Cheviot erratics across East Durham suggests that the Lake District ice was deflected up the valley of the Team and Middle Wear, so that both ice-streams maintained parallel southward courses.
- 4) South of the Magnesian Limestone Plateau, in the valley of the Tees and the rivers of Stainmore, there

was another ice sheet. This had originated from the Lake District, south of the ice parting defined by Trotter (1928) and Hollingworth (1931) and which had crossed the Pennines by the Stainmore depression. This ice-sheet was, in part, deflected southwards into the Vale of York.

- 5) Finally, there were the local Pennine glaciers, which moved outwards, along the radial valleys of the Alston Block. Certain of these penetrated the lowlands of Central Durham and may, at times, have reached as far as the present coast.

These movements of exotic ice, recorded by the present distribution of erratics are, in part, confirmed by the occasional striae which have been recorded in the few exposures of the rock floor (Fig. 32). This is virtually the only other evidence upon which the pattern of glacier movement can be based. The glacial landforms, which elsewhere have proved such useful indicators of ice-movement, are practically non-existent in the eastern part of the tract.

Most writers have agreed that these ice-sheets had little power to erode. It has been generally supposed, therefore, that the pre-Glacial surface was little modified by the passage of these ice-sheets and that the principal result of glaciation was the thick, featureless cover of drift deposited in the lowlands.

The only features in the lowlands which have attributed to glacial erosion are the deeper parts of the buried valleys. This argument, as has been shown in Chapter 5, is largely derived from the difficulty of otherwise explaining the origin of supposed irregularities in the rock floor. It was further shown that the glacial origin of these hollows cannot be accepted without reservation.

The present surface of the drift is generally featureless. It must be admitted, however, that below a height of 320 feet, later erosion or deposition may have modified the original surface of the drift. There are no recognisable terminal moraines in any of the main valleys and very few have been recorded in the tributary valleys. True drumlins are extremely rare, though 'hummocky drift' which approaches drumlinoid form may be found in certain upland valleys (Plate 9, Map Folder, Fig. 33).

The only truly distinctive landforms which originated from the glaciation of North East England are the overflow channels cut by meltwater escaping from glacial lakes and the fluvio-glacial and deltaic deposits which were laid down

around the margins of these lakes. There are few other features of the drift topography which cannot be attributed to post-Glacial erosion.

The only evidence, hitherto recognised, that interglacial periods occurred in North East England depends upon the interpretation of two deposits on the Durham coast and upon the orthodox interpretation of the drift succession.

Trechmann (1915) has suggested that there is a distinct horizon of weathered boulder clay at the top of the succession of Scandinavian Drift and that this is overlain by fresher drift of British origin. Trechmann (1920) also described loess-like deposits associated with the Scandinavian Drift, which was rammed into fissures in the Magnesian Limestone in Warren House Gill. In consequence, Trechmann supposed that there had been a distinct interglacial period between the deposition of the Scandinavian-North Sea drift and the subsequent advance of British ice-sheets.

The second deposit is a so-called raised beach of calcreted gravel which occurs at about 60 feet on Beacon Hill near Easington. This deposit has been described by Woolacott (1920) and by Trechmann (1931). The former considered that this represented a post-Glacial raised beach, but the latter considered that it was an interglacial deposit. Harrison (1935) has suggested that the Easington beach is contemporaneous with the Nar submergence of East Anglia. Thus, it was supposed by Movius (1942) that the Easington deposit formed part of the evidence for a temperate interstadial between Old and New Drift Glaciation (W1/W2 according to Movius or the Warthe/Weichsel interval according to other authorities).

If these deposits are recognised as interglacial deposits, it is possible to show that the Scandinavian Drift represented the earliest recognisable phase of glaciation in the area. The retreat of this ice was followed by a temperate period before the main British ice-sheets advanced. It is sometimes suggested that local Pennine drift antedates the tills derived from the Tweed-Cheviot and Lake District-Tyne Gap glaciers, but not all authorities agree about this. It is usually considered that, these two ice-sheets were contemporaneous with the Stainmore glacier and that the maximum extent of these ice-sheets represents the Main Glaciation of Northern England.

Woolacott (1921) was able to show that the Pleistocene chronology of North East England could be subdivided into four separate glacial periods which were, apparently separated by interglacial or interstadial periods. This sequence was accepted by Trotter and Hollingsworth (1932), who were able to correlate this sequence with their chronology based upon the drifts of the Solway lowlands. Raistrick (1933) showed, however, that the later glacial episodes of this sequence

were probably contemporaneous and his chronological interpretation, illustrated in Table 9, allows for only three distinct glacial periods. It should be noted, however, that Raistrick has now abandoned these conclusions and favours a monoglacial interpretation of the Pleistocene in North East England.

Table 9. After Raistrick.

A Correlation of the Glacial Deposits in the north and east of England.

Glacial Sequence.	Coast of Yorkshire & Lincolnshire.	Mid-Pennines.	Northumberland and Durham.	Lake District.
4			Arctic peat (Crossfell)	Scottish ice readvance into the Carlisle plain.
3	Sands and "head". HESSELE CLAY.	Terminal moraines & valley lakes. Readvance of Vale of York glacier to Escrick and York moraines.	Birtley laminated clays and sands and gravels of Plawsworth etc. Cheviot-Scottish ice swings on to the coast-lakes down coast with sands and laminated clays, as at Bedlington.	Late stages of retreat. Haltwhistle ose train. Early stages of retreat.
	Kirmington plant bed, etc. Sands.	Earlier stages of retreat of Dales glaciers.	Early stages of retreat in West Durham Fells.	
	UPPER PURPLE CLAY.	"Main" Dales glaciation.	Main glaciation. Maximum of Lake District ice stream through Tyne valley. Lake district ice up mid-Weardale and joining Stainmore glacier, passing to North Cleveland & Vale of York.	Maximum of Lake District glaciation.

Table 9. After Raistrick. Continued.

A Correlation of the Glacial Deposits in the north and east of England.

Glacial Sequence.	Coast of Yorkshire & Lincolnshire.	Mid-Pennines.	Northumberland and Durham.	Lake District.
2	Sands and laminated clays. LOWER PURPLE CLAY.	Sands and gravels and laminated clays in lowlands. Lake District and Pennine ice by Tees-mouth to east coast. Maximum Dales glaciation. Local glaciers in Dales.	Occasional sands. Pennine and Cheviot ice passing nearly due east to North Sea (Main lower boulder clay). North Tyne and some Cheviot ice moving south into Tyne valley.	Sands and gravels. Early glaciation of Lake District. Early Scottish glaciation in Eden valley.
1	Sands. SCANDINAVIAN CLAY.		Sands (so-called "Loess" of Trechmann). Scandinavian clay on coast south of Warren House Gill.	

As the drifts of Northern England were studied in greater detail, certain objections were raised to discredit the chronological interpretation of the orthodox school. We owe to the careful studies of Trotter (1928) and Hollingsworth (1931) in the Vale of Eden, the first suggestion that ice sheets can move in different directions at different levels. Thus the juxtaposition of dissimilar drifts on top of one another does not mean that they differ in age, for the ice-sheet may have overridden the other. Therefore, it is not reasonable to conclude, for example, that the Pennine drift of East Durham was deposited during an earlier glaciation than the overlying Lake District or Cheviot drifts.

If, however, sands and gravels and laminated clays are present between the tills, the problem of interpretation becomes more difficult. These stratified drifts have been generally regarded as indication of deposition of sediments in water at some time before the upper boulder clay was transported to the site. The principal objection to such an interpretation is that where unconsolidated, stratified drift deposits are overlain by an upper boulder clay, the bedding of the sands is usually well-preserved. If it is postulated that the upper till represents the ground moraine of an ice-sheet which advanced after these sands were laid down, it is difficult to explain why the ice should not remove this unconsolidated material entirely, let alone leave it in an undisturbed state. Where advancing ice has passed over ill-consolidated material which is certainly pre-Glacial, such as the Permian Yellow Sands, the disruption and incorporation of this material in the boulder clay can be clearly demonstrated.

An attempt to explain this common feature of the drift succession led R.G. Carruthers (1939, 1946, 1950, 1953), to develop his unorthodox Under-Melt Hypothesis. Carruthers has argued that the stratified drifts are contemporaneous with both upper and lower deposits of boulder clay. The lower till represents the ground moraine of a glacier, the upper till represents the surface moraine and the supposedly interglacial deposits are englacial material which was deposited in cavities within the melting ice-sheet. In order to account for this sequence, Carruthers has postulated that an ice-sheet melts from below as well as from above so that the upper deposits are gradually laid upon the ground moraine.

Carruthers has shown, from microscopic examination of the typical laminated clays of North East England, that these are quite different from true lacustrine deposits laid down in melt-water lakes. He has suggested that the glacial laminated clays or 'Shear Clays' represent englacial silts which were ultimately deposited from shear planes near the front of an ice-sheet.

Several important conclusions and implications derive from this hypothesis. First, it may be concluded that major ice-sheets tend to disappear by thinning rather than by actual retreat of the ice front. This may account, in part, for the lack of identifiable terminal moraines in North East England. Secondly, and most important, the foundations of Pleistocene chronology are undermined, for the principal stratigraphical evidence for multi-glaciation is destroyed. Carruthers (1953) has attempted to show that only one true glaciation affected the lowlands of Great Britain and, during the other glacial periods which were recorded in Europe, periglacial conditions existed in Britain. If, as Carruthers

has suggested, this glaciation was contemporaneous with the Saale Glaciation of North West Germany and Denmark, the period during which normal erosion has acted on the post-Glacial surface may be more than six times the length of the post-Glacial period accepted by the Orthodox school (Zeuner, 1947).

Carruthers has received severe criticism from the orthodox school of thought, but such criticism has been largely directed against details of his conception of the physical processes involved. It is significant that no one has proved a satisfactory alternative explanation to the fundamental problem of how an advancing ice sheet can override unconsolidated sand without disturbing it. Neither of the coastal deposits which have been described provide irrefutable evidence of interglacials during the Pleistocene. The loess at Warren House Gill has been obscured by colliery waste for many years, so that no modern interpretation can be made of the significance of this deposit. It is, perhaps, significant that no further examples of loess have been discovered elsewhere in North East England. The Easington Raised Beach has been described as interglacial by Trechmann (1931, 1952) because the gravel contains fragments of shells and is overlain by about twenty feet of boulder clay. The evidence of the recognisable shells is inadequate, for most of these can be attributed to the post-Glacial period. Shell fragments have also been found by Trechmann (1952) in both the boulder clay and fluvic-glacial sands of East Durham as high as 420 feet above Ordnance Datum, so their presence at this site is not unusual. The evidence of the overlying boulder clay is equally indecisive, for here, as Hickling and Robertson (1949) have shown, the possibility of recent land-slip cannot be excluded.

Modern archaeological and palaeobotanical studies in North East England have also failed to substantiate some of the earlier ideas which favoured the multi-glacial hypothesis.

The discovery by Trechmann (1928) of a supposed Lower Palaeolithic artefact from the base of the drift in Limekiln Gill has been discredited by Lacaille (1953). The Palaeolithic finds by Collins in Nidderdale (Collins, 1932) can only be accepted with reservation. Indeed, in recent years, Collins has carried his investigations into Teesdale and Weardale (Mildyard, 1950), but his collection of so-called Acheulian artefacts from Weardale are unconvincing as archaeological specimens and represent a series of water-worn cobbles from the various stream beds where they were collected. The earliest archaeological remains which can be substantiated beyond doubt are of late Mesolithic age.

Palaeobotanical evidence of the extent and plurality of glaciation has been suggested from the studies of

the rare relict Artic-Alpine flora which is now confined to the hills of Upper Teesdale. It was long supposed, following the work of Wilmott (1930) that these moors either offered a refuge to certain species during the glacial maxima, or, according to Blackburn (1931) and Harrison (1949), this flora may have been introduced during an interglacial or interstadial period of the Pleistocene.

The first idea supported the hypothesis that many of the higher summits of the Alston Block were never glaciated; the latter gave additional weight to the multiglacial hypothesis. The latter received further support from the discovery by Lewis (1904) who reported an interglacial deposit in the peat of Cross Fell at a height of 2550 feet. Recently, however, these ideas have all been discredited. It was suggested by Godwin (1949) and confirmed by the analysis of the Neasham peats by Blackburn (1952), that the relict species are merely survivals of a late-Glacial flora which are growing in places where they escaped extermination by the shade of trees covering the land during the forest period. The Cross Fell interglacial deposit has been re-examined by Godwin and Clapham (1952), who found no pollen earlier than Zone VI, and cannot agree that interglacial peats are represented. The Neasham deposit provides the most certain geological and palaeobotanical evidence of periglacial conditions during the late-Glacial period. The elk skeleton, which was discovered here in 1938, has been described by Trechmann (1939a). Examination of the deposits by Blackburn (1953) has shown that there is a full pollen succession from Zone I to Zone VII. The elk was found in the Allerød zone (II) of the succession and the skeleton has been dated by radio-carbon methods. The provisional age of the deposit according to Flint and Deevey (1951) is $10,851 \pm 630$ years. Although Trechmann (1952) has argued that the upper part of the Neasham deposit consists of the characteristic prismatic clay, Blackburn (1952) has shown that this essentially a laminated clay deposited in water. Even Carruthers (1953) has agreed that the laminated clays at Neasham represent a true lacustrine deposit. The pollen sequence of Zones I-III at Neasham is characteristically that of the late-Glacial fluctuation of climate, recorded elsewhere in Northern Europe as : cold-warm-cold-post-Glacial. There is, however, no evidence that true glacial conditions were present in either cold period.

Despite the volume of literature concerning the extent and plurality of Pleistocene glaciation in North East England, practically every aspect of these problems remains a controversial subject. It is clear that any study of the glacial drifts per se leads straight to the major differences in opinion between the orthodox interpretation of the stratified drifts and that of the advocates of the Undermelt Hypothesis.

These differences might be settled in two ways. It is desirable that an objective re-examination be made of most of the classic examples of interglacial deposit which have been recorded in Great Britain and which lie north of the fluctuating margin of the ice during the maximum glaciation. It is reasonable that the terraces and solifluction deposits of the Thames valley should reflect many fluctuations in climate for these were situated at the furthest margin of an extensive ice-sheet where minor climatic variations ought to produce the maximum differences in deposition and drainage. It is uncertain, however, that supposedly interglacial deposits which lie two or three hundred miles further north can be attributed to similar fluctuations. The uncertainty in interpretation of the local interglacial deposits has been described, and it can be argued that many other sites may be similarly equivocal. It is, however, unlikely that many of these sites can be re-examined. Glacial and interglacial sections are frequently ephemeral features which are exposed during excavation or quarrying and soon obliterated or removed. For example, important deposits, such as the Warren House Gill loess cannot be visited again and one must rely entirely upon the published interpretation of the original discovery. The second, and most important, way in which some positive contribution might be made to the controversy of the stratified drifts, would be the study of glacial deposition along the margin of some retreating ice-sheet. Despite the great advances in the study of glacier physics during the last decade, little work appears to have been done on the mechanics of glacial deposition. Carruthers has been forced to rely upon the descriptive writing of such pioneers as T.C. Chamberlain in Greenland and G.W. Lamplugh in Spitzbergen. It is not that these writers provide evidence which is conveniently suitable for Carruthers's arguments; it is that this neglected aspect of glacial geology has attracted few people during later years.

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CHAPTER 7.

THE GLACIAL DRIFTS AND RETREAT DEPOSITS
OF THE WEAR VALLEY.

One of the objects of the field-work carried out during the course of this research has been the determination of the extent and nature of the Pleistocene glaciation and the possible interpretation of the glacial history of the Wear Valley.

The results of the first part of this work can be best summarized in the form of maps. The detailed drift maps (Plates 19-23 inclusive, Map Folder) with the appropriate topographical maps of selected areas (Plates 8-18 inclusive, Map Folder) show the present extent of the glacial deposits of the Wear valley upstream of Chester-le-Street. The distribution of late-Glacial or post-Glacial platforms, overflow channels and proved exposures of laminated clay are shown on Plate 24, (Map Folder).

The present extent of the glacial drift is based upon field evidence, amplified, where possible, by the boring and mining information described in Chapter 5. The drift mapping of H.M. Geological Survey has been taken as the basis for this work, and, as is shown in Appendix 1, the extent and reliability of drift revision varies in different parts of the valley. The drift-free areas recorded on the Geological Survey maps have been revised in Plates 21 and 22 (Map Folder) as areas of 'Thin Drift' by the present writer. These are the places where the superficial deposits consist of clay and are probably less than 10 feet thick. Thus, all known outcrops of sand are shown separately on the maps accompanying this work, irrespective of their thickness, and the few places where superficial deposits are completely absent have been grouped with the much larger area where there is only a veneer of clay. It is interesting to note that, almost without exception, the area of thin drift, defined upon this principle, lies entirely within the boundary of drift-free land mapped by the Geological Survey. In a few places, especially between Bishop Auckland and Wolsingham, the present writer cannot agree with the drift mapping of any edition of the Geological Survey. Certain important river gravels and fluvio-glacial sands, which occur between Harperley and Witton-le-Wear, were not shown on the primary survey and have not been recorded in any post-war revision of the area.

It has been shown, in Chapter 5, that the buried valleys of the Wear drainage system frequently extend one hundred feet or more below the present level of the river. Where these buried valleys lie outside the present confines of the flood-plain, the thickest drift is usually encountered.

The greatest thickness recorded is 236 feet of clay and sand, which was proved by boring in the Browney valley near Bearpark (Plate 16, Map Folder). It is certain, from the relative heights of rock-floor and present surface, that, in parts of the main buried valley the drift must be more than 300 feet thick. This extremely thick drift is probably limited in extent, for the sides of the buried valleys are frequently steep and, as is shown in the various sections (Figs. 28 and 29) the drift thins rapidly along the margins of the buried valleys. It is probable, also, that where the drift exceeds 150 feet in thickness, the upper layers often consist of fluvio-glacial sands which were laid down after the retreat of the ice.

On the uplands, the drift is generally either thin or absent. The steep sides of the West Durham and Magnesian Limestone Plateaux are, over a large extent, practically drift-free and many of the proved exposures of solid rock, shown on Plates 21 and 22 (Map Folder) coincide with these slopes. The plateau surfaces are areas of uneven drift cover and, in many places, are virtually drift-free. Occasional patches of drift, lying as high as the 1000-foot Platform, have been proved by boring to be as much as 20-30 feet thick. On the Magnesian Limestone Plateau, the kame-like mound of Warden Law, which forms the highest summit of the plateau, comprises about 150 feet of sand and gravel and many lower summits of gravel in East Durham are probably kames.

In Weardale, the main drift cover is confined to the valley floor, and, as has been shown in Chapter 5 (p.63), it is generally confined to one side of the valley. In the upland tributaries, also, the principal drift exposures are restricted to one side, generally west of the present stream.

The Boulder Clay :

In Plates 19 and 20 (Map Folder), the majority of the country represented lies to the west of the coal-field, where owing to the lack of borehole evidence thickness cannot be used as a criterion of drift cover. In this area, the present writer has attempted to differentiate between true boulder clay and other superficial clays.

The former can certainly be attributed to deposition by an active glacier; the latter may be glacial deposits which have remained in situ or which have been much altered by weathering. On the other hand, these clays may be periglacial deposits, formed by the comminution of material below and around snow-drifts and which have later been transported by solifluction or soil-creep. It is possible, also, that certain of these clays have been formed in situ by the deep weathering of the bed-rock, in those areas where shales predominate, just as, in the Millstone Grit uplands, deep weathering has often

reduced the grit to a coarse sand which may be four or six feet thick. The clays are so variable in texture, composition and distribution that it is difficult to generalize or formulate adequate definition of the different types of material. It is, however, possible to express the belief that true boulder clay is less extensive than has hitherto been supposed.

The present writer defines a true boulder clay as a stiff clay which contains proven foreign erratics or local rocks which are smooth and striated. This definition is sufficiently loose to cover the local variations in composition and texture but maintains the essential criterion of transport by moving ice. The other clays may approximate to boulder clay in texture, but they are either devoid of erratics or, if stones are present, these are often sub-angular and do not show recognisable striae.

On the higher hills of Weardale, clay may be recognised at considerable altitudes. Some clay may exist below the peat right to the summits of the moors. Examination of this clay has shown that it is often sandy in texture. It is therefore coarser and less cohesive than the sticky boulder clay of the valley floor. The included stones consist predominantly of sandstone fragments which are generally sub-angular, which are seldom smooth and never striated. Limestone fragments only occur close to the parent outcrop. These are frequently angular with sharp edges and their surfaces are rough and pitted. In contrast, the true boulder clay of Weardale, the 'Blue Joss' of the quarrymen, is a stiff or sticky little-weathered clay, which contains large numbers of sandstone and limestone erratics. The limestone content is often extremely high and some magnificent polished and striated erratics may be found. In many sections, fresh clay and unweathered erratics extend right to the present soil-cap. Elsewhere, there is evidence of a certain amount of superficial weathering and the upper layers of the clay are often jointed and fractured like the prismatic clays of the Durham lowlands.

Raistrick(1931a, 1933) has suggested that certain of the deeply weathered upland clays of the Pennines represent the drifts of an early glaciation which was more extensive than the later one when the fresh clays of the valley floors were deposited. This view cannot be supported from field evidence in Weardale, for it is not possible to show, anywhere, that the true boulder clay overlies an older drift. Indeed, in many places, it can be seen that the sandy clay overlies true boulder clay. It can be argued, however, that the sandy clay, irrespective of its origin, has been deposited upon the true glacial drift by later solifluction, soil-creep or land-slip.

It cannot be proved, from the present evidence, that the upper clay is of different origin to the boulder clay. The comparison of texture, included material and the remarkable freshness of the true boulder clay all support the conclusion that this was deposited by active glaciers. The sandy clay of the moors shows no evidence of glacial transport.

The erratics found in the boulder clays examined during the course of this work, generally supports the conclusions recorded in Chapter 6, (Fig. 31). The present writer agrees with Derryhouse (1902) and Trotter (1929) that foreign erratics are completely absent from Weardale and that the glaciers of the dale were isolated from other ice-sheets throughout the Pleistocene.

In Upper Weardale, there is only one place where true boulder clay can be found near the watershed. This is on the col (1790 feet) which lies on the south side of the dale between Ireshopeburn and Langdon Beck (Plate 19, Map Folder). Derryhouse recorded a gravelly drift on this col which he supposed was continuous with the true boulder clay in each valley. On the saddle itself, the peat cover is too thick to prove the nature of the drift or to show whether this can be attributed to glaciation or whether the gravelly material is an accumulation of solifluction debris which overlies true boulder clay. The boulder clay in Ireshopeburn was carefully examined by the present writer for erratics of Whin Sill. In this locality, the presence of dolerite erratics would almost certainly indicate the movement of ice northwards from Teesdale across the col. No erratics of whin were found anywhere in the Ireshopeburn valley and there is therefore no evidence that ice ever moved across the col into Weardale. On the other hand, since there are no suitable indicator erratics which could only derive from Weardale, it cannot be shown, in a similar fashion, that ice never flowed in the opposite direction.

The westernmost place where exotic ice penetrated the Wear valley is near Witton-le-Wear. Examination of drift exposures on the 1000-foot Platform north of Tow Law has shown that the Tyne Gap ice penetrated almost to the crest of the watershed between the River Browney and the Waskerley Beck. Several of the exposures of boulder clay in the Upper Browney, which were described by Derryhouse (1902) have yielded further erratics which originated from the Lake District or Galloway. Further mapping in this area by the present writer has shown that small pebbles of granite occur at a height only fifty feet below the present watershed at Saltergate (1135 feet). Similarly, the disused quarry at Longburn Ford, which lies less than 150 feet below the Browney-Waskerley Beck interfluvium, has yielded numerous erratics of Lower Palaeozoic (c.f. Southern Uplands) grit, Eskdale (?) granite and a specimen probably derived from the

Armbboth Dyke in the Lake District. On the western side of the watershed, in the valley of the Waskerley Beck, only local erratics have been found by the present writer. It is clear that the Tyne Gap ice reached almost to the present watershed, but there is no evidence that it spilled over into Weardale.

On the south side of the dale, the tributaries of the Bedburn valley are now thickly forested so that detailed drift mapping has proved extremely difficult. However, examination of the cobbles in the bed of the Spurlwood Beck and the few accessible exposures of boulder clay in this valley, yielded several examples of andesites of the Borrowdale Volcanic Series and the basement conglomerate of the Carboniferous Limestone Series. It is possible that these might have been derived from the Lower Palaeozoic Inlier in Upper Teesdale, but since this exposure has limited extent and since the erratics in the Spurlwood Beck are numerous, it is considered that these erratics originated from some part of the Cross Fell Inlier and may be considered to represent erratics of the Stainmore ice. In the Bedburn valley, the present writer was unable to find any erratics of Shap granite, which would have been more certainly diagnostic of Stainmore ice. However, Derryhouse (1902) recorded one large Shap granite erratic between Copley and Lanehead (NZ/082,257) which is only two miles east of the Spurlwood Beck. Another Shap erratic was recorded, in 1910 (Boulders Committee Report No.4) near the River Gaunless only one mile southeast of Bishop Auckland. In the Wear valley, however, no Shap erratics have been found and it appears that the main movement of Stainmore ice was confined to the Tees lowlands by the Ferryhill-Westerton ridge.

The lowlands and plateaux of the Middle Wear appear to have been completely overwhelmed by ice and the drifts become more difficult to interpret. It is, however, certain that the West Durham Plateau and Wear valley were dominated by ice which was derived from the north-west, for the typical assemblage of erratics includes material which originated from the northern Lake District, Southern Uplands and South-west Scotland. The orthodox interpretation of ice movement from the northern part of the Vale of Eden has been somewhat upset by the discovery of Johnson (1952) of an erratic of Shap granite in South Northumberland and by the provisional identification by Professor Dunham of a cobble of Emmerdale granophyre from Fence Houses brick-pit. The first discovery modifies the significance of the ice-parting near Appleby which was recorded by Trotter (1929) and Hollingsworth (1931). The second discovery suggests that there may have been some contrary movement of Lake District ice in the opposite direction to the north-westerly flow recorded by Hollingsworth (1931).

The boundary of the Cheviot drift, across the Magnesian Limestone Plateau has been substantiated by the present research for none of the characteristic Tweedside or Cheviot erratics have been found in the valley of the Middle Wear.

On the uplands of the West Durham Plateau and in Weardale, the drift exposures never suggest the presence of ice on more than one occasion during the Pleistocene. In the lowlands, too, there are few exposures which show more than one drift in situ and there are practically none where true intervening sands are exposed. In many sites, such as Fence Houses brick-pit, there is a definite change in the erratic content between the predominantly Pennine suite near the base of the boulder clay and the far-travelled erratics in the in the upper layers of weathered 'prismatic clay'. As was shown in Chapter 6, this is not necessarily evidence of two glacial periods for it may represent differential movement of ice.

The Sands and Gravels.

In upper Weardale there is an almost complete absence of fluvio-glacial sands. A few sand-hills are situated about one mile north-west of Wolsingham (Plate 20, Map Folder) but, apart from these, there is no superficial sand or gravel which cannot be related to terrace development during the post-Glacial period. The first important sands are exposed in the valley of the Bedburn Beck. These occur as a number of small isolated kame-like mounds which lie obliquely across the northern side of the valley.

Below the confluence of the Bedburn Beck with the River Wear, fluvio-glacial sands become more common. In parts of the valley north of Durham, these form the predominant drift at the surface (Plate 22, Map Folder). The principal exposures of the sands occur at the outwash ends of the principal overflow channels and in two belts, east and west of the present river. The exposures associated with overflow channels are often irregular, limited in extent and frequently comprise coarse gravel. In the main valley, the lower exposures of sand form an almost continuous outcrop. To the west of the river, there is an almost unbroken line of sand hills from the present confluence of the River Browney, near Sunderland Bridge, to Ravensworth in the north. On the eastern side of the Wear, the exposures of sand are less continuous, but similar hills may be traced from Shincliffe to Pitlington. The sand-hills are almost everywhere accordant to an altitude of 320-330 feet above Ordnance Datum, which, as was shown in the statistical investigations (Chapter 3), represents a significant height in all the different forms of sampling and analysis. Throughout this text the platform will be called 'The 320-foot Surface.'

In most of the tributary valleys of the West Durham Plateau north of the Browney (Plates 16 and 18, Map Folder), there are sand hills at the same height, which are backed by higher outcrops which rise to about 500 feet above Ordnance Datum.

Where the main interfluvium impinges upon the main belt of sand-hills, on the west side of the Middle Wear, such as the east face of Findon Hill (Plate 14, Plate 22, Map Folder), the sands are replaced by boulder clay above 330 feet. Below 200 feet, the sands are often replaced by boulder clay or laminated clay, but there are certain parts of the valley where sands appear to continue right to the floor of the "Wash" (See Chapter 5).

Thus, in the neighbourhood of Bishop Auckland, the Newton Cap borings (p.64) proved sand and gravel throughout the buried valley and this appears to form the principal infilling material as far north as the confluence of the Bellburn. (Plate 12, Map Folder). Binchester Hill, which lies athwart the Wash, rises to the 320-foot Surface and consists predominantly of sand. The sand is not, however, continuous here, for on the river banks, at a height of 210-220 feet, there is an exposure of laminated clay.

Near Chester-le-Street, north of the break in gradient in the longitudinal profile of the buried valley (p.65), the infilling material appears to be predominantly sandy. Two borings, at Red Rose Cottage and Chester-le-Street Cricket Ground, both recorded more than 150 feet of sand; the Chester Burn boring, referred to in Chapter 5, proved only 20 feet of clay in a total thickness of 168 feet of drift. Similar drift records have been obtained from the borings on Lumley Haughs, east of the river.

Elsewhere, however, both field evidence and borehole records suggest that below 200 feet, the fluvio-glacial sands are generally replaced by clay. The main outcrop of sand is, therefore, a belt which is seldom more than half a mile wide, which is 100-150 feet thick and which occurs between 200 feet and 330 feet above Ordnance Datum and which is best developed west of the river. There are many good exposures of this sand, for it is easily accessible and it has been quarried in many places close to the Great North Road. Typical sections are exposed along the eastern side of the road between Pity Me and Plawsworth. (Plate 14, Map Folder).

These sections show that the sand is remarkably uniform in texture and content. It is predominantly a fine-grained sand, which is often sorted into beds of different grain size. There are very few included pebbles apart from coal fragments. Towards the bottom of the deeper sections and,

in a gravelly capping to some hills, the sand contains pebbles and cobbles of other material. The relationship of coal to sand is important because pebbles of coal as large as 2 cubic inches may be found and the coal fragments are concentrated in definite layers where they trace out the current bedding of the sands. The universal presence of coal fragments within the fine-grained sand and the complete absence of other pebbles, suggest that the deposit was laid down in still water and that the coal, having a lower specific gravity than the other rocks, was deposited with the finer fractions. It has been suggested by Raistrick and others that these sands represent a deltaic deposit. It is reasonable to suppose that these sands were laid down in the glacial lake which occupied the valley of the Middle Wear during certain periods of the Pleistocene.

The distribution of the sand between the overflow channels and the 320-foot Surface and the detailed lithology of the deposits both support the conclusion that these are essentially glacial lake deposits and do not represent stratified drifts which were laid down by sub-glacial waters or by running water during interglacial periods.

A few beds of sand occur within the boulder clays, many have been proved by boring, but few are exposed in the field. Owing, perhaps to the accessibility of the massive deltaic deposits, these lesser outcrops of sand have not been worked and there are few adequate field exposures. The laminated clays, on the other hand, have been extensively worked as brick clays and there are a number of good but small sections of these deposits.

The Laminated Clays :

The distribution of the principal field sections of laminated clay are shown on Plate 24 (Map Folder). Certain of these exposures have already been described in detail by Carruthers (1939), but many of those brick-pits which were worked before the war are now abandoned and overgrown. A number of new sections are now available.

The principal features of the distribution of the laminated clays are that these seldom exceed 20 feet in thickness and that, in the field, they most frequently occur at altitudes between 180 feet and 220 feet above Ordnance Datum.

There are certain exceptions (5) but, between Chester Moor (Plate 14, Map Folder) and Bishop Auckland, the main concentration of these deposits lies just below the 200-foot contour. This is the altitude of a second important late-Glacial or post-Glacial platform which was recognised and described by Anderson (1939). This will be termed the '190-foot Surface'.

Laminated clays have been usually recognised as lacustrine varved clays showing seasonal bands of micaceous silt alternating with stone-free clay. The presence of this thin, but remarkable continuous horizon of laminated clay on the surface of the well-marked 190-foot Surface provides a strong case in favour of such an interpretation. Certain of the exposures at other altitudes might be interpreted as lacustrine deposition in lakes which were more local in extent. Thus the Birtley and Fatfield deposits occur between the levels of the '140-foot Surface' of Anderson (1939) and the 100-foot bench in the valley of the Lower Wear. The significance of these surfaces will be considered later, but, at present, it will suffice to record that these lower laminated clays can, according to the orthodox interpretation, be attributed to a third glacial lake level at or below 140 feet.

The high-level exposure of laminated clays in the Beamish Burn provides a small-scale example of deposition in a supposed lake of local importance. The upper part of the River Team, known in different sections as the Houghwell Burn, Causey Burn and Beamish Burn, rises near Annfield Plain. The pre-Glacial valley, whose direction, continuity and depth has been proved by boring and mining, was the river trending east-north-east from the radial centre of Pontop Fell (Chapter 4, p.41, Fig. 26.etc.) About one mile west of Beamish Hall, the broad

(5) For example, the thickness of the laminated clay at Birtley often exceeds 60 feet (B & S 2423-2432) and may approach as much as 100 feet. The group of brickfields at Birtley have worked these clays at altitudes between 80 and 120 feet above Ordnance Datum. At Fatfield, about one mile east of Lambton Castle (Plate 15, Map Folder), 7-9 feet of laminated clay is exposed above 20 feet of sand at an altitude of 120 feet. In the Beamish valley, near Tanfield Lea, typical laminated clays are exposed in a brick pit on the west side of the Causey Moraine (Plate 24, Map Folder) at an altitude of 460-480 feet above Ordnance Datum. At Willington Brick-works, 9 feet of laminated clay occurs at 260 feet. In the Gaunless valley, near West Auckland, similar clays have been proved by boring and in field sections at the level of the 320-foot Surface.

pre-Glacial valley was blocked by a considerable barrier of drift which must be at least 275 feet thick. This barrier has a crescentic form and has been called the Causey Ridge or Causey Moraine by Anderson (1940). The Causey Ridge consists in part of boulder clay (about 100-150 feet) capped by a similar thickness of fluvio-glacial sands which rise to a height of 575 feet at Oxpasture Hill, in the middle of the crescent. The present course of the River Team lies around the northern edge of the moraine, through the line of an overflow channel. This part of the valley, known as Causey Gill, is a steep-sided gorge cut through Coal Measures strata. On the upstream side of the Causey Ridge, a brick-pit has been excavated in the side of the moraine. This brick-pit has worked a maximum thickness of 15 feet of laminated clay which overlies sand. West of the present workings, the laminated clay has been proved by boring to increase to a thickness of nearly 40 feet. The present section has a cover of boulder clay, but it is probable that there has been considerable recent movement of the overburden, for the surface above the brick-pit is much disturbed.

It is reasonable to suppose at this site, that the upper part of the valley, west of the moraine, was formerly occupied by a late-Glacial lake. The local accumulation of water, augmented by that coming from the Derwent valley through Clough Dene overflow channel, would be dammed back by the Causey Moraine. This escaped northwards through Causey Gill which has been occupied by the River Team ever since. The horizon of the laminated clays at Tanfield Lea occurs at the same height (480 feet) as the break of slope above Causey Gill, where the spillway swings southwards to enter the old valley east of the moraine. It may be concluded, therefore, that the clays were laid down in this lake when it occupied its maximum extent.

According to the interpretation of Carruthers (1953), however, these deposits do not represent lacustrine deposition and may be regarded as 'Pressed Melts' or 'Shear Clays' which originated as the banded dirt of a stagnant ice-sheet. Detailed examination of these clays by Carruthers has allowed him to formulate a series of diagnostic features which show the differences between these and the true varved clays of limnal origin. It must be admitted that the laminated clays of the Wear valley, from Birtley and Tanfield in the north to West Auckland in the south, all fulfil Carruthers' criteria defining typical shear clays. The laminated clays are extremely complex and contain the microscopic laminae, equal-flow structures and tectonic patterns which have been described by Carruthers.

Organic material is absent except from the surface layers where recent plant roots have reached the clays. Dr. F.H.T. Rhodes and the present writer examined specimens from different levels at all the principal sites in the valley (Birtley, Finchale, Durham, Butterby and Willington) in order to discover



Fig. 34 (Right)

Finchale Brick Works (NZ/292,461)
General view working face, March 1953



Fig. 35 (Left)

Cleaned section laminated clays; Finchale Brick Works



Fig. 36

Details of laminated clay; Finchale Brickworks

whether Ostracoda were present. The investigation was incomplete when Dr. Rhodes left Durham University, but none of the specimens from Finchale, Durham or Butterby had yielded any traces of a micro-fauna in either the clays or the silts. It should be noted that Blackburn (1952) has identified Ostracoda in the laminated clays of Neasham. These have been accepted by Carruthers (1953) as true lacustrine clays which are lithologically different from the typical shear clays.

It must be admitted that the investigations of the present writer into the lithology of the laminated clays have been superficial compared with those studies of Carruthers, but the examination of the Wear valley deposits suggest certain features which cannot be explained by the Under-Melt Hypothesis.

The geographical distribution of these clays is important, for, as has been shown, they occur predominantly at the level of the 190-foot Surface and are best exposed near the present land surface. It seems that such constancy in altitude of the main group of deposits cannot be accounted for by the Under-Melt hypothesis. The frequency of occurrence at this critical altitude suggests that it would be too great a coincidence for a melting ice-sheet to deposit the englacial dirt at such a constant level. Secondly, since these are supposed to represent englacial dirt, and, as it were, form the meat in a sandwich of boulder clay, it would be reasonable to expect that, in certain sections, undisturbed till might be proved above the shear clays. This is not characteristic of the sites which have been examined, though it must be admitted that the much deeper sections in the quarry of Coatham Stob illustrate this feature perfectly. Thirdly, since the laminated clays are exposed so close to the present surface, it would be reasonable to expect a certain amount of surface movement, frost-heaving and similar processes which could account for the tectonic features of these clays. This interpretation was favoured by both Professor H. Louis of Munich and Professor P. de Bethune of Louvain when they saw the clean section at Finchale Brick-works during 1953 (Figs. 34, 35, and 36).

Arguments in support of the Under-Melt Hypothesis are, first that there are a number of sites where laminated clays are exposed at levels other than the 190-foot Surface and that there are many borings which have recorded 'leafy clay', 'clay with sand partings' or 'warp' at different heights. Secondly, the present occurrence of laminated clay at or near the surface may be, in part, the result of post-Glacial erosion for although field sections occur only at the surface, some borings have proved laminated clay to be covered by a considerable thickness of boulder clay and sand. Thirdly, if both the 320-foot Surface and 190-foot Surface can be regarded as lake levels, it is necessary to explain why the deposits of the 320-foot Surface are predominantly sand, with only one small outcrop of laminated clay in the Gaunless valley near West

Auckland, whereas the deposits at 190-feet are predominantly clay with only a few minor patches of sand near Finchale and Chester-le-Street. Finally, although these exposures of laminated clays in the Wear valley lie so close to the surface that superficial movements may have disturbed them, Carruthers has noted many similar structures in deeper workings where they were formerly deeply buried. Indeed Carruthers (1946) has admitted the possibility of frost heaving and other processes and for this reason has chosen many of his examples from depths where such movements are likely to be negligible.

It is possible, however, that true varves may occur on the 190-foot Surface, in conjunction with shearclays. The 18-foot section which was cleaned in Finchale Brick-works during 1953, showed a thin horizon (0.6 - 0.8 feet) of relatively broad and simple silt/clay bands near the present surface. (Fig.36). This small section represents the nearest approach to true varves which have been found in any part of the Wear valley. Above the section illustrated, the surface clay was deeply weathered to the soil cap at 186 feet above Ordnance Datum, but laminae could be identified in this zone also. Elsewhere in the brick pit, it was not possible to identify this band of broad laminae, but this was largely owing to the absence of suitable sections at this critical altitude.

It is clear that no certain conclusions can be drawn about the origin of these stratified drifts from the examination of these, alone. It has been shown that their detailed lithology corresponds with Carruthers' observations and on this particular point, it is not possible to discredit the Under-Melt Hypothesis. On the other hand, the geographical distribution of the clays tends to support the orthodox interpretation of these as lacustrine deposits.

By themselves, the glacial drifts of the Wear valley cannot provide certain proof of multiglaciation and, indeed, the evidence tends to favour the monoglacial interpretation suggested by the Under-Melt Hypothesis. Since the supposed interglacial deposits of North East England are either obliterated or permit equivocal interpretation, it is necessary to examine other possible lines of evidence which may indicate the chronology of the Pleistocene in this area. The study of the morphology of the melt-water overflow channels and the late-Glacial surfaces, provides certain evidence which might permit more definite conclusions.

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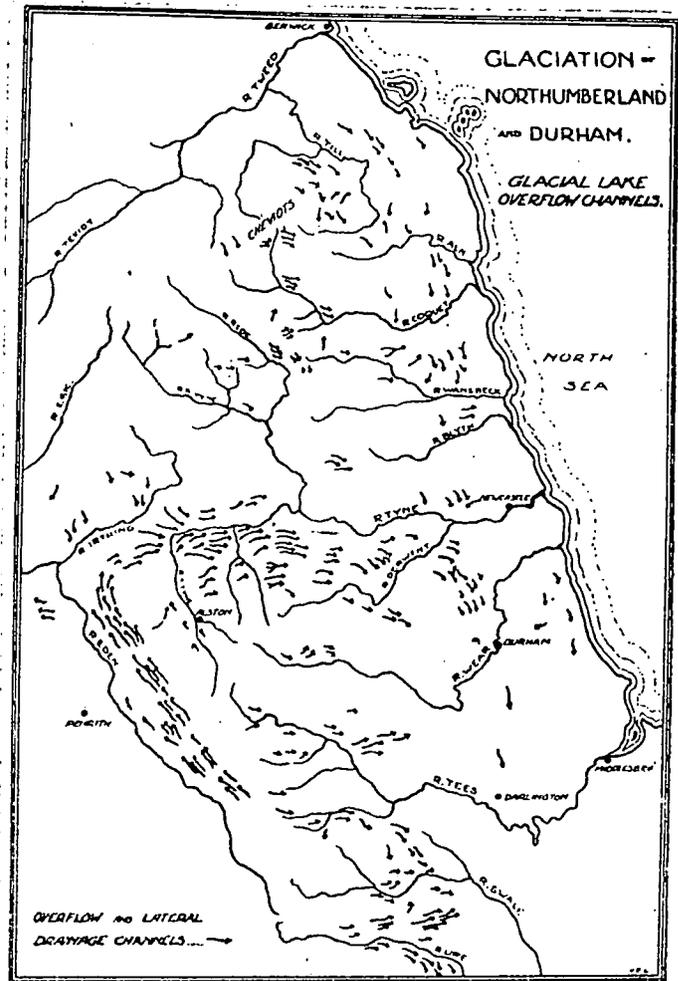


Figure 37 (after Raistrick).

CHAPTER 8.

THE MORPHOLOGY AND DISTRIBUTION
OF OVERFLOW CHANNELS OF THE WEAR VALLEY.

The regional pattern of overflow channels or spillways round the western and northern edges of the Alston Block (Fig.37) shows that, during certain periods of the Pleistocene the bulk of the meltwater from East Edenside and the ice-free uplands of the Cross Fell massif, made its way northwards and eastwards round the northern periphery of the Block and then drained southwards into the Wear valley. Such an analysis depends upon two basic assumptions; first, that the uplands of the Alston Block lost the greater part of their permanent ice-cover before the lowland ice had begun to retreat; secondly, that the edge of a large glacier will act as an effective dam to meltwater, so that the ponded water escaped along the margins of the ice rather than through sub-glacial streams. The descriptions of Dwerryhouse (1902), Herdman, (1909), Trotter (1929), Raistrick (1931a, 1931b) and Anderson (1940) leave no doubt that this regional reconstruction of the meltwater drainage is substantially correct.

During the course of field-work, a few doubtful overflow channels have been eliminated from Raistrick's map (Fig.37) and a few additional channels have been identified. The positions of the channels in the eastern part of the Alston Block are shown on Plate 24 (Map Folder). The principal contribution of the present writer has been a detailed study of the morphology of certain of the overflow channels which are situated along the eastern edge of the West Durham Plateau. The examination of the rock-floor topography in certain of these has shown a number of features which may prove to be of fundamental importance to the interpretation of Pleistocene chronology in Northern England. An explanation of these features which is unchallengeable is not yet possible, but, as will be shown, there is strong evidence to show that the majority of these channels were occupied by glacial meltwater on at least two occasions.

Apart from the classic paper of Kendall (1902), most of the work which has been published is more concerned with the relative heights and positions of the channels and the associated edge of the ice-sheet than with their detailed morphology. In this part of North-East England, the writers quoted above produced an elaborate sequence of retreat stages and movements of the ice-front. No attempt was made to explain the obvious peculiarities of such well-known channels as Beldon Cleugh and East Dipton until these examples were studied in detail by Peel (1949). Peel was able to show that the simple concept of uni-directional flow from an upper to a lower glacial lake could not account for the meanders of Beldon Cleugh or the

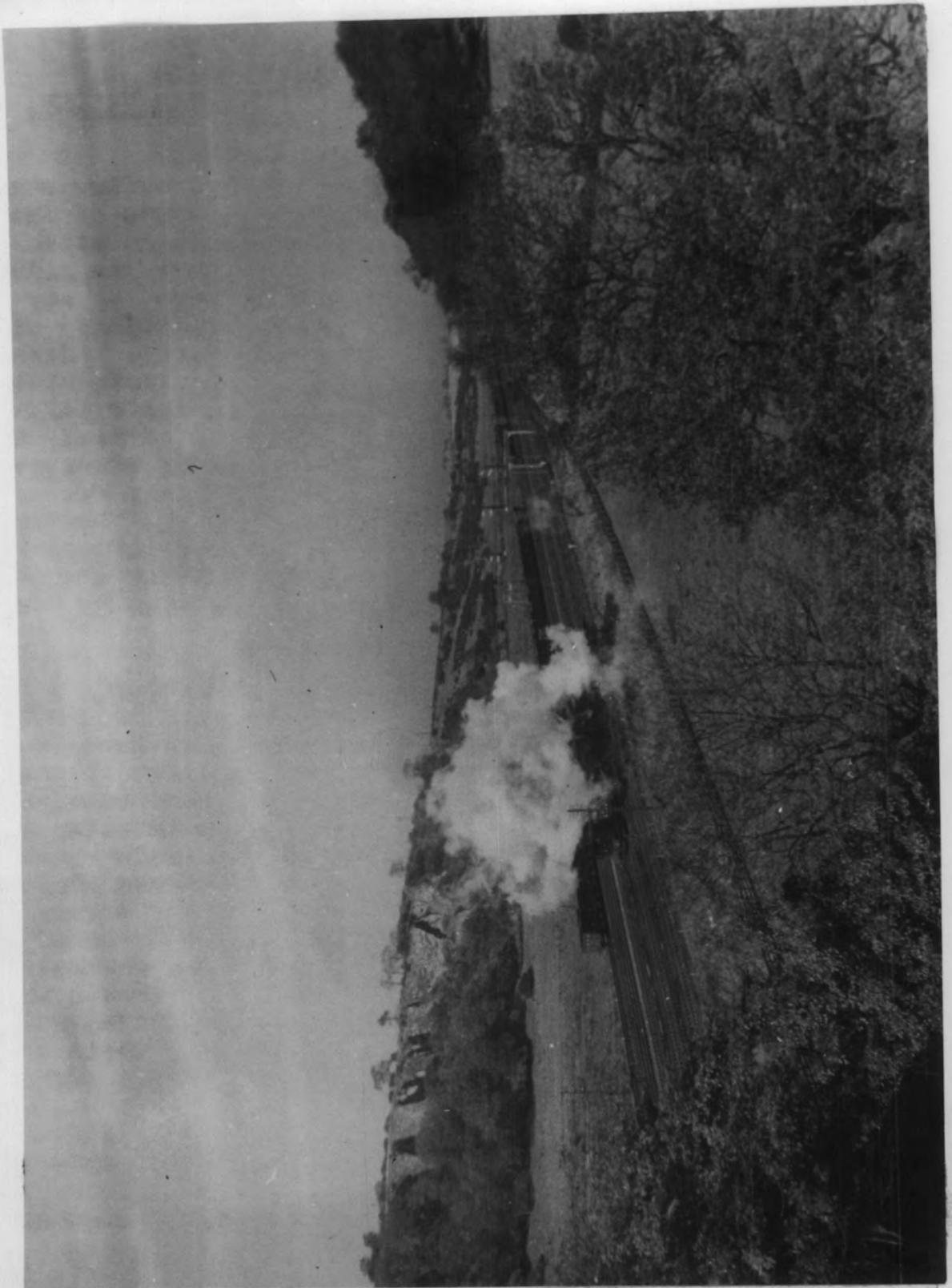


Fig. 38

Ferryhill Gap. View North from Swan House (NZ/304, 325)

longitudinal profile of either channel. Peel was also able to demonstrate that there was a considerable thickness of peat in the floor of the Beldon channel, but he was unable to prove the depth of the rock-floor with the equipment at his disposal.

The Morphology of the Overflow Channels.

In any reconstruction of the late-Glacial drainage of this area, the difference between two basic types of channel must be recognised :-

- 1) Direct Overflow Channels, which are located according to topography. The situation of these channels was determined by the positions of those wind-gaps which formed the lowest points along the interfluvies of the Alston Block. The term 'Col Gullies' of Mannerfeldt(1949) is, perhaps, more clearly descriptive of this form of channel.
- 2) Marginal Overflow Channels which developed where the edge of an ice sheet happened to rest against some valley spur which intervened between two lakes. As the ice retreated or thinned, the higher marginal channels were abandoned in favour of lower channels adjacent to the ice. In this manner, parallel channels were formed across the principal spurs.

Whereas the height and location of the marginal overflow faithfully reflects the position of the ice-edge at any particular stage, the direct overflow channel only indicates a minimum elevation of the ice dam which blocked the entrance to that particular valley. According to the orthodox interpretation, the level of a glacial lake forming in an upland valley would rise until it reached the altitude of the lowest wind-gap in the watershed which was ice-free. The lake waters would spill through this gap and would continue to drain through the resultant channel until the distant ice-dam had retreated or shrunk far enough to lower the lake level and perhaps, to expose a lower col. In the absence of a lower col, the meltwater would escape along the margin of the ice-sheet and form one of the members of a parallel or aligned sequence of marginal channels.

The well-developed channel of either type generally has a flat floor and steep sides. The present floor is usually ill-drained and occupied by a mere trickle of water, or it is completely dry. These are the principal diagnostic features of both types of channel. It is only in areas of thick limestone that such valleys could originate from other causes. The marginal channel is often completely independent of the drainage pattern, but direct overflows maybe occupied by the headwaters of an existing stream. Since many of the direct overflows channels which were mapped by Derryhouse(1902) are of this form, field examination has been necessary to prove whether they were occupied by meltwaters.

For example, Sharnberry Gill (NZ/00,31), which was supposed, by Derryhouse to have drained melt-water from Teesdale into the Bedburn valley, contains a vigorous stream which rises near the intake and forms one of the headwaters of the Bedburn Beck. On the watershed, the intake of the Sharnbury Channel is sharply incised 40-50 feet below the moor and this notch confirms that the valley was originally excavated as an overflow channel.

Elsewhere, however, the evidence is less certain. The two channels, Northern Letch and Southern Letch, which rise on Whitehall Moss, near Lindisfarn, (NZ/08,46) were described by Derryhouse as part of the late-Glacial drainage from a lake in the Derwent Valley eastwards to the Browney Valley. These two streams rise on a gentle col and flow eastwards, along parallel courses which are less than 200 yards apart. East of Lindisfarn farm, both valleys are deeply incised into Lower Coal Measures sandstones to their confluence about $\frac{3}{4}$ mile south-east of the farm. No sky-line notch can be seen on the broad, wet, peat-covered moor of the col. The size of each valley, the misfit nature of the present streams and the limited gathering ground of the col all suggest that normal drainage could not account here for the presence of two parallel and deeply incised valleys. Similar arguments may be applied to the upper parts of the River Browney, (NZ/07,45) one mile further south, and to the headwater of the River Deerness, where it enters an incised channel immediately east of the low col at Tow Law. (NZ/12,39).

In certain marginal channels, where the outer edge was entirely composed of ice, the lines of the channel is now indicated by the steep hillward slope and the flat floor which is represented by a shelf beneath this slope. An example of this form is seen in the Eden Hill Channel which forms one of the lower members of the Beamish group of spillways (Plate 18, Map Folder). Individual marginal channels may bifurcate successively into a complex series of distributaries, or they may integrate from several small channels into one major overflow. These features are not normally characteristic of the direct spillway. The Lindisfarn channels described above, represent the only example in this area. The direct overflow channel usually has the form of a single trough, though this may not be straight. The steep sides are usually symmetrical, except where they have slipped into the channel, but generally the slopes are remarkably stable, for these are formed of solid rock which can be seen to outcrop along the sides of most well-developed spillways.

The longitudinal profile of an overflow channel may be similar to the normal curve of stream erosion, or it may steepen downstream, or the profile may humpbacked across the col into which the channel has been cut. The normal longitudinal profile is rare and only represented by a few of the direct spillways which form the headwaters of existing streams. It is possible that later stream action was responsible for modification

of the profile. More often these channels have the profile form described by Kendall(1902) as 'steepened rapidly downstream ... a feature rarely observed in normal valleys'. Peel(1949) has shown, from levelling through Beldon Cleugh and the East Dipton channel that many of the well-defined, deeply cut overflow channels have a hump-backed profile. This feature is characteristic of most of the important direct and marginal channels of the Wear valley.

None of the channels which have been examined in the field show exposures of solid rock in their floors. Boreholes which have been sunk in such localities have generally recorded considerable thickness of superficial deposits. This fact has long been known, for Watts (1908) noted the record of 25 feet of superficial deposits in a boring in the Knitsley overflow channel. It was not until 1953, however, when a series of four borings were sunk in part of Ferryhill Gap, that the significance of such records was realized.

Ferryhill Gap (Fig.38) has long been recognised as the principal direct overflow channel of the Alston Block and it holds a similar relation to the late-Glacial drainage of North East England as does Newtondale to the drainage of the Cleveland Hills. When the ~~water~~ meltwater from the uplands of the Alston Block reached the valley of the Middle Wear, they were ponded between the West Durham Plateau and the Magnesian Limestone Escarpment. If the northern end of the Wear valley was blocked by ice at any point south of a line from Houghton-le-Spring to Wrekenton and Ravensworth, the level of the lake would rise to the height of the wind-gap at Ferryhill. The height of this col appears to have been about 420-430 feet above Ordnance Datum. Lake water began to spill over this col and considerable masses of fluvio-glacial sand were deposited on the southern slopes of the Magnesian Limestone ridge. These sand hills rise to the approximate height of the original wind gap at 420-430 feet (Plate 21, Map Folder). The level of the lake never exceeded this critical altitude, for, if it had, a further direct line of overflow would have operated through the Raisby-Garmondsway wind-gap (440 feet) and there is no evidence of this. The escaping meltwater cut the steep-sided trough of Ferryhill Gap and the present form of the valley is typical of the major direct overflow channels recorded elsewhere in Britain.

The valley sides are exceedingly steep throughout most of the length of the channel, and exposures of Magnesian Limestone outcrop or have been exposed by quarrying on both sides. The present floor is flat and boggy and it is inclined gently towards the south. The drainage is ill-defined, but much of the present stagnation may result from the presence of settling ponds for colliery waste at the northern and southern ends of the Gap and from the construction of the low railway embankment across the middle of the floor.



Fig. 39

Ferryhill Gap. View N.E. from gravel hills (NZ/301,318)

Fig. 40

Ferryhill Gap. View S.E. along floor of channel.
Swan House meander trends towards right.
A-D indicates sites of borings described in text.

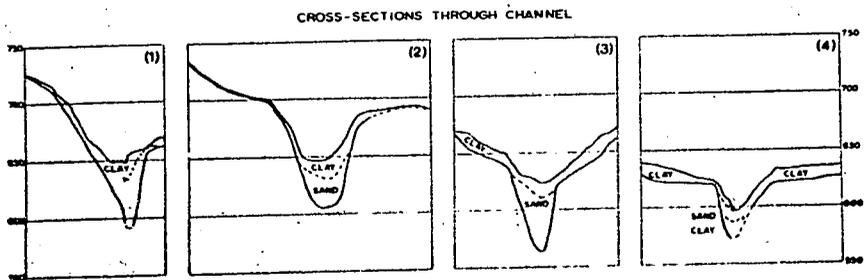
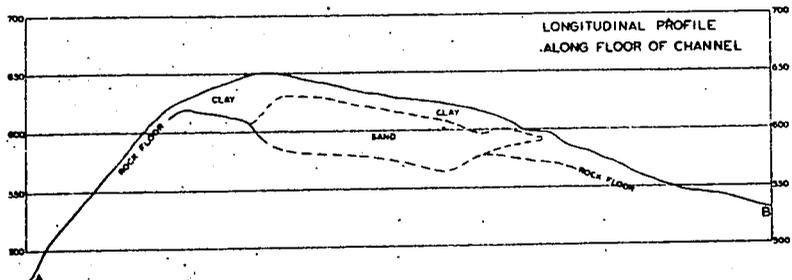
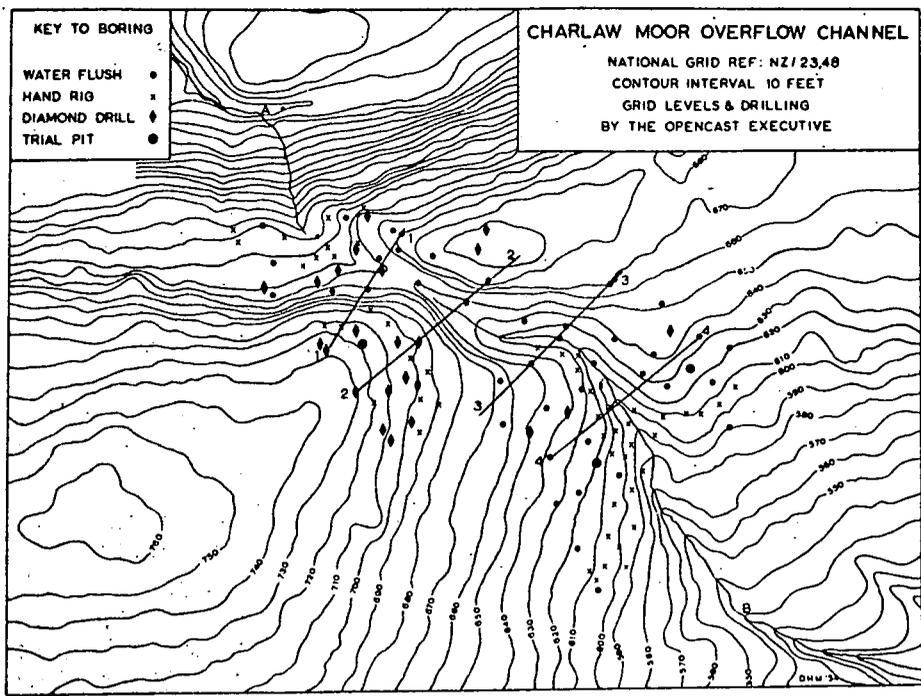


Figure 41.

About one mile from the northern end of the Gap, there is an abrupt meander at Swan House. (Figs. 39 and 40). The main railway line passes through the core of the meander in a cutting where the Permian Yellow Sands are well exposed. The concave surface of the meander core is graded to a height of 320 feet. Ferryhill station is situated immediately south of the railway cutting. Southwards the extent and nature of the floor of the channel is somewhat uncertain owing to extensive railway sidings, buildings and colliery waste. It appears, however, that the valley becomes wider south of Chilton and that the present floor of the channel is graded to the alluvium of Bradbury Carr at 235 feet. The positions of the four borings are shown on Figures 39 and 40. The records of these borings are as follows :-

- A 278.26 feet above O.D., Boring sunk 126 feet 6 inches in boulder clay, gravel and sand. Rock floor not reached at 151.76 feet above O.D.
- B 271.70 feet above O.D. Boring sunk 98 feet in boulder clay, gravel and sand. Rock floor not reached at 173.70 feet above O.D.
- C 287.95 feet above O.D. Boring sunk 112 feet to limestone rock floor at 176.0 feet above O.D.
- D 330.61 feet above O.D. Boring sunk 186 feet in boulder clay, sand and gravel. Rock floor ~~not~~ reached at 144.61 above O.D.

The records of C and D are of especial importance because they were sunk within 400 feet of the edge of a quarry, supposedly on the south-eastern side of the channel, where the rock floor may be seen at a height of 310-320 feet above Ordnance Datum. In other words, eastwards from the quarry, the rock floor falls at least 150 feet in about 400 feet horizontal distance. This gradient (1: 2.6) is far in excess of any slope recorded in the buried valleys of the Wear drainage system.

Although this cannot be proved, it is likely that a buried continuation of Ferryhill Gap lies southward of the meander beneath Nable Hill and Mainsforth Hall. Mainsforth Colliery lies between this buried valley and the present channel. The total drift thickness recorded in the shaft section of 'B' Pit (B & S, 1314) was only 11 feet. North of the site of borehole A, the continuity of a deeper channel cannot be proved, but, just north of the present intake, a series of recent borings and seismic investigations have shown that there is a very narrow buried valley which extends southwards from Tursdale Colliery towards Metal Bridge. The intake of the present channel appears to be blocked by a low knoll of solid rock at Thinford Close, but both field evidence and the records of several old

borings, whose precise location is uncertain, suggests continuity of these buried valleys (Plate 21, Map Folder). It is particularly fortunate that the cores of these Ferryhill borings were examined by officers of H.M. Geological Survey. The clay was identified as boulder clay and erratics were examined. These were identified as Carboniferous and Permian rocks of local origin. Cobbles of sandstone, gneiss and limestone were recorded from most bores; pebbles of coal, shale and sandstone were seen also. This infilling material can only have been derived from one of two sources. Since boulder clay has been proved to constitute the principal element of each drift sequence, the material was either deposited within the Gap by moving ice, or it was later redeposited there by hill-wash, solifluction or slumping from the slopes above. The second processes can hardly explain drift thicknesses approaching 200 feet, for the material could only be derived from the adjacent hillsides, where the gathering ground is relatively limited. It is clear that the overflow channel persisted in its present course for some period after the original channel was blocked for the drift surface of the obstructed portion rises to 320 feet at least, whereas the present floor lies 50 or 60 feet lower.

The other evidence from the overflow channels of West Durham is no less remarkable. The principal data are supplied by numerous boreholes in three groups of marginal overflow channels which cross prominent spurs of the West Durham Plateau north of the Browney valley. The detailed topography of part of this area is shown in Plate 18 (Map Folder) and the detailed rock-floor evidence from the Charlaw Moor Channel is shown in Figure 49.

The relevant information, concerning all the overflow channels of this area, is recorded in the following tables :-

Table 10. Morphological Features of
Certain Overflow Channels in West Durham.

<u>Name of channel and Grid Ref.</u>	<u>Type.</u>	<u>Ht. of present intake.</u>	<u>Form of long-profile</u>	<u>Greatest known drift thickness.</u>
DERWENT-TEAM WATERSHED.				
Clough Dene (NZ/17, 55)	Direct	690 710	Hump-back	x
Burnopfield (NZ/19, 57)	Direct	580	?	x
(Buried continuation) "	"	?	?	c200 feet

Table 10. Morphological Features of Certain Overflow Channels in West Durham. Continued.

Name of channel and Grid Ref,	Type.	Ht. of present intake.	Form of long-profile.	Greatest known drift thickness.
BEAMISH GROUP				
Causey Gill (NZ/20, 56) (Now occupied and modified by Causey Burn).	Marginal	c480	x	x
Hellhole (A) (NZ/22, 54)	Marginal	c420	Humpbacked	x
Acton Dene (B) (NZ/22, 53)	"	580	"	>60 feet
High Twizell (C) (NZ/22, 53)	"	560	"	24 "
Rose Hills (D) (NZ/22, 53)	"	525	"	21 "
Clay Slack (E) (NZ/23, 53)	"	510	"	19 feet
Eden Hills (F) (NZ/23, 53)	" (one-sided)	470	?	40-50 (?)
Handen Howl (G) (NZ/23, 53)	Marginal	c360	Humpbacked	c70 feet
CRAGHEAD GROUP				
Fawside Dene (H) (NZ/21, 50)	"	530	Steepens downstream?	43 "
Humbleburn (J) (NZ/22, 51)	" (Now filled with colliery waste)	490	?	23 "
Tribley (K) (NZ/24, 51)	Marginal (Well developed marginal shelf at intake, eastern side predominantly composed of thick gravel).	315	Steepens downstream	61 "
CHARLAW GROUP				
Charlaw Moor (L) (NZ/23, 43)	Marginal (See Fig. 41)	650	Humpbacked	80 "

Table 10. Morphological Features of Certain Overflow Channels in West Durham. Continued.

Name of channel and Grid Ref.	Type.	Ht. of present intake.	Form of long-profile.	Greatest known drift thickness.
Sacriston(M) and Fulforth Dene. (NZ/23,48)	Marginal	490	Humpbacked	96 feet
Smithy Dene(N) (NZ/24,49)	"	380	Steepens downstream	c40 "
DEERWENT-BROWNEY				
Burn Hill (NZ/06,45)	Direct	c1090	Steepens downstream	Peatbog at intake
Lindisfarn (NZ/08,46)	"	c1015	Steepens downstream	Peatbog at intake
Knitsley (Hown's Gill) (NZ/09,49)	"	620	Humpback	25 feet
Redwell Hills (NZ/13,52)	Direct	810	"	x
BROWNEY-DEERNESS				
Stow House (NZ/14,42)	"	800	Humpback ?	less than 10 feet
Hamsteels (NZ/17,45)	Marginal	700	"	x
Rowley Burn	"	610	"	?
SOUTH OF DEERNESS				
Tow Law (NZ/12,39)	Direct	c970	Steepens downstream	x
(Long profile of channel modified by head water of River Deerness).				
Langley Moor (NZ/24,41)	Marginal	c280	?	c30 feet
(Now filled with colliery waste and rubbish)				
Job's Hill (NZ/18,35)	Direct	c600	Hump-backed	19 feet
(Partly obscured by mineral railway)				

Table 10. Morphological Features of Certain Overflow Channels in West Durham. Continued.

Name of channel and Grid Ref.	Type.	Ht. of present intake.	Form of long-profile.	Greatest known drift thickness.
UPPER BEDBURN TEES-WEAR WATERSHED				
Sharnberry (NZ/00, 31)	Direct	c1460	humpbacked	peatbog at intake (solid rock can be proved across floor between 1250 and 1300 feet).
Blackton Head (NZ/01, 26)	Direct	1355	?	peatbog at intake (Believed to contain more than 50 feet of peat near watershed. Solid rock almost continuous in floor at 1310)
EAST OF THE MIDDLE WEAR.				
Tunstall Hope (NZ/39, 54)	Marginal	155	humpbacked	believed to be considerable
Broom Hill (NZ/29, 36)	"	290	?	x
Ferryhill Gap (NZ/30, 33) (See Figs. 38-40 & pp 103-104).	Direct	290	decreasing downstream	>127 feet in present floor.

It can be seen that most of the better defined, deeply notched, channels contain thick drift and have a hump-backed longitudinal profile. Certain minor channels contain only a veneer of clay on their floors.

In addition to these visible channels there are few buried valleys whose topographical location and apparent morphology suggest that they were initiated as spillways. The best known example is that of the Burnopfield buried valley, (NZ/21, 57) which has been mapped by Anderson (Geological Survey 6-inch, Sheets VI S.W. & S.E. published 1939; XII N.W. & N.E. not published) and has already received passing mention from Anderson (1940). The trend of this valley is in direct line with the Burnopfield overflow channel across the Derwent watershed (Fig. 26). The visible part of the Burnopfield channel ends near the Causey Arch Inn, where branch channels lead north and south towards Marley Hill and Beamish Hall respectively. The buried valley begins here and trends eastwards, south of Hedley Hall to the group of sandhills known as Pockerley Hills.

which may represent a second morainic ridge parallel to the Causey Moraine. This has been called "The Urpeth Ridge" by Anderson (1940). The continuity of this valley has been proved by almost continuous workings in Hutton and Low Main seams and by opencast borings at the eastern end. The floor of this buried valley is quite unlike any of the buried tributaries described in Chapter 5, for the rock floor maintains a constant height of 280-300 feet throughout the mile of its course from Causey Arch to Pockerley Hills. The opencast borings on the slopes of Hedley Fell show that the break of slope along the northern edge of this valley is extremely abrupt. The continuity of this feature with an acknowledged overflow channel and the nature of the rock floor leave little doubt that it represents a buried spillway. A second feature of this sort may exist in the southern part of the Middle Wear, along the shallow depression at the foot of the Butterknowle "fault-scarp" between Binchester and Spennymoor. Boring in the middle part of this valley, near Middlestone Moor, has revealed a deep, steep-sided trough which is now filled with clay and sand. Further west, opencast prospecting near Binchester Blocks has shown that there is another buried valley which corresponds, in part, with the present Bellburn (Plates 12 and 21, Map Folder). The continuity of these valleys cannot be proved, but the available evidence favours the interpretation of these features as a buried overflow channel rather than two buried tributary valleys which are separated by a low col. It has been shown, from the evidence provided by the Ferryhill borings, that the principal infilling material of these channels is boulder clay which was most probably deposited by ice. The records from boreholes in the other channels show that, at times, fluvio-glacial sands are present also but these are capped with clay.

There are thus three basic types of spillway. There are, first, the major direct and marginal channels such as Ferryhill Gap and the Charlaw group of channels, which are situated at critical places on low cols and spurs. These show considerable drift infill which suggests occupation by melt water on at least two separate occasions. Secondly, there are the minor channels such as Stow House and Clay Slack which do not contain thick drift and which were probably formed during the second phase of melt water occupation. Finally, there are the drift-filled channels, possibly cut during the first phase of melt water drainage, which were subsequently plugged with drift and never re-occupied by melt water. The Burnopfield buried valley provides the best example of this type of channel.

If we accept the basic principle that all overflow channels were cut by melt water which was escaping from glacial lakes, these channels could conceivably be formed either ahead of advancing ice or behind retreating ice. This hypothesis was postulated by Wright (1937) who remarked upon the supposed absence of drift in overflow channels. Wright concluded, from this negative evidence, that conditions during

the advance of the ice differed essentially from those under which the retreat took place. Wright supposed that there can have been little or no melt water associated with the advance. Moreover, it would appear that these conditions outlasted the maximum. The margin of the drift lies higher on the hills than the highest traces of glacial drainage, and such channels as are observable near the drift margin show by the feebleness of their development that melting only became active after retreat was initiated. Wright (1937) therefore concluded that glacial advance was, in most cases, dry. From the climatological and glaciological points of view, this assumption is unreasonable. Anderson noted this in his Presidential Address to the Yorkshire Geological Society in 1953. He attributed the initial cutting of the overflow channels to the ponding of water ahead of advancing ice. He supposed that the ice later overwhelmed the channels and plugged them with drift. During the retreat of the ice, melt water drainage again occupied these channels, but only perhaps half of the total infill, was removed before they were finally abandoned.

An alternative explanation postulates the excavation of the channels during two periods of retreat which were separated by a distinct glacial period. There is no evidence to show the magnitude or duration of the phase between the initial cutting of the channels and their later occupation by ice, but since most of the spillways which occur between 300 and 800 feet contain thick drift, it is necessary to assume widespread retreat in this area.

The "monoglacial" or "single-advance" interpretation of the channels poses two important difficulties. It will be remembered that the initial spill over the Magnesian Limestone ridge at Ferryhill occurred at an altitude of 420-430 feet above Ordnance Datum. This necessitates the presence of an ice-sheet in the northern part of the Wear basin, the surface of which rose to this altitude at least. The presence of such thick ice sheets in the lowlands might imply climatic conditions so severe that the supply of melt water available in summer would be inadequate for channel cutting. Nevertheless, if the hump-backed profiles, which are characteristic of many overflow channels, indicate the reversal of drainage demanded by Peel (1949), it may be necessary to invoke the presence of very thick lowland ice at some stage to account for this reversal.

The second argument against the monoglacial interpretation can be based upon the distribution of overflow channels in West Durham (Plate 24, Map Folder). It can be seen, from this map, that there are remarkably few channels south of the Browney valley. Those which occur in the south are only minor channels which show little sequential plan or alignment. The absence of melt water channels on the Dearness-Stockley Beck interfluvium suggests that no melt water reached the Wear valley from the north-west during the period when the ice-front lay south of Durham.

If Anderson is correct in supposing that overflow channels were cut ahead of advancing ice, it would be reasonable to suppose that the lower channels were cut first and replaced by higher channels as these were overridden by ice. During such an advance of Tyne Gap ice into the Middle Wear, it is reasonable to suppose that this ice-sheet would have already dammed the outlets of the northern dales before it reached the Wear valley. The eastward flow of melt water from the Alston Block would have thus been an early feature of the advance. As the ice advanced into the Middle Wear, all outlets to the east would be blocked and water would accumulate to the south of the ice-front. It is certain that the ice occupied the whole of the Middle Wear as far south as the Ferryhill-Westerton ridge and, indeed it is clear from the distribution of Criffel erratics, (Figs. 31, 32) that this ice penetrated the Tees lowlands. During the advance south of Durham, it would be reasonable to expect the development of marginal overflow channels south of the Browney valley. In fact, none can be recognised on the Browney-Deerness interfluvium to the east of the minor Stow House and Hamsteels channels (Plate 17, Map Folder) and none occur on the higher slopes of the Deerness-Stockley Beck interfluvium. The absence of such marginal channels suggests a cessation of melt water channel cutting along the margin of the ice long before it reached its maximum extent. There is no obvious reason why this should happen.

If, on the other hand, the orthodox interpretation is accepted and it is believed that the West Durham marginal overflow channels were only cut during a period of retreat, it is possible to account for their absence in the southern part of the plateau. If the glacial lakes along the northern fringes of the Alston Block only began to form after a definite amelioration of climate, it is reasonable to suppose that a considerable period might elapse before the waters accumulating in the northern dales made their first appearance in the Middle Wear. During this period, it is possible that the southern part of the Tyne Gap ice-sheet, severed, perhaps, where it crossed the Magnesian Limestone ridge, had retreated or thinned to the extent that when the melt water finally reached the Wear valley, there was no definite ice-front to the south of Durham which impinged upon the spurs of the West Durham plateau.

The present writer believes that the drift-infill of the overflow channels can only be explained by postulating excavation during retreat. It is believed that these channels were excavated during the retreat of one ice-sheet, were plugged with boulder clay during some subsequent re-advance and were re-occupied by melt water when the ice finally retreated. It is suggested that since the infilling material appears to consist of boulder clay which can be attributed to the Main (= Maximum) Glaciation and since the floor of the buried part of Ferryhill Gap lies far below the surface of the drifts

of the Skerne and Tees lowlands, it may be presumed that the initial cutting of the overflow channels antedates the Main Glaciation of Northern England. There is no evidence to show the total extent of the retreat which preceded the plugging of the channels. Since the majority of the spillways in the Wear valley show evidence of dual occupation by melt water, it must be supposed that this retreat was at least locally important. It is certain that the retreat which followed the Main Glaciation represented the final retreat of ice from the Durham lowlands.

It is clear that this interpretation of the dual occupation of the overflow channels demands many assumptions and conditions which cannot be proved. It is largely argued from the negative evidence that certain features are absent rather from positive recognition of a certain sequence of events. The foundations of such an argument are inevitably insecure when the processes and mechanics of melt water circulation and spillway formation are still uncertain.

The much simpler interpretation of Anderson is in some ways perhaps more attractive based as it is upon the single, perfectly reasonable, assumption that overflow channels can be cut by melt water ahead of advancing ice. But the abrupt termination of spillways south of the Browney, is, in the author's view, very much against this hypothesis.

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CHAPTER 9.

THE GLACIAL RETREAT FROM THE WEAR VALLEY
AND THE EVOLUTION OF THE LATE-GLACIAL SURFACES.

It has been shown, in Chapter 6, that the higher Pennines were never completely overwhelmed by ice. Although Raistrick (1931a) and Trotter (1929) suggested that Dwerryhouse (1902) had exaggerated the extent of ice-free land during the glacial maximum, most of their criticism concerned the western part of the Alston Block. The present research has largely confirmed the conclusions of Dwerryhouse concerning the extent of permanent ice in the Wear valley.

If there was ice-free land, there would be a certain amount of melt water present, although the quantity would decrease towards the glacial maximum and increase when the ice began to retreat. There is, however, some controversy about the possible amount of melt water available at the glacial maximum and about the possibility of whether glacial lakes persisted at this time.

Wright (1937) has argued from the feeble development of overflow channels near the drift margin that melt water was practically absent during the glacial maximum. Hollingworth (1952) has suggested, from the evidence of permanently frozen ground in North Yorkshire, that during the maximum glaciation, conditions were too severe for the seasonal release of abundant melt water. The present writer believes that these conditions are represented, on a small scale, in the South Orkney Islands, where, on Signy Island, the firm-line lies about 100 feet above sea-level. A number of small melt water lakes have developed below this altitude, but, owing to the short duration of the summer and the low mean temperatures of the summer months, the outflow from these ponds is restricted and the cutting of incipient overflow channels is negligible.

On the other hand, Kendall (1902) concluded that the principal glacial lakes of the Cleveland Hills persisted during the glacial maximum and that the principal melt water drainage channels were actively cut during the period when the lowlands ice-sheets rose to their greatest altitude round the North Yorkshire Moors. Linton (1950, 1952) has accepted Kendall's conclusions and has argued that the evidence of permanently frozen ground is not incompatible with a high snow line and abundant summer movement of melt water during the period of maximum encroachment by ice.

From the evidence of glacial retreat in Weardale, the author cannot agree with the latter conclusions. It has been shown, in Chapter 6, that the hills of Upper Weardale were never covered with permanent ice. The complete isolation

of the Weardale glacier has been confirmed by the present research. If it is argued that abundant melt water was derived from the ice-free slopes each summer, a certain proportion of this would flow into Upper Weardale and occupy the margins of the valley glacier. If the melt water was released in sufficient abundance, it would, presumably, escape eastwards, cutting marginal channels along the edge of the ice. There is no evidence that this occurred anywhere in the dale, for the high-level series of overflow channels shown on Ralstrick's map (Fig. 37) cannot be accepted by the present writer. It must be admitted that, if the conclusions of Chapter 5 can be accepted and it is agreed that the post-Glacial excavation of the River Wear has occurred almost everywhere along the northern edge of the drift, this erosion would have obliterated any marginal channels which were situated at lower altitudes. If this were true, there ought to be marginal channels on the southern side of the drift zone, also, but these cannot be recognised. If the drainage of melt water was sub-glacial, it would be reasonable to suppose that an esker would develop along some part of the valley. It has already been shown that there are virtually no fluvioglacial deposits in Weardale, certainly none which could correspond with an esker. The notion that abundant melt water was present in Weardale throughout the glacial maximum cannot therefore be accepted.

It is reasonable to suppose that a glacier with such a limited névé would respond more rapidly to climatic amelioration than the lowland ice-sheets. Consequently the Weardale glaciers might show signs of retreat before there was notable diminution in the size and thickness of the lowland ice. The retreat in Weardale may have been upstream, as Derryhouse (1902) supposed. Alternatively, the glacier may have retreated downstream, as Carruthers (1946) has suggested. The reason for supposing the latter is that there are no recognisable terminal moraines which might indicate pauses in the headward retreat of a diminishing valley glacier.

If, deglaciation spread from the slopes around the head of the valley, the cessation of firm accumulation and consequent diminution of the hydrostatic head would stop glacier movement. Thus the glacier would become stagnant and decay in situ. Such a process, according to Carruthers, would result in the separation of englacial dirt as shear clays. It has been shown, in Chapter 7 (Plate 24 Map Folder) that there is no trace of laminated clay upstream of Bishop Auckland and there is certainly none in Weardale. The second and graver objection to this hypothesis is that downstream retreat of the ice would favour the accumulation of melt water at the dale head. This would drain eastwards, but there are no marginal overflow channels anywhere in Weardale which indicate such drainage. It is possible to account satisfactorily for the absence of these

features only by assuming that the retreat of the valley glacier was upstream. Virtually continuous retreat without significant pause or readvance could account for the absence of recognisable terminal moraines in the hummocky boulder clay of Weardale.

The final retreat of ice-sheets from the Middle Wear can be interpreted with more certainty than the earlier stages of the glacial history.

It has been shown in Chapter 8, that the first phase of melt water flow at Ferryhill commenced through a wind-gap at a height of 430 feet. It will be remembered that the statistical investigations described in Chapter 3 showed the presence of a significant surface about this altitude. It was shown, in Chapter 4, that many of the summits and platforms at this altitude were gravel mounds associated with the overflow channels of the West Durham Plateau (Plate 18, Map Folder). It will be remembered that gravels occur above the present Ferryhill Channel at 430 feet also. These gravels are unconsolidated and undisturbed and could not survive glaciation. It is certain that the ice-sheets of the Main Glaciation covered the sites of these gravels for not only is drift present at similar altitudes in the vicinity, but the very channels which deposited these gravels were plugged with drift. Since these gravels occur at the height of the Ferryhill wind gap, it is necessary to assume that the original channel was plugged with drift at least to this level. If, however, this drift cover had exceeded an altitude of 440 feet in the Ferryhill channel, the latter would have been completely abandoned and later drainage would presumably have flowed over the Raisby-Garmonds way col.

It seems, therefore, that during the early stages of final retreat, the melt water lake of the Middle Wear occurred at a similar altitude to the lake formed during the first phase of melt water drainage. This repetition helps to explain why so many overflow channels, at all heights, show evidence of occupation on more than one occasion.

Below 400 feet, there are many hills of sand and gravel, especially in the area between Charlaw Moor and Beamish. Few show accordance to any level above the main group of sand-hills at 320 feet.

To the south of Shincliffe, there is a great expanse of the 320-foot surface which largely consists of thick boulder clay (Fig. 42). In Ferryhill Gap, as has been shown, the meander core at Swan House is graded to 320 feet and the infilling material of the former spillway occurs about the same altitude.

It is therefore suggested that the lake level, initially at 430 feet was lowered to 320 feet. The steep

sides of Ferryhill Gap suggest that this cutting was quickly accomplished and may, indeed, have been catastrophic. It appears there was a considerable period during which the lake level stood about this altitude. The quantity of the deltaic sands and the planation of the drift surface both suggest the persistence of a local base-level at this altitude. During this period, the retreat of the ice margin across the West Durham Plateau gave rise to a series of small glacial lakes in the tributary valleys. These have been described in detail by Anderson (1940). Thereafter, the equilibrium was upset and erosion of Ferryhill Gap continued below the 320-foot Surface. The lake level was lowered about 30 or 40 feet to about 290 feet by drainage southwards before Ferryhill Gap was abandoned in favour of some other outlet.

Between Ferryhill and Woughton-le-Spring, there is no place where melt water standing at 200 feet could escape through the Magnesian Limestone Plateau. Further north, there are two lower gaps in the Permian Escarpment. The first occurs between the villages of West Herrington and East Herrington. This rises to an altitude of about 270 feet and consists of a gentle-sided drift-filled depression. The second gap is occupied by the present course of the Lower Wear. In this breach, the distance between the 300-foot contours on Penshaw Hill and the Gateshead-Wrekenton Ridge is nearly three miles.

It has generally been accepted that the Lower Wear was initiated as a direct overflow channel through the latter gap and the River Wear has occupied this course ever since. As will be seen, later in this chapter, the present writer cannot accept this conclusion without certain reservations. It is possible that, when the ice had retreated north to Herrington, the melt water drained through this gap and, north of Silksworth, entered the large overflow channel known as Tunstall Hope, which leads towards the present coast at Lynhope. This idea supposes that the Herrington Gap was already in existence and was not completely blocked by drift, for this is only a difference of about 20 feet between the highest part of the Herrington Gap at 270 feet and the present intake of Ferryhill Gap at 290 feet. If the Herrington Gap was completely blocked with drift, it is unlikely that it could operate as the spillway which took the place of the abandoned Ferryhill Channel. Drainage through the Herrington Gap cannot be proved with the existing evidence and since the morphology of this valley does not resemble that of the typical overflow channel, it is more likely that the main diversion of melt water occurred when the ice front stood north of Penshaw Hill and a more adequate exit to the east had been exposed.

With the possible exception of the steep edge of the Magnesian Limestone Plateau between Penshaw and Offerton, there is, however, no morphological feature which can be recognised as the remnant of an overflow channel at the requisite



Fig. 42

The 320 foot Surface. View S.E. across the Wear Valley from Farewell Hall. (NZ/266,339). The wooded slopes of Shincliffe Wood rise to the 320 foot platform. The Magnesian Limestone Plateau forms skyline.

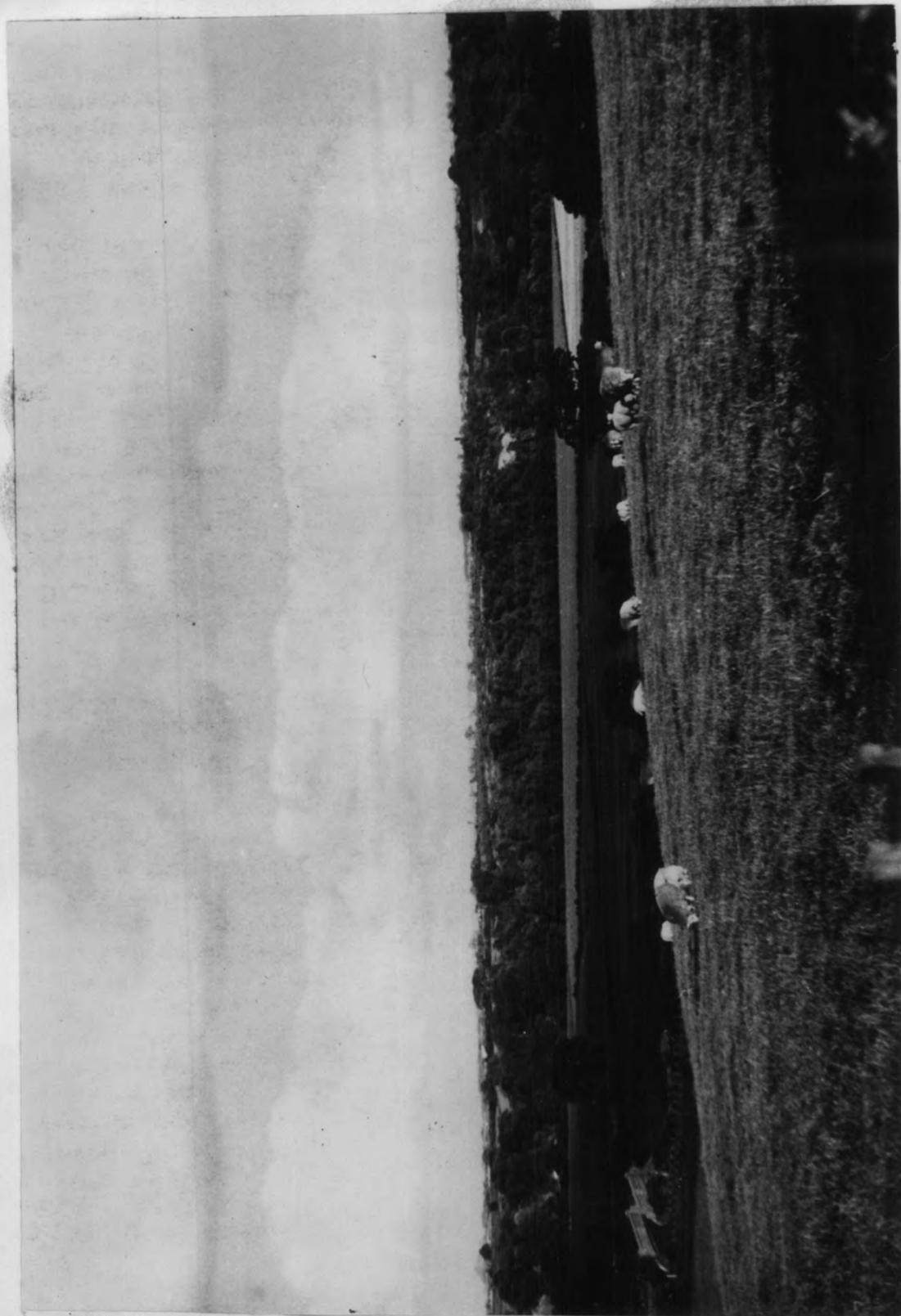


Fig. 43

The 190 foot surface. View S.E. from Cocken. (NZ/277,475)

height. The break of slope along this edge of the plateau rises to 400 feet above Ordnance Datum and generally exceeds 300 feet, so this cannot be regarded as one wall of a spillway which must have been initiated when the lake level stood about 290 feet.

It is not possible, therefore, to determine the later stages in the evolution of the Wear Lake from the evidence of overflow channels. It may be presumed that, if the ice-front retreated north of the Penshaw-Wrekenton Gap, the exposure of a greater extent of lowland to the east would cause considerable changes in the dimensions and level of the lake. It may be presumed that either the lake level would fall because the melt water would occupy a much larger area, or the lake would disappear altogether. At any rate, there are no remnant overflow channels corresponding with the initiation of the Wear lake drainage through the northern part of the Permian Escarpment towards its present mouth. This is not to say, however, that this initiation was not of this nature but merely that, if it was, the evidence of marginal drainage has not survived subsequent valley cutting and possible marine erosion.

One hundred feet below the final recognisable level of the lake in the Middle Wear, a second late-Glacial surface has been recognised. This has been termed the 190-foot Surface.

Anderson (1939a) originally recorded the presence of terraced gravels graded to 190 feet above Ordnance Datum in the valley of the Cong Burn (Plate 18, Map Folder) and he supposed that these were associated with the final stages in the drainage through the Tribley overflow channel. Later work in North East England showed that many other platform remnants could be recognised at this altitude. Anderson was able to show the presence of the 190-foot Surface throughout East Northumberland, in the Tyne valley, in the Middle Wear, the Tees-Leven lowlands and round the fringes of Lake Pickering. He further showed that platforms were developed at the same altitude in the drift deposits of the Vale of Eden, the Solway Lowlands and Northern Ireland. Anderson (1939a, 1939b, 1954) has argued that extensive development of remnants at such a constant altitude can only represent a surface of marine erosion. Since it is predominantly formed in lowlands covered with thick drift, this surface is clearly post-Glacial.

It was shown, in Chapter 7, that the laminated clays of the Middle Wear occur predominantly between the heights of 180 feet and 220 feet above Ordnance Datum. Orthodox interpretation of the clays would conclude that these were deposited in a melt water lake at this level. As shown in Chapter 7, the geographical distribution of the clays tends to favour such an interpretation; the lithology of the deposits favours Carruthers' opinion that they had englacial origin. It is possible, therefore, that the 190-foot Surface represents

the floor of the late-Glacial lake which developed after the abandonment of Ferryhill Gap. The remnants of this surface may have been created in part by the deposition of lacustrine clays, in part by erosion. This conclusion cannot bear careful analysis for three reasons.

(1) Although the laminated clays are exposed at this critical altitude, these do not represent the principal cover of the 190-foot Surface. The laminated clays are only thin and often the surface of the platform is composed of thick boulder clay or solid rock with a thin cap of drift.

(2) It has been shown, in Chapter 7, that whereas the 320-foot Surface is largely composed of deltaic sands, these are practically absent from the 190-foot Surface. Conversely, the laminated clays of the lower level do not normally occur at 320 feet. If both platforms had similar origin associated with a glacial lake level, it would be reasonable to suppose that the character of the deposits would be similar at both levels. It is certain that the 320-foot Surface represents the level of a late-Glacial lake and, for this reason, the absence of deltaic sands at 190 feet suggests that this platform had different origin.

(3) It is difficult to believe that lake waters could erode such an extensive surface, which is far from homogeneous in composition. The extent of this hypothetical lake must have been relatively limited for it would have been surrounded almost everywhere by hills which rise continuously above the 200-foot contour and the lengths of fetch would be so limited that wave action, alone, could not form the present surface. The only evidence of erosion by waves in a British glacial lake, which cannot be disputed, is the minor terracing of the sides of Glen Roy. There are no examples of extensive remnants comparable to the 190-foot Surface of the Middle Wear.

An alternative origin of the platform is that suggested by Anderson that this surface was formed by marine erosion during a late-Glacial marine transgression. If marine conditions are postulated, the laminated clays cannot be regarded as contemporaneous deposits, for, as Flint (1947) has shown, sea water would cause flocculation of the sediments which would then be deposited as a homogeneous mass. Without prejudice to the argument that the platform between 190 and 200 feet is well-developed throughout Northern England, the author is unable to accept a marine origin for the well-preserved fragments of the Middle Wear, for it is difficult to believe that wave action could be of importance in such an enclosed estuary.

The third possible explanation of the origin of the 190-foot Surface is that this platform, in the Middle Wear, represents the meander-trimmed floor of a valley graded to some level slightly below this height. Such an origin of the

surface is suggested by the incised meanders of the Middle Wear.

One of the principal features of the valley are the magnificent series of incised meanders which occupy gorges between Chester-le-Street and Bishop Auckland. (Plates 12, 13, 14 and 24, Map Folder; Fig. 26 etc.). These occur in four parts of the valley and are separated by reaches where the valley is straight or where the present river has developed a broad flood-plain. Certain of the tributary valleys also contain deeply incised gorges (Plates 16, 18 and 24, Map Folder; Fig. 26 etc). The principal breaks in the almost continuous gorges occur where the present valley coincides with the pre-Glacial valley.

In general, the whole of the Middle Wear north of Bishop Auckland shows a similar degree of incision into the drift surface, but it is only where the present valleys depart from the course of the buried valleys that this incision is spectacular. The reason can be clearly seen in the field. Where the present river has cut deeply into thick drift, the instability of the resultant slopes has tended to cause considerable landslips. There is no doubt that near Cocken Bridge (Plate 14), Kipper, High Houghall (Plate 13) Page Bank and Willington (Plate 12), the development of an open valley with a broad flood-plain has been greatly assisted by the inherent instability of one or both sides of the valley.

Near Sunderland Bridge (Plate 13, Map Folder) there is, however, a marked change in the trend of the valley. Above Sunderland Bridge, the valley is practically straight for more than four miles; below Sunderland Bridge there are considerable incised meanders.

If the valley sides are examined in this critical area (Plate 13, Map Folder), it will be seen that there is a break in slope which occurs at or near 200 feet above Ordnance Datum. This can be recognised above the gorge at Butterby, on the spurs south-east of Burn Hall and below Croxdale Point and in the Burn Hall gorge of the River Browney.

If the river is followed downstream, the principal break in slope above the incised meanders occurs at or slightly lower than the level of the 190-foot Surface. This may be seen at Durham, where the University Science Laboratories are situated upon a fragment of this platform and is most marked between Bradside and Finchale Priory (Plates 14 and 24, Map Folder, Fig. 43) where the 190-foot Surface is particularly well-developed.

Examination of the valley upstream of Sunderland Bridge confirms the continuity of the break in slope at higher levels. The break in slope above the broad flood-plain rises gradually to 265 feet at Willington (Plate 12, Map Folder; Section B, Fig. 28) where the well-developed shelf lies above the middle of the pre-Glacial valley. A little further upstream,

the break in slope above the highest gorge in the Middle Wear occurs at Hunwick Station and Nowfield at 280 feet. This is the height of Farnley Hill which lies in the core of this incised meander (Plate 12, Map Folder, Section D, Figs. 28, 44, 45, and 46). The flat-topped spur which lies at 300 feet between the River Wear and the gorge of the River Gaunless, upon which Auckland Castle is situated, and the shelf at 320 feet between Escomb and Witton Park (Plate 12, Map Folder) may, in part, constitute further remnants of this surface. At this critical altitude, however, further reconstruction becomes difficult owing to the presence of remnants of the 320-foot Surface which also occur in this area. Each of the features described lies almost exactly 80 feet above the present flood-plain. Below Durham, however, this relationship does not continue, for the gradient of the narrow flood-plain in the lower incised meanders is steeper than it is upstream (Plate 28, Map Folder). In consequence, the present flood-plain lies 120 feet or more below the 190-foot Surface where this is best developed around Finchale.

Between Durham and Chester-le-Street (Plate 14, Map Folder), the very presence of large sweeping meanders suggest that there is little doubt that the 190-foot Surface was formed by normal erosion and trimmed by the downstream migration of these meanders. The pattern of these meanders and the character of the broad, flat valley preserved here suggests the presence of a large river graded to a base-level at or near this height. The evidence elsewhere in Northern England, which has been accumulated by Anderson (1939a, 1954) leaves little doubt that there was a significant period when the regional base-level occurred about 190 feet above Ordnance Datum. Although it is not possible to show that marine transgression occurred in the Wear valley or that wave action could here have formed the platform remnants at this height, it is possible that elsewhere this widespread surface could have been formed, partly by marine erosion, partly by the development of large rivers graded to about 190 feet above Ordnance Datum.

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CHAPTER 10.

THE POST-GLACIAL EVOLUTION OF
THE RIVER WEAR.

The 190-foot Surface represents the highest and earliest platform which can definitely be attributed to normal erosion during the post-Glacial period. Although the drainage which formed this valley was initiated upon unconsolidated deposits and this valley was largely cut in the deltaic sands and glacial drifts of the Middle Wear, the magnitude and character of the valley floor both suggest that some considerable time may have elapsed between the final retreat of the ice and the negative change in base level which caused the rejuvenation and incision of the gorges. It is clear from the pattern of the meanders, that the rejuvenation was so rapid that, once the stream was incised into the 190-foot Surface, few modifications occurred.

This rapid incision explains the present departure of the present drainage from the pre-Glacial course north of Durham and answers the question of Hindson and Hopkins (1947) why the present river should prefer to excavate its valley through solid Coal Measure strata along a course which was parallel to a pre-existing trough which is deeper, broader and contains only unconsolidated material. The incision was, however, intermittent. It can be seen from Plates 13 and 16 (Map Folder) that the meanders are ingrown with marked slip-off slopes. Certain meanders have low cols developed at their necks. The significance of these will be described later. The initial depression of base level appears to have been only about fifty feet and was followed by a still-stand at approximately 140 feet above Ordnance Datum. This was followed, at some later period by a further negative movement of base level to about 100 feet above Ordnance Datum and thence, with further pauses, to the present sea-level.

The principal area of planation at 140 feet occurs on Boldon Flats, the large lowland area between the Tyne and Wear and east of the Gateshead-Wrekenton ridge. The predominant level in the western part of this area, near Usworth and Washington, occurs at 140 feet, but eastwards, the surface falls without perceptible break to a height of 90-100 feet in the vicinity of Hylton and Sunderland. The eastern boundary of the 140-foot Surface on Plate 24 (Map Folder) is misleading for although two separate facets may be recognised along the edge of the Lower Wear valley, the main lowland area gives no indication of any break in the continuity of a single surface.

Throughout its tidal course from Lambton to Sunderland, the Lower Wear flows in a steep-sided trough. The flood-plain is seldom more than fifty yards wide. The valley

sides are frequently composed of solid Coal Measures strata, overlain in the east by Permian rocks. The sides of the valley rise abruptly to about the 100-foot contour and about this level there is a marked break in slope. To the east, at Hylton and Sunderland, the well-defined platform above this break occurs at heights between 90 and 100 feet above Ordnance Datum. The altitude of the platform rises upstream to about 110 feet where this is exposed near Washington. In the east it forms a well-defined shelf; in the west, near Lambton Castle, the bench at 100 feet has almost disappeared and the principal break in slope occurs at about 140 feet. There are, however, two distinct facets attributable to these different platforms which shows that these are morphologically separate. The 100-foot Surface cannot be traced upstream from Lambton and there are only a few minor fragments of the 140-foot Surface which are confined to the part of the valley between Cocken and Chester-le-Street (Plate 24, Map Folder).

In general, this tidal portion of the river follows an almost straight course from Lambton to Sunderland. There is one incised meander just west of Hylton - the Hylton Gorge - and a second within the town of Sunderland. The surface at the neck of the Hylton meander occurs just below 100 feet and rises to 115-120 feet either side of this slight col. Seen from either direction; upstream from Claxheugh Rock or downstream from Washington, the continuity of the 100-foot Surface across the valley appears complete.

The discontinuity between the two surfaces and the evidence suggesting their marine origin has been supplied by the raised beaches and sea caves which were formerly exposed near Sunderland. These occurred on Fulwell Hill and Cleadon Hills, the isolated hills of Magnesian Limestone which rise from this otherwise featureless lowland.

The "sea caves" of Cleadon Hills which occurred at the level of the 140-foot Surface, were discovered during quarrying in 1877 and were subsequently destroyed. However these caves yielded important archaeological remains (this is the only English site where bones of the Great Auk have been found) and in consequence attracted a certain amount of contemporary attention. The caves have been described by Howse (1879) who attributed them to marine action. This interpretation has been accepted by Woolacott (1905, 1906, 1907 etc) Trechmann (1952) and Anderson (1954). Woolacott further showed that there were raised beaches at 140 feet on Tunstall Hills, and southwards to Daxton. Woolacott (1906) also recognised the 100-foot beach on Cleadon Hills and considered that it was represented at other exposures along the Durham coast. There is, therefore, little doubt about the origin of these surfaces. Nevertheless, a raised beach at 100 feet is not a significant feature of the Durham coast.

Although the cliff top frequently occurs at this altitude there is neither the uniformity or regularity which is usually associated with the "100-foot Raised Beach" of Scotland. It is possible, however, that the extremely rapid erosion of parts of the North Durham coast, which has been proved by the recent research of W.A. Westgate, may have removed all except isolated protected parts of this platform.

The Longitudinal Profile of the River Wear:

Certain of these post-Glacial changes in base-level can be recognised in the longitudinal profile and terrace sequence of the present river and its tributaries.

During the course of this work, the heights of the flood-plain and principal river terraces were determined by levelling. A continuous line of levels were surveyed from the tidal limit of the river near Lambton, to the foot of the waterfall at Burtreeford, near Cowshill, on the Killhope Burn. In addition, the profiles of the Middlehope Burn, the lower part of the River Browney and part of the Lumley Park Burn were measured accurately by level. Certain other tributaries have been surveyed by aneroid, but it was not possible to complete the height determination of the others in the time available for field-work. Details of the techniques which were employed are given in Appendix I.

For the construction of the longitudinal profile, (Plate 28, Map Folder), the horizontal distance has been measured along the middle of the flood-plain and through the incised gorges. The reason for this choice of abscissa has been to facilitate the plotting of river terraces according to their appropriate positions along the floor of the valley. The overall length of the river, measured this way, is 6.3 miles (11%) less than the hydrological distance measured along the middle of the present watercourse. On the longitudinal profile, the principal river terraces, the flood-plain and the "summer" (low water) water profiles have been plotted. The few gauge and floor records which have been examined have indicated that the present alluvium does, in fact, represent the flood-plain of the river as far downstream as Durham. This profile therefore represents the longitudinal profile of the river when it approximates most clearly to graded conditions in times of flood. Downstream of Durham, there is a divergence between the surface of the alluvium and the water which has probably been caused by human interference. In these lower parts of the valley, seasonal flooding now seldom approaches the surface of the alluvium.

The immediate conclusion which can be drawn from the longitudinal profile of the River Wear is that there are no important breaks in the curve upstream from Durham. There is a break in the flood-plain profile in the Finchale gorge which

occurs at a height of 80 feet above Ordnance Datum. The position and height of this break in gradient indicates that this must be a recent feature in the development of the valley and can probably be attributed to some stage in the changes in base-level between 100 feet and the present datum.

The profile in Weardale is, indeed, slightly irregular, but most of the irregularities can be attributed to lithological differences in the stream bed and few are present in the profile of the flood-plain. These irregularities only become significant in the upper part of the valley. In lower Weardale, where the river passes over the outcrops of the three resistant beds which have been shown to influence most frequently the topography of the valley sides. These are the Firestone Sill, the Great Limestone and the Whin Sill. None of these beds have any marked influence upon the present profile of the flood-plain. Of these resistant outcrops, only the Whin Sill, which outcrops just above the confluence of Stanhopeburn (B on Longitudinal Profile; Plate 28, Map Folder), shows any trace of a former gorge. At this site, the river banks, which are composed of dolerite, rise sheer from the water to a height of 20 or 30 feet. Associated with this constriction there are a number of small remnants of gravel terraces which cannot be related to the main cyclical terraces of the valley. It is obvious that this lithological barrier formerly represented an important break in the longitudinal profile of the upper Wear. The river has now cut through the dolerite and the present profile through the gorge shows no sign of its former irregularity.

An important difference between the upper valley of the Wear and those of the North Tyne and the Tees is the lack, in the Wear, of any marked change in valley form above some well-defined knick-point. In the North Tyne, Peel (1941) was able to show the presence of a knick-point near Redesmouth and has cogently argued that this may represent rejuvenation which, at Tynemouth, approximated to a negative change in base-level of 150 feet. If the broad upper valley of the North Tyne represents the valley excavated during the still-stand at 140 feet, there is nothing comparable which can be recognised in the Wear valley. The partial reconstruction of the valley graded to 190 feet, which was described in the last chapter, suggests that this may be the nearest approximation to the equivalent Wear. The longitudinal profile of the Tees has not been surveyed, but the marked contrasts in the valley forms of Upper Teesdale suggest the value of further research in this valley and the comparative study of the profiles of the three rivers.

Although certain of the tributary profiles have been measured, some with precision, it is not yet possible to draw adequate conclusions about certain of the breaks in profile which have been established. The tributaries of the Middle Wear; the Browney-Deerness system, the Croxdale Beck, Southburn

Dene and Lumley Park Burn all show breaks in profile which can reasonably be attributed to the changes in base-level which have occurred during the post-Glacial period. Thus, grading to the 100-foot Surface may be recognised in all these profiles and the tributaries downstream of Durham show evidence of grading to the lower surfaces. The tributaries of Weardale also show marked breaks in profile but the origin of these cannot be explained with the evidence which is available. Only half the Weardale tributaries have been surveyed and there is an important gap downstream of Stanhopeburn where none of the north bank tributaries have been measured. It has been shown, from the study of the buried valleys and from drift mapping in Weardale, that all these tributaries flow in beds which are certainly post-glacial in origin. It is not certain, however whether the "hang" of these tributaries above the Wear can be attributed to glacial erosion or whether these are composite breaks which reflect the several changes in base-level since the retreat of the ice. Most of these valleys can be reconstructed visually to show grading to a height between 75-150 feet above the present flood-plain of the River Wear. From the detailed levelling of the Middlehope Burn by the present writer, Bowes (1955) has calculated the theoretical continuation of the longitudinal profile of this stream and has shown that this north-bank tributary was probably graded to a level 83 feet above the alluvium at Westgate. On the other hand, Swinhopeburn, on the south side of the dale, appears to be graded to a much higher level than the Middlehopeburn, although these streams reach the Wear within 500 yards of one another. It appears, however, that the Swinhopeburn may be anomalous, for this is the only tributary valley in Weardale which is dammed by a terminal moraine. (Plate 9, Map Folder).

The River Terraces:

The height relationships of the principal river terraces are represented on Plate 28, (Map Folder) and the sites of the various terraces are shown on Plates 19-23 inclusive (Map Folder). The terraces are composed of coarse gravel with a certain amount of sand. During the course of the field-work, the composition of each terrace has been examined to show whether it represented a true river gravel terrace or whether it was a pseudo-terrace cut in glacial drift. In Weardale it is possible to distinguish the river gravels clearly, for there are no fluvio-glacial sands which might allow ambiguous interpretation. Further downstream, however, it has not always been possible to distinguish between true river gravel and the fluvio-glacial or deltaic sands and gravels which were deposited during glacial retreat. In the critical reach, between Witton-le-Wear and Bishop Auckland, the presence of both features at the same altitude causes uncertainty in the downstream reconstruction of the terraces.

The primary survey of H.M. Geological Survey recognised two separate terrace levels, but, on many of the six-inch sheets, these were not differentiated and a number of important outcrops of river gravel were not recognised. The present work has shown that these two terraces may be recognised as cyclical features of rejuvenation but there are also a large number of small remnants of gravel terraces which are non-cyclical in origin. These occur downstream of the minor gorges and where tributaries are confluent with the Wear. There may be a third, higher, terrace sequence above the two main "cyclical" terraces. In upper Weardale, where there is a certain amount of topographical evidence to support this supposition, none of the platforms have yielded true gravel. Further downstream, there are occasional gravel outcrops above the so-called Upper Terrace, but the remnants are too discontinuous and ill-preserved to permit reconstruction.

Paired terraces are exceptionally rare and, in general, the two significant terraces are only exposed on one side of the valley. This, in itself, suggests that the terraces were formed during the continuous excavation of the valley and are thus non-cyclical in origin. There is, however, one short reach of river, between Wolsingham and Frosterley, where both terraces are represented on both sides of the river. Detailed levelling of the remaining exposures has shown that the isolated terraces in the rest of the dale are probably continuous with these paired features and may, in consequence, be regarded as cyclical in origin.

The higher terrace, which is the most continuously exposed, can be recognised at the confluence of the Bedburn Beck and can be traced upstream through Weardale to Ireshopeburn. This will be termed the "Upper Terrace". The Upper Terrace can be recognised at Middle Blackdene, opposite St. John's Chapel, where the outcrops of the Five Yard Limestone and Scar Limestone form a series of rapids and small waterfalls in the present stream. The highest waterfall in the series occurs just below West Blackdene Bridge (A on Plate 28; Map Folder) between Ireshopeburn and Wearhead (Plate 9, Map Folder). Above these rapids, the Upper Terrace merges with the flood-plain of the present river.

The height relationship of the terrace edge to the flood-plain in different parts of the valley can be tabulated as follows :-

Table 11. Differences in Height between the Edge of the Upper Terrace and the Flood-Plain.

	Height of Terrace Edge.	Height of Flood-Plain.	Difference.
St. John's Chapel (Plate 9)	979	969	10
Daddyshield (" 9)	931	918	13
Cambo Keels	815	790	25
White House, Eastgate	754	725	29
Shittlehope, Stanhope	642	614	28
Rogerley Hall	614	577	37
Half-way House) N. Bank	537	505	32
Half-way House) S. Bank	552	504	28
Gallows Gate (Plate 10)	441	400	41
Bradley Hall (" 10)	409	387	22
Harperley Station (Plate 11)	387	360	27
Wadley Beck (Plate 11)	377	344	33
Bedburn Beck (" 11)	368	326	42

Downstream of the confluence of the Bedburn Beck (Plates 11, 23, Map Folder) precise correlation of the terrace remnants is not possible. At Witton-le-Wear, the supposed altitude of the terrace is about 320 feet above Ordnance Datum and, as is shown by the maps of Drift Deposits (Plates 21 and 23, Map Folder) there are sands at this altitude which can be attributed to deltaic accumulation in the late-Glacial lake.

The second, or "Lower" River Terrace lies approximately half-way between the Upper Terrace and the flood-plain. This can be traced from the paired terraces between Wolsingham and Frosterley as far upstream as Rogerley. Although a few equivalent terrace fragments can be recognised higher up the dale, these occur, without exception, where tributaries enter the Wear and cannot be regarded as cyclical terraces. The break in the present longitudinal profile, whence the Lower Terrace is derived, appears to occur at Rogerley, between Stanhope and Frosterley. (C. on Plate 28, Map Folder). The present river falls 38 feet in less than one mile whereas the alluvium falls less than 30 feet in the same distance. Below the small gorge thus formed by the river, a new flood-plain has developed and the higher alluvium is exposed, opposite Frosterley, as a river terrace.

The height of this terrace rises to about 15 feet above the present flood-plain as is shown in the following table :-

Table 12. Difference in Height between the Edge of the Lower Terrace and the Flood-Plain.

	Height of Terrace Edge.	Height of Flood-Plain.	Difference
Frosterley Bridge	572	566	6
Broadwood Bridge	544	533	11
Half-way House) North Bank	514	502	12
) South Bank	514	502	12
Holme Cottage	482	472	10
Gallows Gate (Plate 10)	413	401	12
Shipley Beck (" 11)	375	362	13
Witton-le-Wear (Plate 11)	308	297	11
Newton Cap, Bishop Auckland (Plate 12)	226	212	14
Farnley (Plate 12)	224	209	15

The last two examples of the Lower Terrace are situated in the Middle Wear and since these can be traced to the upper limit of the incised meanders, they provide some indication of the relationship between the incised meanders and the valley development of Weardale.

From Bishop Auckland, the present river flows northwards for about 1½ miles before it reaches the Farnley incised meander. It can be seen, from Plate 12 (Map Folder) that this stretch of river largely coincides with the buried valley and borings have shown that the principal infilling material is sand. The river sweeps round a horseshoe meander at Newton Cap Flatts and the eastward migration of the river during the formation of this meander has preserved a good example of the Lower Terrace on the western side of the valley. On the east bank just north of the present confluence of the River Gaunless and slightly higher than the terrace, there is a dry valley which trends northwards towards Bell Burn and completely isolates the hill of thick sand upon which Binchester Roman camp is situated. This dry valley has steep sides and a flat, boggy floor. In consequence it closely resembles a marginal overflow channel. However the floor of the valley, at its highest point, occurs at only 236 feet above Ordnance Datum so it clearly has no relation to the melt water drainage of the Wear valley.

The alignment of this valley with the post-Glacial gorge of the River Gaunless suggests that the Binchester Dry Valley represented the former course of the Gaunless to an earlier confluence with the Wear one mile further downstream. During the eastward swing of the Newton Cap meander, the river



Fig. 44

The Farnley Col. View N.W. from Binchester Crag (NZ/210,326)



Fig. 45

The Farnley Col. View East from Hunwick Station (NZ/201,327)

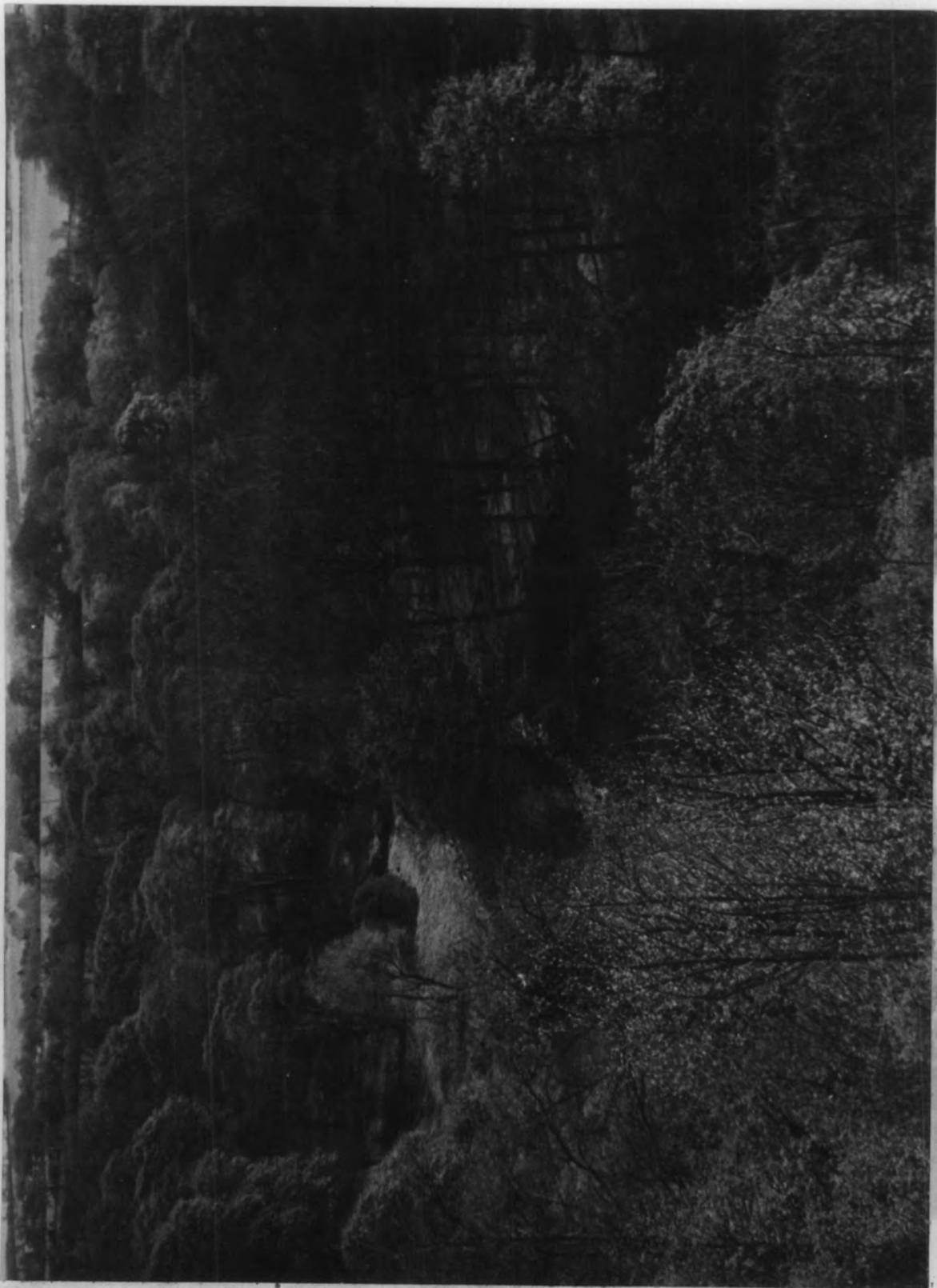


Fig. 46

The Farnley incised meander. View from North (NZ/208,332)

excavated the unconsolidated drift which forms the eastern side of the valley and probably captured the Gaunless by that rare process known as incision. It is suspected that the terrace fragments which have been recognised in the Gaunless valley may grade to the height of the Dry Valley, but since it has not been possible to determine the longitudinal profile of the Gaunless, this suggestion cannot be properly substantiated. To the north of the confluence of the Bell Burn, the present river enters the narrow and steep-sided gorge which lies between Farnley and Newfield. The essential topographical features are represented on Plate 12 (Map Folder) and Figures 44-47. The ridge between Hurwick Station and Farnley Hill falls from these extremities to a gentle smooth col some forty feet lower. The lowest point on the col occurs at 243 feet above Ordnance Datum. At this point, where a path has cut into the surface, there is a small exposure of loose coarse gravel. Farnley Farm is situated on a slip-off slope upstream of the gorge and a fine example of the Lower River Terrace is exposed here. This can be followed into the gorge and can be traced to the right-angled bend in the gorge just south of Newfield, where there is a magnificent terrace cut in solid rock and thinly covered with gravel (Fig. 47). A pair of terraces occur at 200-210 feet between Newfield and Rough Lea and although it is not possible to trace their continuity with the Farnley terrace, these occur at the appropriate altitude. The middle of the buried valley of the Wear appears to cross the Hurwick-Farnley ridge, slightly to the west of the col and the western part of the ridge is believed to be composed of thick drift. The gorge itself is entirely cut through solid Coal Measures strata and opencast borings on Farnley Hill and the Byers Green Hill to the east have shown that there is only a thin veneer of superficial deposits (Section D. Fig. 28). It cannot be shown that the Wear formerly flowed over the Farnley col, for it is impossible to explain how it could abandon this course in favour of the present route cut through a rocky gorge. It is clear, from the isolation of Farnley Hill that the river flowed round the eastern side of the hill for some time before it was incised into the present gorge.

There are four similar examples of incised meanders further downstream. These are at Butterby (Plate 13, Map Folder), Durham, Harbourhouse (Plate 14) and Hylton. The Hylton meander has already been described on p. 124.

The first three have certain features in common with the Farnley meander. Each is incised partly into solid Coal Measures strata, partly into drift. In each example, the neck of the meander occurs where the drift is thick and a low col has developed. The origin of all these meanders is clear, for the main break of slope, preserved where the meander is cut in the solid rock, shows that they had developed in the broad valley



Fig. 47

The Lower River Terrace
Farnley incised meander (NZ/209,331)



Fig. 48

The Flood-Plain of the Middle Wear near Chester-le-Street. Lumley Castle is in the background.

which graded to 190 feet and that they were incised into the floor of this valley. It is clear, however, that during the subsequent periods of still-stand, the combined processes of sapping with creep and wash have been able to reduce the unconsolidated deposits until the lower cols have been formed. This condition is best developed at Butterby (Plate 13, Map Folder) where it is clear that breaching of the low col and abandonment of the incised gorge was imminent when the artificial diversion of the river described by Griffiths (1932) was effected in 1811. The nocks of the other meanders have been less reduced, but all show a definite depression below the reconstructed valley floor of the 190-foot Surface, and a definite height relationship with the present flood-plain.

Thus at Farnley, the lowest part of the col, where the gravels are exposed, occurs 38 feet above the present flood-plain. At Butterby, the low hill which stands isolated on the valley floor and which is capped with gravelly soil, is also 38 feet above the floor-plain. Durham Market Place, which forms the neck of the third meander, lies about 30 or 40 feet above the flood-plain. No precise value can be given for either the flood-plain or the col at Durham for the presence of settlement here since Saxon times has probably modified the original surface considerably. The Harbourhouse col occurs at about 130 feet above Ordnance Datum and lies 80 feet above the flood-plain, but the change in gradient near Finchale prevents agreement with those examples further upstream. Downstream, however, the neck of the Hylton meander is situated at about the same height of 80 feet above the alluvium. The heights of the meander necks which occur upstream of Durham lie close to the supposed altitude where the Upper Terrace of Weardale might occur. Thus there are grounds for suggesting that correlation may be made between the Upper Terrace of Weardale and the 100-foot Platform of the lowlands of North East Durham which is clearly developed at the Hylton meander.

From the confluence of the Bedburn Beck, where the last certain exposure of the Upper Terrace is situated to the Hylton gorge is a distance of more than thirty miles. Within this distance, there are only four or five points upon which such correlation can be based. Two of these sites permit ambiguous interpretation, for the Harbourhouse col lies only five or ten feet lower than the supposed height at Durham and both of these lie close to the critical height of 140 feet above Ordnance Datum. For this reason, it is not possible, at this stage, to suppose more than a tentative correlation between the still-stand which deposited the higher river gravels of Weardale and that which modified the incised meanders of the Middle Wear.

This work has confirmed the conclusion of Anderson that there is evidence that, during the late-Glacial and post-Glacial periods, the local base-level successively stood at about 190 feet, 140 feet and 100 feet. This evidence is based



Fig. 49

Platform at 130-140 feet above O.D. formed in thick drift in the neck of Harbourhouse incised meander. View from North West. (NZ/280/482)

in part upon the recognition of platform remnants in the Lower Wear, in part upon the study of the incised meanders, in part upon the longitudinal profiles of the few lower tributaries which have been surveyed. Confirmation of the marine origin of the 140 foot and 100-foot surfaces is derived from the early discoveries of caves and raised beaches near Sunderland.

It may be possible to correlate the 100-foot Surface of the Lower Wear with the Upper Terraces of Weardale, but the evidence is inconclusive. It may be possible to correlate this platform with the 100-foot Raised Beach of North Britain, but such a study is beyond the scope of the present work.

It is not possible to trace the development of the Wear valley below the 100-foot Surface. The critical area at the mouth of the river is so built-up that little field-work is possible. The coastal evidence has been studied by W.A. Westgate and his conclusions will be available in due course. Thus, it is reasonable to suppose that the recent movement of base-level which have been recognised by Agar (1954) in the Tees estuary and Armstrong (1951) in the Lower Tyne probably affected the Wear Valley also.

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CHAPTER 11.

THE GEOMORPHOLOGY OF THE WEAR VALLEY.

Throughout the text of this thesis, the writer has attempted to show the possible origin of the present topography of the Wear Valley and to arrange the sequence of events in an approximate chronological order. It is desirable, at this stage, to summarize the principal conclusions and to suggest possible correlation with other parts of Britain in order thereby to establish a time-scale for the denudation chronology of the Wear Valley.

The Tertiary Evolution:

The interpretation of the Tertiary evolution of the Alston Block depends largely upon the interpretation of the structural movements. The author has shown that the Alston Block remained depressed relative to its surroundings during the greater part of the Mesozoic Era. Trotter (1929) has argued that there were two periods of fault-block uplift during the Tertiary. The present writer suggests that the evidence adduced to support this conclusion can be interpreted in another way. The present geological evidence favours only one phase of fault-block movement, but all the geomorphological studies have demanded that there were at least two periods of uplift during the Tertiary. It is possible, therefore, that the initial uplift of the Alston Block was part of the general movement which affected most of the British Isles during the early Tertiary and that this was followed, at a later date, by differential fault-block uplift. It has been shown that the Summit Surface of the Alston Block is truncated by the fault-scarps. For this reason, it is probable that this surface, with any higher (earlier?) remnants, have been differentially moved by fault-block movements.

For this reason, it is not possible to accept the conclusion of Linton (1951) that the higher summits of Cross Fell and Mickle Fell may represent fragments of the sub-Cenomanian Surface. Although these summits coincide closely with Linton's reconstruction of this surface, according to the available geological evidence, there appears to be no causal connection. The Carboniferous rocks, of which these summits are composed, were depressed at the time of the Cenomanian Transgression and were subsequently lifted relative to the neighbouring uplands which Linton used for the reconstruction of this surface.

Unless the present accordance of these higher hills with the sub-Cenomanian surface is to be regarded as coincidence, one is forced to conclude that the fault-block uplift of the Alston Block occurred earlier than the Cenomanian Transgression, or the highest upland surface of the British Isles is much younger than Upper Cretaceous. It has been shown that

it is only possible to date the later movements of the marginal faults as post-Triassic, so that there is no a priori objection to the first conclusion. There is, however, no orogenic period during the Mesozoic to which major faulting, on the scale of the Outer Pennine Fault can be attributed. The freshness of the marginal fault-scarps and the fact that these scarps truncate the Summit Surface further militate against such conclusion. On the other hand, the elimination of these two summits from Linton's regional analysis does not materially influence the validity of his reconstruction for the British Isles as a whole. Linton has cogently argued that no period of marine transgression other than this phase of the Upper Cretaceous could have covered the British Isles so completely.

¶ It is necessary to conclude, therefore, that the correspondence of the tops of Cross Fell and Mickie Fell with the supposed level of the sub-Cenomanian Surface is purely coincidental.

For the same structural reasons, it is unlikely that the Summit Surface of the Alston Block can be attributed to any recognisable phase in the Tertiary evolution of the rest of Britain. It is known that, in the eastern part of the Alston Block, the latest movement of the Butterknowle Fault amounted to a throw of some 800 feet and that the throw of the Stublick/Ninety-Fathom system increases from about 360 feet at Tynemouth to 1750 feet near Brampton. The throw of the Outer Pennine Fault cannot be determined, though Hickling and Robertson (1949) have suggested that it may be of the order of several thousand feet. For this reason, the total amount of displacement of the upland surfaces cannot be evaluated and no adjustment can be made for the amount of eastward tilting. Consequently, no altimetric correlation can be made with the upland surfaces of neighbouring areas.

The second surface which can be recognised with certainty - the 1000-foot Platform - is definitely later than the final phase of fault-block uplift. Not only is this surface recognised by Wright (1955) in those parts of Teesdale which lie south of the Butterknowle Fault, but, to the South-west of Bishop Auckland, in the Woodland-Butterknowle area of the Gaunless valley, this fault transgresses the platform without affecting the present surface. In addition, the great ridge of Magnesian Limestone which constitutes the Ferryhill-Westerton ridge, lies to the south of the Butterknowle Fault. The edge of this ridge is not a fault-scarp, for it lies on the downthrow side of the fault. It owes its origin to the preservation of Permian rocks on the southern side of this major disturbance. Where the Butterknowle Fault enters the East Durham Plateau, near Raisby, there is no sign of any discontinuity in the

surface of the plateau which can be attributed to faulting. It is possible, therefore, that some correlation may be made between the 1000-foot Surface and some platform which can be recognised elsewhere in Britain. Wright (1955) has argued that this surface is probably sub-aerial in origin and he has suggested that there are grounds for believing that this may represent the remnants of the mid-Tertiary peneplain which has been recognised elsewhere in Britain. The writer agrees with this conclusion, but must submit the reservation that, there is no direct evidence which can show the sub-aerial origin of this surface; it is the later dissection of the surface which appears to have been wholly sub-aerial.

The present writer cannot recognise the presence of Pliocene marine features on the West Durham Plateau or the Magnesian Limestone Escarpment. It has been shown that there is no real break in the continuity of the 1000-foot Platform above 780 feet and, indeed, a case has been put forward to suggest the sub-aerial origin of the plateau surfaces as low as 500 feet.

Below 500 feet, however, the pre-glacial evolution of the landscape is somewhat difficult to interpret on account of the thick accumulation of glacial drift and retreat deposits. It is possible, therefore, that there are lower pre-glacial benches which may be marine in origin. After all, it has been shown that in all probability, the glacial lake of the Middle Wear was a transient feature between 430 feet and 320 feet. Although the masses of gravel associated with the higher level of the lake could be deposited quickly by torrential streams flowing through the overflow channels, it is unlikely that the rock benches which also occur between 400 and 420 feet could have been eroded at the same time. There is, however, no adequate evidence of the length of the period ~~was shown~~ which elapsed, or of the processes which were involved, during the excavation of the Wear valley ^{between} the time of the capture at Bishop Auckland ^{and} the period when the pre-glacial river-system was graded to some level approaching - 130 or - 140 feet below Ordnance Datum.

It is probable that the greater part of the buried drainage system was excavated by running water, but the possibility of some glacial erosion cannot be denied. The difficulties of accounting for the origin of the overdeepened parts of the "Wash" have been discussed in Chapter 5. Although glacial erosion may provide the easiest explanation which can account for the apparent irregularities in the rock-floor. This process cannot account for the presence of thick sand in the most clearly defined and apparently isolated depression in the rock-floor.

It is certain that these buried valleys ante-

date the main period of glaciation in North-east England but it cannot be shown whether the final occupation by streams occurred before the first advance of ice or whether they were reoccupied during an interglacial period which occurred before the main glaciation. The denudation chronology of these valleys depends largely upon the conflicting evidence for one or several glacial periods in this area.

The Chronology of the Pleistocene in North-East England:

The author approaches this subject with a certain amount of apprehension, for the evidence accumulated during the course of this work is largely negative and it is hazardous to argue on the side of the heretics without any important positive contribution in favour of the monoglacial hypothesis.

As has been shown in Chapters 6 and 7, there is little evidence in the drift stratigraphy of North-east England which can support the conclusion that more than one period of true glaciation affected the area. The orthodox interpretation of the stratified drifts cannot adequately explain the remarkable preservation of undisturbed sands beneath boulder clay of supposedly later age. Carruthers has provided an explanation which can take account of this difficulty, but his Under-Melt Hypothesis inevitably poses the far greater problem of reconciling lithological evidence of a single glaciation with the considerable evidence for multiple glaciation which has been derived from a number of natural sciences.

It can be argued that, as in County Durham, many of the supposed interglacial deposits of Northern Britain may bear equivocal interpretation. In Durham, the only stratigraphical evidence which supports the conclusion that more than one period of true glaciation affected the area is that provided by two deposits on the present coast. Both the Easington Raised Beach and the loess-like deposit of Warren House Gill have been attributed by Trechmann (1952) to the interglacial period which elapsed between the arrival of the Scandinavian Drift and the subsequent glaciation by ice-sheets of British origin. The Easington Raised Beach may be interpreted as a post-Glacial feature which has been covered by recent movements in the drift cover near the edge of the present cliff. Recent discoveries, by officers of H.M. Geological Survey, of allied deposits at the same height, in the same area, may ultimately prove the post-Glacial origin of the feature. The loess of Warren House Gill cannot be re-examined owing to the dumping of colliery waste in this valley. It remains, therefore, the doubtful but only evidence of an interglacial period which occurred before the Main or Maximum Glaciation of North-east England.

It is possible to produce a strong argument that those fluctuations which produced the complex Pleistocene chronology of retreat-and-advance, erosion-and-aggradation along the margins of the ice-sheet in Southern England did not materially affect the extent of glaciation 250 miles further north. It might be argued that there was long-continued ice-cover in the Durham lowlands which might confirm the monoglacial interpretation of the drifts. However, not even Carruthers has postulated such long-continued glaciation in the north, for he has supposed that the single glaciation of lowland Britain occurred during the Saale and that the subsequent interglacial removed all traces of permanent ice. The principal argument derived from Carruthers' studies is that there was no re-advance of ice-sheets into the lowlands during any later stage of the Pleistocene.

The present work has largely confirmed the validity of Carruthers' observations in the area covered. Detailed examination of the laminated clays in the Middle Wear has confirmed the lithological objections to regarding these deposits as lacustrine varved clays and the present writer has shown that, on the whole, the morphological evidence cannot support the view that these clays were laid down in glacial lakes towards the end of the final retreat of the ice.

On the other hand, the evidence provided by the overflow channels on the West Durham Plateau and the absence of spillways in Weardale suggests that active cutting of these features was largely restricted to periods of glacial retreat. The study of the morphology of the overflow channels within the coalfield has shown that most of the channels were occupied by meltwater on at least two occasions and that, during the intervening period, the channels were plugged with glacial drift. It is not yet possible to show the magnitude of the episode which intervened between the first retreat and second advance of the ice. In the West Durham Plateau it was apparently significant, for most channels between the altitudes of 300 and 800 feet show evidence of drift-plugging. If it can be proved that overflow channels in widely separated areas show the same phenomena, it may be possible to postulate the intervention of interstadial or interglacial conditions during this period.

Following the retreat after maximum glaciation, the only deposit whose age and significance is beyond all doubt is that at Neasham Brick Works where the Elk skeleton was found. It is certain that the Elk skeleton can be dated to the Allerød (II) and Blackburn (1952) has proved the typical pollen succession from the Lower Dryas upwards. It is certain, from the lithology of the clays at Neasham, that open water was present during the Lower Dryas (I) and

and possibly during the Upper Dryas (III). Neither of these horizons is completely sterile and Blackburn (1952) has suggested the possibility of solifluction at this site during the Upper Dryas period. There is certainly no evidence to suppose that permanent ice was present in the Tees lowlands during the later phases of the last glaciation. This does not preclude the possibility of minor cirque glaciers in the uplands, such as Manley (1952) has suggested were present in the Lake District throughout these late-Glacial climatic fluctuations. In the Northern Pennines, however, the evidence of corrie glaciation is almost wholly lacking. None of the Weardale tributaries, not even Swinhopeburn which has a terminal moraine, have either the form or the sharpness of detail which would be characteristic of a cirque which might have contained a glacier as recently as 8900 B.C. The only basin in the Northern Pennines which can be regarded as a true cirque which is comparable to these of the Lake District is High Cup Gill (Figure 6, p.23), though it is possible that certain other re-entrants on the Pennine Escarpment may have had modification of their form by similar processes.

A different line of evidence is provided by the study of the post-Glacial platforms which have been described in Chapters 9 and 10. From the point of view of height relationship alone, the evidence is, to say the least, conflicting.

Miller (1938) has recognised a well-marked 200-foot Platform around the Irish Sea Basin, which, from the evidence near Dublin, he considered was formed by marine planation just before the onset of Quaternary glaciation. In South-east England, a well-marked platform at 200 feet has been recognised by Wooldridge and Linton (1939) who supposed that it ante-dated the maximum glaciation of East Anglia. This surface has therefore been considered to represent marine transgression during the first or Antepenultimate Interglacial and that it is, therefore, the British equivalent of the Milazzian shore-line of the Mediterranean. In Northern England, Anderson has recognised the 190-foot Platform extending from the Fifeshire coast to Lake Pickering on the east coast and from Antrim to the Carlisle Plain on the west coast. This surface is definitely post-Glacial with respect to North-east England and, from the evidence in the Solway Lowlands, this surface was formed later than that phase of glaciation known as the Scottish Readvance.

Anderson formerly attributed this phase of marine transgression to the "late-Glacial" or "post-Glacial" periods, as indeed can be abundantly proved, but, in recent years, Anderson has attempted correlation of this surface with the Milazzian shore-line of South-east England.

At the lower level, Anderson has recognised the 100-foot Surface of the Durham coast and correlated this northwards with the "post-Glacial" 100-foot Raised Beach of Scotland and with the Tyrrhenian (Penultimate Interglacial) terraces of the Thames and the Goodwood Raised Beach of the Sussex coast.

It seems clear to the writer that certain of these conclusions must be modified. It is necessary, in the first place, to conclude that if these surfaces, ~~are~~ of similar heights, are contemporaneous, there can have been little or no warping of the land since their formation. Thus arguments in favour of isostatic recovery of North Britain following deglaciation are unacceptable and the well-known researches of W.B. Wright must be ignored. Without prejudice to this initial objection, and if correlation of the 190-foot surface with the Milazzian be accepted, the only conclusion which can be derived from the study of the 190-foot Surface in Northern England is that the entire glaciation of the Border counties, including the Scottish Readvance, was completed before the Antepenultimate Interglacial. Not even the heretical opinion of Carruthers, that the single glaciation of Northern England occurred during the subsequent Saale, can, however, be related to this extreme hypothesis. It is clear, therefore, that in default of adequate stratigraphical evidence, the apparent altimetric accordance of these platforms must be regarded as a coincidence.

Although the 100-foot Surface of the Durham lowlands may possibly represent a southward continuation of the 100-foot Raised Beach, this cliff-top feature of the Durham coast cannot be regarded as morphologically similar to the true raised beaches of North Britain. It is, however equally unsatisfactory to equate these surfaces with the interglacial deposits of South-east England for the only feature which they have in common is their present relation to Ordnance Datum.

Nevertheless, it is surely unsound to ignore or lightly to discard these non-conformist heresies which have originated in Northern England in recent years. Carruthers and Anderson between them, have an unrivalled knowledge of the drift deposits of Northumberland and Durham. Raistrick, whose earlier writings largely formulated the present orthodox interpretation of the glaciation of North-East England, has abandoned those conclusions in favour of the monoglacial hypothesis of Carruthers.

No one who has worked upon geomorphological problems in this part of Britain could fail to be impressed by the enormous amount of normal erosion which has occurred

since the final retreat of the ice. The present writer has shown how the development of the 190-foot Surface of the Wear valley can reasonably be attributed to river action during the postglacial period. Although this valley was largely cut in drift, ^{development} ~~it~~ reached the stage where a large meandering river was flowing over a broad, flat valley floor. It is not yet possible to trace the floor of this valley into the upper part of the Wear valley but it is believed, though this cannot yet be substantiated, that the flood-plain development in the middle reaches of certain Weardale tributaries may represent surviving fragments of the drainage which graded to the 190-foot Surface. It is possible, too, that the upper North Tyne Valley may be related to this period also.

Following this important period of valley development, there have been the various phases of rejuvenation which produced the present incised meanders. The negative changes in base-level were interrupted, first by the development of the 140-foot Surface, later by the stillstand at or near 100 feet which may possibly be correlated with the Upper River Terrace of Weardale.

A possible minimum age of the Upper Terrace is provided by the recent discoveries of several large Mesolithic sites in the vicinity of Eastgate. These have been described by Fell and Hildyard (1953) to represent late Tardenoisian occupation.

Following the stillstand at 100-feet, there must have been further depression of the regional base-level and this may have culminated in the extreme depression during the early Boreal (Zones IV-VI) when the North Sea peats were deposited, and, as Agar (1954) has shown, the River Tees cut a gorge in the side of its pre-Glacial valley as low as -90 feet below Ordnance Datum. A similar post-Glacial gorge, of similar depth, has been recorded by Armstrong and Kell (1951) in the Tyne valley. None can yet be recognised in the Wear. This was followed by the transgression of the so-called Neolithic submergence and the gradual adjustment of sea-level to the present datum.

It is not possible to assess the speed at which erosion has proceeded in the Wear valley, for apart from the absence of an adequate chronology at any stage, varying conditions of climate and vegetation would make it difficult to assess the different phases of post-Glacial erosion. However, the post-Glacial denudation chronology, which has been described here, is so varied and so complex that it is almost impossible to evade the conclusion that normal erosion must have continued without interruption for a much longer

period than the length of the post-Glacial period as it is usually accepted for other parts of Britain.

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APPENDIX I.METHODS OF FIELD-WORK,
SURVEY AND COMPILATION.

The principal object of this research was to make a detailed study of the different aspects of the geomorphology of the Wear valley. As stated in the introduction, the original programme was modified to take account of other work in the area and partly curtailed by interruptions during two of the three summers which were available for field-work. Apart from the general field studies, it has been necessary to concentrate upon two types of detailed field-work:-

- 1) Examination of drift deposits where these are adequately exposed.
- 2) Additional surveying, particularly to increase the height information which is available upon published Ordnance Survey maps. It was soon found that the interpolated contours of the 1:25,000 Ordnance Survey maps were frequently unreliable and an attempt has been made to draw more satisfactory contours for certain selected parts of the valley. The recommendations of Peel(1949) were followed and modified to suit local conditions.

The published topographical maps available at the outset of this work were as follows :-

One-inch Ordnance Survey,	New Popular Edition, Full coverage.
1:25,000 Ordnance Survey,	Provisional Edition, " "
Six-inch Ordnance Survey,	Complete coverage for the 1921-1924 Edition. In 1952, only two or three sheets of the Provisional Edition(National Grid) Six-inch maps were available, but, during the course of this work, all the sheets in this area were published.
1:2,500 Ordnance Survey,	In the east, these were revised in 1937-1939. In the west of the county, plans dating from the 1921-1924 revision were available. Certain 1:2,500 plans for moorland areas have never been published.

The six-inch sheets and 1:2,500 plans of the eastern part of the county were revised and levelled between 1937 and 1939, but, in Weardale and the higher moors, there has been no revision of levelling since 1897, and there are few differences in detail between the new six-inch Ordnance Survey maps and those quarter sheets published more than thirty years ago.

A full set of all scales except the 1:2,500 plans were provided by the Geography Department. Photo-copies of a number of 1:2,500 plans of the coalfield were supplied by the National Coal Board.

Since the new grid-line six-inch sheets are awkward to handle in the field, the writer used the older quarter-sheets for all field-work. These were unsatisfactory in the neighbourhood of large towns where there has been much industrial and urban development since 1939. Elsewhere, however, there have been remarkably few changes in that detail which was recorded in the 1921-1924 revision.

H.M. Geological Survey have now revised a considerable part of the area. Sheet VI of the six-inch Geological Survey was published before the war, but publication of the remainder of the pre-war revision was postponed until 1955. During the period of writing this thesis, six-inch Geological Survey sheets, XIX and XXVI and parts of sheets XI, XII and XVIII have become available. At an early stage of this work, however, the author was able to examine the manuscript field slips and clean copies of all those parts which have been revised. It was also possible to discuss important aspects of interpretation of the structure with the individual field geologists who surveyed these sheets. Where revision is incomplete in East Durham and in upper Weardale, where no drift revision was attempted, the present writer has relied upon the primary mapping of the Geological Survey.

Most of the Wear drainage system has been photographed from the air by the R.A.F. The only important gap in the coverage of vertical photographs lies in the extreme south, in the Bedburn valley and the Wear valley between Witton-le-Wear and Escomb. Most of the photographs are available upon approximate scales of 1:25,000 and 1:10,000, though there are a few sorties in the urban areas which have a scale of 1:5,000. It was intended to use air photographs for photogrammetric work in Weardale and much of the surveying which was carried out during the first year of field-work was directed towards obtaining additional height control for this purpose. As will be shown later, many of these photographs are unsatisfactory for precise height determination.

In order to cover the large area in sufficient detail during the time available, the writer adopted a systematic method of field-work and examined each six-inch quarter-sheet in three stages :-

- i) I walked across each sheet, making a general examination of the area, and sketching slopes and breaks in slope. I made a superficial examination of all natural outcrops and of sections in quarries, sand pits, clay pits and opencast workings. I looked for all Ordnance Bench Marks shown on the latest revision of the sheet.
- ii) This was followed by detailed examination and measurement of critical sections of drift and river gravel, and the establishment, by plans table, of height control along the valley sides.
- iii) The final stage was to level along the flood plain and terraces to determine the long profile accurately. Approximate heights of the river surface have also been obtained. In certain tributary valleys, the long profile was measured by aneroid.

In detail, the routine examination of the country was varied according to the information available and the particular information required. Before starting field-work in any area, I attempted to compile the following information on each six-inch maps :-

- i) Additional Ordnance Survey spot heights from 1:2,500 plans.
- ii) Boundaries of alluvium, river terraces and glacial drift from the six-inch Geological Survey.
- iii) Sites of boreholes and areas of opencast prospecting.
- iv) Additional height information such as lines of levels measured by the Rural District Surveyor, or the County Surveyor.

This preliminary work, routine but vitally necessary, took up a considerable amount of my time during the first nine months of my research.

In the lower part of the valley, there is already considerable information about levels, which provided adequate height control without much further field work on my part. In addition to that published by the Ordnance Survey, surface levelling has been carried out by a number of surveyors for different purposes. The compilation of data obtained from

the County Surveyor, Water Board, National Coal Board and Opencast Executive, gave a network of spot heights which facilitated the drawing of 10-foot contours over many miles of the valley sides. Only the flood-plain of the river, the gorge between Chester-le-Street and Durham, and the floors of the tributary valleys required special measurement in the field.

In Weardale, most of the Ordnance Survey height control is confined to the river terraces, where the main road and villages lie, or to the hill tops. Above 1000 feet the contour interval is only 250 feet. Supplementary information is very scanty in rural areas. Throughout the dale I found it necessary to supplement the existing information with a considerable number of spot heights obtained by trigonometric methods or aneroid observation.

One of the principal objects of the field-work in the lower valley and along the fringe of the West Durham Plateau was to determine the limits of the buried valleys. As shown in Chapter 5, most of this work was done by studying mine plans and borehole schedules, but useful work was also done in the field. By mapping and height determination of the rock floor, where solid rock definitely outcrops at the surface, it was possible to supplement and confirm my interpretation of the borehole evidence. It was also necessary to measure the surface levels, or check the supposed heights of certain old shafts and borings.

In the lower valley much more time was necessary to examine and measure the complex drift associations. Examination of the drift in Weardale was a relatively simple matter, though here, the determination of drift boundaries has proved almost impossible.

SURVEYING METHODS.

On the six-inch topographical maps, there is generally enough detail to permit sketching of morphological detail on the field sheet by "lining-in" and without detailed instrumental measurement. On the moors, where the detailed information was less, it was necessary to fix the position of important features by plane-table resection, or by prismatic compass bearings. Some of the information has also been sketched on the field sheets from air photographs.

Almost all the detailed instrumental work has been to obtain adequate height control, whether for the drawing of profiles and contour interpolation, or to provide adequate height control for photogrammetric measurement. This has been done by trigonometric methods, by aneroid observations and by levelling.

TRIGONOMETRIC MEASUREMENTS.

Once I had established the existence of certain bench marks, I was able to make a series of one hundred or more observations from each station. I chose wall inter-sections and other features on the opposite side of the valley which were easily identifiable on the six-inch Ordnance Survey and on the air photographs rather than features of morphological interest. I used the plane table with a telescopic alidade. This instrument was admirable for this work. The high magnification of the telescope facilitated identification of the various objects. The accuracy of the instrument (the vernier has a least count of 1 minute of arc) allowed me to observe distances of 6000-7000 feet with confidence. Computations were made to one decimal of a foot and a small correction applied for curvature and refraction. Where possible I tried to obtain two or three observations, from different bench-marks, of the same object.

However, west of Frosterley, no bench-marks have been replaced since 1896, and at least half of those shown on the 1923 edition of the six-inch map have disappeared. Consequently I suffered many disappointments and could not obtain the continuous trigonometric height control which I should have liked.

ANEROID OBSERVATIONS.

Where bench-marks were lacking, or inconveniently placed, I tried to establish height control by aneroid traverses. The instrument used was a three inch mining aneroid made by Watts. Reading on the height scale is made by a vernier, which has a least count of two feet. With care, this instrument proved very useful. I made short traverses of generally less than one hour, between Ordnance bench-marks or spot heights and most of the results are satisfactory. I found that pacing aneroid traverses along walls required very little adjustment providing some control was available every half mile or so.

The first important series of aneroid traverses were made in June 1953, when a long period of calm, overcast weather provided ideal conditions for the use of this instrument. During this period, a large number of aneroid heights were determined on the hill sides between Wearhead and Greenfield Quarry. The detailed contours shown on Plate 8, (Map Folder) are largely based upon these aneroid observations. It was later possible to check the heights of 145 separate aneroid observations by trigonometric methods. ~~The frequency of the error in height is largely based upon the difference between the aneroid and trigonometric altitudes of these stations.~~

LEVELLING.

The route followed depended usually upon access to the flood plain and bench marks. Normally only one side of the river was levelled, but where paired terraces and other features occur on both banks, it was usually possible to include them all. Fortunately, with the exception of the gorges, there are plenty of bridges. All other things being equal, I chose easily identifiable places for staff and instrument positions, so that I could pick up these spot heights on air photographs or for further trigonometric work. Temporary bench marks were made by driving pegs into the ground, or by ~~making~~ choosing large stones, gate and fence posts which would not be moved during the period of this research.

for staff positions

Water surfaces are obtained every half mile or so. By starting and finishing with an observation on the water surface, it was possible to relate each day's levelling to the others and ultimately to gauge records on the river. This data is being studied by Miss E.M. Shaw.

In order to cover the distances in the time available, I modified the textbook methods of levelling to suit the work in hand. I made no attempt to equalize back and foresights because this would probably have doubled the number of staff and instrument stations. Individual sights were as much as 500 feet if the relief permitted, but more generally they were of the order of 300-400 feet. Three readings were always made, one on the centre hair and one each on the stadia hairs. Calculations of the mean of the stadia readings prevented gross errors in reading the centre hair, and it was possible to plot all spot heights by tachymetry. At each instrument station, the surrounding country was examined to see whether any identifiable object lay at the height of collimation. This was very useful for determining the height range of the flood plain or terrace at any particular place. At each instrument station I measured the height of the eyepiece above ground level for this gave an additional spot height.

Most lines of levels are tied to two different Ordnance bench-marks. I tried to obtain some control at least every two miles. The staff was read and the results computed to 0.01 feet, but the spot heights were only plotted to 0.1 feet on the long profile and to the nearest foot on the map. All levels above Belmont Viaduct have a closing error of less than 0.3 feet; those in the gorge, less than 0.5 feet.

It is important to emphasize, once more, that this work required assistance and could only be carried out when someone was prepared to help. During one period when I was unable to get any assistance, I attempted to level part of the flood

plain of the Middlehope Burn with a hand level and two 6-foot ranging poles. The results were perfectly satisfactory, but the method was too slow and laborious for practical application. I succeeded in completing rather less than one mile of very easy country in the course of a long summer day.

At the end of the field-season of 1953, it was clear that detailed levelling of all the Weardale tributaries was neither practicable nor desirable. It was thought that there would be enough height control in Upper Weardale to measure additional heights from air photographs, and that the longitudinal profiles of these streams could be based upon photogrammetry with aneroid control.

Several groups of photographs, were used and experimental measurements were made in those parts of the dale where the height control was readily intensive. For this purpose, a binocular stereoscope and parallax bar were used. Radial-line plots were made for each group of photographs. The readings of the parallax bar were consistent for any given point for both my supervisor and I obtained readings which agreed within 0.02 mm. However, it was not possible to obtain satisfactory heights from any of the experimental strips which were examined. It is believed that the tilt errors in individual photographs are considerable. It would have been possible to make proportional corrections for each pair of photographs, but since the adjustments would, in places, have exceeded 200 or 300 feet, it is unlikely that the corrected height could be accepted within 5 feet. There were many places in the tributary valleys where the height control was inadequate for all except the most reliable photographs.

It might have been possible to use the Multiplex Aeroprojector in the Department of Surveying, King's College, Newcastle-upon-Tyne. It was discovered, however, that the apparatus would not take the standard size of diapositives and it was found that neither Air Ministry, nor any other government department were prepared to supply diapositives of the appropriate photographs. For these reasons, it was only possible to use photogrammetric methods in those areas where there was already considerable height control and, for this reason, the value of the technique was restricted.

The failure of the photogrammetric measurements caused a certain re-organisation of the survey programme for the summer of 1954. It was necessary to complete as much work as possible in the field and to concentrate upon the determination of longitudinal profiles and spur sections rather than upon an overall coverage of trigonometric and aneroid altitudes. During this season, the flood plain levels of the River Wear were completed. The longitudinal profile of the Middlehope Burn, where Miss Shaw was measuring rainfall and run-off, was also determined by level. Further lines of levels were measured in the valleys of the River Browney and the Lumley

Park Burn. Most of the survey work was by aneroid, and, owing to the stormy summer, slow progress was made. It was possible to complete the longitudinal profiles of certain tributary valleys, but only about half of this work was completed. Moreover, certain of the aneroid traverses which were made during 1954 are much less reliable than those made in completely settled weather.

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APPENDIX II.

DEVELOPMENTS IN THE TECHNIQUE AND METHODOLOGY OF ALTIMETRIC
FREQUENCY SAMPLING.

The Altimetric Frequency method of sampling, proposed by Baulig (1935) has been used on many occasions to show accordance of summit levels within certain well-defined limits of altitude. In the original form, Baulig's method consisted of sampling the highest point per unit area of the county. The smaller the unit area, the greater the total number of samples and the closer the approach towards the form of the Area-Height curve, for this analysis, becomes, in effect, measurement of area by means of small squares. Hollingworth (1938) modified this form of analysis and confined himself to the selection of all summit levels within the tracts investigated. In the simplest form, therefore, Hollingworth's analysis consists of nothing more than a list of separate summits grouped in their order of magnitude.

Both methods show certain defects. In the 'Baulig Method', the highest point in any unit square does not necessarily represent a fragment of any erosion surface. All the main summits are recorded by this method, but the occasion may arise when a spur summit cannot be recorded because higher ground, above the spur, occurs within the same unit square. Certain squares will coincide with sides or floors of vales so that the altitudes of these units may have no relation to hill-top or other surfaces. These must be regarded as random errors in sampling which owe their origin to the arbitrary position of the boundaries of the unit squares. If the analysis can proceed as an objective exercise, these random errors must remain in the frequency curve. In practice, where the total area is large, the majority of these random errors occur at relatively low altitudes where total frequencies are large and where the addition or subtraction of a few units would not influence the form of the frequency curve. ~~In p^r~~ If objectivity is abandoned and those units which are obviously incorrect are eliminated, the stage is soon reached when there is uncertainty whether the highest point in a particular unit square represents a fragment of an erosion surface. If the process of elimination is carried to the logical conclusion, the point is reached when only the main summits are recorded in the frequency table. This approximates to the 'Hollingworth Method' of analysis. There are ~~two~~ notable defects in the 'Hollingworth Method'. First, the total number of summits is relatively small, so that errors in sampling and surveying may become significant. Secondly, one must take the fundamental assumption that all summits are of equal area. Each hill-top recorded in the analysis receives equal weight, irrespective of its size. Spurs are not recorded unless they happen to contain enclosed

contour. For this reason, the paradox arises that a deeply dissected spur or plateau surface, which happens to lie close to the altitude of an Ordnance Survey contour, will receive greater weight than a well-preserved feature which is not divided into a series of separate summits, or which is not recorded by the coarseness of the contour interval. Any attempt to include those spur features with unenclosed contours would introduce a high degree of subjectivity to the Hollingworth method of analysis.

A third type of sampling, carried out during the course of this research has been derived from the estimation of the surface height at each intersect of the grid used for the 'Baulig Method'. This experimental method is more crude, for it is a coarser sample, but it has the advantage of being more rapid than the 'Baulig Method'.

In this study of the Alston Block, one square kilometre of the National Grid has been regarded as unit area for the 'Baulig Method'. The boundaries of the tract has been selected from those National Grid lines which approximate most closely to the marginal faults of the Block. The coastline of Durham, from the Tyne to the Tees, forms the eastern boundary. The same limits have been used for all the methods of measurement and sampling described in this thesis with the exception of W.A. Westgate's analysis of the Magnesian Limestone Plateau (Fig.14, p.35). The boundaries are shown on Figures 10 and 11, pp 33 and 34. The total area of the Alston Block, thus defined, measured 1384 square miles. There are 3602 separate units for the 'Baulig Method' of altimetric frequency sampling.

Where the highest point lies between contours, the altitude has been estimated to the nearest ten feet with the aid of the interpolated contours of the 1:25,000 Ordnance Survey maps. Heights were initially grouped in ten-foot class intervals. Certain systematic errors are immediately apparent from the histogram plotted from these figures and these may be probably attributed to personal preference in estimation. It has been noted that, within each hundred-foot range of altitude, a significant minimum occurs in the ten-foot class interval 90-99 feet and, less consistently, in the class interval 40-49 feet. Similar errors were noted in the altimetric frequency analyses carried out by the present writer, in those of W.A. Westgate and in certain class exercises which were carried out by honours students under the supervision of the author. This feature is illustrated by the 20-foot groups (Curves A and D) which were adopted by W.A. Westgate in his analysis of East Durham (Fig.14, p.35). It can be seen that

that a definite minimum has been recorded just below each 100-foot contour and a definite maximum occurs just above each 100-foot contour.

To take account of these obvious personal errors, of possible errors in the interpolation of Ordnance Survey contours and the assumed irregularity of relict erosion surfaces, the altimetric frequencies must be grouped in some larger class interval than 10 feet. Various methods of grouping have been tried. Cumulative summations, representing the 20-, 40- and 50-foot groups of Hollingworth (1938) have been attempted and compared with simple grouping of the data into 20-, 30-, 40- and 50-foot class intervals. There is very little to choose between either method for the same group or class interval in each curve shows similar combinations of significant peaks and troughs at about the same altitude.

It was shown, in Chapter 3, that the hypsometric or altimetric frequency analysis which is based upon the horizontal datum of sea-level is, in a sense, unreal. If the Summit Surface of the Alston Block represents one or more erosion surfaces which were subsequently tilted, it may be presumed that irregularities upon this surface may be masked by the regional slope of the tilted tract. It is therefore desirable to study the upland surface with respect to some sloping surface rather than Ordnance Datum. Such an analysis is fraught with difficulties. It is not possible to determine, by any simple method, the angle of regional tilt, which probably differs from the hill-top profiles, which may differ from the regional dip of the data and which almost certainly varies between different parts of the tract. In addition, once this imaginary surface has been established, it is necessary to relate every part of the present surface to this new and variable datum. Since a full analysis of this sort would be extremely laborious it is doubtful whether the potential value of the results could justify the method. It is, however, possible to make certain approximations which may serve equally well. It has been shown, in Chapter 3, that analyses of restricted areas within the tract may eliminate the overall effect of regional slope and that it is possible to recognise certain features which might otherwise be overlooked. If this technique is applied to the whole tract and the altimetric frequency figures are adjusted to a local datum, the resultant curve for the whole tract, based upon variable data might indicate significant features which are hidden by the regional slope.

It was thought that, if the tract was sub-divided into units of 25 square kilometres, the mean or median value of the highest points in each 5-Km block might provide the series of data. If, at the same time, the residuals of each

unit were measured, the standard deviation could be computed for each block. This analysis is a modification of that carried out by Jones (1952) in his study of the drainage of Wales.

It was found, in practice, that the calculation of mean heights and standard deviation involved more time in computation than could be spared. For this reason, the median height was obtained and the semi-interquartile range extracted as a measure of dispersion.

This work was not completed, for it represented a digression from the main research programme, but it was not abandoned until values had been obtained for most of the upland tract of the Alston Block. The median values were plotted in the centre of the appropriate 5-Km square and isopleths drawn relative to these points show a similar, but more regular pattern than the Generalized Contours. The degree of dissection, as shown by the semi-interquartile range, varied less with absolute height than with the location of a particular square. Thus, the 5-Km Square (530-535 N; 365-370 E), which contains both the summit of Cross Fell and the Pennine Fault-scarp, has a median height of 1960 feet and the enormous semi-interquartile range of 537 feet. On the other hand, the 5-Km square which is situated on the best-preserved part of the 1000-foot Platform near Saltergate (540-545 N; 405-410 E) has a median height of 1130 feet and a semi-interquartile range of only 52 feet.

A method of assessing the degree of gross dissection has been based upon the 'Baulig Method' of altimetric frequency analysis. In addition to recording the altitude of the highest point in each kilometre square, the lowest height was also recorded. From this data, the height range within each unit square may be obtained. This data may be used in two ways:-

It may be used to obtain approximate mean values of the height of each unit and thus provide a rough hypsometric figure of the tract without the labour of planimeter measurements, or alternatively, the range of height per unit area may be used directly to give an indication of the degree of dissection in different parts of the area.

Both applications are largely experimental and the conclusions are of methodological interest rather than of practical application to the present research. If the altimetric frequency of average height per square kilometre is tabulated and plotted as a cumulative frequency curve, the resultant figure approximates closely to the true hypsometric figure. Although this method is,

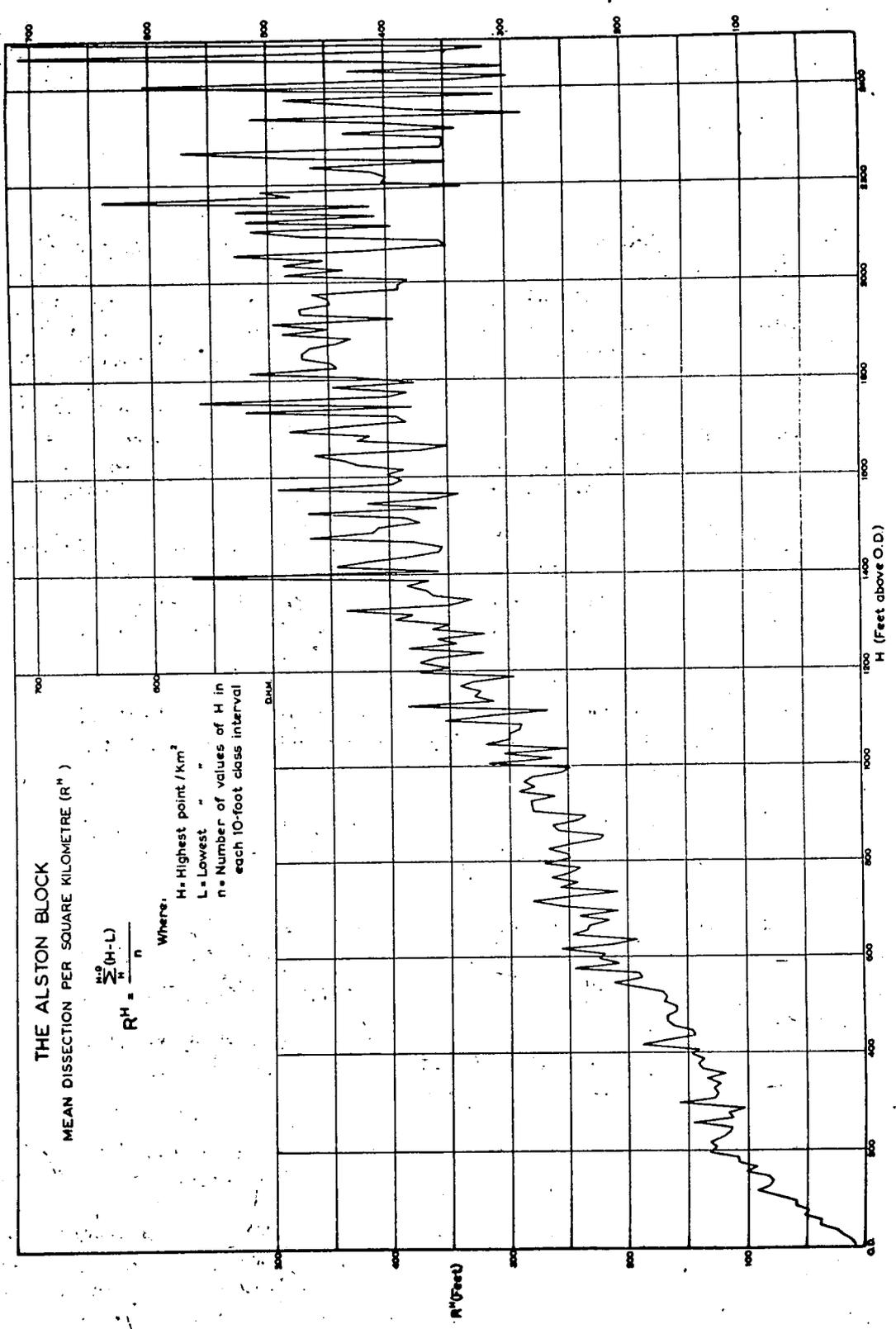


Figure 50.

at best, only an approximation, experimental use of the different techniques suggests that this method is no more laborious and no less inaccurate than the method of sampling by measurement proposed by Miller (1953).

The principal weakness in the method lies in the basic assumption that the slope of the present surface is uniform within the area of the unit square. If the slope is not uniform, a mean which is obtained from the extremes of altitude will be an unreliable indicator of the average height of the unit area. This data can also be used to ascertain the degree of dissection in different places and at different altitudes. The height range may be plotted directly in the form of the Specific Relief map of Wright (1955). This can give a graphic illustration of the amount of dissection in any part of a tract of varied relief.

Alternatively, the data may be so assembled that it is possible to assess the average gross dissection at any given altitude. The curve illustrated in Figure 50 was obtained from the altimetric frequency data in the following way:-

- 1) The values for the highest and the lowest points per square kilometre were extracted from the topographical maps.
- 2) The values for the highest points per square kilometre were grouped in 10-foot class intervals. This value represents H.
- 3) For each kilometre square, the total range in height was obtained. These values were grouped according to the 10-foot class of the highest point.
- 4) The mean value of the range was obtained from these several values in each 10-foot class. This value represents RM.
- 5) The values of RM were plotted against the height of their appropriate class interval (H).

This curve shows two obvious features. These are the increase in dissection with altitude and the greater variability of dissection with increase of height. The second feature may be influenced by the variations in the total frequency in any class interval such as is illustrated by the simple Altimetric Frequency Curve. It is not yet possible to explain the significance of the step-like rise

of the smoothed curve below 1000 feet or the tendency for mean dissection to decrease above 2000 feet. By itself, this curve, is, perhaps, of limited value. It would be of greater value for comparison with curves based upon the relief of other parts of the British Isles, or, within the Alston Block itself, it would be useful to make similar analyses of smaller areas for comparison with one another.

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APPENDIX III.

INDEX OF PLACE NAMES USED IN TEXT, WITH NATIONAL GRID

CO-ORDINATES.

ACTON DENE NZ/217,528	BRASSIDE NZ/ 290,450
AUCKLAND CASTLE NZ/214,302	BROOM HILL NZ/294,360
BARNARD CASTLE NZ/05,17	BROOM HILL NZ/241,425
BEACON HILL NZ/440,453	BROUGH NY/79,15
BEARPARK NZ/24,43	BROWN FELL NY/587,565
BELDON CLEUGH NY/92,50	BRUSSLETON NZ/204,250
BILLINGHAM NZ/46,22	BURN HALL NZ/261,387
BILLING HILLS NY/949,375	BURN HILL NZ/065,452
BINCHESTER NZ/209,313	BURNOPFIELD NZ/17,57
BINCHESTER BLOCKS NZ/230,320	BURTREEFORD NY/854,405
BIRTLEY NZ/27,56	CAMBO KEELS NY/934,384
BISHOP AUCKLAND NZ/21,30	CARDUNNETH PIKE NY/565,521
BLACK HILL NY/873,411	CASSOP NZ/340,380
BLACKTON HEAD NZ/01,26	CASTLE CARROCK NY/543,553
BOLDON NZ/36,61	CAULDRON SNOUT NY/814,286
BOLTSEBURN MINE NY/937,427	CAUSEY ARCH INN NZ/207,563
BRADBURY CARRS NZ/33,30	CAUSEY GILL NZ/204,561
BRADLEY HALL NZ/109,362	"CAUSEY RIDGE" or
BRAMPTON NY/53,61	"CAUSEY MORAINÉ" NZ/20,55
BRANDON NZ/232,402	CHARLAW MOOR NZ/22,48

CHARTERSHAUGH NZ/309,535
CHATTERLEY NZ/076,359
CHESTER MOOR NZ/27,49
CHESTER-LE-STREET NZ/27,51
CHESTER-LE-STREET CRICKET
GROUND NZ/277,509
CHILTON NZ/304,312
CLAY SLACK NZ/226,531
CLEADON HILLS NZ/39,64
CLEVISON CURRICK NY/839,431
CLOUGH DENE NZ/174,552
COATHAM STOB NZ/402,162
COCKEN NZ/281,472
COLD FELL NY/606,557
CORBRIDGE NY/99,64
COUNDON NZ/24,30
COWHORSE HILL NY/818,422
COWSHILL NY/856,406
CRAWLEYSIDE NY/993,402
CRONKLEY FELL NY/84,29
CROOK NZ/16,36
CROSS FELL NY/687,344
CROXDALE POINT NZ/279,386
CULLERCOATS NZ/36,71
DADDRYSHIELD NY/894,379
DAWDON NZ/42,49

DUNSTON-ON-TYNE NZ/23,62
EASINGTON NZ/42,43
EAST DIPTON NY/9659
EASTGATE NY/953,387
EAST HERRINGTON NZ/36,53
EDEN HILL NZ/227,527
EDMONDSLEY NZ/237,490
EGGLESTON NZ/00,24
ESCOMB NZ/190,302
FARNLEY HILL NZ/207,329
FAWSIDE DENE NZ/216,504
FATFIELD ~~NXX/KX~~ NZ/31,54
FENCE HOUSES BRICK WORKS
NZ/308,504
FERRYHILL NZ/29,33
FERRYHILL GAP NZ/303,320
FINCHALE BRICK WORKS NZ/288,459
FINCHALE PRIORY NZ/297,472
FINDON HILL NZ/245,466
FROSTERLEY NZ/03,37
FULWELL HILL NZ/39,60
GALLOWS GATE NZ/098,366
GARMONDSWAY NZ/34,34
GRANGE HILL NZ/235,293
GREAT DUN FELL NY/710,322
GREAT LUMLEY NZ/29,49

GREENFIELD QUARRY NY/851,420	HUNWICK STATION NZ/199,326
GREENFOOT QUARRY NY/982,391	HYLTON NZ/35,57
GROVE RAKE NY/895,440	HYLTON GORGE NZ/346,562
HALEWAY HOUSE NZ/052,370	IRESHOPEBURN NY/867,386
HAMSTEELS NZ/174,449	JARROW NZ/33,65
HANDEN HOWL NZ/232,532	JOB'S HILL NZ/174,351
HARBOURHOUSE NZ/283,483	JUBILEE BRIDGE NZ/209,343
HARGILL HILL NZ/15,33	KEPIER NZ/283,433
HARPERLEY STATION NZ/117,347	KIBBLESWORTH NZ/24,57
HARRATON COLLIERY NZ/290,538	KILLHOPE LAW NY/919,448
HEDLEY HALL NZ/222,561	KNITSLEY See HOWN'S GILL
HEIGHT'S PASTURE NY/93,39	KNITSLEY FELL NZ/10,34
HELLHOLE NZ/21,54	LAMBTON CASTLE NZ/298,526
HELME PARK NZ/126,368	LAMESLEY NZ/253,580
HIGH CUP GILL NY/74,25	LANGLEY MOOR NZ/253,407
HIGH HOUGHALL NZ/279,396	LIMEKILN GILL NZ/477,382
HIGH TWIZELL NZ/222,526	LINDISFARN NZ/080,462
HOLME COTTAGE NZ/065,368	LINTZFORD - NZ/150,572
HOUGHALL COLLIERY NZ/282,406	LITTLE DUN FELL NY/705,330
HOUGHTON-LE-SIDE NZ/223,218	LITTLETOWN NZ/339,433
HOUGHTON-LE-SPRING NZ/34,50	LONGBURN FORD NZ/072,447
HOWDEN-ON-TYNE NZ/33,66	LOUD HILL NZ/157,517
HOW GILL NY/571,549	LUMLEY CASTLE NZ/287,511
HOWN'S GILL NZ/10,49	LUMLEY HAUGHS NZ/283,515

MAIDEN LAW NZ/173,497
MAINSFORTH COLLIERY NZ/307,315
MAINSFORTH HALL NZ/314,314
MARLEY HILL NZ/210,574
MARSDEN NZ/40,65
METAL BRIDGE NZ/300,350
MICKLE FELL NY/806,245
MIDDLE BLACKDENE NY/877,386
MIDGEHOLME NY/64,59
MOORHEN STONE NY/841,435
NABLE HILL NZ/310,313
NEASHAM NZ/334,105
NEWFIELD NZ/206,335
NEWTON CAP COLLIERY NZ/203,308
NEWTON CAP FLATTS NZ/208,306
NEWTON GRANGE NZ/278,457
OFFERTON NZ/344,553
OLD DURHAM COLLIERY NZ/293,416
OUTBERRY PLAIN NY/94,33
OXPASTURE HILL NZ/198,552
PAGE BANK NZ/233,356
PELTON FELL NZ/24,53
PENSHAW NZ/33,54
PENSHAW HILL NZ/334,543
PITHOUSE FELL NZ/21,40
PITTINGTON NZ/33,45
PITY ME NZ/266,456
PLAWSWORTH NZ/265,480
POCKERLEY HILLS NZ/227,550
PONTOP FELL NZ/150,528
POPPET HILL NY/956,423
QUARRY HILL NY/991,379
QUEBEC NZ/180,437
RAINTON NZ/33,47
RAISEY NZ/35,35
RAVENSWORTH CASTLE NZ/232,591
REDGATE HEAD NZ/090,382
RED ROSE COTTAGE NZ/278,504
REDWELL HILLS NZ/133,520
RODDYMOOR COLLIERY NZ/152,363
ROGERLEY HALL NZ/018,372
ROGERLEY INTAKE NZ/027,380
ROSE HILLS NZ/225,530
ROUGH LEA COLLIERY NZ/194,334
ROWLEY BURN NZ/172,421
RYHOPE NZ/41,53
SACRISTON NZ/24,47
St. JOHN'S CHAPEL NY/885,380
SALTERSGATE NZ/077,426
SHARNBERRY GILL NZ/00,31
SHERBURN HILL NZ/34,42
SHILDON NZ/23,27

SHINCLIFFE NZ/290,406

SHITTLEHOPE NZ/003,384

SHITTLEHOPE EDGE NZ/010,385

SILKSWORTH NZ/38,53

SMITHY DENE NZ/245,495

SPENNYMOOR NZ/25,33

STANHOPE NZ/00,39

STANDAGAINST ALL NZ/194,472

STOW HOUSE NZ/137,426

SUNDERLAND BRIDGE NZ/265,377

SWAN HOUSE NZ/304,323

TANFIELD LEA NZ/19,55

TARNMONATH FELL NY/586,545

TEAM COLLIERY NZ/266,579

TEAM VALLEY TRADING ESTATE

BORING NZ/245,605

THINFORD CLOSE NZ/302,348

THORNBOROUGH NZ/008,645

THRISLINGTON NZ/307,334

TINDALE FELL NY/61,57

TOW LAW NZ/12,39

TRIBLEY NZ/240,510

USWORTH NZ/31,58

WADLEY BECK NZ/127,332

WALDRIDGE FELL NZ/25,50

WARCOP FELL NY/78,20

WARDEN LAW NZ/370,506

WARREN HOUSE GILL NZ/447,424

WASHINGTON NZ/32,56

WEARHEAD NY/858,395

WEST AUCKLAND NZ/18,26

WEST BLACKDENE NY/867,391

WEST BUTSFIELD NZ/102,450

WESTERTON NZ/240,310

WESTGATE NY/91,38

WEST HERRINGTON NZ/35,53

WHITBURN NZ/41,62

WHANGDON HILL NZ/440,341

WHITEHALL MOSS NZ/07,46

WHITE HOUSE (EASTGATE) NY/960,38

WILLINGTON NZ/20,35

WITTON-LE-WEAR NZ/15,31

WITTON PARK NZ/17,30

WOLSINGHAM NZ/08,37

WREKENTON NZ/27,59

