# The Morphological Evolution of Clydesdale and Its Neighbouring Regions

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List of papers submitted by Mei-Nge Jen for Ph.D. in science

(1) The Morphological Evolution of Clydesdale and Its Neighbouring Regions

(2) Illustrations to "The Morphological Evolution of Clydesdale and its Neighbouring Regions"

(3) Maps and Diagrams for "The Morphological Evolution of Clydesdale and Its Neighbouring Regions" ( Enclosed in separated roll)

(4) On the Meander-terraces of Middle Clydesdale

# Foreword

The object of the present work is to elucidate the stages in the physiographic evolution of the Clyde Area. Evidences are advanced to show that the region has undergone five stages of morphological development. The existence of five erosion surfaces in the region is demonstrated by morphometrical analysis, river profiles and field observations. The distribution and disposition of the surfaces are shown in a morphological map. Detailed analysis of boring records has been made to elucidate the effect of drift on the erosion surfaces. Finally, the origin and age of the surfaces are discussed and their correlation with other regions attempted. The paper is illustrated with 17 maps and diagrams and 33 photographs by the author.

The writer wishes to take this opportunity to thank Mr. A. Stevens of the Glasgow University for his valuable guidance and help in the research. Thanks must also be given to Dr. M. Macgreggor and Dr. J.G.C. Anderson of the H.M. Geological Survey for their help in compiling boring records at the writer's disposal and to Prof. A.G. Ogilvie and Mr. D.L. Linton of the Edinburgh University for their kind demonstration of the new method of profile projection.

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# THE MORPHOLOGICAL EVOLUTION OF CLYDESDALE AND ITS NEIGHBOURING REGIONS.

## Chapter I Problems and Implications in the Study of Erosion Surfaces.

Recent morphological study has offered many interesting problems and revealed a number of fascinating fields for investigation among which the study of morphology of erosion surfaces is perhaps one of the most interesting in itself and in its implications. In the last century, research in geomorphology was chiefly directed towards the explanation of land forms as influenced by geological structure. Only during the last ten years has greater emphasis been laid on the study of morphology as the evolutionary history of a region.

In older writings the mountains of Scotland and Wales were regarded as having arisen by long and continued denudation acting upon very ancient rocks at high elevations within these areas. It is now universally recognized that repeated changes of levels have occurred which have left sufficient evidences to enable us to distinguish successive cycles of erosion. It is evident that the more recent the cycle, the better is the evidence of its processes preserved. Therefore erosional history naturally lays special stress on geologically recent times and its study reveals the last and the most important, but often entirely missing, chapter of the geological history of a region.

In the investigation of erosion surfaces, a number of difficulties are encountered. In the first place, the higher erosion surfaces as preserved in the form of high platforms or terraces have often suffered considerable dissection and modification with the result that their remnants can only be traced here and there in a fragmentary way. It is often difficult to determine these fragmentary terraces by any simple method of map study; therefore recourse has to be made to more delicate method of morphometrical analysis to show the indication of their existence.

Moreover, erosional platforms or terraces, especially those of subaerial origin, must be expected to possess some slope or gradient which,though small in amount, will lead to a significant difference of level if terraces extend for a considerable distance. Wooldridge has given 15 to 20 feet per mile as the average gradient of the Diestian platform of the London Basin. (1) It is evident that if any terrace with such gradient extends for a distance of over ten or twenty miles, the remnants of the same terrace may occur at considerably different altitudes according to their appropriate positions. Moreover, in the case of sub-

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(1) S.W. Wooldridge, The Pliocene History of the London Basin, Proc. Geol. Assoc., vol. 38, pp. 49-132, 1927.

aerial terraces, their altitudes also differ according to their respective positions with regard to the main river which moulded them. In the region to be considered, which extends for about 42 miles from north to south and 26 miles from east to west, remnants of terraces belonging to the same stage may be traced longitudinally for over ten miles and are consequently of different altitudes. For example, remnants of terraces belonging to the 1200 foot stage were traced from the Upper Daer Water to near Lesmahagow for a distance of over 19 miles as the crow flies and their altitude decreases from 1362 to 1017 feet.

Morphometrical analysis consists essentially in special studies on maps. As the maps, while indispensible for morphological research, are incomplete in their indications, certain methods have been devised by which their testimony can be supplemented, rendered clearer, or translated into other terms. During recent years, growing attention has been paid by geographers to morphometrical analysis and a number of methods is now available for such research. While most students employ only one method to demonstrate or prove the existence of platforms, in view of the difficulties enumerated above, it is unlikely that any single statistical method would be sufficient or satisfactory. In studying surfaces of such fragmentary nature and with such an appreciable gradient, confirmative evidence can be obtained only through careful comparison and mutual checking of the results of different methods of morphometrical analysis. As the field of morphometrical analysis has been up to the present but little explored, it seems desirable that a detailed account should be made of implications and limitaions 'of these methods.

## Chapter II General Characteristics of Geology and Topography of the Region

The region under consideration includes the Clyde basin between its headwaters and Bothwell and the upper parts of Tweedesdale and Annandale. It lies within the Ordnance 1 inch sheet 79, the western part of sheet 73 and eastern part of sheet 84. The total area is about 880 sq. miles.

Topographically, the region may be broadly divided into two parts: in the headwaters of the Clyde, Tweed and Annan, the ground is largely mountainous with only narrow plains along the valleys of larger streams. Here mountains generally rise above 1200 feet in height but it is only towards the waterpartings that higher mountains of over 2000 feet are encountered. While these mountains sometimes rise steeply from the river valleys, they are usually broad and rounded at the top which is often covered with thick peat. The Tinto Hills may be taken as separating a hilly region in the south from broad level plains to the north. North of the Tinto Hills, the ground is not so intensively dissected as the hilly region on the south and consequently it consists of a series of broad and level plains usually below 1000 feet in height.

Geologically, the region is divided into two unequal halves by one of the greatest faults in Scotland, the Southern Upland Fault, which traverses the Clyde valley from Lamington to Roberton in a south-westerly direction. North west of the Fault, the region constitutes essentially of Old Red Sandstone and Carboniferous formations, the latter being generally arranged in complex synclines. Igneous sheets and intrusions of the Old Red Sandstone and Carboniferous age are frequently met with and cause considerable variety in landscape. But solid rocks are usually mantled by superficial deposits, as the region is essentially one of glacial accumulation. South-east of the Southern Upland Fault, the ground is formed largely by strongly folded greywackes, shales and conglomerates of Ordovician and Silurian age, with the exception of a small patch of New Red Sandstone along the Annan Valley near Moffat. Generally speaking, in the mountainous area the glacial deposits become relatively thin and insignificant, the boulder clay being limited chiefly to valleys.

## Chapter III  Methods of Morphometrical Analysis and their Limitations

The morphometrical analysis aims at demonstrating the accordance of summit levels and the existence of definite breaks of slope at the inner and outer margins of these levels which furnish the main evidence for the presence of erosion platforms. Broadly speaking, methods of morphometrical analysis may be grouped under three categories: profile projection, construction of altimetric curves and compilation of hypsographic and clinographic curves.

In the present investigation, all these three methods were included and the popular edition of the 1 inch Ordnance maps was used as the basis for analysis. As the value of the results of this study depends primarily on the certainty with which fragments of erosion surfaces can be identified on maps, it seems advisable that before going into the details of different methods, the common limitation imposed by the nature of the maps available should be first discussed so that the results of morphometrical analysis may be correctly interpreted. On the 1 inch Ordnance maps, for the ground below 1000 feet, the hundred foot contours were actually surveyed while the 50 foot contours were obtained by interpolation. Above 1000 feet, contours were surveyed only at the intervals of 250 feet and all other contours were obtained by interpolation. According to the Ordnance Survey, the limit of error in the surveyed contours is about 10 feet and for the interpolated contours, it must naturally be of greater amount. Regarding the error in interpolated levels, it is estimated by the same authority that in some cases where the spot levels are few, error may develop between the surveyed contours to the extent of from 5 to 10 feet in altitude. From these estimates, it may be said that the error of the maps is probably less in amount than that associated with morphometrical methods.

Clydesdale is largely a region of glacial accumulation and as will be shown later, the average thickness of superficial deposits may amount to 20 or 30 feet. Therefore the total aggregate uncertainty in regard to elevation of any erosion surface may be as high as 50 feet. Under these circumstances, it may be illegitimate to separate surfaces by a vertical interval of less than 100 feet on the evidence of map study alone. Therefore, it is proposed in this study to employ 150 feet as the criterion on which to distinguish surfaces from the evidence of morphometrical analysis.

(1) Profile projection The purpose of profile projection may be summarized as assembling of heights; for

by bringing together different summits into one picture, it provides one an easy means for depicting the accordance of summit levels, breaks of slope between different surfaces and other important features. Various kinds of profile projection have been suggested, among which Barrell's projected profile (1) and Fridley's superposed transparency profile (2) are the best known and have been adopted by some British students with considerable success. Although they are comparatively satisfactory, a number of defects present themselves. In a projected profile, it is evident that the base-line profile in the foreground may considerably obscure a number of summits behind and moreover, a projected profile being at most only a very generalized picture of the region is of little use for the construction of the morphological map which constitutes the principal aim of the morphological research. As to the superposed profile, since it is constructed by superposition of a number of sections drawn at regular intervals from the map, it can be readily seen that the section lines may happen to cross the middle slopes of spur-terminations

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(1) J. Barrell, The Piedmont Terraces of the Northern Appalachians, Amer. Jour. Sci., 4th ser. vol. 49, pp. 227-58, 1920

(2) H.M. Fridley, Identification of Erosion Surfaces in South Central New York, Jour. Geol., vol. 37, pp. 113-34, 1929.

with the result that many false summits necessarily appear on the profile which may present a false picture of the ground.

A modification of Barrell's method of projected profiles was introduced by Prof. Johnson which is the one that has been finally adopted in the present research. This method includes the construction of a composite skyline profile for each strip of country of two miles wide from the 1 inch maps according to the process described elsewhere. (3) Plottings were made of the greatest heights in the two miles vertical strip at the horizontal intervals of one tenth of a mile (1/10 inch) and these plottings were then joined together to form composite skyline profiles which were drawn both in N-S and E-W directions. Each profile therefore presents an assembly of heights from a strip of ground two miles wide. In the present study, the profiles were prepared to the horizontal scale of 1 inch to a mile and the vertical scale was 10.56 times exaggerated. These profiles have advantage over the pro-

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(3) For the details of methods of preparing composite skyline profiles, see H. Fleet, A Morphometric Analysis of the Grampian Highlands, Ph.D. Thesis in Edinburgh University, 1936.

jected or superposed profile in, that they enable one to examine two miles strips of the country in succession and provide an easy means for recognizing the remnants of platforms. In addition, the drawback of plotting false summits in profiles is eliminated by constant comparison with profiles drawn in perpendicular directions. Moreover, like the ordinary profiles, they can be projected or superposed to form projected or superposed composite skyline profiles. An example of the projected composite skyline profile is shown in Fig. 1.

Horizontal sections drawn along the main watersheds of the region may be also useful since the watersheds constitute the part of the country that has suffered least subsequent denudation. The profiles so drawn are called crestline profiles and often depict in a remarkable manner accordance of summits.

(2) Altimetric curves  This method of morphometrical analysis was elaborated by H. Baulig and applied with some success in France. (4) In Baulig's curves based on French maps, only spot heights were employed, but it has been held that these can not be taken from British maps

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(4) H. Baulig, Le Plateau Central de la France, pp. 563-74, 1928.

for such a purpose as spot heights are not evenly distributed in the 1 inch Ordnance maps. In the present study, all actual summits as encircled by contours were included. Since Clydesdale and its neighbouring region have been considerably glaciated, summits for this purpose possess an additional advantage over spot heights that on the summits drift deposits are usually thin or absent and errors due to thickness of drift are thus reduced.

In the present research, altimetric curves were constructed for the one inch maps No. 73, 79 and 84. The construction was done by purely mechanical means according to Dr. Hollingworth's method as described in his recent paper. (5) All actual summits were ascertained within each 10 feet of altitude so that the total number of summits in each ten feet can be counted. In the case of closed contours each encircling a hill top on which no summit level is indicated, height was assumed at 25 feet above the closed contour and the case specially noted as belonging to a group of heights less certainly determined and called the X-group. In the grouping of results, the 50 feet grouping at each 50 foot contour and at each 25 foot contour between was adopted as it was found to be the

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(5) S.E. Hollingworth, The Recognition and Correlation of High-level Erosion Surfaces in Britain: A Statistical Study, <u>Quart. Jour. Geol. Soc.</u>, vol. 94, pp. 55-84, 1938.

most suitable for representing the results. For hilltops of the X-group, it was assumed that half of them were above the 25 foot and another half below the 25 foot.

It should be clearly understood that the altimetric curve does not in any way present the actual proportions of area in different altimetric zones. But by bringing together all summits into one diagram, it gives a clear representation of the frequency of occurrence of summits. A maximum in the curve shows a greater frequency of occurrence of summits at that level and may indicate an accordance of summit level and the presence of a level platform.

In the interpretation of altimetric curves, certain limitations may be noted. The method is most suitable for use in regions where the range of altitude over individual platforms is small which is specially the case for platforms of marine abrasion. In such cases, the maxima and minima in the curve may be expected to be few in number but sharp and distinct. But for platforms of subaerial denudation with an appreciable gradient as in the region under consideration, it is obvious that maxima are often too numerous to give definite indications of individual terraces. In studying surfaces of this kind, no single statistical method is likely to be satisfactory.

From the study of altimetric curves alone, there is always a tendency to recognize too many surfaces. Hence careful consideration should be taken with regard to limits in vertical and horizontal coordinates of the curves. In the present study, 150 feet was taken as the limit for vertical difference (plotted on horizontal axis) and on vertical axis ten points was taken as the limit. That is to say that no maximum was considered significant unless it was separated by minima of over ten points below it and unless it was separated from the neighbouring maxima by an interval of 150 feet or more.

(3) Hypsographic and clinographic curves The classic hypsographic curve of A. Penck shows the relative proportion of different altimetric zones. It is in fact a curve smoothed by plotting cumulatively the percentage of areas between two levels against the means of these levels. Indications of the occurrence of platforms may be found in sharp breaks in the smoothness of the resulting curve, since the hypsographic curve for an area undergoing uninterrupted denudation is presumed to be of a regular form. In fact, however, the curve so constructed usually fails to indicate the platforms with any clarity as the altitudes of points of inflexion are often difficult to determine precisely. Especially in higher altitudes where remnants of platforms are only represented by scattered summits of small areal extent, the effect of smooth-

ing is entirely to obliterate irregularities in the curve. In order to meet this defect, an unsmoothed curve was constructed in which the actual percentage of area within different altimetric zones was plotted against the mean altitudes. A maximum in this curve indicates flattening of the ground, at the corresponding altitude and the possible occurrence of a level platform. A comparison of the ordinary hypsographic curve with this modified curve clearly demonstrates the distinct advantage for the present purpose of the latter over the former especially in higher altitudes. ( cp. Fig. 2 and 3)

Another curve of a similar nature is called clinographic curve in which the average gradient between any two available contours is given. The data required for it are exactly the same as for the hypsographic curve and its method of construction has been described elsewhere. (6) Usually the values of average gradients as expressed by angles are plotted in the diagram with the aid of a protractor. In the case of Clydesdale, from the Ordnance 1 inch sheet 79 and the western part of sheet 73, it was found that the difference in angles was often too small to be sufficiently well shown by the clinographic curve drawn according to the ordinary method. Hence, a special

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(6) Hanson-Lowe, The Clinographic Curve, Geol. Mag. vol. 72, pp. 180-83, 1935.

method of plotting the clinographic curve was adopted in which angles of average gradient between any two levels were plotted against the means of these levels. It was found that the resulting curve gave a clearer expression of the results. A minimum in the curve indicates a decrease of average gradient at the corresponding level and suggests the existence of a platform. ( Fig. 4)

In this connection, a point regarding the accuracy of the hypsographic and clinographic curves may be noted. The construction of the hypsographic and clinographic curves involves error in the measurement of area between different contours. In the present study, area was measured by means of squared paper superposed on the 1 inch maps and counting the number of squares at each 50 foot intervals of altitude. The results thus obtained were found to be fairly accurate as the aggregate measured area differs in only less than 3% with the actual total area in question. Although this error is not so considerable in amount as Baulig supposed, yet it is well to bear in mind that hypsographic and clinographic curves were not constructed with the same accuracy as profiles and altimetric curves.

Chapter IV Interpretation of Results

The results obtained by applying the foregoing methods of investigation may now be summarized and interpreted. In composite skyline profiles, five major surfaces are clearly recognizable at 1800, 1500, 1200, 700 and 300 feet, separated from each other by steep slopes. Profiles a, b and c in Fig. 5 may be taken as the representative of each area. In profile a, the 300 foot surface is seen sloping gently to the Clyde valley from about 400 feet to 200 feet while a higher surface at 650-750 feet is also distinctive on the southern corner of the profile. In profile b, the 700, 1200, 1500 and 1800 foot surfaces can be distinguished at their usual altitudes. In profile c, the 1800 and 300 foot surfaces are clearly shown, the 700 foot surface extends in a wide area from 950 feet to 750 feet, but remnants of the 1200 and 1500 foot surfaces are too small in this profile for identification. In addition, a minor level surface can be seen at about 500 feet above sea level.

The existence of these surfaces is more clearly demonstrated in the projected composite skyline profile. Fig. 1 is such a profile of the 1 inch map No. 79 in which five major surfaces except the lowest one can be readily distinguished. If we draw parallel lines across the profile at 750, 1150, 1500 and 1800 feet, it can be seen that most of the summits falls within 50 feet on either side of the lines. The accordance of summits is thus clearly demonstrated.

It may be argued that composite skyline profiles are but general pictures of the country and do not represent actual sections on the ground. But the same surfaces are also presented on the crestline profiles drawn along the main watersheds of the region. In Fig. 6 and 7, the perfect smooth 1800 foot surface is clearly shown and separated from the gently undulating 1500 foot surface by steep slopes of about 200 feet per mile.

The separation of the five major erosion surfaces is further confirmed by the construction of altimetric, hypsographic and clinographic curves. As has been explained in Chapter III, for the terraces with an appreciable gradient, no single statistical method is likely to be satisfactory. Besides, it must be admitted that the conclusion derived from these curves depends a good deal upon correct interpretation. However, the general coincidence of the results may be noted. In Fig. 5, three altimetric curves are shown, representing part of the 1 inch sheet 73, the whole 1 inch sheet 79 and part of the 1 inch sheet 84 and are indicated as curves a, b and c. The data of curves a, b and c are compiled together to construct the combined curve d which is also shown in Fig. 5. In curve a, a distinct surface at 300-350 feet is clearly shown; maxima occur at 525, 625 and 725 feet and correspond to the 700 foot surface which slopes down to about 550 feet in Lower Clydesdale. In curve b, the 700 foot surface is singularly clear. Maxima occur at 1025, 1150 and 1250 feet showing that the 1200 foot surface in this area slopes from 1250 feet down to about 1050 feet in some places. The 1500 foot surface is shown by two distinct maxima at 1425 and 1525 feet which represent approximately its range of height, while the 1800 foot surface is evident from the clear maximum at 1750-1800 feet. The indication given by curve c on the occurrence of the erosion surfaces is on the whole very clear, showing surfaces at 250-300 ft, 1250-1300 ft, 1500-1550 ft and 1750-1800 ft with small range of altitude. However, the 700 foot surface is here represented by a series of maxima from 750 to 1000 feet which corresponds to the condition of the ground as also revealed by the profile c in Fig. 5. In curve d which is a combination of curves a, b and c, the 1800, 1500, 700 and 300 foot surfaces are shown by clear-cut maxima at their corresponding altitudes separated by deep minima on both sides. The 1200 foot surface is not so well indicated on the curve d but this is due to the fact that in curve b, the 1200 foot surface slopes down to about 1050 feet, while in curve c the upper margin of the 700 foot surface reaches an altitude of 950-1000 feet. Therefore, owing to the slope of surfaces, certain overlapping of maxima and minima seems inevitable in a curve including a considerable area.

Indications of the occurrence of platforms are also found in hypsographic and clinographic curves. The maxima in the hypsographic curve and minima in the clinographic curve indicate the presence of level surfaces at the corresponding altitudes. In hypsographic curve Fig. 3, distinct maxima occur at 250-300, 650-750 and 1250-1300 feet. But the two higher surfaces are not so well represented, their presence being indicated only by a flattening of the curve at 1450-1550 and 1700-1800 feet. This is inevitable in view of the fact that the areal extents at these altitudes are too small to give distinct rises in the curve. In clinographic curve (Fig. 4), the five surfaces are clearly indicated by minima at the appropriate heights. The indications for the 1500 and 1800 foot surfaces are clearer here than those in the hypsographic curve as the clinographic curve expresses the average slope between different altimetric zones and is therefore not so much influenced by their actual areal extent. It may be noted that ordinarily, a sharp and clear minimum in the clinographic curve indicates the clear and steep margins of the surface; on the other hand, if the boundaries of a given surface are not well defined, the corresponding minimum tends to be broad and ill defined. In Fig. 4, all minima are clear and sharp except for the one at 650-750 feet the upper margin of which is more or less ill defined. This seems to be in accordance with the actual conditions of the ground as the 700 foot surface descends to 650 feet in the lower reaches of the Clyde but rises above the 900 foot contour in the upper reaches. In the tributary valleys, moreover, wide flat surfaces belonging to this stage occur at or above 1000 feet O.D. as in the Elvan Water valley. But in lower Clydesdale, this altitude is occupied by traces of a higher platform.

It may be noted that there is also some indication of the occurrence of a minor surface at about 500 feet O.D. This is shown by a slight maximum in the hypsographic curve (Fig. 3) and slight smoothening of the curve in the clinographic curve between 500 and 600 feet. (Fig. 4) In altimetric curve c (Fig. 5), a slight maximum at the corresponding height is also indicated. But as field examination does not confirm the separation of this surface which is but slightly indicated on the morphometrical curves, we may omit it until conclusive evidences can be presented to prove its existence.

Field examination in many critical localities confirms the existence of these more or less level surfaces separated by steep intervening slopes. While no single method of morphometrical analysis is itself sufficient to demonstrate the existence of these surfaces, the close coincidence of the results from the four different methods of morphometrical analysis coupled with field confirmation rule out any chance of accidental occurrence and must be regarded as a weighty evidence in favour of existence of different level surfaces.

However, doubt may still exist as to whether these surfaces are structural platforms due to difference in rock resistance or erosional platforms due to changes of baselevel. Usually, it can be quite safely assumed that the consistent occurrence of level surfaces at approximately similar altitudes over such a wide area as 800 sq. miles is a sufficient indication of the cyclic origin of the platforms. But concrete and conclusive evidences for their cyclic origin may be derived by a broad comparison of geological maps with the morphological map and a general study of the terrace forms along the present river valleys.

A casual examination of geological maps shows that these surfaces truncate indifferently formations of diverse resistance and nature. Although the 1800 foot surface is confined essentially to hard greywackes of Silurian and Ordovician age, its existence is not determined by the resistant nature of these formations which are truncated by the lower surfaces at 1500 and 1200 foot and constitute a considerable part of their terrain, as in the region around the Upper Tweed and Upper Clyde and also in Kype Muir, south of Strathaven. Silurian and Ordovician greywackes have been intensely folded and faulted and in most localities are inclined at high angles. It is conceivable that these highly inclined strata can be made into a smooth and gentle surface only by erosional agencies. For example, in the mountains near Clyde Law, Silurian greywackes dip generally northward at high angles but the general slope of the 1800 foot surface there is gently southwards. In Coom Dod west of Elvanfoot, the 1800 foot surface truncates a syncline of Silurian greywackes with dips up to about 65° on both sides. In addition, the 1800 foot surface is not strictly confined to the Silurian and Ordovician strata; in Tinto Hills it is situated in felsite of Old Red Sandstone age.

The 1500 foot surface is also chiefly developed in greywackes and grits of Silurian and Ordovician age, but a considerable part of the surface truncates Old Red Sandstones and felsite and granite intrusions. For example, the level surface of Hagshaw Hill (1540 ft) traverses Silurian greywackes and Old Red Sandstones side by side and the fault which cuts across the two formations exerts no influence on the level surface at all. The remarkable deseent to the 1200 foot surface in the neighbourhood of Nutberry Hill is but little influenced by the fault which is shown on the geological map definitely extending from Long Bank to Grouse Hill, for Spirebush Hill (1539 ft) on the upthrow side of the fault and Goodbush Hill (1556) and Auchigilloch (1514) on the downthrow side constitute the same surface.

The 1200 and 700 foot surfaces are developed in formations of even greater variety and difference in resistance. In the Upper Clyde and Upper Tweed valleys, the 1200 foot surface cuts across highly inclined or vertical strata of Silurian age. In Middle Clydesdale where the 1200 foot surface extends in a wide area, the underlying strata consist of diverse formations from Silurian greywackes and Old Red Sandstones to felsite and basalt sheets. The 700 foot surface is developed mainly in Old Red Sandstones and Carboniferous formations in the lower Clyde valley. But in the region west of Beattock where a large extent of this surface is developed at about 800 feet, the underlying strata consist essentially of highly inclined greywackes of Silurian age. South of Hamilton, where a broad limestone plateau at 600-750 feet rises steeply and clearly from the lower 300 foot surface, its steep rise may have been influenced by a fault, but as a large number of faults is shown in this region and finds no expression on the relief, it seems inconceivable that this escarpment is chiefly determined by the fault. Nor can the escarpment be explained as due to resistant nature of limestone, because the steep slope is mainly formed by barren red measures under which the limestones dip, the whole structure of the region being a complex syncline. While it is highly probable that the resistant nature of limestones and basalts may have some effect on the preservation of this surface, the surface itself is neither caused by the stronger resistance of these formations, nor limited to areas where these formations occur. For example, Law Hill south of Wishaw is an outlier of the 700 foot surface developed on unresistant rocks of Millstone Grit age.

The 300 foot surface lies chiefly in a region of compound synclines of Carboniferous strata in the lower reaches of the Clyde. Its independence of geological structure can also be easily demonstrated.

In Fig. 5, geological structures as generalized from the 1 inch geological maps are inserted on the profiles and they show at a glance that these level surfaces are essentially not determined by geological structures. Hence we are compelled to appeal to erosional agencies for the explanation of these step-like level platforms.

Another evidence for the cyclic origin of these level surfaces is obtained from the study of terrace remnants along the river valleys. Although higher terraces have suffered a considerable amount of subsequent dissection and modification, their remnants as preserved at present are sufficient for a broad reconstruction of valley-in-valley forms. In the upper Tweed valley, major terraces are distinguished at the levels of about 1800, 1500 and 1250 feet and additional terraces at 750 and 350 feet are shown in the lower Clyde valley. As these terraces are usually covered with only a thin veneer of superficial deposits or show bare rock surfaces, they may be taken as representing rock floors of ancient river valleys.

While minor irregularities of terrace levels inevitably occur and reconstruction of ancient river valleys from terrace remnants involves many difficulties and complications, a general restoration of ancient river valleys on the basis which will be discussed in a later chapter shows that the 1500 and 1200 foot terraces slope gently but consistently downstream in the upper Tweed and upper Clyde. In the upper Tweed, the 1500 foot terrace as shown by the actual remnants descends steadily downstream from 1522 feet to 1443 feet in a distance of about 5.5 miles while the 1200 foot terrace can also be traced downstream in decreasing altitudes. The terraces in the Clyde valley are more interesting as they can be traced for a considerable distance downstream. The 1500 foot terraces were traced from the head of the Daer Water to the Clyde near Crawford for a distance of nearly 18 miles. The restoration of the ancient river valley at this stage shows that it slopes consistently downstream in decreasing gradient. The 1200, 700 and 300 foot terraces on the Clyde exhibit approximately the same character. (see Chapter VII.) It seems evident that if the terraces were structural platforms, they would not occur so consistently along the rivers and it is still more improbable that they would be so arranged as to have height and slope steadily decreasing downstream.

From the above considerations, we are compelled to entertain the cyclic origin for these level surfaces the occurrence of which emerges from detailed morphometrical analysis and field observations.

## Chapter V. The Morphological Map

The morphological map constitutes the ultimate object of morphological study and represents the final result of the whole research. Once the separation of erosion surfaces is justified by reliable evidences, it is natural that a morphological map should be compiled to show the nature and distribution of the surfaces. It should be noted that a morphological map represents a reasonable interpretation rather than the results of pure observation.

It may be appropriate here to state the basis upon which the morphological map was constructed so that its relative reliability may be appreciated. Firstly, as the map was based mainly on the 1 inch maps, surfaces were separated only by breaks of not less than 150 feet unless there were special grounds for doing otherwise. Secondly, as the higher surfaces have been strongly dissected, the correlation and reconstruction of a surface from its remnants must imply the filling of wide gaps. Correlation over too great distance must result in some uncertainty, but evidently it is very difficult to determine the limit of the width of the gap which may be filled. In practice, the arbitrary step was taken of connecting two remnants of the erosion surface when the intervening distance between them was less than 4 times as the total width of the two remnants in question.

A third and the most serious difficulty in the construction of the map is to set a limit of gradient (or slope) by which surface may be distinguished as an erosion flat. This can be decided only in a more or less arbitrary way although helpful checks may be provided by the known gradient of erosion surfaces in other regions and the present gradient of the principal river of the region. Regarding the gradient of the river valley, the longitudinal gradient should be clearly distinguished from the transverse gradient as the former is generally much less than the latter. For the erosion surfaces shaped by subaerial agencies, the general or regional slope may be taken to be generally similar to the longitudinal profile of the principal river.

In Clydesdale, the regional slope of the erosion surfaces is roughly from S.S.E. to N.N.W. following the direction of the Clyde. The present Clyde is regarded as having reached approximately a mature stage of development from Watermeetings downstream, descending from 900 feet near Watermeetings to 650 feet at Wolfclyde in a distance of 14.5 miles as the crow flies. The average longitudinal gradient is therefore about 17.2 feet per mile. On the other hand, its average transverse gradient is much greater. Neglecting minor irregularities, the Clyde valley descends from 750 feet to 671 feet in a distance of 1.7 miles on the left side of the river north of Symington, with an average transverse gradient of about 46.5 feet per mile. Lower downstream, on the south of Lanark, the valley descends from about 750 feet near Mosshead to 650 feet near Boat-haugh in a distance of 1.8 miles, with an average gradient of 55 feet per mile. Thus the transverse gradient may be three or four times greater than the longitudinal gradient.

The average longitudinal gradient of the mature section of the Clyde corresponds closely with the computed gradient of erosion surfaces in other regions and with that of the higher surfaces in Clydesdale. Wooldridge gave 15 to 20 feet per mile as the average gradient of the Diestian platform in the London Basin. In Clydesdale, the 700 foot surface extends in a continuous plateau from south of Strathaven to near Quarter, sloping gently northward at 15 feet per mile. The longitudinal gradient of the 1200 foot surface as observed from a small stretch of level plateau at Kype Muir is about 27 feet per mile. However, it should be noted that the longitudinal gradient between any two closely situated single remnants may be of much greater value and is not representative of the general slope. Therefore, the general gradient of erosion surfaces must be obtained by taking a considerable extent of land within which are a number of elements separated by less than the distance at which correlation is considered unreliable. Of the transverse gradient, we have no comparable value. But it may be stated that the values cited above are computed from the broadest parts of the Clyde valley; for the less mature parts, they must necessarily be higher.

Evidently, it is extremely difficult to establish a rigid criterion for the gradient of erosion surfaces. But taking these figures as a basis and making certain allowances, we may take 50 feet per mile and 100 feet per mile as the upper limit for longitudinal and transverse gradients of erosion surfaces respectively. Although these limits can in no way be taken rigidly, yet they are useful for practical purpose. The value of gradients of erosion surfaces relative to the gradients of their intervening slopes is also of major importance. We have worked on the assumption that in all cases the gradients of intervening slopes must be well over three times as those of the respective erosion surfaces.

These arbitraty limits greatly facilitate the construction of the map. For example, in the waterdivide area between the Clyde and Tweed, there are a number of hills between 1650 and 1700 feet which may represent slopes or cols. The Hazelbush Hill is a good example. It rises to the 1800 foot surface and slopes down to the level of the 1500 foot surface at a gradient of about 190 feet per mile, whereas the 1800 and 1500 foot surfaces in the neighbourhood slope gently southward at about 20 feet per mile. (Fig. 7) The correlation of valley stages is also made easier. For example, the isolated hill of Nemphlar can be correlated with the broader remnants in Cartland on the ground that the transverse gradient between them is only 80 feet per mile.

The morphological map (Fig. 8) was compiled in accordance with these arbitrary limits. First, the composite skyline profiles were put along the 1 inch maps in their proper positions and carefully studied both in N-S and E-W directions. Applying the principle of gradient as stated in the preceding paragraph, the hilltops judged to represent remnants of slope and be without cyclic significance were eliminated. The remnants of individual surface, as represented by hilltops and flat areas, were then traced down from the hachured edition of the 1 inch maps and their altitudes marked, and they were checked by field mapping and observation. The scattered remnants were then correlated and connected together according to the principles and limits set forth in the preceding paragraphs. The boundaries between various surfaces thus drawn were compared with those marked down on the map from the study of composite skyline profiles. Where the margins between different surfaces can actually be traced on the ground, they are shown in heavy solid lines while those merely restored are shown in heavy broken lines. Where the relation between the surfaces is not clear, the space is left blank. Fig. 9 is a map showing the actual remnants of erosion surfaces in the headwater region between the Clyde, Tweed and Annan. It may serve to illustrate the basis upon which the generalized map (Fig. 8) was compiled.

In conclusion, it may be said that as the morphological map was constructed by plotting actual remnants of erosion surfaces and correlating them according to the limits and principles defined, its impartial and objective nature can hardly be doubted although the limits and principles for correlation may be open to criticism.

## Chapter VII Characters and Distribution of Erosion Surfaces

A glance of the morphological map (Fig. 8) shows that erosion surfaces in the region are arranged essentially in accordance with the main drainage lines. Each surface gradually becomes narrow as it is traced upstream. Broadly speaking, both longitudinal and lateral slopes of the surfaces follow the directions of the present main streams of the region, the Clyde and Tweed, which flow generally northward in the region under consideration. On the whole, the lower the erosion surface is, the more completely it is preserved. Also the range of height of a lower surface is generally greater than that of a higher one. This may be in part due to the fact that a considerable part of the higher surface has been consumed owing to its longer exposure to denudation agencies and the range of altitude of its remnants is consequently smaller.

(1) The 1800 foot stage The highest hills in the region show a very close accordance of summit levels, rising generally to 1750-1850 feet above sea level. Of 64 hills above the 1700 foot contour in the Ordnance 1 inch map No. 79, only 13 are above 1900 feet. The range of height of this surface is comparatively small, as most of the hills belonging to it fall between 1750 feet and a little over 1850 feet; it is only occasionally that we find hills

of a little over 1700 feet near the present stream. This surface has long been exposed to denudation so that in the region only scattered remnants remain visible. The most extensive area of this surface is preserved in the water divide region between the Clyde, Tweed and Annan where subsequent denudation has been comparatively insignificant. Duncangill Head between the headwaters of the Culter Water and Camps Water and the level ridge from Coomb Dod to Clyde Law are probably the only areas in the region where really wide tracts of level ground belonging to this surface are still preserved. (Plate 1) From the top of Craigmaid Hill looking west, the level nature of the surface in the neighbourhood of Clyde Law and Black Dod can be strikingly seen. (Plate 2) Elsewhere, as the surface is highly dissected and only preserved in comparatively small patches, it is difficult to determine exactly the direction and amount of its regional slope. Its small range of height which generally amounts to only 100 feet probably indicates that the surface may have reached an old stage of development and approximated the condition of a peneplane.

The 1800 foot surface rises steeply to hills of over 2000 feet above sea level. There seems to be a rough accordance of summit levels at about 2050-2200 feet among those higher hills, but as remnants of a surface, they are very fragmentary and it is premature to state their true nature without a detailed study over a much larger area.

(2) The 1500 foot stage This surface is shown in the map as roughly enveloping the 1800 foot surface. It has also been highly dissected so that it is only represented by a large number of flat topped hills and few wide tracts of level ground belonging to it can be found. However, its remnants are better preserved and more continuous than the 1800 foot surface. For example, near Nutberry Hill, summits representing this surface can be traced from west to east for over six miles and their heights range from 1500 feet to about 1600 feet. (Plate 3) A broad continuous stretch of hills generally just over 1500 feet in altitude is seen in the headwaters of the Tweed where they ride as distinct hills from the level ground belonging to the 1200 foot stage. (Plate 4) In the Upper Clyde, remnants of this surface are preserved at closely spaced intervals and they were traced from the head of the Daer Water down to Watermeetings for a distance of nearly 10 miles. From restorations of old valley profiles, the details of which will be described in a later chapter, it is possible to estimate its direction of slope and its amount of gradient. It was found that the 1500 foot surface in the Upper Clyde generally slopes down in the direction of the present stream, i.e. from south to north, and decreases in height from 1611 to 1506 feet in a distance of just less than 18 miles with

a gradient of about 6 feet per mile.* (Fig. 13)

The range of height of this surface is more considerable than that of the 1800 foot surface, ranging from over 1600 feet to 1450 feet. Therefore, the altitude of its remnants differs widely according to their longitudinal and lateral positions with regard to the main streams. The 1500 foot surface usually rises in distinct and steep slopes to the higher surface, the breaks of slope sometimes amounting to over 250 feet. This relation is best witnessed in the upper Daer Water where the level topped hill of Over Law (1574 ft) ascends directly to Lamb Hill (1777 ft) which represents the 1800 foot surface. Near Craigmaid in the Upper Tweed, a comparatively wide tract of the 1500 foot surface (at about 1575 ft) occurs around Craigmaid which rises to 1811 ft.

It may be interesting to note that most of cols dissecting the 1800 foot surface falls between 1500 and 1650 feet in altitude. For example, in the whole high ground of Culter Hills between the Clyde and Tweed, 17 cols are encountered among hills belonging to the 1800 foot surface, of which 9 are at 1600-1650 feet, 5 at 1500-1600 feet and only 3 are above 1650 or below 1500 feet. As the superficial deposit in these high cols is generally insignificant for the present discussion, the close accordance of altitudes of high cols seems to

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* It may be noted that the distance stated in this chapter all refers to the distance along the river course in order that comparison may be readily made between this chapter and the next chapter on the river profiles. The actual gradient of the surfaces is considerably greater in amount if the distance is taken in straight line as the crow flies. For the 1500 foot surface, the distance is 12.5 miles as the crow flies and the corresponding gradient is therefore about 8.3 ft per mile. In the case of the 1200 foot surface, the distance from the Daer Water valley to Liberton is about 20 miles as the crow flies and the corresponding gradient is 18 feet per mile.

indicate the concurrent dissection of the 1800 foot surface by streams in the 1500 foot stage and may be taken as another evidence for the existence of the 1500 foot surface.

(3) The 1200 foot stage     Commencing as narrow valley terraces in the upper reaches of the Clyde, the 1200 foot surface gradually widens towards downstream while its height steadily decreases at the same time, descending from about 1350 feet in the Daer Water valley to just over 1000 feet near Liberton in a distance of 29 miles, with a gradient about 12 feet per mile. The surface is generally less dissected so that extensive level stretches can be seen in the region. Perhaps the most notable example is Kype Muir where considerable level ground occurs at a general level of 1150 feet (Plate 5). The surface is so broad and flat that a traveller would scarcely realize he is on the top of a high platform until he reaches its lower edge at about 1060 feet where a steep descent begins which amounts to nearly 200 feet in a distance of less than ½ mile. (Plate 6) A considerable area of the 1200 foot surface is preserved in the region between Douglas and Roberton where it stretches as an undulating plateau between 1100 and 1250 feet. (Plate 7) In the headwaters of the Tweed, broad stretches of the surface are also encountered at the altitude of about 1300 feet from which the 1500 foot hills rise in a sharp and

distinct manner. The famous Devil's Beef Tub owes its steepness to the fact that here vigorous headward erosion of the River Annan has consumed a greater part of the 1200 foot surface and therefore the cliff descends directly from the 1500 foot surface to the river valley which is but 700 feet above the sea level. (Plate 8) However, in Middle Clydesdale, north of a line extending roughly from Thankerton to Biggar, the surface is much broken by encroachment of the 700 foot surface so that its remnants are scattered in small patches. Quothquan Law, Carmichael Hills, Dillar Hill and Black Hill near Lesmahagow may be cited as examples. Although these and other hills correspond to the outcrops of some resistant igneous rocks, for the reasons discussed below, they are not regarded as due to the results of differential erosion in rocks of unequal resistance. First is their remarkable accordance of summit levels which almost universally reach a height of 1050-1100 feet. Secondly, hills of the same altitudes are not limited to igneous rocks, but have wide occurrence in formations of very different nature. For example, Dillar Hill (1017 ft) east of Lesmahagow consists of felsite intrusion, but just a mile on the south east, a hill at 1073 feet is composed of Old Red Sandstone which is generally less resistant than the felsite. In the third place, there are localities where this same felsite has been reduced to the

700 foot level which occurs side by side with felsite hills representing the 1200 foot stage, as in the flat surface at about 650 feet in North Hillend and Auchnotroch near Hazelbank. From the above considerations, it seems conceivable that the accordance of summit levels of these igneous hills in Middle Clydesdale suggests the same erosional stage.

The 1200 foot surface has a wide range of altitude amounting to nearly 350 feet which has caused some confusion in the altimetric curves as described in a previous chapter. Hills of over 1300 feet usually occur only in headwater regions where they sometimes represent the original water-divide. Tinny Bank (1369 ft) and Whiteside Hill (1393 ft) north-west of Nether Howecleugh village are probably a case in point. They probably represent the original water-divide between the Clyde and Evan Water during the 1200 foot stage and are consequently of higher altitudes. From the reconstruction of erosion surfaces, it is conceivable that the capture of the Clyde Burn by the Evan Water must have taken place after the 1200 foot stage for otherwise, instead of the vigorous and narrow gorge near Nether-Howecleugh as at present, the valley would show greater profile towards maturity.

The ascent from the 1200 foot surface to the higher hills at the 1500 foot level is usually steep and distinct, especially in the headwater regions of the Clyde and Tweed where valley terraces constitute a distinct feature in the landscape as will be described in a later chapter. (Plate 9 and 10)

(4) The 700 foot stage    If one travels in the neighbourhood of Lanark and Carstairs, the most striking feature in the landscape is the exceedingly level nature of the ground and the extremely mature character of the Clyde valley above the Falls. This region belongs to the 700 foot surface which reaches its most extensive development in the middle reaches of the Clyde. Elements of this surface vary widely in elevation from over 1000 feet in the Upper Clyde to just over 600 feet east of Airdrie. But the main remnants of the surface stand generally just above 700 feet. Therefore, it is proposed here to call this striking surface the 700 foot surface.

The 700 foot surface in Clydesdale may be conveniently divided into three parts. In Upper Clydesdale, the surface is represented by narrow "valley flats" of less than half a mile broad both in the main stream and the tributaries. In the Elvan Water and Clyde Burn valleys, considerable "valley flats" occur at a little over 1000 feet. In the upper reaches of the Daer Water and Potrail Water, "valley flats" also rise to above 1000 feet. (Plate 11) (1)

While the surface occurs only in scattered narrow valley flats in Upper Clydesdale, it extends as broad level plains in middle Clydesdale between Lanark and Lamington where it is only broken here and there by scattered hills representing the 1200 foot surface. (Plate 12) The most impressive single stretch of the 700 foot surface is found between Lanark and Carstairs where it extends from east to west for over 7 miles in a plain, essentially featureless, except for glacial accumulations. (Plate 13 and 14) The same landscape type may be seen also between Lesmahagow and Coalburn where the surface is at 700-800 feet and its monotonous level nature is especially striking. (Plate 15) Thankerton Moor which was conceivably base-levelled by an old eastward tributary of the Tweed before capture (2), rises gently from 650 feet near the Clyde to about

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(1) It may be pointed out that these "valley flats" are far from level but slope downstream with an appreciable gradient. On the whole, the gradient of the 700 foot surface is decisively steeper in the upper reaches of the streams than that in the lower reaches. For example, on the Daer Water, from Nether Sweetshaw to near Watermeetings, the longitudinal gradient of the "valley flat" is about 30 feet per mile which is twice as much as the longitudinal gradient of the 700 foot surface in Lower Clydesdale. ( the longitudinal gradient of the 700 foot surface from Strathaven to near Quarter is 15 feet per mile and that from Cartland to Law Hill is 17 feet per mile)

(2) D.L. Linton, On the Former Connection between the Clyde and the Tweed, Scot. Geog. Mag., vol. 50, pp. 82-92, 1934

750 feet and may be taken as another typical example of the 700 foot surface. From the top of Quothquan Law, an impressive view of the 700 foot surface can be advantageously obtained. The surface is seen sloping gently from the inner margin of the Clyde valley merging imperceptibly into the present floodplain. (Plate 16 and 17) However, as middle Clydesdale is a region of glacial accumulation, the rivers cutting through glacial deposits often form terrace features which usually rise about 20-30 feet above the present floodplains but sometimes are over 50 feet high, as along the Clyde near Carstairs and in the lower reaches of the Douglas Water. They constitute essentially "false terraces" according to Mlle Lefevre's classification (3) and are without any cyclic significance. (4)

Below the Falls of the Clyde near Lanark, streams have entrenched themselves deeply in the 700 foot surface which consequently rises as broad platforms or plateaux in Lower Clydesdale. (Plate 18) The broad flat valley of the Clyde above the Falls and its entrenched character below presents a remarkable contrast. Below the Falls,

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(3) M.A. Lefevre, La Basse Meuse, Etude de Morphologie fluviale, Societe belge d'etudes geographiques, Memoire No.1, Louvain, 1935, p.34.

(4) The terrace features of middle Clydesdale are described in detail by the writer in an accompanying paper, "On the Meander-Terraces of Middle Clydesdale".

the steep rise to the 700 foot surface from the present floodplain of the Clyde is often more than 400 feet. It extends as broad undulating plateaux at the height of a little over 700 feet to the west of Glassford and to the east of Airdrie. In the neighbourhood of Carluke, its remnants are less extensive: Law Hill and Nemphlar Hill may be taken as outliers or detached remnants of the 700 foot surface.

The relation between the 700 foot surface and the higher platforms can be well seen in middle Clydesdale. The steep drop of over 200 feet from Kype Muir to the 700 foot plain is impressive both on the map and in the field. Around Thankerton, the picturesque rise of the 1200 foot hills from the flat plains of the 700 foot stage constitutes a feature distinctive in the landscape. (Plate 19) The inner margin of the 700 foot surface is at about 720 feet near Thankerton; walking from Thankerton to Cross Ridge, one passes across a featureless plain in the first two miles, rises imperceptibly from about 660 feet at Thankerton Bridge to 720 feet at the foot of the ridge near Bowhouse, whence begins the steep ascent, and in less than a mile we climb up nearly 300 feet.

A number of interesting cases of river capture are developed during the 700 foot stage and the abandoned courses of the captured streams as shown by windgaps provide additional evidence for the identification of the surface. In Upper Clydesdale, the capture of the Clyde Burn by the Evan Water has long attracted attention: the small sluggish flow of the Clyde Burn is in most vivid contrast with the wild dash of the Evan Water in its rocky gorge near Nether Howecleugh. (Plate 20) The windgap of this capture is at 1029 feet which corresponds roughly with the general altitude of the 700 foot surface in Upper Clydesdale. In middle Clydesdale, the notable Biggar Gap (659 ft) is among the most remarkable features in Scottish landscape. (Plate 21) South of Biggar Gap, there is an analogous through valley formed by river capture at 750-800 feet which we may term the Culter-Kilbucho Gap. (Plate 22) In Carmichael Hills, the abandoned course of the Millhill Burn is preserved as a windgap at 731 feet which we may call the Millhill Burn Gap. Another interesting case of river capture may be noted in the upper reaches of the South Medwin, north east of Dunsyre, near Garvald House. Here, the Medwin Water and the West Water originally continued south-eastward to join the Lyne Water were cut off by the headward erosion of the South Medwin. The windgap near Garvald House is just over 750 feet. The present Garvald Burn and Tarth Water are clearly out of proportion to the wide valley they occupy and represent the weakened remnants of a once much vigorous stream.

(Plate 23) In fact, their flow is so much reduced by beheading of the upper reaches that they are often kept flowing only by contributions from field drains. The heights of the last three gaps accord remarkably with the general level of the 700 foot plain, whereas the lower altitude of the Biggar Gap may be accounted for by processes connected with glaciation. (5)

Traces of the 700 foot surface have also been found in Upper Annandale as scattered hills on both sides of the river. Altitudes generally range from 750 to 850 feet but near the headwaters of the River Annan, north of Moffat, they rise to a little over 900 feet. The slope of the surface is generally downstream, from 954 feet north of Moffat to 744 feet near St. Anns in a distance of 9 miles with a gradient of about 23 feet per mile.

(5) The 300 foot stage    This surface is well developed in the lower reaches of the Clyde as can be distinctly seen in the neighbourhood of Coatbridge, Motherwell and Hamilton. Its upper parts sometimes rise to 500 feet as near Wishaw and Crossford, but the greater part of the surface lies between 200 and 300 feet above sealevel: hence the sharp maximum between these altitudes in the altimetric

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(5) Charlesworth, J.K., The Re-Advance, Marginal Kame Moraine of the South of Scotland, Trans. Roy. Soc. Edin., vol. 55, 1926, pp. 25-50.

curve a, Fig. 6. Viewed from the present floodplains of the Clyde, the 300 foot surface is seen as distinct high platforms or terraces rising steeply from the river. This feature is especially clear in the Lower Clyde below Dalserf. For example, near Netherton, ascending from the present flood-plain of the Clyde at about 90 feet O.D., one climbs up a steep slope over 200 feet high before reaching the town of Netherton on the 300 foot surface; the town lies at about 330 feet. (Plate 24) Near Hamilton, the same relation is also distinct. The town of Hamilton is mainly built on the level ground of the 300 foot surface which lies generally at the level of 200 feet in the neighbourhood, while Hamilton Low Park occupies the swampy flood-plain along the Clyde at about 75-90 feet O.D.

With regard to the upper margin of the 300 foot surface, it must be admitted that in some places, its relation to the 700 foot surface is not quite clear, especially in the area south of Stonehouse where no distinct break of slope between the two surfaces is distinguishable. But elsewhere, the ascent from the 300 foot surface to the 700 foot one is generally steep, as south of Hamilton and east of New Monkland. The relation of the 300 foot surface with the two outliers of the 700 foot surface provides conclusive evidence for distinguishing the two surfaces. Law

Hill is particularly interesting. It has been consumed on all sides by erosion in the 300 foot stage so that the hill assumes its present smooth outline. However, breaks of slope from the surrounding 300 foot surface are generally clear. Approaching the hill from south-east, one ascends from the level surface at about 540 feet near Carluke Gas Works to 675 feet on the top of the hill in a distance of ¾ of a mile. Descending from the hill towards west, one reaches flat ground at about 450 feet in a distance of less than half mile. Nemphlar Hill is separated from the main tract of the 700 foot surface in Cartland by the remarkable dry valley of the Lee which lies at the level of 400-450 feet and is probably of preglacial age as it is mantled by glacial deposits. From its altitude and location, it seems probable that the Lee valley may represent an abandoned valley excavated during the 300 foot stage.

The 300 foot surface is deeply incised by the present Clyde by nearly 300 feet near Crossford, about 200 feet near Larkhall and just over 100 feet near Hamilton. (6)

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(6) It seems difficult to explain the increasing amount of entrenchment upstream. Recourse can be made to postulation of the level surface at 450-500 feet near Crossford as a separate surface belonging to a minor stage of erosion, but this must be open to doubt in view of insufficient evidences available.

The deep incision suggests that after the 300 foot stage, change of baselevel occurred which resulted in the rejuvenation of streams in the region. The rejuvenation is clearly preglacial as some sections of the deeply entrenched valleys like the Avon Water and River Nethan are now completely buried under glacial drifts while remnants of the 300 foot terraces along the Clyde are also covered with boulder clay. That stream rejuvenation in the region was not long developed is shown by the fact that although the valleys of the Clyde and its major tributaries are deeply incised, the smaller tributaries have been but little affected. This seems to indicate the comparatively recent date of the incision and it is possible that the change of baselevel which brought about stream rejuvenation took place not long before the glacial epoch.

There is indication of a great submergence after the uplift. Numerous borings revealed a number of buried valleys in the Clyde Estuary which lie at a considerable depth below the present sea level. The buried channel at Drumry near Clydebank descends to 240 feet below the present sea level. Recent boring in the Leven valley near Dumbarton also revealed deep buried valleys extending to 200 feet below the present sea level. (7) Therefore, it

(7) Dr. M. Macgregor's paper read to the Glasgow Geol. Soc., Nov. 10, 1938.

is generally held that the amount of submergence must be at least 300 feet. (8) The present height of the 300 foot surface, which descends to about 150-200 feet in its lower margin, represents therefore net result of recent uplift and submergence. It is interesting to note that a similar sequence has been described for the Liffey Basin of Ireland. (9)

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(8) c.p. H.M. Cadell, The Story of the Forth, Chapt. 6, 1913 and The Geology of the Glasgow District, Mem. Geol. Sur. 2nd edition, 1925, pp. 215-19.

(9) A. Farrington, The Preglacial Topography of the Liffey Basin, <u>Proc. Irish Academy,</u> vol. 38, 1928, pp. 148-69.

## Chapter VII River Profiles and Erosion Surfaces

A detailed examination of the longitudinal and transverse profiles of rivers gives additional evidence for the separation of the surfaces. The evidence as now available may be discussed under two headings.

(1) Longitudinal Profiles The Clyde is the main stream of the region. Rising from the wild mountains of Lowther Hills, it cuts across the strike of Silurian rocks as a transverse stream flowing roughly northward. As the river passes through the Southern Upland Plateau and enters the Old Red Sandstone area, its valley begins to widen, so that below Lamington it flows in a broad open strath in contrast to the narrow constricted glen above. The curious course of the Middle Clyde and its former connection with the Tweed has been described in detail by Linton. (1) After receiving the Douglas Water, it resumes the north-westerly direction and descends by two steps, the Bonnington and Corra Linn Falls and the Stonebyres Falls.

Longitudinal profiles of the Clyde and its chief tributaries were constructed from the 1 inch maps and checked with the 6 inch maps and field measurements. In addition, longitudinal profiles of the Upper Tweed and its

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(1) D.L. Linton, 1934, opp. cit.

tributaries were prepared from the 1 inch maps. Primary examination was also made on the profiles of rivers in the neighbouring regions so that a broad comparison might be obtained. The profiles of the Upper Tweed and other rivers being derived exclusively from the 1 inch maps, are obviously less accurate than the Clyde profile. (Fig. 10)

The knickpoints indicated in the longitudinal profiles fall into three groups:

(a) The 1200 foot knickpoints     In the Upper Clyde and Upper Tweed, small patches of flat ground often occur in the heads of various tributaries at the altitude between 1200 and 1300 feet. These probably represent the 1200 foot surface which becomes wider downstream. The small flat near Whiteholm village in the upper Crook Burn may be taken as an example. The flat ground there lies between 1350 and 1400 feet and stretches eastward right to the divide between the Crook Burn and the Kinnel Water. The water-divide which lies at about 1360 feet appears a featureless flat when approached from the west but on the east, it descends steeply to 1260 feet in the deep Kinnel Water valley below. The water-divide is apparently one-sided and the capture of the Crook Burn by the vigorous Kinnel Water seems imminent.

Corresponding to these flats, the longitudinal profiles of the tributaries often show a flattening of gradient between 1200 and 1350 feet below which the profiles steepen again. (Fig. 11 and 12) It may be noted that profiles of the tributaries were based on the contours of the 1 inch maps on which spot heights are scanty. But the knickpoints as revealed by them are generally at the same level, i.e. 1200 feet. The wide occurrence of these knickpoints at similar altitudes evidently rules out explanation by the error of interpolation or other factors, but strongly suggests a cyclic interpretation. Owing to long continued headward erosion, the 1200 foot knickpoints have retreated far upstream and become more or less inconspicuous.

List of the 1200 foot knickpoints

| Clyde Basin | | Tweed Basin | |
|---|---|---|---|
| Daer Water | 1350 ft | River Tweed | 1100 ft |
| Crook Burn | 1300 | Badlieu Burn | 1200 |
| Wintercleugh Burn | 1250 | Hawkshaw Burn | 1100 |
| River Nethan | 1200 | Fingland Burn | 1200 |
| | | Holmes Water | 1200 |

(b) The 700 foot knickpoints    The Clyde meanders in broad open valleys in its middle reaches but near Bonnington Linn, it suddenly plunges down in picturesque falls and cuts into deep rocky gorges. (Plate 25 and 26) The well known Falls of the Clyde actually consists of two individual falls with short stretch of more or less quiet reach between, namely Bonnington Linn about 30 feet high and Corra Linn about 80 feet high. On the whole, the river descends rapidly from 570 feet at the head of Bonnington Linn to just about 400 feet below Corra Linn in a distance of $\frac{3}{4}$ of a mile. As shown in Fig. 10, the Clyde as well as its tributaries are generally well graded in smooth curves above the Falls, but the tributaries entering the Clyde below the Falls exhibit profiles of an entirely different nature. They often begin in the 700 foot plateau as insignificant streams occupying open flats and marshy valleys (Plate 27) but descend in falls and rapids as soon as the edge of the plateau is reached and their well graded smooth curves are thus broken by stretches of suddenly steepening gradient in the lower reaches. In the field, this senility of the upper courses and the vigorous youth of the lower reaches constitute a striking contrast. The Mouse Water and the Fiddler Burn are among the best examples. (Plate 28 and 29)

In spite of considerable modification of the river courses due to glacial accumulation (2), corresponding breaks of slope were found in the Clyde and its various tributaries at approximately similar heights. The higher altitudes of the same knickpoints in some smaller tributaries like the Cadzow Burn and Jock's Burn are evidently due to their steeper gradients for in such streams a short horizontal recession means a considerable increase in altitude of knickpoints.

The 700 foot knickpoints are usually very distinct and are of very wide occurrence. On the Tweed, a steepening

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(2) There is evidence to show that the present knickpoint of the Clyde at 570 feet was in existence in the preglacial times. During the construction of the Clyde Valley Power Works, a tunnel was put through near Bonnington revealing a buried channel the bottom of which lies at a little below 500 foot O.D. A large number of bores put down along the Douglas Water show the rock surface at about 530 feet O.D. near Douglas Castle and probably indicate the preglacial channel of the Douglas Water. If the Douglas Water joined the Clyde in preglacial time, the gradient of the Douglas Water must have been extremely small amounting to only 4.4 feet per mile. Below Kirkfieldbank Bridge, according to Dinham, the old course of the Clyde was continued through the remarkable dry valley of the Lee east of Nemphlar which lies at about 400 feet O.D. Even without taking into account the glacial deposits which mantle the Lee Valley, the descent of the preglacial Clyde from Bonnington to the head of the Lee Valley would amount to a full hundred feet in a distance of about 2½ miles which represents a gradient of 40 feet per mile. ( For details of boring records, see G. Ross, The Superficial Deposits in the Clyde Valley at Bonnington, in <u>Sum. Progress Geol. Sur.</u> for 1926, pp. 158-60 and C.H. Dinham, in The Economic Geology of the Central Coalfields of Scotland, Area IX, Mem. Geol. Sur. , 1921, pp. 126-28.)

of gradient is also observed between 550 and 600 feet where the gradient of the river is about twice that of the sections immediately below and above. Similar knickpoints at broadly corresponding heights occur in the tributaries of the Tweed, in the River Ayr and its tributaries, and in the tributaries of the River Nith. The close agreement in altitudes of knick-points in the Clyde Basin and in other rivers evidently rules out any explanation by chance occurrence, river capture, hard rock barrier, or glacial modification. The fact strongly suggests a cyclic origin. The knickpoints are generally at 550-600 feet and may be correlated with the 700 foot stage. That the 700 foot knickpoints are of wide occurrence and distinctive appearance seems in close agreement with the fact that the 700 foot surface is most extensively and maturely developed in the region.

<u>List of the 700 foot knickpoints</u>

**Clyde Basin**

| | |
|---|---|
| Clyde | 570 ft |
| Mouse Water | 610 |
| Avon Water | 550 |
| South Calder Water | 700 |
| Fiddler Burn | 700 |
| Cadzow Burn | 700 |
| Jock's Burn | 800 |

**Nith Basin**

| | |
|---|---|
| Mennock Water | 550 |
| Crawick Water | 550 |
| Euchan Water | 600 |

**Tweed Basin**

| | |
|---|---|
| Tweed | 550 ft |
| Leithen Water | 550 |
| Ettrick Water | 550 |

**Ayr Basin**

| | |
|---|---|
| River Ayr | 550 |
| Lugar Water | 550 |
| Glenmuir Water | 600 |

(c) The 300 foot knickpoints   The Clyde resumes its quiet flow below Corra Linn until 3½ miles further downstream where it again rushes down in a series of waterfalls about 80 feet high, known as Stonebyres Falls. Stonebyres Falls, the head of which lies at 280 feet O.D., can probably be correlated with the 300 foot stage for similar knickpoints are shown in a number of tributaries at corresponding heights. They are situated at about 400 feet on the Jock's Burn, 300 feet on the Dalserf Burn, 200 feet on the South Calder Water and 175 feet on the Cadzow Burn: their heights varying according to the positions of tributaries with respect to the main stream and the gradients of their individual profiles.

Tributaries entering the Clyde below Stonebyres Falls generally show two steepenings of gradient; the upper one corresponds to the 700 foot stage while the lower one may be correlated with the 300 foot stage. The Cadzow Burn and Earnock Burn may be quoted as examples. On the 700 foot plateau, they begin as insignificant streams. But on descending from the plateau, the streams acquire youthful vigour with rapid flow cutting in rocky gorges until in the neighbourhood of Hamilton where they reach the 300 foot surface and again resume more or less quiet flow.

A few exceptions may be noted. As can be readily seen from Fig. 10, the 300 foot knickpoint is absent on the Fiddler Burn, while the 700 foot knickpoint is not shown on the Dalserf Burn. In the former case, it is probably due to the fact that the Fiddler Burn joins the Clyde not far from Stonebyres Falls where the 300 foot surface is not sufficiently well distinct and consequently the 300 foot knickpoint may be merged in the higher one, forming a single steep descent. In the latter case, as the head of the Dalserf Burn has not reached the 700 foot plateau, it is but natural that no higher knickpoint is developed.

On the Tweed, the 300 foot knickpoint is represented by a steepening of gradient at 250 feet below Melrose. The descent of the river from 250 to 200 feet is about four times steeper than the immediate reaches below and above.

List of the 300 foot knickpoints

Clyde Basin

| | |
|---|---|
| River Clyde | 280 feet |
| Jock's Burn | 400 |
| Garion Burn | 400 |
| Dalserf Burn | 300 |

| | |
|---|---|
| Mill Burn | 350 feet |
| Hall Gill | 300 |
| Avon Water | 350 |
| South Calder Water | 200 |
| Cadzow Burn | 175 |

(2) Transverse Profiles Successive transverse profiles were constructed across the Clyde and the Tweed. They are lettered A-N in the Clyde valley and S-W in the Tweed valley and the lines of sections are shown in Fig. 8. In general, terrace remnants corresponding to the 1800, 1500, and 1200 foot stages are clearly distinguishable both in the Upper Tweed and Upper Clyde, while distinct and continuous terraces at the 700 foot level are well exhibited along the Clyde below the Falls where the 300 foot terraces can also be traced. The subject may be conveniently discussed under the following headings:

(a) Character of terraces The existing terrace remnants in the region may be grouped into two types. Those above the 1200 foot are much dissected and their remnants occur as flat-topped hills at closely spaced intervals. But the lower terraces are less fragmentary and they may be traced as continuous platforms.

As can be seen from Fig. 14, different terraces are generally separated from one another by clear and steep slopes of over 150 feet high. The relation is best exhibited in section W and B where the 1800, 1500 and 1200 foot terraces and the present river valley belonging to the 700 foot stage make direct contact and their distinct breaks of slope may be observed in the field. The relation between the 300 foot and 700 foot terraces are sometimes not so distinct on the maps, but the breaks of slope between them often can be clearly seen in the field, for example between Shawfield Collieries and Law Hill in section L. Near Nemphlar on section K, the change of slope between the 300 foot and 700 foot terraces is also noticable in the field. Descending from Nemphlar to Stonebyres Falls, one notices that the school and post office of Nemphlar are situated on the flat surface at an altitude of a little over 600 feet. The descent from Nemphlar to Haltown of Nemphlar at about 530 feet O.D. is fairly gentle but from the latter village down to Falls, the slope becomes steepened to a gradient more than twice as that from Nemphlar to Haltown of Nemphlar. Here, the flat ground where Nemphlar is situated probably represents the 700 foot terrace, the steeper slope from Haltown of Nemphlar down to the edge of Stonebyres Falls at a little over 300 feet the valley eroded during the 300 foot stage and the steep rocky gorge of the Fall the result of post-glacial excavation.

(b) Method for the restoration of profiles Restoration of ancient river levels was attempted wherever terrace remnants are sufficiently well preserved. As heights of terraces differ considerably according to their positions with respect to the axis of the ancient river valleys of which we have no precise knowledge, two arbitrary but reasonable bases were laid down for the purpose. In the first place, it was assumed that the axis of ancient river valleys were about the same as the present. This seems reasonable especially for the upper reaches of the Tweed and Clyde where valley-in-valley forms are arranged in such a symmetrical way. For example, in section T and B, if we restore and extend the remnants of terraces from both sides, they will meet in the present valley axis at approximately the same altitude.

In the second place, terrace remnants were extended to the present valley axis by the shortest distance available and the gradient for such extension was obtained from the gradient of the terrace remnants themselves where they are of sufficient width for the computation of gradient. For example, in section W on the Upper Tweed, the transverse gradient of the 1500 foot terrace is 76 feet per mile and that of the 1200 foot terrace is 80 feet per mile; in section B and C on the Clyde, the transverse gradient of the 1200 foot terraces is 80 and 84 feet per mile respectively. But in many sections in the Upper Tweed and Upper Clyde, terrace remnants are often preserved only in isolated hills and are not of sufficient width for estimating their transverse gradients. In such cases, values of transverse gradient were obtained by a comparison of the known values from the nearest sections. It is significant that on the Upper Clyde and Upper Tweed, the values of the transverse gradient of the 1500 and 1200 foot terraces are approximately the same, i.e. about 80 feet per mile. As the 1500 foot terraces on the Upper Clyde and the 1500 and 1200 foot terraces on the Upper Tweed were traced for only comparatively short distances, the restoration of old valley levels was based on the assumption that the transverse gradient for all cases was 80 feet per mile. But as terraces may be traced for longer distances, it is evident that their transverse gradient must also decrease downstream. Therefore, in the restoration of the 1200 foot terraces in the Clyde, the values of 70 and 60 feet per mile were assigned for the transverse gradient of terrace remnants further downstream. With regard to the 700 foot terraces, the transverse gradient between Cartland Mains and Nemphlar in section K is about 60 feet per mile whereas that of the present valley of the Clyde near Symington is about 45 feet per mile. Therefore, a round figure of 50 feet per mile was taken for the restoration of section J and K. For section L, M and N further downstream, the transverse gradient was estimated as 33 feet per mile which is the transverse gradient of the 700 foot platform near High Coldstream. For the 300 foot terraces, 50 feet per mile was used as the transverse gradient, which is in accordance with the computed values from section M and N. In Fig. 12 and 13, the values of transverse gradient upon which restoration of old valley levels was effected are marked out in red ink.

Along the present Clyde and Tweed, terrace remnants are often preserved only in one side and consequently restoration can be effected from one side only. In some localities, however, terraces are shown on both sides. In such cases, restoration was effected from both sides and the resulting values of restoration compared with each other. The value that fits better to the general line of the restored profiles was the one that had been adopted whereas the other value was put in parenthesis immediately below for comparison. It may be noted that in most cases, the heights of ancient valley levels restored from opposite sides are closely comparable; this may be taken as an evidence showing the reasonableness of the above bases for restoration.

(c) Results of restoration The ancient valley levels as restored from transverse profiles were plotted at their appropriate positions in the longitudinal profiles and they were connected to form the restored logitudinal profiles. It should be noted that in the lower reaches of the Clyde, as the gap between the terraces grows wider, the results of restoration naturally become less accurate. Nevertheless, except for a few minor variations, the restored longitudinal profiles generally show perfectly smooth and graded curves. For example, the restored longitudinal profiles of the Clyde during the 1500 and 1200 foot stages show, on the whole, successively decreasing gradient of the river as one goes downstream. During the 1500 foot stage, the river descends 56 feet in the first 4.5 miles, but for the second 4.5 miles further downstream, it descends only 38 feet. (Fig. 13) The longitudinal mean gradient of the restored profile of the Clyde at the 1500 foot stage is about 6 feet per mile from the source of the Daer Water to the neighbourhood of Crawford, while that at the 1200 foot stage is 8.7 feet per mile from Wintercleugh to Thankerton. The former is comparable to the present mean gradient of the well graded section of the Clyde between Abington and the Falls while the latter corresponds to that of the section between Watermeetings and the Falls. These figures give some indication of the stage of erosion in various stages. The restored profile of the Clyde at the 700 foot stage is also perfectly mature with a mean gradient of 6.1 feet per mile but that at the 300 foot stage is much less mature for its mean gradient amounts to 16.4 feet per mile. The less mature nature of the 300 foot restored profile seems to be in accordance with the observed fact that the 300 foot surface is generally not well defined except in its lower parts.

The restoration of the ancient longitudinal profiles of the Upper Tweed reveals a sequence of events comparable with the history of the Clyde. The section of the Tweed corresponding to the 1500 foot stage has a mean gradient about 10 feet per mile which is comparable to the mean gradient of the mature section of the Tweed between Drumelzier and Peebles. As in the case of the Clyde, the restored longitudinal profile of the Tweed at the 1200 foot stage is considerably less mature, its mean gradient amounting to 35 feet per mile which approximately equals to that of the present section of the Tweed between Nether Rig village and Patervan village (between 700 and 900 feet). It is probable this less advanced development of the 1200 foot stage that may account for the more or less confusion and mixture of maxima between 1000 and 1300 feet in altimetric curves. (Fig. 5)

Finally, it may be interesting to note the close correspondence of the results obtained from a study of longitudinal and transverse profiles. In the Upper Tweed, the restored valley levels in the 1200 foot stage generally lie between 1250 and 1300 feet which may be compared with altitudes of the 1200 foot knickpoints in a number of tributaries of the Upper Tweed. The highest restored valley level of the 1200 foot stage in the Upper Clyde (1276 ft) also closely corresponds to the 1200 foot knickpoints in the neighbourhood which lie between 1250 and 1300 feet. The 700 foot restored profile of the Clyde may be taken as a direct continuation of the present Clyde profile above the Falls. From restoration of terrace remnants, it was found that in the neighbourhood of Bothswell, the valley level was at 508 and 160 feet above the present sea level during the 700 and 300 foot stage respectively. These figures are closely comparable with the results of extrapolation based on Prof. Jones' formula (3) and may give some

(3) O.T. Jones, The Upper Towy Drainage System, Quart. Jour. Geol. Soc., vol. 80, 1924, pp. 568-609.

indication of the height of the sea level during the 300 and 700 foot stage. (4)

Thus the study of profiles of rivers has been rewarded not only by discovery of strong additional evidence in favour of the separation of the five main surfaces of erosion but also by revealing of interesting indications with regard to the relative stage of development of various surfaces which in turn help to explain certain points in the morphometrical analysis.

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(4) From provisional extrapolation, it was found that the Clyde near Bothswell lies at about 475 and 170 feet above the present sea level during the 700 and 300 foot stage.

## Chapter VIII Surface Drift and Erosion Surfaces

In regions not affected by glaciation, the accumulation of sediments on the rock surface constitutes an integral part of the normal cycle of erosion and the residual soils are as a rule comparatively thin and insignificant. But the present region has undergone considerable glaciation which has covered most parts of the region with a mantle of drift. In some cases, surface drift of a hundred feet or more is recorded. As they are evidently unrelated to the normal process of erosion and constitute new and later additions to the original ground, doubt may be thrown on the validity of existence of various erosion surfaces in the region unless due consideration is given to the effect of superficial deposits.

On the basis of difference of glacial drifts, the present region may be conveniently divided into three parts. In the mountainous region of Upper Clydesdale south of Crawford or Abington, drifts are as a rule scattered in small patches along the valleys and their thickness is generally insignificant. In the Middle Clyde which lies roughly between Lanark and Abington, the superficial deposits include notably fluvio-glacial accumulations which impart considerable variations to the landscape. Below Lanark, the region is essentially mantled under boulder clay with only a few rock outcrops in valleys and quarries.

In Upper Clydesdale, the accumulation of boulder clay is chiefly confined to the valleys while the higher grounds and hill tops are invariably free from drifts. A casual examination of the drift edition of the 1 inch geological maps of the region would amply confirm the statement. Here, the present streams essentially follow the same courses as their preglacial predecessors and they generally flow in boulder clay which fills the preglacial valleys.

The basin of the middle Clyde between Abington and Lanark is essentially a region of glacial accumulation where fluvio-glacial mounds and ridges are especially numerous. They have been described in detail by Gregory and later by Charlesworth. (1) Kame-moraines marginal to the ice front have been described from various localities. Perhaps the most striking example is the great kame-moraine of Carstairs, stretching from the eastern flank of the Pentland Hills south-westward through Carstairs and Lanark to Douglas and Muirkirk. (Plate 30) It is best developed near Carstairs where it consists of several parallel ridges with broad peaty hollows between. The ridges range from 20 to 40 feet high but occasionally rise as high as 80

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(1) J.W. Gregory, The Kames of Carstairs, Scot. Geog. Mag., vol. 31, 1915, pp. 465-75 and J.K. Charlesworth, 1926, opp. cit.

feet above the adjacent ground. The undulating billowy scenery formed by these moraines adds considerable variety to the landscape. Esker-like ridges have been noted near Symington and Linnhead. (Plate 31) They extend in clear and sinuous ridges rising about 20-30 feet above the adjacent ground.

In Lower Clydesdale, from Lanark downstream, boulder clay forms the characteristic superficial deposit and covers practically every part of the country. Generally, it forms only a featureless covering, but east of Coatbridge, it is moulded into a series of drumlins trending roughly in an east-westerly direction and rising sometimes over 50 feet above the adjacent ground. Here, the boulder clay is commonly deepest in the ridges where there are drumlin forms and thin or sometimes absent over small spaces in the intervening hollows. Thus in the drumlin area, glacial drifts tend to roughen the relief instead of smoothen it.

Although kame-moraines and drumlins stand out more or less prominently in the landscape, they are rather limited in occurrence and therefore are not of general importance. In the present study, we are more concerned with the thickness of drifts over the extensive featureless ground in Middle and Lower Clydesdale and must enquire whether the drifts are thick enough to modify the essentials of erosion surfaces. Evidently, it is rather difficult to give a figure for the average thickness of drift in the area, but an approximate estimate may be obtained from a detailed analysis of boring records and other evidences.

Through the kindness of Dr. M. Macgregor, the writer was allowed to study the boring records of Clydesdale as preserved in the Scottish Office of the H.M. Geological Survey. The area where such records were available and studied in detail is indicated on Fig. 15 with sheet-lines of the 6 inch maps as convenient boundaries. All together, over 1400 boring records were studied, most of which come from the mining areas of the Lower Clyde near Airdrie, Motherwell, Wishaw, Larkhall etc. but none were available from Upper Clydesdale south of Roberton.

According to the thickness of superficial deposits encountered, the bores may be grouped under the following three categories: (a) Bores showing thin surface drifts They reach rock head in less than 6 fathoms (36 feet). Superficial deposits of this thickness have little effect on the validity of the arguments advanced for the existence of erosion surfaces since the surfaces and terraces are generally separated from one another by difference of level of 150 feet or more. It is significant that class a bores in fact constitute 78.6% of the total 1400 bores studied and therefore may be taken as representing the average thickness of surface drifts in the region. (b) Bores showing surface drifts of medium thickness They reach rock head at 36-60 feet below the surface and are of less frequent occurrence, constituting only 14.5% of the total number of bores studied. (c) Bores showing thick surface drifts These bores sink down over 60 feet below the surface before reaching rock head and a number of them reveal surface drifts of over a hundred feet thick as near Larkhall and Netherburn. They constitute only 6.8% of the total number of bores studied. (Fig. 16)

In addition to the 1400 bores, there are another hundred and more bores put down in Murdiston Estate (in the 6 inch sheet No. 13) reaching rock head at 2 or 3 fathoms below the surface. They were not included in Fig. 16 owing to the difficulty in finding their precise locations. If these were included, the number of bores showing superficial deposits of less than 6 fathom thick would amount to over 80% of the total.

The variation in thickness of superficial drifts in different localities seems to be governed by certain definite rules. In general, the superficial deposits are thicker in valleys than on the slopes and higher grounds where they seldom exceed 5 or 6 fathoms thick. Regarding to the class b bores, they partly occur near sites of buried river channels but are partly situated on the high ground where they may indicate original depressions. Bores showing drifts of greater thickness (class c) can generally be related to the buried preglacial river channels which are encountered here and there in the region, notably the Avon Water and River Nethan. Fig. 17 is a sketch map showing the general variation in thickness of drifts in Lower Clydesdale; the boring records for the construction of this map were compiled from the 6 inch geological maps. As only a comparatively small number of bores are shown on the 6 inch geological maps and as the class a, b and c bores are not proportionally represented on these maps which neglect more class a bores than class c bores, the record presented by Fig. 17 should not be regarded as anything approximating the actual proportion of the number of bores of various classes. Nevertheless, it shows clearly the general characters of the distribution of surface deposits in Lower Clydesdale. With few exceptions, bores revealing surface deposits of over 60 feet thick ( shown as red dots on the map) are as a rule situated in the present floodplains of the Clyde or near the sites of preglacial channels of the Avon and Nethan. On the higher grounds and plateaux, bores are fewer but almost invariably belong to class a, i.e. with superficial deposits less than 6 fathoms thick.

The overwhelming majority of the number of class a bores and the characteristic localization of different classes of bores in the region amply indicate that the general thickness of superficial deposits in Clydesdale probably does not exceed 5 or 6 fathoms. (2)

The evidences derived from study of numerous stream sections, railway cuttings, quarries etc. point to the same conclusion. Near Thankerton, numerous abandoned quarries and stream sections on the Clachan Burn south-east of Annieston show that rock is generally not far from the surface. The gorge cut by the Clyde near Bonnington Linn shows rock at about 570 feet O.D., rock surface along the Mouse Water at Cleghorn Bridge lies at about 620 feet O.D. and the railway cutting just north-west of Cleghorn station reveals rock at about 730 feet O.D. In each case, the surface of the ground lies but a few feet higher. Below Lanark, the lower courses of tributaries of the Clyde usually cut through rock formations and their sections amply exhibit the thin nature of superficial deposits, notably that of the lower Nethan where only a thin veneer of till covers the underlying rock formations. On Law Hill, an outlier of the 700 foot surface, Carboniferous millstone grits crop out here and there on the surface. On the opposite side of the river, the Glassford Plateau is also dotted with numerous rock exposures on the surface, for example, in the neighbourhood of Cadzow Reservoir and Hartfield.

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(2) In an oral communication to the writer on Nov. 1938, Dr. M. Macgreggor regarded the above figure as a fair estimate.

From the above consieration, it seems reasonable to conclude that superficial deposits in Clydesdale are generally less than 36 feet thick. Glacial accumulation naturally has had a smoothening effect on the general relief of the country and has not in any way strenthened the relative relief. On the contrary, by accumulating thicker drifts in the valleys and lowlands while leaving higher grounds comparatively free from them, the coming of glacial epoch may have somewhat reduced the original relative relief and therefore have lessened the difference in level between adjacent elements of different surfaces. It is interesting to note that the effect of glaciation on the original topography is approximately the same in the Liffey Basin of Ireland as described by Farrington. (3)

In conclusion, it may be said that the separation of erosion surfaces in the region is based on difference of level of over 150 feet; and this is an amount to which uncertainty due to superficial deposits and other factors is not likely to accumulate.

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(3) A. Farrington, 1928, opp. cit.

## Chapter IX The Probable Origin and Age of Erosion Surfaces and their Correlation with Other Regions.

(1) Origin The origin of erosion surfaces is often difficult to determine. Subaerial denudation and marine abrasion are generally envisaged as the two major processes capable of producing even platforms. A long series of controversy has ensued regard to the subaerial or marine origin of various platforms. It must be admitted that few infallible criteria exist for the distinction of subaerial platforms from marine. Among the common criteria are the nature and distribution of surface deposits, the character and gradient of surfaces, the occurrence of steep ancient sea cliffs and the nature of drainage systems and their degree of adjustment to the underlying structures.

By mapping the distribution of marine Diestian beds, Wooldridge has shown the extent of transgression of the Pliocene sea in the London Basin. (1) But the possibility is not excluded that the platform on which marine deposits occur may represent a plain of subaerial denudation later submerged and covered by the marine deposits, the sea having only a minor effect on the actual levelling of the surface. On the other hand, the narrow localization of old

(1) S.W. Wooldridge, 1927, opp. cit.

river deposits and the occurrence of deposits long subjected to atmospheric weathering indicate the subaerial origin of surfaces. The Clyde Area has been extensively glaciated, a large part of the surface is mantled under drifts and original deposits, if any, scarcely remain visible. Therefore, in Clydesdale, the search for surface deposits as a clue in the elucidation of the origin of erosion surfaces seems unlikely to yield any fruitful results.

It is often assumed that a plain of marine abrasion is definitely even and with very low gradient, whereas a surface of subaerial denudation often possesses an appreciable gradient and is more or less of an undulating nature. But the distinction based on the difference of gradient alone is often difficult of practical application, as no definite characteristic gradient values have been set up by which marine and subaerial surfaces may be distinguished. It is frequently happened that only the inshore or landward parts of marine platforms are uplifted and form plateaux. As shown by Barrell, over the first five miles from the shore, the gradient of marine platforms is as a rule comparatively high, the value for quiet epeiric sea, stormy sea and stormy shelf sea being 7, 11 and 19 feet per mile respectively. (2)

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(2) J. Barrell, Rhythms and Measurements of Geologic Time, Bull. Geol. Soc. Amer. vol. 28, 1917, p.780.

For the London Basin, Wooldridge has taken 15-20 feet per mile as the gradient for the 400 foot Pliocene marine platform. These values are of the same order as the gradients of different river terraces in the Clyde Area as given in a previous chapter. Nevertheless, as these terraces were shown to slope downstream with decreasing gradient along the present stream, their origin must be reasonably attributed to stream erosion.

With regard to the third criterion, although remnants of ancient shoreline may be terminated by a sharp and steep rise on the inner edge of the marine platform and islands projecting from it would show steeper slopes due to cliffing than subaerial monadnocks, this is a distinction which tends to disappear with the passage of time. Especially in older platforms, we have no reason to expect that original steep cliffs will still remain intact. In the Clyde Area, the breaks of slope separating various surfaces so far as they can be traced on the ground are in no way resemble old shore cliffs. This apparent absence of old sea cliffs may be taken as negative evidence against the marine origin of the erosion surfaces in Clydesdale.

In Clydesdale, some positive indication of the origin of erosion surfaces may be found in consideration of the disposition of drainage systems. It is a well known fact that a drainage system initiated de novo on a plain of marine denudation is inevitably less adjusted to the underlying structures than a drainage system inherited from a previous fûrther advanced cycle now in a rejuvenated condition. In some favourable localities, like the Western Chilterns, Wooldridge and Linton have demonstrated that the landscape of the former Pliocene land is fully mature while that of the adjacent sea floor region is still in a state of youthful dissection. (3) In the case of the thousand foot platform of Arran the origin of which has been attributed to marine abrasion, it has been pointed out that the drainage on the platform is remarkably immature and the surface is practically untrenched by stream erosion. (4) The Clyde and the Tweed are both well supplied by numerous tributaries and the dendritic pattern of the drainage system is especially marked in the headwater regions. It seems that here the drainage system has on the

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(3) S.W. Wooldridge and D.L. Linton, The Influence of Pliocene Transgression on the Geomorphology of Southeast England, Jour. Geomorphology, vol. 1, 1938, p. 46.

(4) G.W. Tyrrell, The Geology of Arran, Mem. Geol. Sur., 1928, p. 257.

whole developed to an advanced stage. Moreover, streams in the region are definitely adjusted to the underlying structures with the development of numerous subsequent rivers. The courses of the Douglas Water, Medwin Water and that part of the Middle Clyde below the Medwin confluence are evidently longitudinal, etched out along the strike of the newer rocks. They may be regarded as subsequent in development.

In the Clyde area, both the longitudinal and transverse slopes of the erosion surfaces are essentially in accordance with the directions of the principal streams of the region. This fact coupled with the well adjusted and well developed nature of the streams in the region probably indicate a subaerial origin of the surfaces.

(2) Age It must be admitted that few definite criteria are available for dating of erosion surfaces. Evidently, a certain platform must be younger than the underlying strata it bevels and older than the overlying superficial deposits. These when fossiferous are usually helpful in providing an upper limit to the age of the platform. As the time interval between the underlying strata and overlying deposits may be considerable, in the absence of fossils, any estimate of age must be a

matter of personal judgement.

In the Clyde Area, no fossiferous deposits have been described. Without any definite clues, the age of the surfaces can only be estimated by analogy with the corresponding platforms in other regions where their approximate age has been determined.

The 300 foot surface in the region is definitely preglacial as it is covered by glacial drifts. The change of baselevel which initiated rejuvenation of the streams probably took place not long before the glacial period because although main valleys on the surface are deeply incised, tributaries are not. Surfaces near a 300 foot level are of wide occurrence in different parts of Great Britain. In the London Basin and the Liffey Basin of Ireland, surfaces at similar elevation have been assigned to late Pliocene or early Pleistocene. (5) It may be that the 300 foot surface in the Clyde Area is approximately of the same age.

The 700 foot surface has been recognized over a very wide area. It is generally assigned to the Pliocene and it is possible that the extensive 700 foot surface in

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(5) S.W. Wooldridge, The 200 foot Platform in the London Basin, Proc. Geol. Assoc., vol. 39, 1928, pp. 24-26 and A. Farrington, 1928, opp. cit.

Clydesdale is also of Pliocene age. The 1200 foot surface in Clydesdale may be correlated with the well known thousand foot platform of Arran and following the analogy of the later may be assigned to early Pliocene. (6) Of the higher surfaces, no definite dating has been assigned. Perhaps it would be wise not to fix any definite age to them in the present state of knowledge.

(3) Correlation During the last decade, numerous erosion surfaces of widely different altitude have been described from various parts of Great Britain. It is extremely difficult to analyse the vast number of data scattered in various publications. In some papers, the description is in-adequate to the understanding of the precise nature of the erosion surfaces in question, while in other cases, evidence advanced is not always convincing. Even with adequate and convincing description, it is illegitimate to correlate erosion surfaces over wide areas merely on the basis of correspondence in altitude. More reasonable correlation may be made from a study of the relative altitudes of former sea level and from the sequence of the erosion surfaces. It is evident that if two surfaces were shown to be graded to a former sea level common to the areas under consideration, they may be legi-

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(6) G.W. Tyrrell, 1928, opp. cit.

timately correlated. In Clydesdale, the 700 and 300 foot surfaces were probably developed by a system of rivers graded to potential sea levels at about 450 and 150 feet O.D. respectively. It is significant that a former potential sea level at 150-200 feet and at 400 feet O.D. has been recognized from different parts of Great Britain, notably the London Basin, Herefordshire and Wales. (7) Regarding the succession of surfaces, if the same number of terraces were recognized at similar altitudes in two regions not unduly separated in space, correlation of different members may be attempted without serious danger. Unfortunately, in many cases, only brief mention is made of the occurrence of a particular surface without due consideration of its place in the whole sequence of morphological development of the region. Under these circumstances, it must be confessed that any correlation is difficult and must remain more or less speculative.

The following table has been constructed to show sequence of morphological development in various parts of Great Britain. It may be noted that in the table, only

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(7) S.W. Wooldridge, 1927 and 1928, opp. cit., A.A. Miller, The Entrenched Meanders of the Herefordshire Wye, Geog. Jour. , vol. 85, 1935, pp. 160-79 and The 600 foot Plateau in Pembrokeshire and Carmarthenshire, Geog. Jour., vol. 90, 1937, pp. 148-59, and O.T. Jones, 1924, opp. cit.

some of the more systematic data are entered for comparison and they must be regarded as suggestions not to be taken very seriously in the present state of knowledge.

In Scotland, a 700 foot surface has been widely recognized. In Arran, a coastal platform at 400-500 feet above sea level has been reported which is presumed to be marine origin. (8) The extensive system of valley bottoms in Rannoch Moor and Kinlochleven lies between 750-1000 feet and was regarded by Bailey as formed by the wandering of streams. (9) In this case, if correlated with the 700 foot surface of Clydesdale, the higher altitude of the surface may be attributed to the remoteness of Rannoch Moor from the sea. Around Clydesdale, the 700 foot surface is of wide occurrence. Charlesworth mentioned a broad valley flat in the upper Nith valley at 700 feet above sea level and in the upper reaches of the Doon and Dee between ranges of the Merrick and Kells at 700-900 feet. (10) In Ayrshire, the surface is strikingly represented

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(8) G.W. Tyrrell, 1928, opp. cit and F. Mort, North Arran, A Physiographic Study, D.Sc. Thesis in the Glasgow University, 1914.

(9) E.B. Bailey, The Interpretation of Scottish Scenery, Scot. Geog. Mag., vol. 50, p. 323, 1934.

(10) J.K. Charlesworth, The Glacial Geology of the Southern Upland of Scotland, West of Annandale and Upper Clydesdale, Trans. Roy. Soc. Edin., vol. 55, 1926, p. 22.

by the wide flat of Airds Moss at 600-850 feet which slopes westward at a gradient about 19 feet per mile. It is probable that the flat was produced by earlier members of the River Ayr-Lugar Water system. (11) Similar broad flats occur between West Linton and Penicuik, known as Auchencorth Moss. The surface is broadly undulating and lies generally at 750-900 feet above sea level. Some streams have incised deeply into the surface and their valley sections show rock exposure almost right up to the surface of the plateau, indicating that drift on the plateau is generally thin. (Plate 32 and 33)

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(11) It may be noted that the altimetric curve for Ayrshire (1 inch sheet 78) shows two strong maxima at 200-350 feet and 700-750 feet.

Table Showing Sequence of Morphological Development in Various Parts of Great Britain

| Region | Erosion Surfaces | Marine or Subaerial | Authority | Corresponding Surfaces in Clydesdale |
|---|---|---|---|---|
| London Basin | 400 feet | marine (transgressed by sea) | Wooldridge | 700 ft. |
| | 200 | subaerial | " | 300 |
| Hereford-shire | 900-1000 | ? | Miller | 1200 |
| | 500-700 | subaerial } | " | |
| | 400 | marine } | " | 700 |
| | 250 | subaerial } | " | |
| | 150-200 | marine } | " | 300 |
| Pembroke-shire and Carmarthen-shire | 600 | subaerial | " | 700 |
| | 150-450 | marine | " | 300 |
| South Wales | 400 | marine | Goskar & Trueman | 700 |
| | 200 | marine | | 300 |
| East. Midland | 1000 | ? | Swinnerton | 1200 |
| | 650 | ? | " | 700 |
| | 300-450 | ? | " | 300 |
| Liffey Basin | 400-600 | ? | Farrington | 700 |
| | 200-300 | ? | " | 300 |

## Chapter X. Summary and Conclusions

In Clydesdale and its neighbouring regions, five major erosion surfaces have been distinguished corresponding to elevation of about 1800, 1500, 1200, 700 and 300 feet above sea level. The occurrence of the flat surfaces at these levels is indicated by detailed morphometrical analysis in profiles and altimetric, hypsographic and clinographic curves. Evidence was given to prove the cyclic origin of the platforms by showing that they were essentially independent of geological structure. Further strong support for the occurrence of these surfaces was derived from the longitudinal and transverse profiles of the Clyde and the Tweed and their tributaries, the knickpoints and terraces of which were correlated with different surfaces in the region. In addition, cols in the high mountains of Upper Clydesdale were found to correspond with the 1500 foot platform and the wide wind gaps in the region gave additional indications of the extensively developed 700 foot surface. In examining the validity of the separation of the erosion surfaces, over 1400 boring records in Lower and Middle Clydesdale were analysized and it is contented that the thickness of drift in the region can generally be taken not to exceed 36 feet and therefore will not affect the essential conclusion in regard to the surfaces. Other details regarding the distribution and disposition of the erosion surfaces were represented in a morphological map (Fig. 8) which was compiled according to certain well found principles.

The general morphological development of Clydesdale may be now summarized. Regarding the history of the higher platforms, little is known. From the disposition of valley terraces, it is contended that the 1200 and 1500 foot surfaces were probably shaped mainly by subaerial denudation. The reconstruction of the longitudinal profiles of the Clyde and Tweed for the 1200 and 1500 foot stages shows that these are broadly comparable with those of the middle reaches of the present rivers, although the 1200 foot stage was the less mature of the two.

The 300 foot and 700 foot platforms are widely represented and in Clydesdale they probably owe their forms chiefly to subaerial erosion, developed by a system of rivers graded to "potential" sea levels at about 150 and 450 feet respectively above the present. But this does not exclude the possibility of the drainage system having developed on an emerged surface of marine erosion of an earlier date. The sea must have remained stationary at the 450 foot level for a very considerable time as the 700 foot surface in the region and elsewhere is of very extensive development. Streams on the surface become well adjusted to the underlying structure and numerous cases of river capture occurred during this period. The withdrawal of the sea from the 450 foot "potential" sea level was probably slow and gradual with the result that the breaks of slope between the 300 and 700 foot surfaces are generally not very distinct. The sea finally halted at the 150 foot level to which the river system of the 300 foot stage was graded. The less mature development of the 300 foot surface in Clydesdale shows that the sea possibly did not remain constant at the 150 foot level for sufficiently long time before it fell again and caused the streams to entrench themselves into the 300 foot surface. This latest entrenchment can scarcely have been very remote in time since the new valleys are all steep sided and gorge-like. There is ample evidence to show that the sea level at that time stood some 300 feet below the present sea level. But this cycle was still in infancy when interrupted by the last rise of the sea which brought the sea to the present level producing buried valleys and drowned forests.

It may be noted that the above sequence of morphological development in Clydesdale is by no means unique. In fact, it finds abundant analogies in other regions, notably the London Basin, the Wye Valley, Pembrokeshire and Carmathenshire, the East Midland and the Liffey Basin of Ireland. The close coincidence of morphological history and broad correspondence of altitudes of the 700 foot and 300 foot surfaces over wide areas can not be dismissed as purely accidental but seems to point to the comparative stability of the land since the 700 foot stage, i.e. Pliocene, and strongly suggests a eustatic interpretation. However, more work is needed before a conclusion of such general significance can be definitely formulated.

Illustrations to "The Morphological Evolution of Clydesdale and Its Neighbouring Regions"

By Mei-Nge Jen, B.Sc.

June, 1939.

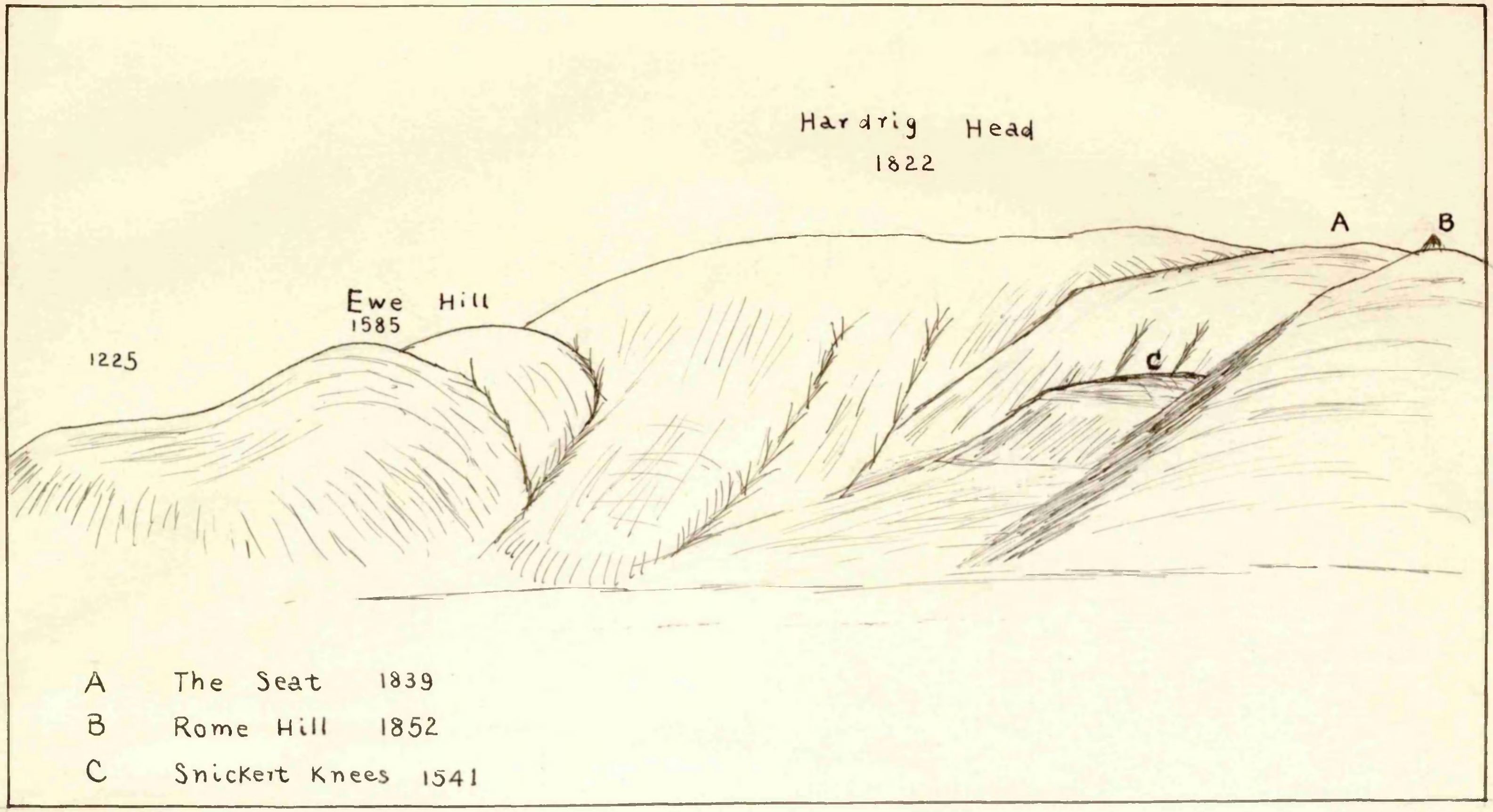



Plate 1. From Rome Hill near Crawford, looking north, showing the 1200, 1500 and 1800 foot surfaces in the neighbourhood.

Plate 2. The flat topped ridge of Clyde Law and Black Dod at 1750 foot level. View from Bught Shank on the Upper Tweed, looking west. Glencraigie Burn in the foreground.

Plate 3. The 1500 foot surface near Nutberry Hill, view from Grouse Hill, looking south. Showing also the flat 1200 foot surface of Grouse Hill in the foreground and its steep rise to the 1500 foot hills.

Plate 4. Annanhead Hill (1566 ft) rising steeply from the level surface in the foreground at 1300 feet. Notice also the unsymmetrical watershed between the River Annan and River Tweed.

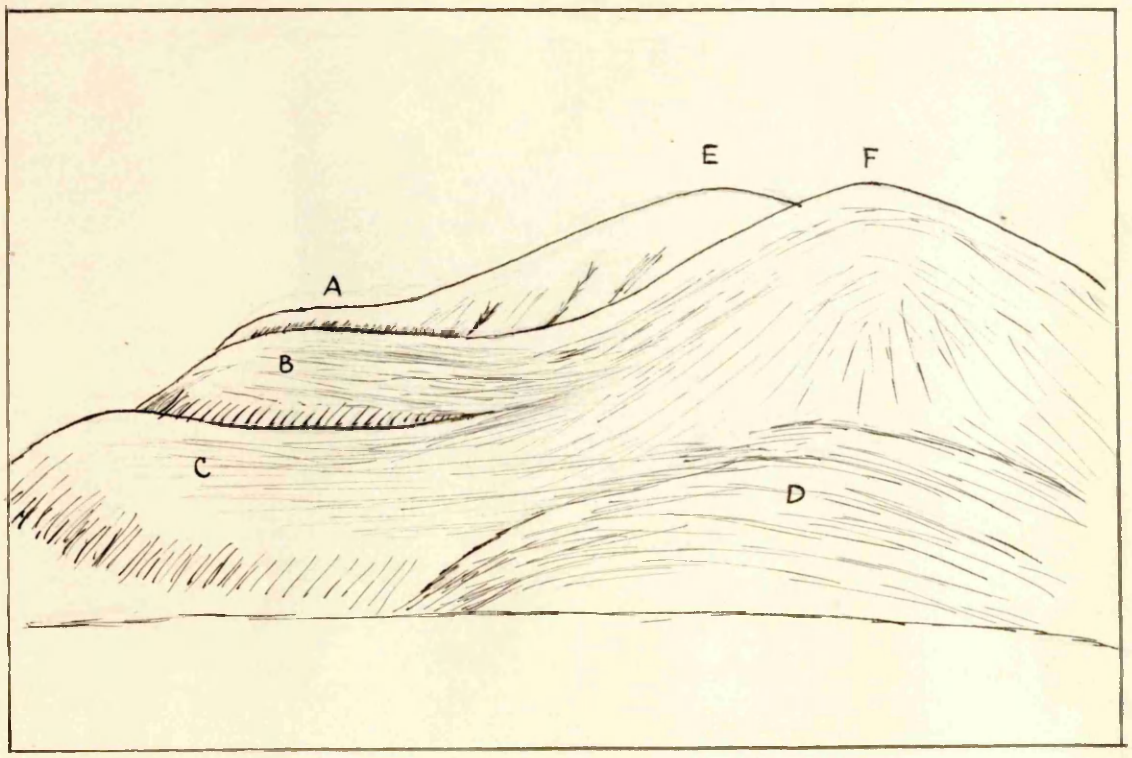
Plate 5. The flat featureless plateau of Kype Muir at the general level of 1150 ft.

Plate 6. The level plateau of Kype Muir and its steep descent to the 700 foot surface on the north. View taken from Netherside village, near Strathaven, looking south.

Plate 7. The Duneaton Water valley near Crawfordjohn Mill, looking downstream. Notice the mature character of the river valley and the level surface of hills on the background at 1200-1300 feet.

Plate 8. Devil's Beef Tub, view from the south, showing steep cliff formed by headward erosion of the River Annan.

Plate 9. The steep rise from Crookedstone Rig at 1300 feet to Archibald Gair Head at 1600 feet. Both hills are near Watermeetings. View from south-west.




A Craig Rig, 1366

B. Crookedstone Rig, 1319

C White Hill, 1226

D. Midheight, 1362

E. Archiebald Gair Head, 1621

F. Tomont Hill, 1652.

Plate 10. View from Brown Knees near Wintercleugh looking north, showing 1200 and 1500 foot surfaces.

Plate 11. The Daer Water valley near Watermeetings, view looking downstream, showing narrow valley flat at 900 feet. The flat topped hills (Brown Hill and White Hill) on the right are a part of the well developed 1200 foot terraces in the Upper Clyde.

Plate 12. Thankerton Moor from Cross Ridge, looking east. Showing wide flat of the Moor at 650-700 feet. The village in the foreground is Bowhouse (770 ft) which lies approximately on the inner margin of the 700 foot surface. The distant hills are Quothquan Law (1097 ft) and Biggar Common (1272 ft), stretching as a nearly continuous level surface.

Plate 13. The Clyde Valley near meetings, looking south. Notice the remarkable wide and open flat at 650 feet. Tinto Hill and Quothquan Law in the background.

Plate 14. The South Medwin valley near Dunsyre, looking downstream, showing the broad flat along the stream at about 700 feet above sea level.

Plate 15. The remarkable 700 foot surface near Coalburn, view from Auchlogan, near Lesmahagow.

Plate 16. The Middle Clyde from the top of Quothquan Law, looking north, showing the extensive area of flat surface at 700 feet in the neighbourhood of Lanark and Carstairs.

Plate 17. The Clyde near Thankerton, showing the wide open mature valley and meander scarps.

Plate 18. The 700 foot plateau south of Hamilton, looking south. The plateau rises over 200 feet from the 300 foot surface which is represented here as the flat ground in the foreground. The size of a house at the foot of the plateau gives some indication of the height of the break of slope.

Plate 19. The picturesque rise of the flat topped Cairngryfe Hill (1100 ft) and Swaite Hill (1049 ft) from Thankerton Moor, view from south. Notice Thankerton kame-moraine stretching in undulating mounds in the middle of the picture.

Plate 20. The Clyde Burn valley near Little Clyde village (seen on the right). The low scarp and small stream on the left is just at the elbow of capture. Notice the wide and open nature of the valley.

Plate 21. The Biggar Gap near Biggar.

Plate 22. The Culter-Kilbucho Gap, looking west. Notice the small size of the present stream.

Plate 23. The Tarth Water Gap across Shaw Hills. Notice the misfit between the broad floor of the gap and the insignificant stream which occupies it at present. The artificial nature of the present stream is clearly shown by its straight course.

Plate 24. The 300 foot surface rises as distinct terraces from the present Clyde valley. View taken from Bog Farm near Larkhall looking towards Netherton on the opposite side of the river.

Plate 25. Fall of the Clyde near Bonnington Linn Power Station, looking downstream, showing deep and rocky gorge cut by the river.

Plate 26. Fall of the Clyde near Corra Linn.

Plate 27. The upper reaches of the Blackbog Glen on the 700 foot plateau. View taken near Cadzow Reservoirs, showing the insignificant and sluggish nature of the stream on the plateau.

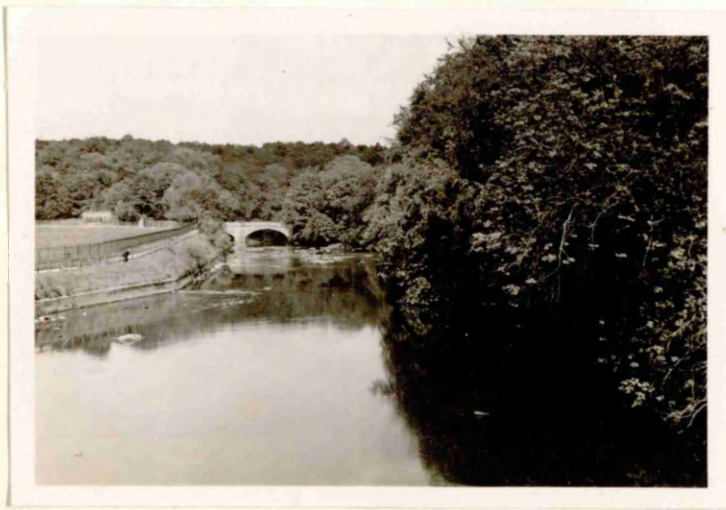


Plate 28. The lower reaches of the Avon Water entrenches deeply in the 300 foot surface. View taken at Fairholm Bridge, looking upstream. Notice the level plateau in the ~~left~~ background at 300-350 feet.

Plate 29. The deep gorge of the lower Mouse Water, from Cleghorn Bridge looking downstream. The flat topped hill in the background is a part of the extensive 700 foot surface near Lanark.

Plate 30. Kame-mounds near Easton. N.E. of Dunsyre, showing the effect of glacial accumulation on the 700 foot surface.

Plate 31. Esker-like ridge near Linnhead

Plate 32. Auchencorth Moss, view from near Auchencorth village, looking S.S.E., showing extremely flat surface at about 900 feet. Moorfoot Hills in the background.

Plate 33. The Harlawmuir Burn near Harlawmuir village, looking downstream. Deep gorge of the burn incises about 150 feet in the 850 foot platform. Notice outcrops of rock along the gorge.

# On the Meander-terraces of Middle Clydesdale

By Mei-Nge Jen, B.Sc.

June, 1939.

# On the Meander-terraces of Middle Clydesdale

By Jen Mei-Nge, B.Sc.

The ability of a stream to form terraces by its own swinging has long been noticed and described elsewhere.(1) If a wandering stream is slowly degrading its valley floor, each meander sweep past a given point at a slightly lower level than its predecessor; and each time a meander swings across the valley from one side to the other and back again, it will return at a level distinctly lower than that which it formerly occupied. This is the essential consideration underlying the current explanation of the formation of such river terraces. The resultant terraces have been variously called lateral terraces or alluvial terraces. It is desirable to distinguish terraces the formation of which is a normal element in the development of a valley within a single cycle of erosion from such as depend for their occurrence on the interruption of the cycle itself, and it is proposed here to group terraces of the first kind under the term, meander-terraces.

Terrace features are of common occurrence in the Clyde valley between Carstairs Junction and Crawford. But

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(1) See, for example, Hugh Miller, River Terracing: Its Methods and Their Results, Proc. Roy. Physical Soc. Edin. Vol. 7, pp. 263-306, 1883 and W.M. Davis, River Terraces in New England, in Geographical Essays, pp. 514-86, 1909.

a large number of features hitherto described as terraces consists of morainic ridges cut off by meander-scarps. They are not terraces according to the strict definition of the term. It seems desirable that the term meander-terrace should be restricted to forms due to erosion in previously formed floodplains, i.e. in a rivers own deposits. The general level surfaces of such features enable them to be readily distinguished.

In Middle Clydesdale, meander scarps are very common. As this part of the Clyde valley contains innumerable glacial and fluvio-glacial mounds and ridges, the river, swinging against them, rapidly undermines the loose deposits and meander scarps are readily formed. This is well illustrated in a series of cliffs along the Clyde cut in inter-kame sand ridges from Liberton to the junction of the Douglas Water, the most striking of which, on the south-east of Lampits, rises about 60 feet above the river. (2) As the river swings from one side to the other, the older cliffs will in time rise from the newly formed floodplain instead of directly from the river. They will then form abandoned meander scarps.

Because of undulating surface of morainic deposits, scarps in areas of glacial accumulation show a marked irre-

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(2) J.W. Gregory, The Kames of Carstairs, Scot. Geog. Mag., vol. 31, pp. 471-72, 1915.

gularity in height even within short distances. Near Covington, a set of abandoned meander scarps, remarkably fresh and about 10 to 15 feet high, occurs at the inner margin of a broad floodplain. This floodplain has already suffered erosion by the meandering river and in the near future there will be a true meander-terrace below the present scarps. On the east side of the river, deposition has been going on and part of the former watercourse is left as a small oxbow lake, above which rises a cliff about 25 feet high. Abandoned meander scarps also occur near Broadfield about 1½ miles south-west of Symington, cutting esker-like ridges; the heights of these scarps vary from 20 to 30 feet.

Interesting examples of meander-terraces occur just beside Lamington Station. About 150 yards north-east of the Station, a narrow meander-terrace with clear scarp rises about five feet above the present much wider floodplain, while the inner margin of the terrace is bordered by another less marked scarp of about the same height. Further downstream, a single higher scarp rises directly above the river. On the up-stream side, the two scarps are also represented by a single higher scarp, but owing to the construction of the railway, it is not certain whether the scarp has been artificially modified. A few yards south of the Station, meander-scarps sweeping south-westwards follow the 700 foot contour, rising about 10 feet above the present floodplain. It is highly probable that they are continuous to the north of the Station. (Fig.1) Near Broadfield, on the opposite side of Langholm village, a line of low scarps a few feet high is cut along the old floodplain and a new meander-terrace has thus been formed below which sand and gravel are rapidly accumulating to build a narrow new floodplain. (Fig.2) A good meander-terrace occurs at Longwell and Dingelburn about a mile north-east of Roberton. The villages are built on the flat meander-terrace with marked scarp about 20 feet above the present floodplain. The inner margin of the terrace is marked by a faint abandoned scarp of about the same height. (Fig.3)

It is interesting to note in this connection certain features of the tributary valleys which result from or are influenced by the meandering behaviour of the main stream. In the process of meandering, a main river is lowering its bed and undermining its banks. By the continuous shifting of meanders and widening of floodplains, the courses of tributaries are shortened. As the baselevel of a tributary is the level of its point of confluence with the main stream, the lowering of the bed of the main stream causes the lowering of baselevels of its tributaries and therefore cutting down of their beds which may keep pace with the falling baselevels. The effect of this relative rapid down-cutting in the tributary valleys is similar to that produced by rejuvenation. (3) Theoretically, in the transverse profiles it will include the formation of parallel terraces which will have approximately same heights on the two sides of the tributary valleys. As the downcutting will start from the mouth of tributaries where it will be most profound, the terraces will be highest and most prominent in their lower reaches gradually becoming lower and fading away further upstream.(4) The height of each of these terraces corresponds to the height of an individual meander-terrace or meander scarp on the immediate banks of the main stream. As the height of the latter varies from place to place, these terraces necessarily show a definite difference of heights from tributary to tributary. It is thought that certain criteria may be found by which they can be readily distinguished from such features as are formed essentially

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(3) Mallott calls the rejuvenation brought by drainage changes, i.e. river capture, static rejuvenation as distinct from the proper rejuvanation caused by the interruption of the cycle. ( C.A. Mallott, Static Rejuvenation, Science, vol. 52, pp. 182-82, 1920 ) As it will be shown here that the meandering and cliff-making of a main stream affect the formation of terraces or allied features on its tributaries and the resulting features are comparable to those produced by the rejuvenation proper, only on a much smaller and yet distinguishable scale, the process described may be regarded as a kind of static rejuvenation.

(4) This process of terrace formation in tributary valleys has been noticed by John Challinor who states: " The baselevel of a tributary is its point of confluence with the main stream, and this level is, in general, constantly falling. This will affect the conditions tending to produce river terraces in the lower reaches of tributary valleys." ( River-terraces as Normal Features of Valley Development, Geography, vol. 17, p. 147, 1932.)

by the interruption of the cycle. If a main stream is affected by rejuvenation, parallel terraces mostly cut through rock will be formed, the heights of which above the river will be greatest near its mouth, decreasing regularly upstream towards head of rejuvenation. The corresponding terraces developed in tributaries will therefore also show a regular and systematic relation to them. They will be higher in tributaries of the lower part of the main stream and decrease in height in those of the upper reaches of the main stream. Terraces produced by the meandering behaviour of the main stream will be related to different features of the main valley and their heights will not exhibit the same regular arrangement. In the longitudinal profiles of tributaries, the effect will be to develope a break of slope or knickpoint although the amount of downcutting may be too slight to make this particular break of slope very conspicuous.

In actual cases, a number of factors tends to modify the features produced. In Middle Clydesdale, between Crawford and Carstairs Junction, the lower courses of tributaries generally flow through the remarkable erosion surface at the height of 700 to 800 feet which is extensively developed in the neighbourhood of Lanark, Lesmahagow, Carstairs and Symington. Near their junctions with the Clyde, tributaries often moderately incise the flat peneplain surface as a result of the meandering behaviour of the main stream. But in this case, the incision doesnot cause the production of parallel terraces, because their old valley floors are masked and rendered undulating by the extensive glacial accumulation in this region and the resulting features are not really terraces. The incision results only in the development of steep scarps with approximately similar heights on the two sides of the tributary valleys. Scarps so formed may be called valley scarps, the steepness and fresh-cut nature of which distinguish them from the ordinary valley sides. In small burns which have not yet assumed meandering action themselves, valley scarps are most conspicuously developed near their junctions with the master stream. The Coldchapel Burn enters the Clyde at Coldchapel village ¾ mile north of Abington. Along its lower course, it flows in a narrow valley flanked with remarkable valley scarps about 30 feet high. Here on the Clyde, a series of abandoned meander scarps rises about 40 feet above the floodplain. The Brow Burn about 1½ miles north of Covington, the small unnamed burn near Annieston Plantation about 1½ miles south of Thankerton, and the Dingelburn about one mile north-east of Roberton, show similar features. Along the lower courses of these and other burns, valley scarps can often be traced for considerable distances. Their heights correspond roughly with the heights of meander scarps or meander-terraces on the immediate banks of the main river indicating the control exerted by the latter. Valley scarps are distinct from meander scarps both in origin and in form, for the former, resulted from simultaneous down-cutting of valley floors, are arranged in pairs and have approximately similar heights on both sides of tributary valleys, while the latter, being originated by the irregular erosion of a meandering stream, are generally more irregular.

A further modification is introduced by the meandering behaviour of the tributaries. In some larger tributaries of the Middle Clyde which meander freely in their valleys, valley scarps are modified into features intermediate in form between valley scarps and meander scarps. The Duneaton Water, one of the largest tributaries of the Middle Clyde, is interesting in this respect. Scarp features are well developed along the Water between Duneaton Bridge and Duneatonfoot Bridge where it joins the Clyde, but further upstream they become less and less marked. They are developed essentially in fluvioglacial deposits, but on the northern bank, near a wood about ¼ mile south east of Middencots, the scarp rising about 30 feet above the river exposes a rock base about 15 feet high which indicates the amount of downcutting through rock. These scarps show little tendency to occur in pairs, but in some places their heights corresponds fairly well. In the locality just mentioned, they are about 30 feet high on both sides of the river. The origin of these features is undoubtly due to the meandering action of the Duneaton Water itself but undermining on the immediate banks of the Clyde probably accentuates its formation. From Duneatonfoot Bridge to the wood mentioned, Silurian greywackes and grits frequently crop out in the valley floor and the slightly quickened flow of the river contrasts with the quiet sluggishness above. This probably indicates the minor discordance caused by the meandering and cliff-making of the main stream to which the adjustment has not yet completed.

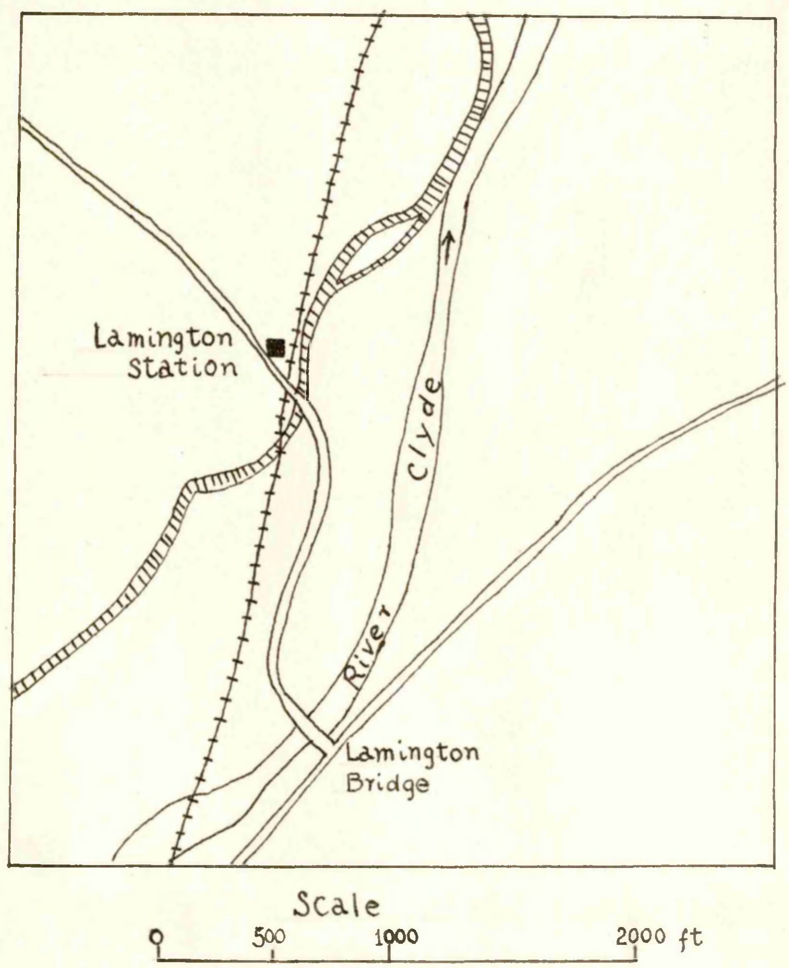



Fig. 1 Meander-terrace near Lamington Station. ( based on six-inch map)

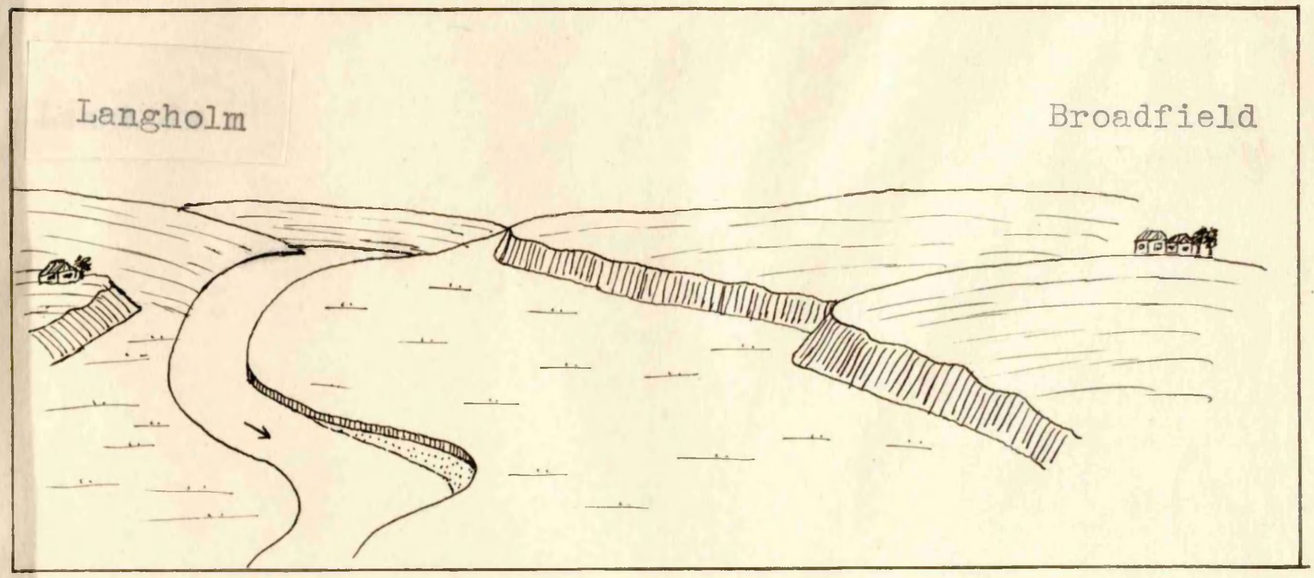



Fig. 2 New meander-terrace and abandoned meander scarps near Broadfield.

Fig. 3 Longwell village on the meander-terrace. Present floodplain in the foreground. Notice the two abandoned meander scarps. View looking upstream.

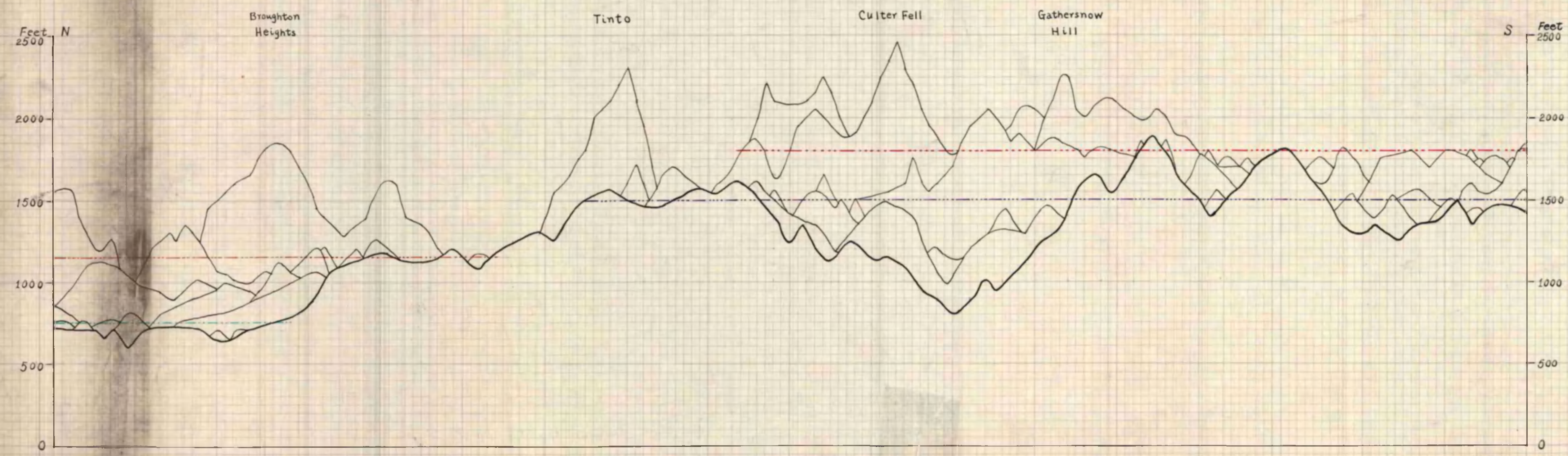



Fig. 1. Projected Composite skyline Profile of the 1 inch sheet 79, false summits eliminated, direction of Projection from W to E

Horizontal Scale: 1 inch to a mile Vertical Scale 10.56 times exaggerated (For explanation of colours, see Fig. 1a)

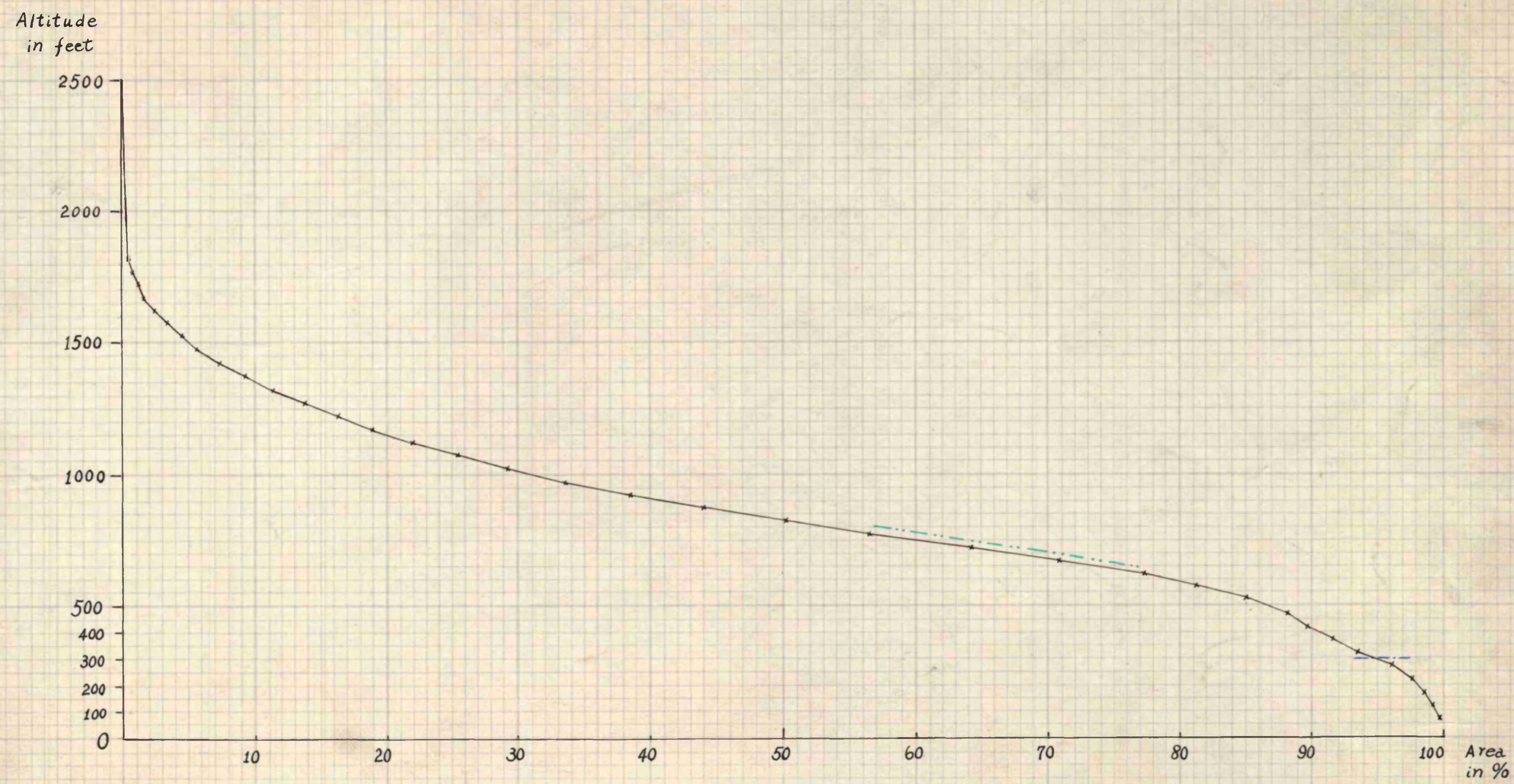



Fig. 2. Hypsographic Curve of Clydesdale

( 1 inch sheet 79 and western part of sheet 73 [D-M. 2-7], total area 663 sq. miles )

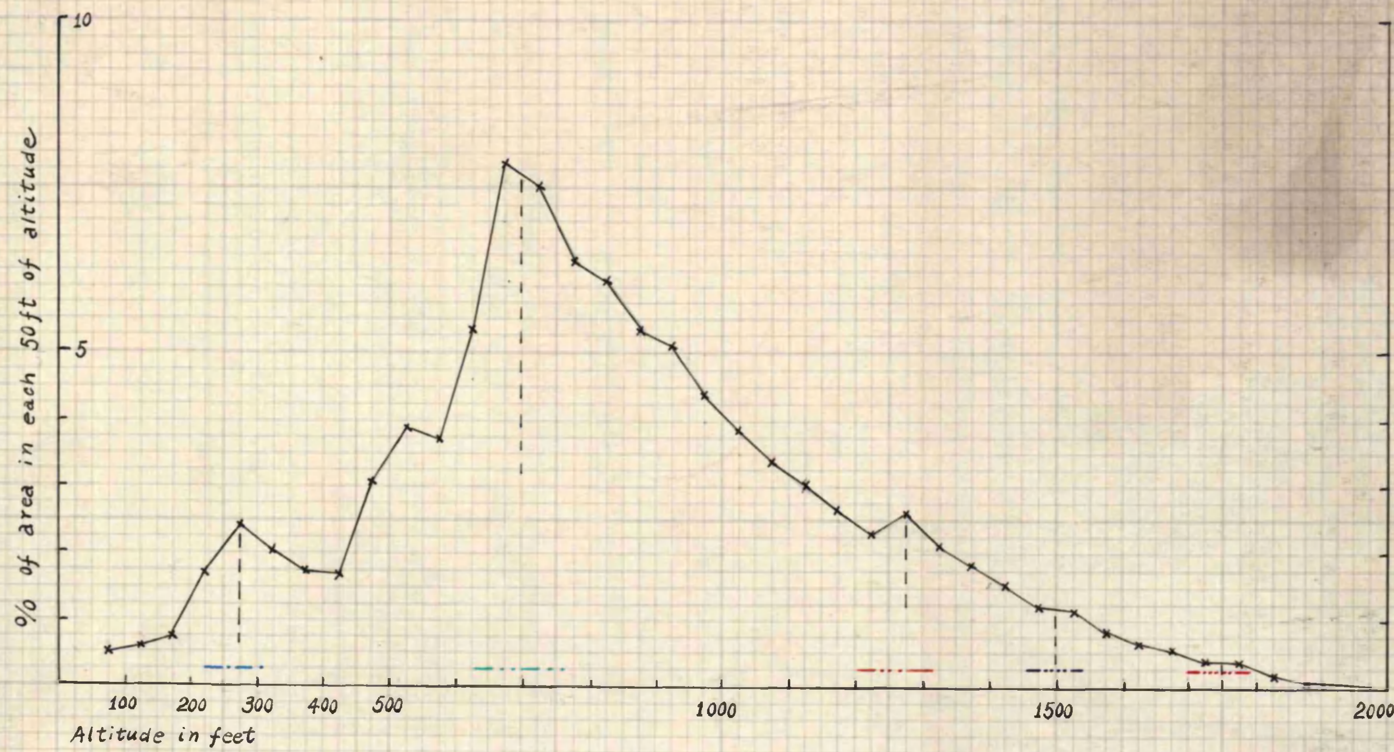



Fig. 3 Modified hypsographic curve of Clydesdale

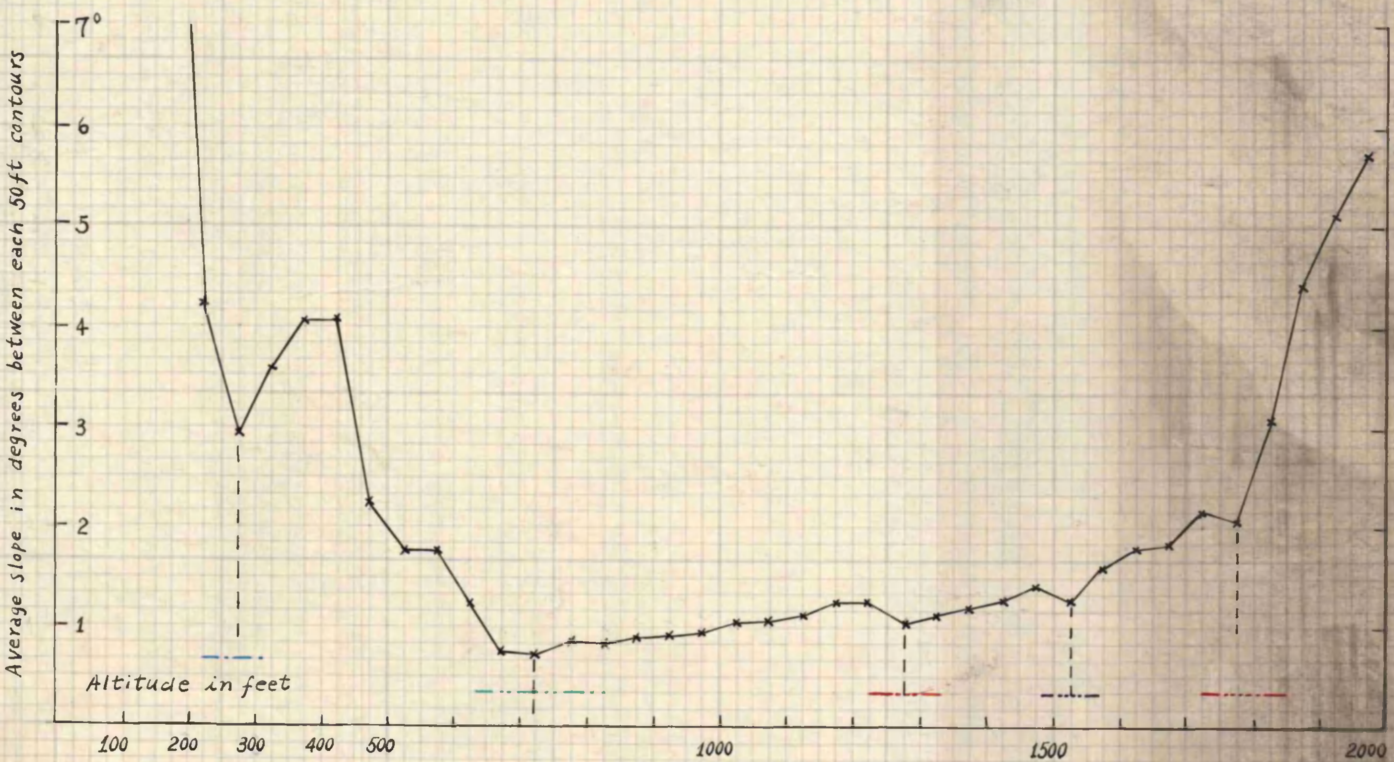
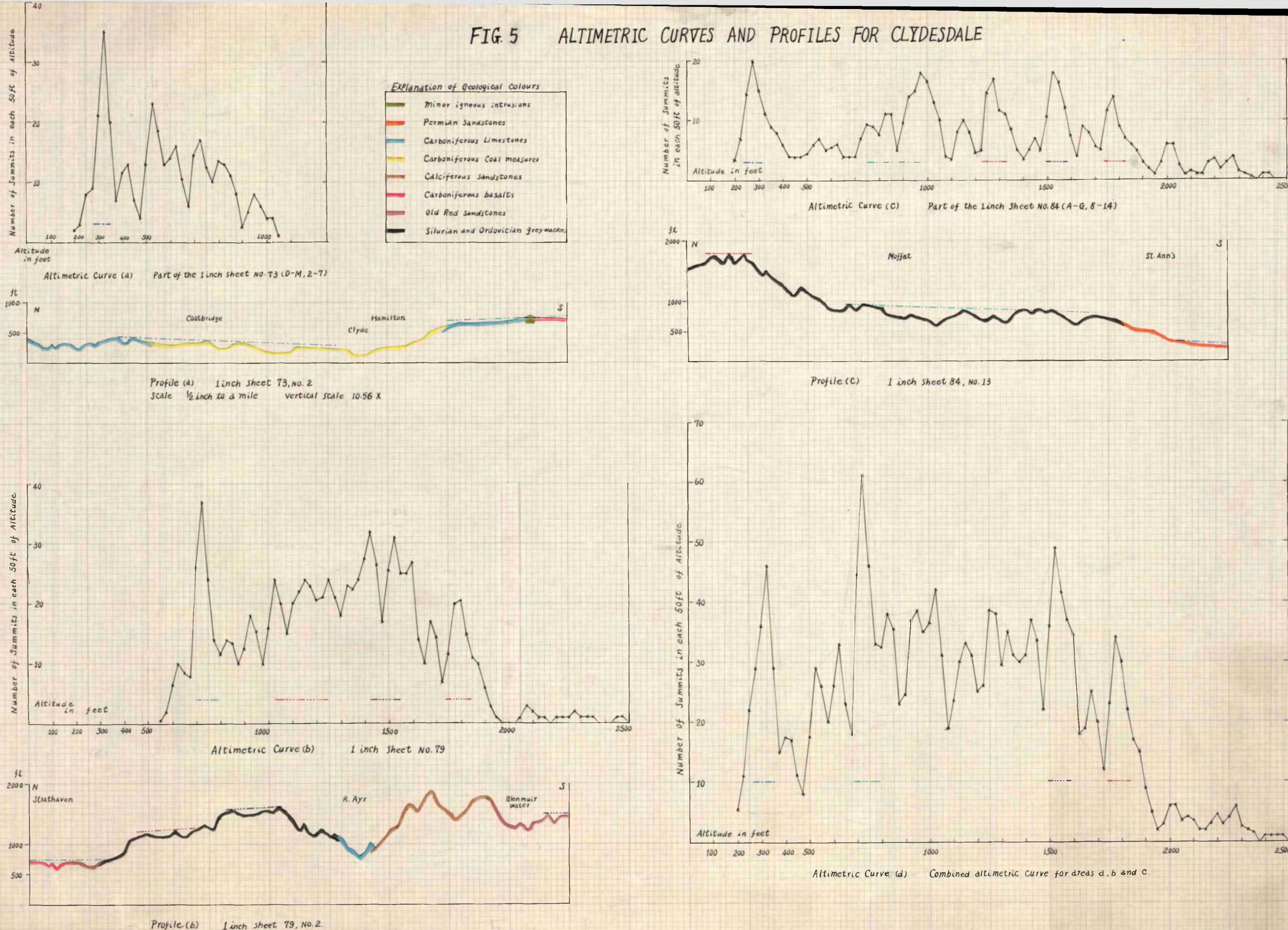



Fig. 4 Clinographic curve of Clydesdale

FIG. 5 ALTIMETRIC CURVES AND PROFILES FOR CLYDESDALE



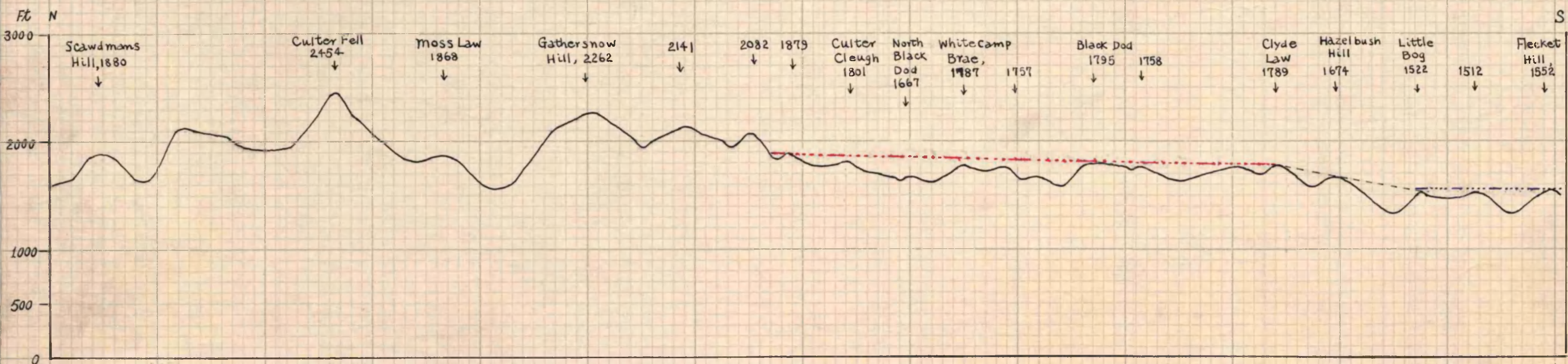
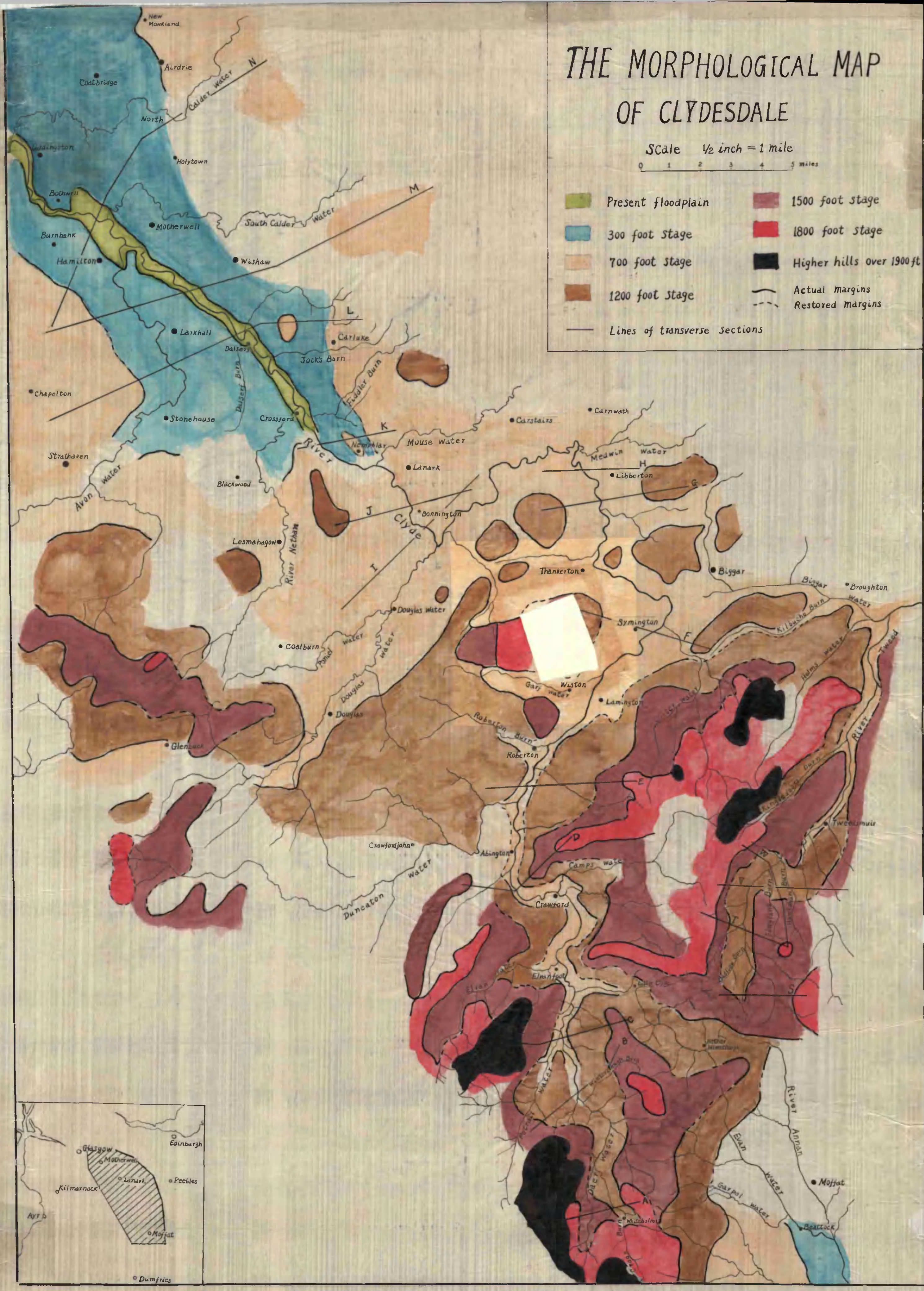



Fig. 7 Crestline Profile of the Waterdivide Region between the Clyde and Tweed
Showing 1800 and 1500 ft Surfaces.
Scale 1 inch to a mile Vertical Scale 5.28 times


THE MORPHOLOGICAL MAP
OF CLYDESDALE
Scale 1/2 inch = 1 mile
0 1 2 3 4 5 miles
Present floodplain
300 foot stage
700 foot stage
1200 foot stage
1500 foot stage
1800 foot stage
Higher hills over 1900 ft
Actual margins
Restored margins
Lines of transverse sections
New Monkland
Airdrie
Coatbridge
Calder Water
North
Holytown
Bothwell
Motherwell
South Calder Water
Burnbank
Hamilton
Wishaw
Larkhall
Dalserf
Carluke
Jock's Burn
Fiddler Burn
Chapelton
Stonehouse
Crossford
Carstairs
Carnwath
Strathaven
River
Mouse Water
Medwin Water
Lanark
Libberton
Blackwood
Avon Water
Bonnington
Clyde
Lesmahagow
River Nethan
Thankerton
Biggar
Biggar Water
Broughton
Douglas Water
Symington
Coalburn
Poniel Water
Douglas Water
Kilbucho Burn
Holms Water
Tweed
Garf Water
Wiston
Lamington
Douglas
Robertson Burn
Robertson
Glenbuck
River
Tweedsmuir
Crawfordjohn
Abington
Camps Water
Duneaton Water
Crawford
Elvanfoot
Elvan
River Annan
Evan Water
Garpol Water
Moffat
Beattock
Daer Water
Potrail Water
Glasgow
Motherwell
Edinburgh
Lanark
Peebles
Kilmarnock
Ayr
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A

FIG. 8

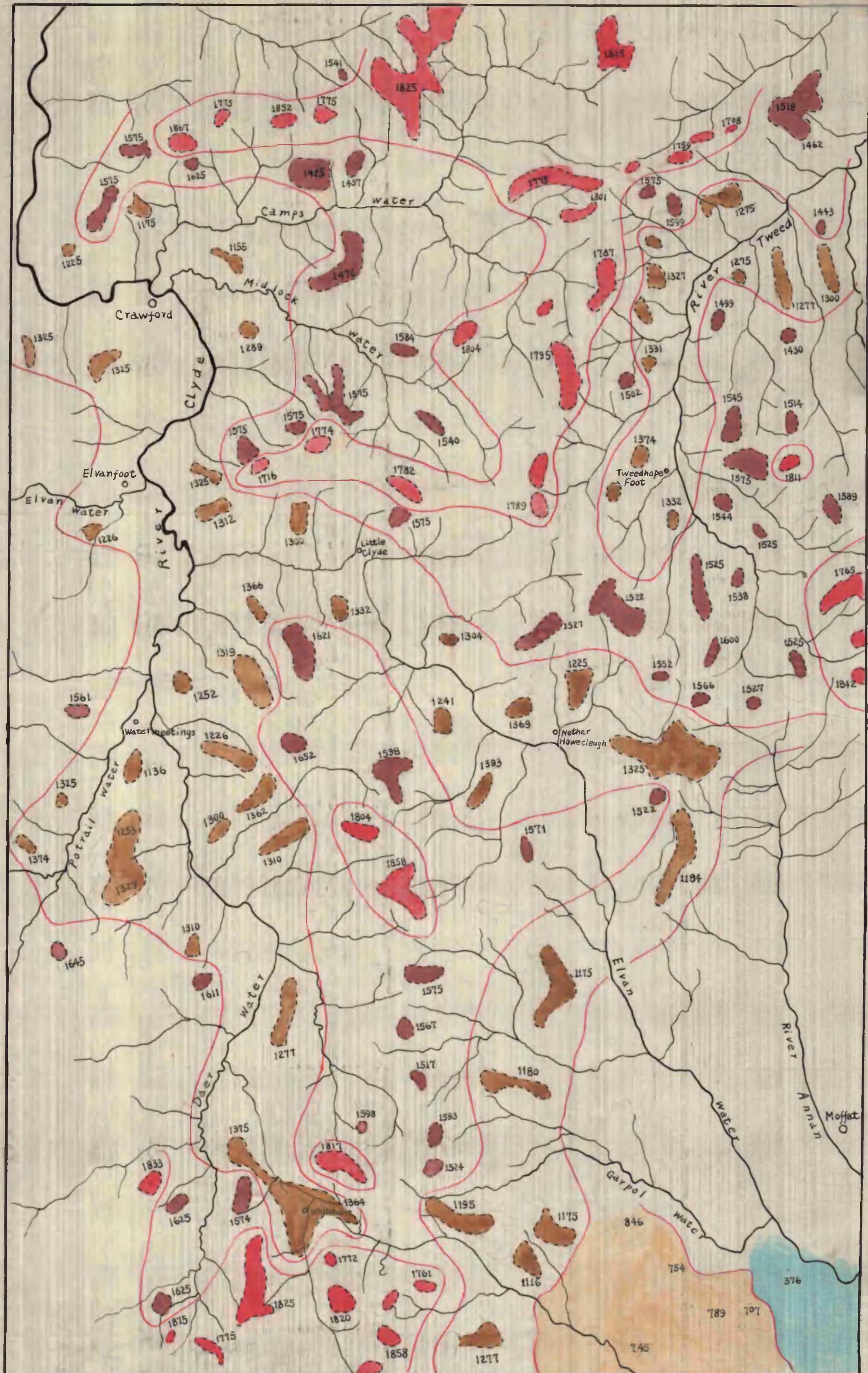


FIG. 9 SKETCH MAP SHOWING ACTUAL REMNANTS OF EROSION SURFACES IN UPPER CLYDESDALE

Scale 1 inch to a mile

For Explanation of Colours, see Fig. 8.

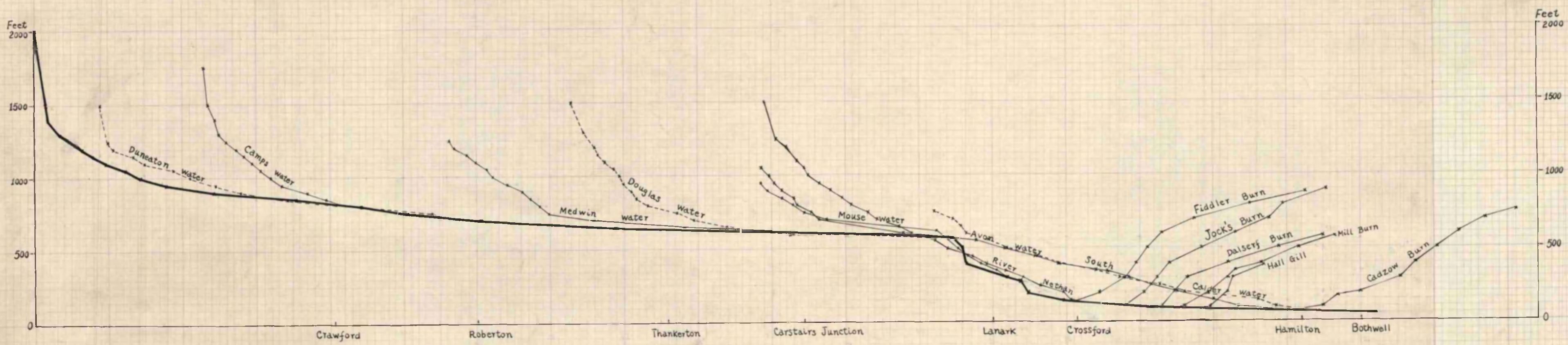


FIG. 10 LONGITUDINAL PROFILE OF THE CLYDE AND ITS MAIN TRIBUTARIES

Scale ¼ inch = 1 mile (Scale for Smaller burns drawn on the right: ½ inch = 1 mile)

Vertical Scale about 42 times exaggerated

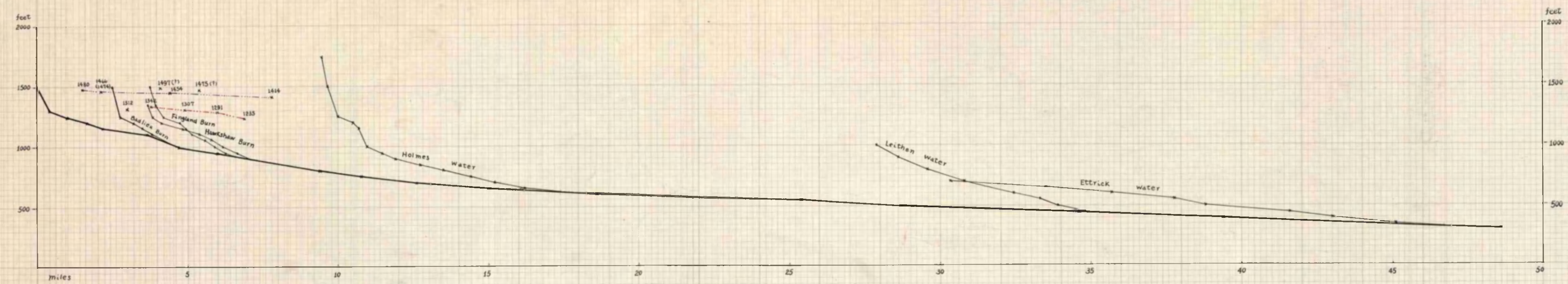


FIG. 12 LONGITUDINAL PROFILE OF THE TWEED AND ITS TRIBUTARIES

Scale ½ inch = 1 mile    Vertical Scale 21 times exaggerated

Restored Profiles in Coloured Lines (For Explanation of Colours, see Fig. 1a.)

Transverse Gradient for Restoration = 80 ft. per mile

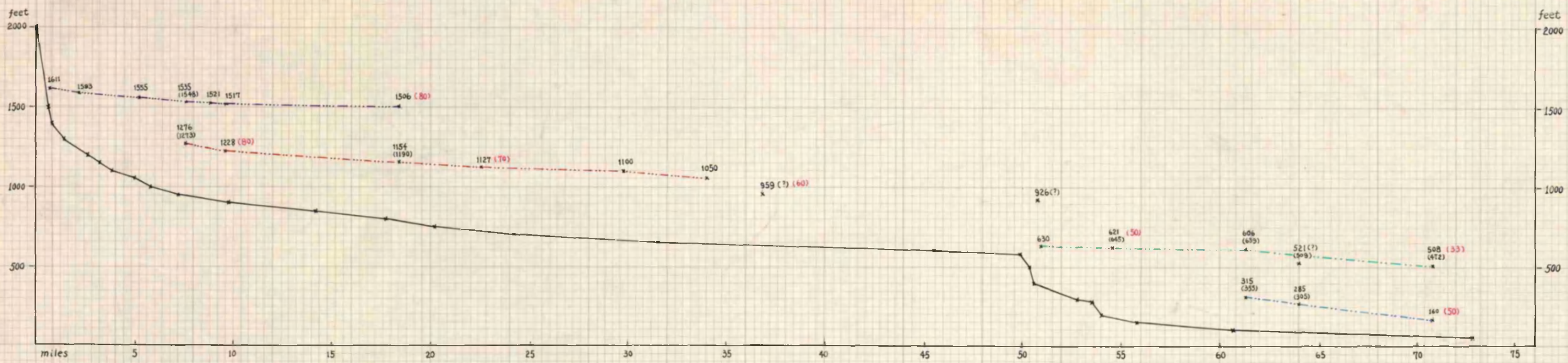


FIG. 13 RESTORED PROFILES OF THE CLYDE DURING VARIOUS STAGES

Scale: ¼ inch to 1 mile    Vertical Scale 42 times exaggerated

Profiles restored from terraces in Coloured lines (For explanation of colours, see Fig. 1a)

Assigned value of transverse gradient for restoration marked in red

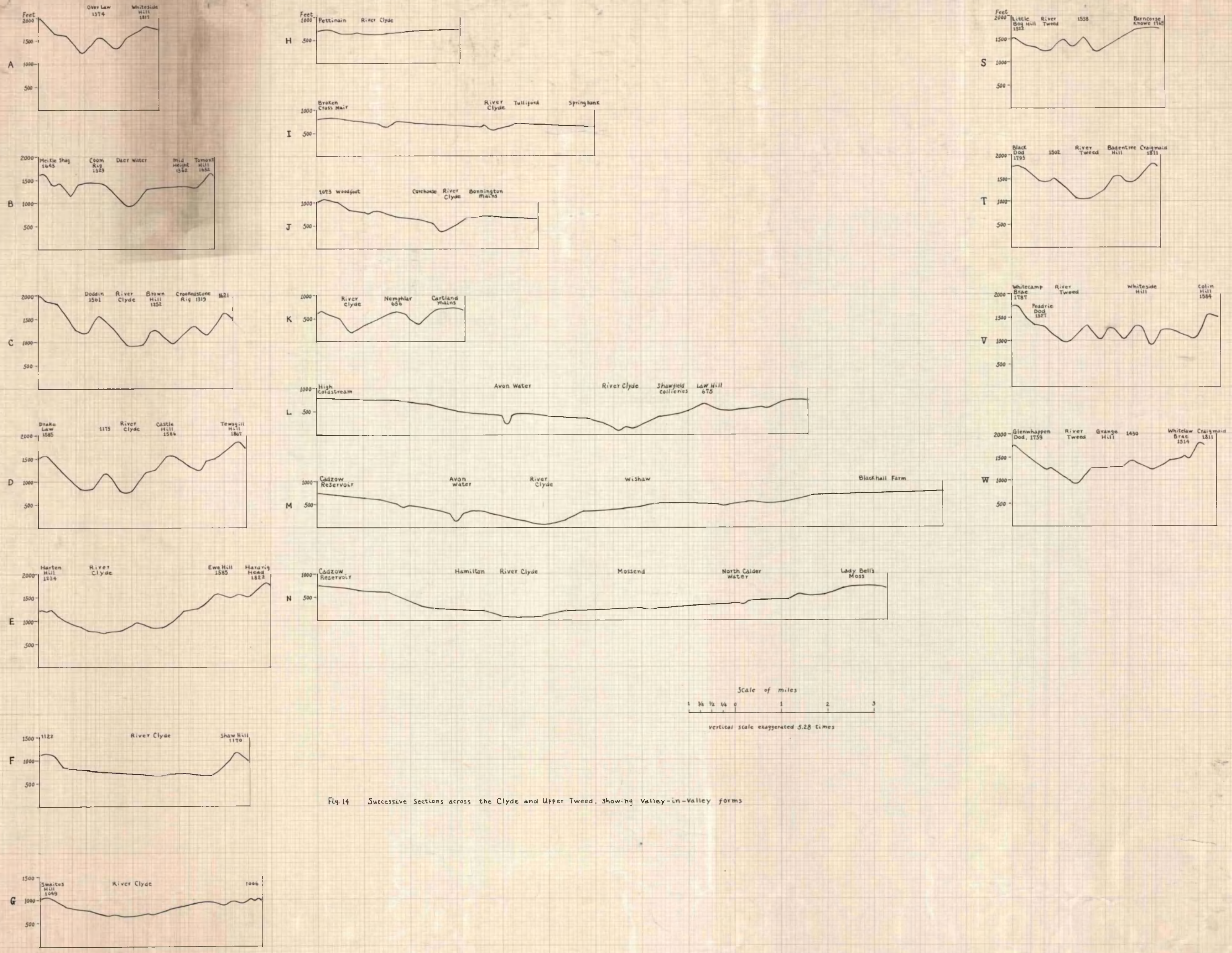


Fig. 14 Successive Sections across the Clyde and Upper Tweed, Showing Valley-in-Valley forms

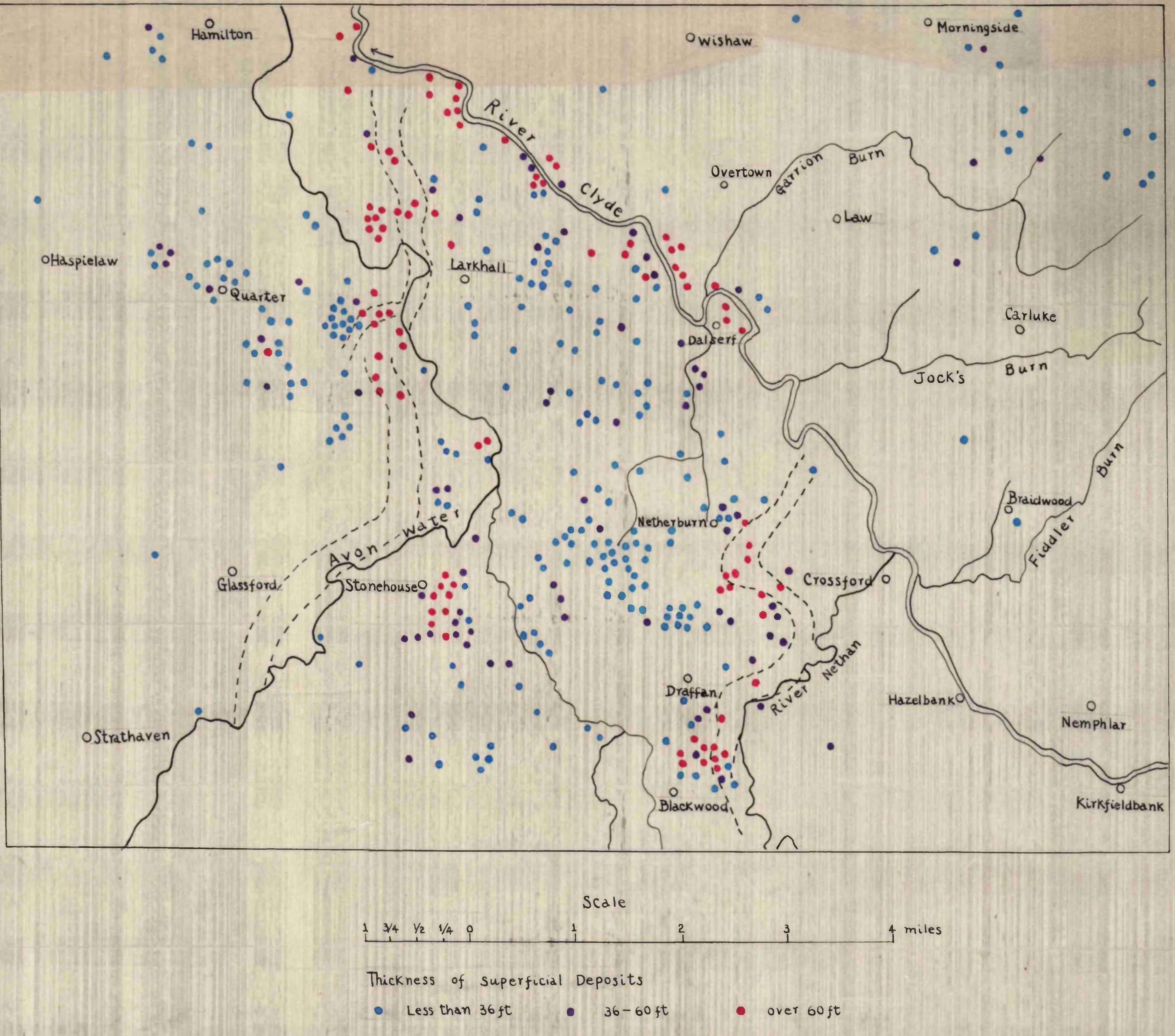


Fig. 17 Sketch Map Showing Variation in Thickness of Superficial Deposits in Lower Clydesdale