THE GEOMORPHOLOGY OF THE OCHIL HILLS

Thesis for the degree of Ph.D. Glasgow

by

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Photograph 1. THE SOUTHERN SCARP FACE.
On the left is Dumyat; from left to right may be seen the openings of the Menstrie, Balquharn, and Alva valleys.

INTRODUCTION

The Ochil Hills, running northeastwards from the Forth at Stirling, to Tentsmuir on the North Sea coast, are the most impressive and most extensive of the several uplands which diversify the Central Lowlands of Scotland (Fig. 1). Separating Strathmore from the coalfields and agricultural lowlands of Clackmannan, Kinross and Fife, for much of their length they offer a formidable barrier to north-south communications, only two really good roads crossing them in a distance of some twenty-five miles. In the west, the hills rise from the flat, near sea-level carselands of the Devon in one of the most magnificent escarpments in Britain, reaching heights of 1,600-1700 ft. above sea-level in one unbroken slope (Photographs 1 and 2). In the east, beyond Glen Farg, they deteriorate into a "tail" of low, isolated hills: this area has not been included in the present study. The width of the range varies, from ten miles in the west, to less than five in the east. In the west are the highest summits, culminating in Bencleuch at 2,363 ft. O.D., and enclosing the deep valley of Glen Devon. Further east, although the Water of May occupies a deep, longitudinal valley, there is no development of an independent drainage system comparable to that of the Devon and its tributaries, and the hills become a relatively simple divide between drainage to the Earn and to the Firth of Forth.

Photograph 2. THE OCHILS FROM THE UPPER FORTH VALLEY.

Surrounding the Ochils, which are completely isolated from neighbouring hill-masses, are a number of broad lowlands - on the north, Strath Allan and Strath Earn; on the south, the Lower Devon Valley, and the low Clackmannan Plateau*, the Plain of Kinross, and the Howe of Fife (see Fig. 1). These contrast with the hills in many respects: while much of the contrast is due to the difference in altitude and relative relief, it seems also to reflect differences in rock type, and in the effects of glaciation. Thus most, but not all, of the lowlands are developed on sedimentary rocks, probably of lower resistance to denudation than the andesitic lavas, tuffs and agglomerates of the Ochils; and all are characterised by thick and extensive fluvio-glacial and Raised Beach deposits. The hills, although on the whole not heavily glaciated, as compared with parts of the Highlands, nevertheless show more evidence of the erosive power of ice.

The position of the Ochils, extending for some distance along the Midland Valley, their upstanding nature, and the evidently greater age of their landforms, as a whole, as compared with those of the surrounding lowlands, suggests that they may retain evidence of stages in the development of the landscape which have largely disappeared from the lowlands. The identification and description of such stages may be expected to explain some, if not all, of the existing landforms.

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* This name has been given to the area of low altitude, lying between the carselands of the Devon and Forth, extending eastwards to the Cleish Hills.

Such an account can hardly be complete - inevitably much of the evidence must have been destroyed - but enough may remain to make a study of the geomorphology of the area of value. Considered in relation to their wider setting, the Ochils may be expected to throw some light on problems of more general interest - notably, on the nature of the initial drainage pattern of Scotland, whether this consisted of NW-SE consequent streams as suggested by Mackinder,[1.] and later by Peach and Horne,[2.] or of W-E consequent streams, as suggested by Bremner[3.] and Linton.[4.]

Abundant evidence remains of the modifications of the landscape due to the ice-sheets of Pleistocene times, particularly of those associated with the withdrawal of ice-fronts from the area. The pre-glacial drainage pattern was temporarily disrupted, and has not been entirely re-established in some areas, the deposition of enormous quantities of sands and gravels having largely obliterated it. The description and explanation of these features must inevitably indicate the probable lines of advance and retreat of the ice-fronts concerned, and may well contribute to the understanding of the period over a wider area.

Published material on the Ochil Hills is limited, and no complete study of the area appears to have been attempted. Most writers have been concerned, not so much with the hills, as with the wider area of which they form part. This is particularly evident in the work of Gregory,[5.] Charlesworth,[6] and Simpson,[7] all of whom consider the deglaciation of the whole, or part of the Midland Valley mainly as it affected the lowland areas. Certain peculiarities of the Devon drainage system have been the subject of more detailed investigation, but have not been related to the development of the drainage pattern of the hills as a whole.[8,9]

Memoirs published by the Geological Survey cover part of the area, but none has been published for Sheet 39, covering the western part of the hills. That by Sir Archibald Geikie,[10] however, dealing with Sheet 40, also contains valuable observations on the general structure and character of the hills. More recently Dinham contributed a short description of the geology of the western part of the Ochils to the account of the geology of the district around Edinburgh, edited by Flett and published in the Proceedings of the Geologists Association.[11] The memoir on the Economic Geology of the Stirling and Clackmannanshire Coalfield[12] contains more information on the superficial deposits of the Lower Devon and Forth valleys, and various other features have been discussed in the annual Summary of Progress published by the Geological Survey.

The present account is based on fieldwork carried out during the years 1953-56, but particularly in the summer months of 1954 and 1955. In the course of fieldwork the detailed morphology of the area was mapped on the scale of 1:25,000 using conventional symbols for various features of importance - e.g. breaks of slope, terraces and meltwater channels.

Details of the maps used, and of the technique of mapping, are included in an appendix.

The writer wishes gratefully to acknowledge the financial assistance granted by the University of Glasgow, but for which the extensive programme of fieldwork could not have been undertaken. Grateful acknowledgements are also due to Professor D.L. Linton, of the University of Sheffield, and to Mr. H.A. Moisley and Dr. R. Common of the University of Glasgow, for their advice during the preparation of the manuscript and maps.

The series of maps illustrating this thesis have been bound into a separate volume, together with the relevant 1-inch Ordnance Survey maps. National Grid references have been used to identify certain points mentioned in the text.

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THE GEOLOGICAL BACKGROUND: THE RELATION OF GEOLOGY TO MORPHOLOGY

Information on the geology of the Ochil Hills is chiefly to be found in Geological Survey publications, and in particular in the memoir by Geikie on Central and Western Fife and Kinross, published in 1900.[1] Although concerned mainly with the eastern parts of the hills, covered by Sheets 40 and 48 of the 1-inch Geological maps, Geikie also considers the general structure, and some features of the western hills. The only recently published geological map of the area is Sheet 40 (1954) the remaining areas being covered by Sheets 39 and 48, published in 1897 and 1893 respectively. Some 6-inch maps of the Lower Devon Valley have been published and it is possible to consult a number of unpublished manuscript maps on both the 1-inch and 6-inch scales in the library of the Geological Survey in Edinburgh.

The Lower Devonian andesites of which the hills are largely composed are arranged in a broad anticline trending SW-NE. This appears to be of simple structure, with little subsidiary folding. It has been truncated in the south by the important Ochil Fault while in the north-east the crest has been dropped by trough-faulting along the line of the Firth of Tay and the Carse of Gowrie (Fig. 1) so that younger strata, including members of the Carboniferous series have been thrown against the andesites.[2] The oldest sedimentary rocks exposed in the area are found lying conformably on the andesites in Strath Allan and Strath Earn and are of Lower Devonian age (Fig. 2). They consist of conglomerates, sandstones and marls, the intercalation of lava flows with the lowest of the conglomerates and sandstones indicating that deposition had commenced before vulcanicity had entirely ceased. Andesite pebbles are found in the conglomerates.

A considerable unconformity apparently exists between the Lower and Upper Devonian. The younger series also consists of conglomerates, sandstones and marls. Geikie notes that in a quarry at the western end of the Firty of Tay downfaulted area, the unconformity was formerly visible.[3] Elsewhere its presence can only be presumed, owing to the cover of superficial deposits, but Upper Devonian strata appear to overlap on to the Lower Devonian sedimentary series, and in places, chiefly in the Plain of Kinross, on to some of the ~~lower~~ members of the volcanic series. At Monk's Grave near Powmill (36/010972) a small area of andesites rise through the Upper Devonian, showing, as Geikie remarks "on what an unconformable and uneven surface the Upper Old Red Sandstone must be resting"[4]. Throughout the area, the Middle Devonian is missing.

Rocks of Carboniferous age occur in the small area north of the hills at Doon (37/140158) where they consist of sandstones, marls and shales forming the Cementstone groups at the base of the series, and to the south in the Lower Devon Valley and the Clackmannan Plateau, where they include coal bearing strata. Here they are disposed in a syncline running north-south, and pitching towards the Ochils. The Ochil~~s~~ fault truncates the syncline, throwing the strata against the Lower Devonian andesites. West of Menstrie the Carboniferous Limestone series is present, passing eastwards under the Millstone Grit, which in turn passes under the productive Coal Measures in the centre of the syncline. The Devon Red Sandstone, correlated with the Barren Red Measures at the top of the Carboniferous, lies uncomformably on the Coal Measures between Alva and Tillicoultry.[5.]

The la~~y~~vas are described by Geikie as consisting chiefly of "the varieties of somewhat altered andesite which were formerly included under the general term 'porphyrite'".[6.] Except on Sheet 40 the geological maps show no sub-division of the lavas, which are dismissed as "Unclassified andesites" (Sheet 39) and "Porphyrite with occasional sheets of diabase" (Sheet 48). More detail is given on Sheet 40, pyroxene-andesite, Hornblende-andesite and Trachyte being distinguished, although there still remains a category of "Unclassed-andesite and basalt". The andesites are intermediate to basic in character, but more acid felsitic rocks also occur. Geikie remarked of the latter: "That they are true contemporaneously erupted lavas and not intrusive sills is proved by the abundant fragments of them contained in the intercalated conglomerates and sandstones".[6.] On the geological maps, however, they are classed as intrusives, notably on the revised edition of Sheet 40. Interbedded with

Photograph 3. THE NORTHERN SCARP FACE.
The inclination of the strata may be clearly seen. At the foot of the scarp, on the left-hand side, is a part of the Farg fan.

the lavas are agglomerates and tuffaceous conglomerates. The agglomerates frequently containing very large blocks of andesite, measurable in terms of feet, while the fragments in the conglomerates are smaller and usually slightly water worn. Alternation between lavas and agglomerates, etc., is probably much more rapid than appears on the maps, and detailed mapping would probably reveal considerable variation among the lava-flows themselves. Such variations can frequently be picked out in the field, emphasised by their varying resistance to erosion, and are particularly well demonstrated along the fault-line scarps both on the north and south of the hills, and in certain valleys, especially those of the Hillfoots streams* (Photographs 1 and 3).

A number of dykes occur within the hills: their effect on relief is generally negligible (Fig. 2). Some are picked out by gullies in the valley sides: where the dykes are metalliferous such gullies have been enlarged by mining activities - an example of this may be found in the Glen of Sorrow, near Dollar - but the more gently sloping upland surfaces are cut indifferently across them. It may be assumed that these surfaces are of later date than the dykes, but the age of these

* The Hillfoots streams are those draining south to the Lower Devon. At the point where each leaves the hills an alluvial fan has been deposited, on which a line of small towns has developed, known locally as "The Hillfoots". The name was applied to the valleys behind these towns by C. Davison in describing the earthquakes affecting the area, in "A History of British Earthquakes" 1924.

is undertain. On Sheet 48 certain small dykes are described as basalt "of Tertiary age"; Geikie, also, regarded the longer west-east trending dykes as of Tertiary age, describing them as members of the system having its greatest development "among the Tertiary volcanic plateaux of the Inner Hebrides".[7.] They are not, however, included in the map of the system included in the more recent memoir on the Tertiary volcanic districts,[8.] and are described as of Permo-Carboniferous age on Sheet 40, agreeing with the dating suggested in the 1925 memoir on the Glasgow District.[9.] It would thus appear that the dykes throw little light on the precise age of the upland surfaces.

In the southwestern parts of the hills a number of faults running W.N.W. are accompanied by intrusions, usually metalliferous. During the 18th and 19th Centuries many of these intrusions were worked for silver and copper.[10.] The Ochil Fault is also accompanied by an intrusion, of quartz-dolerite identical in composition with that of sills at Stirling and in Fife. These are considered to be of Permo-Carboniferous age,[11.] and a similar age has been assigned to the Ochil Fault sill. This is not visible at all exposures of the fault, but the individual occurrences, which may attain a width of 200 yards, appear to belong to the same intrusion. A short distance east of Dollar the intrusion forsakes the main Ochil Fault, and follows a branch fault (Fig. 2). In several exposures, one or both edges are chilled, and this is regarded by Haldane as evidence that the intrusion is later than, or at the earliest, contemporaneous with, the fault itself.[12.] As it has affected the highest members of the Carboniferous series, a Permo-Carboniferous age may thus be assigned to the Ochil Fault. Later movement may have taken place along it, but "Faulting later than the intrusion must have been relatively insignificant or the indications of subsidiary fracture along the line could scarcely fail to be more intense than appears to be the case". (Haldane.)[13.]

The Ochil Fault is the most important of all those occurring in the Ochils and the adjacent areas, and the amount of throw has been estimated at 10,000 feet.[14.] Where it cuts the northwestern limb of the Ochil anticline, between Bridge of Allan and Muckart, the impressive southern face of the hills has been developed. That this is an erosional feature, and not a true fault-scarp, is indicated by the fact that, further west, the somewhat similar northern face of the Campsie Fells is due to the presence of resistant Carboniferous lavas on the downthrow side of the fault, as is that of the Cleish Hills in the east (Fig. 1). It is noticeable that no comparable feature has been developed between Muckart and the Cleish Hills, where the fault crosses the southeastern limb of the anticline. While this may be partly a reflection of a decreased amount of throw, the fact that there is no physiographic expression of this limb at all comparable to that of the northwestern in this area is probably of greater significance. The fault ceases to be closely associated with the edge of the hills (as this is defined by the generalised 600 ft. contour) but continues first eastwards, then south-eastwards, while the edge of the hills trends north-eastwards (Fig. 1). Between the Ochils and the Cleish Hills, much of the Plain of Kinross is developed on the Lower Devonian andesites (Fig. 2).

The second major fault of the area is that on the south side of Strathearn and the Firth of Tay. Here downthrow is to the north, the amount being estimated by Geikie at several thousand feet. Upper Devonian strata, and near Dron, Lower Carboniferous strata also, are thrown against the andesites (Fig. 2). Geikie inferred that the later systems were at one time continuous across the hills, and that even younger strata may have covered them.[15.] No date has been assigned to this fault: it may be of the same age, or possibly earlier than, the Ochil Fault. The fault-line scarp along this northern edge of the Ochils is by no means as impressive as that to the south, being at the most not more than half the height of the latter (Photograph 3).

Most of the faults shown on the Geological Survey maps within the Ochils have not been the subject of detailed investigation. In the west, however, a number trending in general NNW, which terminate against the Ochil Fault (Fig. 2) and are not continued in the Carboniferous strata to the south, may be pre-Carboniferous in age. All throw to the west, lowering successive blocks of the andesites. Other faults with a

Photograph 4. THE GLEN OF SORROW.
Looking downstream. The meandering stream and slumped sides are typical of most valleys where the stream is incised into a boulder-clay infilling.

similar direction occur in the Central Ochils, in the area between Dunning (37/019145), Milnathort (37/120048), and Glen Farg, but are few in number. Their direction suggests that they may be of similar age to those in the west.

The alignment of certain valleys suggests a possible fault system with a direction roughly SW-NE (Fig. 4). Only two such faults are actually mapped, neither of great importance, to the north of Tillicoultry and Dollar. The line of the valleys in which these occur, namely, those of the Gannel and Care streams, is continued by Glen Sharup and Glen Quey, and is roughly paralleled by the lower Frandy valley. Certain other valleys show a similar direction, notably that of the Water of May, Glen Anny and Glen Farg (Figs. 3 and 4). While there is little evidence of structural control of these valleys on the geological map, apart from the small faults mentioned, and certain small dykes west of Dollar, their alignment is so marked as to suggest that a series of sub-parallel faults may in fact have influenced their development. In view of the presence of thick deposits of boulder-clay in all the valleys (Photograph 4) the failure of observers to detect such faults in the field is not altogether remarkable; it is notable that where such deposits are absent, and the andesites well-exposed, in a spillway joining the Care and Quey valleys, a fault running SSW-NNE has been traced. In the coalfield to the south of the Ochils a number of faults trending E 30°N, and E 40°N are

Photograph 5. GLEN QUEICH.
The beginning of the Keerie Glen spillway just appears halfway up the right-hand margin of the photograph.

recorded, and are considered to be later than the east-west faults of the same area, which are probably of Permo-Carboniferous age.[16] It seems possible that the movements giving rise to these also produced faults of a similar direction in the andesites, and that, approximately parallel as they are to the anticlinal axis, they may represent renewed movement along Caledonian lines. A number of valleys have a general NW-SE trend, but are not all associated with the faults having this direction. The alignment is, however, well-marked and may indicate a greater measure of structural control than is suggested by the geological map. Included in this group are the Coul-Cloan valley, the Lamb valley, the Daiglen valley, the Glen of Sorrow and Glen Queich, (Photograph 5). Of these only the latter, a spillway, is known to be fault-guided. It is also the only valley of the system in which the andesites are exposed over any distance. These linear elements in the landscape are shown in Fig. 4.

The initial arching of the Ochil anticline would appear to have taken place, as was suggested by Geikie in "Scenery of Scotland",[17] in the period following the deposition of the Lower Devonian, and prior to the deposition of the Upper Devonian on the folded and denuded strata. The conformable junction between the Lower Devonian volcanic series and the overlying sedimentary strata in Strath Allan and Strath Earn indicates that no great movement took place during Lower Devonian times.

It seems probable, from the extent to which the Upper Devonian overlap the andesites, that the absence of the southeastern limb of the anticline in the Plain of Kinross may be largely attributed to denudation during the Middle Devonian period, and it is possible that other areas were similarly affected at this time. Although some faulting may have taken place in pre-Carboniferous times, the major faults of the area appear to be of Permo-Carboniferous age, and have considerably modified the anticline, truncating it in the south, and dropping the crest in the north-east. Later faulting may have provided lines of weakness along which some of the present valleys were developed.

Structural control of the morphology of the Ochils appears to be strong, in that the upstanding hill-mass is developed entirely on the resistant volcanic rocks, and contrasts strongly with the surrounding lowlands developed on sedimentary strata - a contrast that is emphasised by the abrupt rise of the northern and southern fault-line scarps above flat, Raised Beach deposits. There are, however, certain features which reveal that this structural control is not as important as might at first appear. Certain of the surrounding lowlands are developed on andesites apparently identical with those forming the hills - in particular, a large part of the Plain of Kinross, and also a small area of Strath Earn (Fig. 1). In the Plain of Kinross, andesites underlie a considerable area of the western plain, extending almost as far east as Loch Leven. The edge of the hills, rising relatively steeply from the lowland (indicated on Fig. 3 by the generalised 600 ft. contour) corresponds to nothing on the geological map* (Fig 2). In Strath Earn, the andesites form a narrow strip between Forgandenny (37/088183) and the western end of the Sidlaws, across which the low, flat-floored valley of the Earn has been cut. The contrast between the hills and the lowlands would thus appear to be not simply a matter of contrasts in lithology. In the Plain of Kinross denudation in Devonian times appears to have been responsible for the lowering of the andesites, a process that was probably continued in a more recent epoch, while in Strath Earn the development of the valley was possibly aided by the faults responsible for the dropping of the crest of the anticline.

Within the hills, there are features which suggest that the physiographic evolution of the area has been of greater importance in the development of the present landforms than has the structure. In an area with an anticlinal structure such as that of the Ochils the development of streams along less resistant outcrops forming strike or longitudinal valleys, and associated with cuestas, might be expected. In view of the faulting that has taken place, some irregularities in this pattern would be understandable, and fault-guided valleys might occur. Later, glaciation must have produced further modifications. In fact, however, the relation of the drainage

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* It should, however, be noted that in both the Plain of Kinross and Strath Earn the exact boundary of outcrops is uncertain, owing to the presence of extensive superficial deposits.

pattern to the structure does not appear close. The map (Fig. 2) demonstrates that nearly every stream cuts across successive outcrops of lavas and agglomerates, and few, if any, longitudinal valleys have developed. It seems probable that, on this scale, with valleys cut to depths of 500 feet and more, the lavas, tuffs and agglomerates show insignificant variations in resistance to erosion, and the drainage pattern has developed much as if in homogeneous rock. Differences in lithology seem to be important only in minor features, and small beaches and series of crags on valley sides can be readily related to such variations. Over much of the hills the trap featuring commonly associated with volcanic rocks is not conspicuous, but may be found along certain of the watersheds between the Hillfoots valleys.

The trend and sub-parallelism of some valleys suggests that they may be strongly controlled by faults or by lines of weakness which are not indicated on the geological map. Apart from these, known fault lines appear to exert some control over the position and alignment of small tributary valleys, and of glacial overflow channels. Glen Queich is the most obvious example in the latter category, but there are many others. A much smaller channel has developed along a fault just west of the summit of Dumyat (26/836977); Glenfarg Reservoir occupies a valley whose southern side lies along a fault, and there is reason to believe that the present valley form was developed largely by the passage of meltwater through it. The Care and Quey valleys are linked by a spillway developed along a fault, and it is interesting to note that another aligned pair of valleys - the Coul and Lamb valleys - are joined by a spillway, while another continues the line of the Gannel valley towards Glen Sherup, although this does not cut completely across the watershed, but leads into the Sorrow valley.

Apart from certain spillways and the fault-line scarps on the north and south of the hills, faults do not appear to influence the landforms as much as might be expected from their number. This is more noticeable in the Hillfoots area, where several faults join the Ochil Fault at high angles, and would appear to lend themselves to headward erosion by streams working back from the scarp face (Fig. 2). Only two valleys, apart from that of the Burn of Care, discussed earlier, are to any extent influenced by these faults. The line of the Menstrie valley partly coincides with that of one fault, but curves round more sharply to the west than does the fault, while the lower part of the Alva valley follows the line of another. Throughout the hills, the association of faults with tributary valleys and spillways, rather than with the major drainage lines, suggests that on the whole they became important in controlling relief forms only as and when the major drainage lines became established.

Even more than in the case of the valleys, the widespread upland surfaces found in the Ochils (Fig. 3) appear to have been developed largely by denudation, and owe little of their form to the underlying structures. The strata forming the Ochils dip at a fairly constant angle away from the anticlinal axis (Figs. 1 and 2), this angle being rarely lower than 10°, and not usually more than 15°, although in places it may rise to 20°- 25°. It can be measured in many places throughout the hills, where a more resistant stratum outcrops in a steep valley side. Frequently these more resistant bands may form a narrow bench on a valley side, or may be responsible for some development of miniature cuestas along a watershed. There are numerous examples of such features, and they serve to demonstrate that the upland surfaces have been cut across the tilted strata. This is perhaps best illustrated along the watersheds between the Hillfoots valleys where individual lava flows etc. can be readily traced from the watersheds into the valleys, and where the Ochil Main Surface, here between 1700' - 1800' O.D., forms a relatively even surface along the ridges, contrasting strongly with the deeply cut valleys. It is perhaps less easy to demonstrate that valley benches, apparently representing early stages in valley development, are not structurally controlled, but the more extensive have a slope less than that of the strata, while in some valleys, notably those of the Hillfoots streams, where the dip is consistently up-valley, benches falling in the opposite direction may be assumed not to be structurally controlled.

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The Pre-Glacial Development of the Landscape

I. Introduction

Regarded as a whole, the Ochil Hills have a plateau form, widespread upland surfaces of low relative relief being reached by steep slopes rising from the surrounding lowlands (Photograph 2). Such is the appearance of the range as seen from the flat floor of the Upper Forth Valley, the steep face of Dumyat rising sharply from the Lower Devon Valley, while on the north slightly less steep slopes rise from Strath Allan to the well-developed upland surface found in the west of the hills (Fig. 3.). From a viewpoint to the north, this surface appears to descend towards the east, falling to less than half the altitude at which it occurs in the west. Closer examination reveals that more than one surface is present. The valleys cut below these surfaces are usually deep and steep-sided, with a pronounced V-shape. In the higher, western parts of the hills, valley benches representing stages in the development of the landscape intermediate between the upland surfaces and the present valley floors are not extensive, but become more prominent further east.

Three major divisions of the hills are recognisable, one of which may be further subdivided. The Western Ochils comprise the broadest and highest parts of the hills, with summits rising to 2000' O.D. and over, while wide areas are above 1500' O.D. Relative relief is also high, being as much

1000
as ~~100~~-2000 ft. measured between the watershed summits and the valley floors; in the Hillfoots area it rises to 1600 ft. and over, culminating in the rise of 2,300 ft. from the Lower Devon Valley to the summit of Bencleuch in a distance of two miles (Fig. 5). North of Glen Devon the figure becomes 700-800 ft., but the whole area is characterised by deep, narrow valleys and long, continuous watershed ridges, on which there are fairly extensive remnants of a high-level erosion surface. East of the succession of valleys followed by the Muckart-Dunning road - Glen Dey, the upper South Queich and upper May valleys and the Dunning valley - the character of the hills begins to change. Both absolute and relative relief decrease, only two hills rising above 1500' O.D. In this West Central area relative relief decreases to 700-400 ft., and many valleys appear to be wider than those of the Western division. Except for the long ridges on either side of the upper Water of May the watersheds tend to take the form of series of individual hills, and no well-developed upland surface appears to have remained.

Beyond the N-S line formed by the lower Water of May and its tributary the Chapel Burn the hills show many contrasts with the Western area. Only along the southern edge of the hills, and in Culteuchar Hill (37/096153) is 1000' O.D. exceeded, and much of the area is below 800' O.D. Relative relief decreases to 200-300 feet, and valleys are for the most part shallow and open, although several of the larger streams occupy narrow and deep incisions below such broad, higher valleys. Watersheds are relatively broad, carrying a well-developed erosion surface. (Fig. 3). This East Central area appears to end at, or a short distance to the east of, Glen Farg. Beyond it the Eastern Ochils extend to the North Sea coast, as a series of usually low hills, separated by broad, flat-floored valleys.

Within the Western and Central Ochils two major watersheds can be traced for long distances, separating the drainage to the main trunk streams outside the hills (Fig. 6). These watersheds run in a west-east direction, cutting obliquely across the trend of the hills. North of Glen Devon, the watershed separating streams draining to Strath Allan and Strath Earn from those draining to the Devon and Eden runs from Core Hill (27/885048) by way of Innerdouny Hill (37/032074) to Tillyrie Hill (37/105080). Starting at over 1700' O.D. in the west, close to the northern edge of the hills, it remains mainly above 1500' O.D. as far as Innerdouny, where it forms a central ridge or backbone. Further east it runs along the southern edge of the hills, falling to 1000' O.D. In a few places it is breached by valleys of varying size: these appear to be mainly of glacial origin. For much of its length this watershed forms the divide between Earn and Forth drainage. Linton has traced this divide westwards from Eastbow Hill (27/947080) to Slymaback and Uamh Bheag, and suggests an

continuation
eastern ~~contamination~~ across the vale between the Ochils and the Lomond Hills, through the Lomond Hills to Fife Ness, regarding it as one of the original elements in the development of the Scottish drainage pattern.[1] (Fig. 7.)

The second major watershed, south of Glen Devon, is considerably shorter than that traced above. On it, however, or on spurs from it, lie all the summits of 2000' O.D. and over (Fig. 3). It extends from Blairdenon Hill (27/865019) to Whitewisp Hill (27/955014) without descending much below 1800' O.D., but further east falls to 142' O.D. in Seamab Hill (27/993017), above lower Glen Devon. There is no obvious eastern continuation. It is possible, however, that the original line of this watershed, separating Devon drainage from that to the Forth, prior to a relatively recent diversion of the Devon at Crook of Devon, ran from Bencleuch to King's Seat Hill (26/936998) and across the present Dollar Burn to the Cleish Hills and Benarty. Three streams now cross this line - the Dollar Burn, the Cowden Burn, and the River Devon. Of these the last two may be of post-glacial origin, their valleys being developed in thick deposits of sands and gravels. Pre-glacially the Devon may have continued southeastwards across the Plain of Kinross. The present course of the Dollar Burn may be of pre-glacial origin, but does not appear to be of great age. It may initially have continued eastwards by way of a depression north of Law Hill (26/978993), joining the Devon in its course across the Plain of Kinross (Fig. 7).

The major drainage system within the hills is that of the Devon, which collects the run-off from most of the Western Ochils. Its drainage basin falls into two distinct parts - Glen Devon, occupying the interior of the range, and the Lower Devon Valley, receiving the drainage of the Hillfoots area, and probably having a different history from Glen Devon. The Water of May also collects the drainage of a wide area, but is not so important as the Devon, and has not developed so large a valley. Outside these two drainage systems, run-off from the hills is collected by a number of streams, usually short, draining directly to the larger rivers of the lowlands. On the north-western slopes several such streams drain to the Allan Water; from Glen Eagles eastwards a series of larger streams, reflecting the increasing divergence of the northern watershed from the northern edge of the hills, flow to the Earn. East of the Devon system drainage is mainly to Loch Leven; still further east a number of streams are tributary to the Eden.

As the Ochils are essentially a watershed area, drained by streams eventually joining widely separated trunk streams, whose morphological evolution may have differed considerably, the individual drainage basins have been considered separately, but have been related to each other, and common phases of development noted, both at the end of this section and in the summary.

References

1. Linton, D.L. Some Aspects of the Evolution of the Rivers Earn and Tay. S.G.M., 56, 1940, p. 7 and Fig. 5.

II. The Early Evolution of the Devon Drainage System

Description of the area.

Glen Devon is the longest valley in the Ochils, and is occupied by the largest river. It trends, with some sinuosities, from west to east, from Sauchanwood Hill to Tormaukin, a distance of nearly twelve miles. At Tormaukin the valley takes on a south-easterly direction for two miles before reaching the edge of the hills at Yetts of Muckhart.

South of Sauchanwood Hill the small headstream of the Devon occupies a broad, open hollow forming part of the main upland surface of the hills. In a short distance it leaves this and descends into a narrow, but still shallow, V-shaped valley, which becomes fifty to seventy feet deep as the Devon is joined by the Finglen Burn. The stream continues in a generally northerly direction, then turns to a course slightly north of east. Its valley now becomes more steep-sided and trench-like, probably due to modification by meltwater entering by a spillway across the Sauchanwood-Core Hill col. Further tributaries enter, each in some degree displaying features similar to those of the south-north section of the Devon, but joining it by abrupt descents, while the valley increases in depth to over three hundred feet, with a pronounced V-shape. At the entrance to Glen Bee, Glen Devon may be said to begin. At this point the valley opens out, the southern slopes becoming gentler, and a relatively broad valley, over half a

Photograph 6. GLEN EAGLES. Looking south.
The entrance to Kincardine Glen lies among the trees on the left-hand side.

Photograph 7. GLEN EAGLES.

mile across, is developed, below which the river is slightly incised. This open section continues for only a short distan to the entrance of the Broich valley. Below this point the valley form is more trench-like with steep sides on which occasional outcrops appear to be due to the movement of ice down the valley. East of the entrance to Glen Eagles a flat, alluvium-covered, but narrow floor, is developed, over which the Devon meanders. For most of its length the valley is 400-500 feet deep, while its floor is everywhere less than 300 yards wide. Above it is a series of gently sloping bench the remnants of earlier and higher valleys. Glen Eagles, a trough at its southern end closely resembling Glen Devon, joi the main valley about half way along its length. A short distance north its floor falls sharply northwards, descending from 881' O.D. to 600' O.D. in less than a mile. The whole valley exhibits signs of severe glacial modification in its depth and over-steepened rocky sides (Photographs 6 and 7).

<u>Existing Literature</u>.

J.E. Wynfield Rhodes[1] was the first to put forward a hypothesis as to the origin of the Devon valley in any detail He noted the existence of several valleys trending NW-SE, including Glen Eagles and Glen Devon, and regarded the stream that he supposed to have occupied them as forming part of "th original consequent drainage of the country"[2], later dismember by piracy along structurally favourable lines. Thus he regar the ~~Knaik~~ Lednock as having joined the Devon by way of Glen Eagles, t combined stream then reaching the sea by way of Gairney Water and the Blairadam gap. Dismemberment was effected by the Earn, capturing the ~~Knaik~~ Lednock. and causing a reversal of drainage in Glen Eagles to give the present northern fall of this valley, and by the Lower Devon working back along the line of the Ochil Fault to produce the elbow bend at Crook of Devon.[3] There are many objections to this hypothesis; the most important of them were put forward by D.L. Linton, who suggests a very different evolution for the Devon.[4] The chief objection to Rhodes' hypothesis lies in his complete failure to appreciate the importance of glacial erosion and deposition in modifying the pre-glacial landscape.

Linton attributes the Glen Eagles through valley to glacial breaching of a pre-glacial watershed,[5] citing as evidence the typically glaciated form of the valley; its interruption of an otherwise continuous west-east watershed; and its great depth and steep sides at a point where the continuation of that watershed might be expected. The Crook of Devon elbow he regards as "a very recent diversion at the margin of a stagnant portion of the last ice-sheet",[6] pointing out that the gorge apparently associated with capture by the Lower Devon in fact terminates some distance downstream of the elbow bend. In view of this, the evolution of the lower part of the Devon as suggested by Rhodes is dismissed as "based upon a false premiss".[7] Linton's own reconstruction of the earlier drainage of the hills is based on the continuity of Glen Devon from west to east, on the existence of the high level valley benches, and of two cols, one at the western end of the valley between Sauchanwood Hill and Core Hill, and one at the eastern end between Mellock Hill and Lendrick Hill. He considers the drainage of the area to have been from west to east, the Devon entering the hills from some external source (? continuing the Loch Katrine-Loch Vennachar line), leaving them along the line of the North Queich and continuing east along the line of the River Leven.[8.] The further evolution of the drainage is not considered. The hypothesis advanced by Linton may be supported by field evidence which he does not cite. Thus, the high valley benches, which probably represent not one, but three early stages, are remarkably broad, and suggest that the Devon may indeed be the remnant of a larger stream. The dismemberment of this stream to produce the present drainage pattern must be explained, but before this can be attempted the evidence of the present landscape, bearing on the early pattern, must be considered.

The Evidence of Early Stages in the Present Landscape.

The oldest stage in the development of the landscape, of which there are fairly extensive remains, is the main upland surface of the hills. This will be referred to as the Ochil Main Surface, and is best developed at heights of about 1700'-1800' O.D. (Fig. 8). It is extensive around the Devon head-stream and its neighbouring tributaries, which, except immediately near their sources, are slightly incised below it, as noted in describing the Devon valley (Fig. 8). The characteristic feature of this surface is its undulating nature, with broad, open valleys rising gently to low rounded hills along the watersheds. Peat mosses are developed over much of its area, reflecting the low gradients, but are probably also related to periods of higher rainfall than at present, as the peat is everywhere eroded. The hills of the southern watershed rise above this surface, their summits lying from 200-500 feet higher, reached by smooth, relatively steep slopes (Fig. 3).

As seen in the field, this surface appears to have been produced by sub-aerial denudation, reduced to a state of maturity over most of its area, and formed at the expense of an older, higher landscape of which the hills along the southern watershed may be remnants. This impression is supported by the difficulty of defining the inner edges. While best developed between 1700'-1800' O.D., in some areas the surface can be clearly seen to extend to heights of 1900' O.D. at the base of the higher hills (Fig. 8). It does not seem probable that such a surface could be produced by marine erosion, when an inner edge of more uniform height, representing the base of a former cliff-line, might be expected.

The lower limit is everywhere ill-defined. It forms the summit of Wether Hill, at 1647' O.D., and probably continues in the northern watershed east of Glen Eagles. Evidence for this lies in the ease with which the Devon valley benches can be traced below this watershed as below the well-developed part of the surface in the west. It is possible that here it has been lowered from its original height by reason of its narrowness and liability to attack by the streams that rise on it. Further east along the same watershed Innerdouny Hill rises to 1630' O.D. corresponding to the less-modified parts of the surface, possibly because it is formed by trachyte.

Both the development and the destruction of the Main Surface are apparently due to the Devon and its tributaries. That they were instrumented in its formation is seen in the way in which the valleys in the headstream area are essentially part of it. That its destruction can also be attributed to them is shown by the formation of valley benches at its expense. The highest valley, forming part of the surface, is represented in the west by gently sloping facets and benches between the north-flowing Devon tributaries, at heights of approximately 1600' - 1700' O.D.* Along the northern watershed it appears as a gentle slope from the summit of Core Hill at similar levels.** Further east it remains as the highest of three valley benches on the spurs beyond Glen Eagles, falling in level to 1500' O.D. On the south side of eastern Glen Devon

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* Except where otherwise indicated, heights are estimates, based on the contours of the Ordnance Survey 1:63360 and 1:25,000 maps. See Appendix.

** A line of benchmarks down this slope gives its height accurately.

there are no extensive benches. However, below Innerdownie a narrow spur, whose height, as indicated by bench-marks, is between 1524' and 1580' O.D. may correspond to the same stage (Fig. 8).

Between Ben Shee and Scad Hill is a broad col, at its lowest about 1400' O.D. In view of the almost complete absence of high valley benches on the north side of Ben Shee this might indicate that at the 1st valley stage the Devon followed a course across this col. A long, gentle slope below Mailer's Knowe appears to be at a level corresponding to that of other benches of this stage. However, since both the first and later stages are well-developed at this point north of Glen Devon, it is difficult to explain both benches and col. assuming a diversion of the river. A possible explanation lies in the upper course of the Frandy Burn, which is aligned with the col. At this stage the Frandy may have joined the Sherup, being later diverted to the present course by a stream aided by the structural weakness postulated earlier (Fig. 3). A similar col occurs on the narrow watershed between the Broich and Frandy valleys. It is possible that the Grodwell Burn originally crossed this col, forming the headstream of the Frandy-Sherup stream (Fig. 7). In view of the height of the col (shown by benchmarks to be little less than 1490' O.D., except where a small spillway cuts across it), any stream occupying it must have been diverted at a relatively early stage, corresponding to the second Devon valley stage.

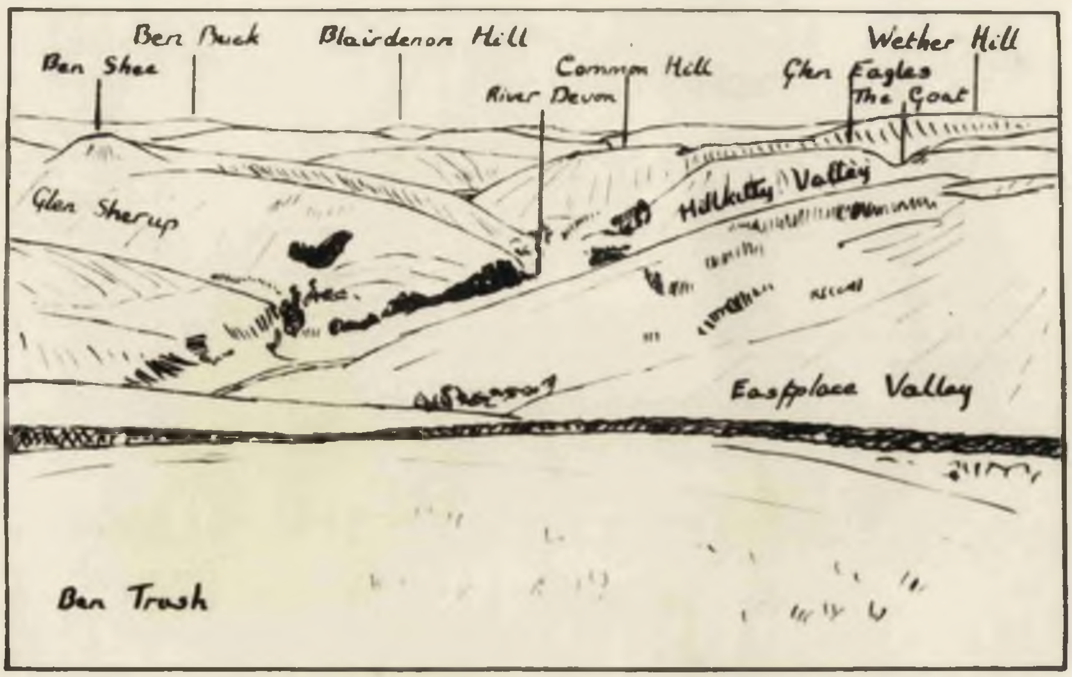
There is some slight evidence elsewhere indicating that the early drainage pattern of Glen Devon may have been one of small tributaries joining the main stream at a low angle, rather than the present rectilinear pattern. Thus, north of Ben Trush there is a col at ca. 1300'. An early course for the Eastplace Burn across this col and possibly also across the White Creich - Black Creich spur, before joining the Devon, may be envisaged. It is perhaps significant that all the diversions such an initial drainage pattern would entail are along S.W.-N.E. lines.

The second Devon valley stage is represented in benches and facets occurring immediately below those of the first stage (Fig. 8). Thus, on Core Hill, one such facet lies between 1500' - 1600' O.D., falling slightly eastwards, and there are similar features on the spurs south of the Devon. East of Glen Bee the stage is continued by a bench on Craigentaggart Hill at ca. 1500 - 1550' O.D. and still further east by a number of well-marked benches between ca. 1400-1450' O.D. The difference in height between the latter and those to the west, together with the existence in one or two places of small benches between those of the first and second valley stages suggests thatwhat has been described as the second stage may in fact represent two stages, separated by relatively slight falls in base level. On the south side of eastern Glen Devon, Berry Hill, below Ben Shea, and a similar spur below Innerdownia belong to the same stage, as may the White Creich -

Black Creich spur east of the Borland Glen.

At both these early stages, the Devon was possibly still part of a larger stream, since both are higher than the two cols already noted. The westward extension of the first stage may be found in the flat summit of Little Corum (1685' O.D.), and of the second stage in the gentle slopes about the headstreams of the Danny Burn, below which the latter is incised. It is probable that the Danny headwaters formed a small tributary of the Devon, comparable to the Medaff and Greenhorn Burns to the east. There is no clear extension of the valley beyond Tormaukin at these early stages. As seen from a distance, the broad Melloch - Lendrick col is convincing and lends support to Linton's view that the Devon then flowed east by this route. If so, it must have been at a height above the present level of the col, although the summits of Carmo~~o~~dle (ca. 1325') and Nether Town Hill (1225' O.D.) may approximate to the level of the valley floor during the second stage. At the point where the river now leaves the hills, however, Auchlinsky Hill and Seamab Hill present surfaces resembling those of the northern watershed and its spurs at similar heights (i.e. 1400' - 1500' O.D.) It may, therefore, be suggested that these surfaces are further benches of the Devon, and that this has always been the route by which the river has left the hills. However, they may be explained with reference to the Glenquey stream, to which lower benches

Photograph 8. GLEN DEVON.
Looking west from Ben Trush. Note spurs carrying benches of the 3rd Valley Stage, and Ochil Main Surface forming the skyline.



on Auchlinsky Hill may certainly be attributed and to streams which, at the time the benches were formed, were tributaries of the extended Burn of Sorrow (Fig. 7), in turn tributary to the Devon at a lower point in its course. The development along a tributary valley of benches at a similar height to those on the main stream would not be improbable.

The third stage of the Devon valley is marked by much less extensive remnants than the first two (Fig. 8). In the west, it is represented by a relatively narrow, V-shaped valley, which is continued further west by the floor of the Sauchanwood-Core Hill col. This must have been the last stage at which the col was used by an extension of the Devon, but its narrowness, as compared with its width at the higher levels, suggests that it was no longer carrying such a large volume of water. This may indicate that the river had already lost some of its headwaters, possibly by the action of a stream working back in the sedimentary rocks of Strath Allan. The eventual abandonment of the col may have been due to similar piracy by the Danny Burn. Downstream, in Glen Devon, the third valley stage appears in the broad summit of Common Hill, possibly in Bald Hill on the opposite valley side, and in a number of narrow spurs, between 1250' - 1350' O.D., east of Glen Eagles (Photograph 8). The floor of the eastern col at this time may be represented by the summits of Braughty and Cloon. There are no benches at a similar level below either Auchlinsky Hill or Seamab Hill, although the broad shoulders of Lendrick Hill, their outer edge followed closely by the 1250' contour, may correspond to this stage.

The form and heights of spurs and summits above the South Queich Valley, north of Myrehaugh, suggest that this valley existed when the high-level valleys of the Devon were formed, and that the South Queich was an early tributary of the Devon. Lamb Hill, Fanny Hill and Burnt Hill are all at similar heights (1300+' O.D.) and probably correspond to the third Devon valley stage. Together with that of the Dunning Burn, this valley forms a depression running north-south across the hills. The apparent absence of any structural weakness favouring its development indicates that this feature is probably of considerable age. Few other valleys tributary to the Devon, east of Glen Eagles, show benches which can be related to those in the main valley. Nearly all are steep-sided and narrow with few signs of the early stages of their development. The tributaries of the Hilkitty Burn, however, rise in a wide, gently sloping valley that probably corresponds to the third stage in the main valley. The western tributaries of the Devon occupy less deeply cut valleys, and facets on the upper slopes can be followed downstream until they merge with those above the Devon.

Evidence of later valley stages has been largely destroyed by the development of the present deep, narrow valley. A certain amount of roughening of the valley sides suggests that they may have been slightly steepened by the movement of ice through the valley, but there seem to be no reasons for believing that any great modification took place, and the valley must have presented an appearance similar to that of to-day even in pre-glacial times. The final stages of valley development appear tohave been the results of considerable falls in base-level following each other relatively rapidly, as compared with those of the earlier stages. There can have been insufficient time at any stage for the production of wide, gently sloping valleys comparable to those of the first three stages, and such benches as may have been formed were largely destroyed in the last phase. Remnants occur in Corim Hill, Black Hill and Teth Hill, and in the open section of the valley between Glen Bee and the Broich valley, but are not adequate to permit the reconstruction of the valleys they represent. Broad benches north of Tormaukin at ca. 1100' - 1150' O.D., and at 1025' - 1050' O.D. may have been cut by the Devon in the stages immediately preceding the adoption of its present course. At the lower end of Glen Quey, below Auchlinsky Hill, a spur with a gently sloping surface, corresponding in height to the lower Tormaukin bench, may have been formed by the Glenquey Burn at this period.

Several lower benches are found in the broad gap between Lendrick Hill, Seamab Hill and Auchlinsky Hill. These are best developed between 900' - 1000' O.D., but are nowhere very extensive. Below them is a relatively steep slope, after which the gradient decreases again, and a broad valley appears to have been developed between 750' - 850' O.D. Thick fluvio-glacial deposits mask the full extent of this feature, and have been partly removed from a more deeply cut valley at a lower level. This appears to have been the immediately pre-glacial valley of the Devon, and the river is now very slightly incised into its floor, but may not be following exactly its pre-glacial course. The two gorges through which it flows - the Black Linn gorge (27/99403) and that near Nether Auchlinsky (37/001028) appear to have been caused by slight diversions, due to the presence of glacial deposits in the earlier valley.

To summarise, it would appear that there have been two major stages in the development of the part of the hills considered above. In the first, the Devon and its tributaries developed broad, open valleys. Three series of benches representing such valleys are recognisable, at high levels above the present river, the earliest forming part of a widespread upland surface, characterised by relatively gentle slopes, and produced at the expense of an earlier landscape now represented only by the monadnocks of the southern watershed. Throughout the period during which these valleys were formed, the relief of the Ochils must have been low, compared to that of the present day. The second major stage of development was apparently associated with larger falls of baselevel than had produced the earlier valley benches, possibly succeeding each other at shorter intervals, so that valley deepening proceeded rapidly, and only a few isolated benches testify to the existence of valley stages intermediate between those of the first stage and that of the present day. In both the tributary valleys and lower Glen Devon the streams have lowered themselves through the glacial deposits covering the floors to the underlying rock, suggesting that pre-glacially the valleys were probably as deep and narrow as they are to-day.

The way in which the three high-level valleys of the Devon can be traced into and beyond the Sauchanwood-Core Hill col strongly favours the hypothesis that the river is but the remnant of a longer stream, whose sources lay somewhere west of the Ochils, possibly, as Linton suggests, in the Highlands of western Perthshire. There seems to be less evidence for a continuation eastwards beyond Tormaukin. The Mellock-Lendrick col appears to have been much more dissected than that to the west, and except for the summits of certain hills, has been lowered below the level of the first three valley stages. The disposition of the benches north of Tormaukin, however, is such as to suggest that they were formed by the Devon in flowing east. The higher of the two, at ca. 1100'-1150' O.D. is matched by a northerly spur of Lendrick Hill; at this level, the Devon could have continued east by the col through which Glen Quaich was later cut. It may still have been able to use this route when the lower bench was formed - the shoulders above Glen Quaich indicate that prior to the development of the spill-way the col was at, or a little below, 1000' O.D. Yet, while it seems possible that the Devon followed this route, it must be admitted that the gap between Lendrick Hill and Seamab Hill, by which the river now leaves the hills, is broad, and must be of considerable age (Photograph 22). The almost complete absence of benches which might correspond to the various valley stages further west, however, suggests that it was not initially formed by the Devon. There seems to be no trace of the further course of the river at these early stages beyond either the Mellock-Lendrick col, or the Lendrick-Seamab gap. In both cases the level of the ground falls sharply below that at which such traces might be expected.

At the western end of the hills, also, there is a sudden fall below the level at which the Devon must have had its westward extension, and it seems probable that this was developed across strata which were removed as Strath Allan was opened out. A similar explanation may account for the absence of evidence of its eastward continuation. The surrounding Lowlands are developed on less resistant, younger, rocks than those of the Ochils, and at the time when the early Devon was disrupted, such less resistant rocks must have surrounded the andesites and covered them to a greater degree than at present. The explanation for the reduction in size of the Devon, and for the preservation of evidence of its old valleys across the hills, may lie, to some extent, in this contrast in rock types.

The Possible Early Drainage Pattern and its Development

The major watersheds, already traced within the hills, suggest that the streams contemporary with the Devon also pursued generally west-east courses. Following Linton,[9.] these may be regarded as the predecessors of the Earn and Forth. Owing to the development of their valleys largely in less resistant rocks, changes in base-level might affect these streams more rapidly than the Devon, thus giving their tributaries an advantage that would enable them to enlarge their drainage basins at its expense. Similar arguments are suggested by Linton to explain the diversion of certain west-east flowing streams in the Grampian Highlands.[10.] Perhaps even more important than the lithological differences, however, was the considerable difference between the size of the Devon drainage basin and those of its neighbours. If the Loch Vennachar - Loch Katrine trough indeed represents the line of its headwaters, the Devon could have drained only a long, narrow area, and have had few large tributaries. Some indication of this is given by the watersheds as shown on Fig. 7, even allowing for possible migration of the Southern Ochil watershed as a result of active headward erosion by the Hillfoots streams. It is probable, however, that Vennachar stream followed a line similar to that of the present Teith and joined the Forth, while the Devon rose at a point not far west of the Ochils, and had thus still fewer tributaries. In either case it would have been a much less powerful stream than either of its neighbours, highly susceptible to capture by their tributaries along structurally favourable lines.

Features that must be explained in discussing the development of the present drainage pattern from one of major west-east streams are associated with certain smaller streams in and near the Ochils. One such is the Menstrie Burn, with the curious direction and form of its valley - curving round Dumyat at the western end of the hills, unusually wide compared to other Hillfoots valleys, and open at its upper end. The stream heads in a broad col, divided into two parts by a low hill (896' O.D.). To the north is the equally curious Wharry Burn. The lower parts of this, downstream from the farm of Lynns, may be disregarded for the present, being probably of post-glacial origin. Upstream, however, in Glen Tye, it begins as a north-flowing stream, then swings to a westerly direction, and after leaving the glen turns southwestwards. A stream flowing in such a direction, if that direction is original, is difficult to reconcile with the suggestion that the early trunk streams of the area flowed from west to east. However, it is possible that the Wharry Burn originally flowed northwards, by a col between Mickle Corum and Glentye Hill, adopting its present course only as a result of piracy by another stream.

At high levels on the south side of Strath Allan are benches probably corresponding to the Devon valley stages within the hills. Below ca. 1200' O.D., however, the slopes are generally smooth, except in the west. Here, above Sheriffmuir are well marked benches, all with gentle slopes, but none shows any definite fall along its length. Thus there is evidence of a valley stage at ca. 1150' - 1250' O.D., appearing in Black Hill (27/837032) and above Carim Lodge (27/861047), and of lower stages on Sheriffmuir itself. The latter have poorly defined limits, between approximately 800' - 1000' O.D. Similar benches are found on the opposite side of Strath Allan, suggesting that they do not owe their origin to structural features. The generally undulating appearance of these benches, and the variation in the height of their inner edge, indicates that they are of sub-aerial origin, but there is no indication of the direction of the stream, or streams, in the main valleys at the time they were formed.

The col at the head of the Menstrie valley makes it conceivable that it may even have been responsible for the initial diversion of the upper Devon. The height of the col, however, (750' - 800' O.D.) suggests that, at much the same time as the lower Sheriffmuir benches were formed, it also suffered the loss of its headstreams, as a result of the development of the broad valley further west, through which the Allan Water now flows. Earlier, the extended Menstrie Burn may have been responsible for the diversion of the Wharry Burn from its northward course. This may have joined the Menstrie Burn by way of the eastern part of the col, now lowered to 729' O.D., partly by the action of ice and glacial meltwaters. The existence of a broad, shallow valley below which the present slot-gorges of the Wharry have been developed (Fig. 3) indicates that it was diverted from the Menstrie valley prior to glaciation, but there seems to be no real evidence as to when this took place.

At the beginning of the Pleistocene period, Strath Allan must have had very much its present form, and have appeared as a broad strath, falling very gently from a low watershed, separating it from the Ruthven Water, to the Forth. Between Dunblane and Bridge of Allan are benches apparently representing three stages in the valley development later than those represented by the Sheriffmuir benches. The highest descends from over 500' O.D. near Dunblane, to 400' O.D. at Bridge of Allan, on the eastern valley side: it may appear also in the moorlands, north west of Dunblane, between the Allan and the Ardoch Burn, at similar heights. A second bench occurs about one hundred feet lower on the eastern side; west of the Allan it may be found in the summits of low hills - at 370' O.D. near Anchorscross (27/775017), and a little above 300' O.D. in Knock Hill (26/785989). The third and lowest stage is not well developed, but appears to descend to 200' O.D. near Bridge of Allan, immediately south of the Wharry Burn. It is but little above the valley formed at the time of the Late-Glacial Raised Beach, and may be the immediately pre-glacial valley of the Allan Water.

While the disruption of the early Devon, at the western end of the Ochils, may be fairly easily envisaged as due essentially to the development of Strath Allan in the sedimentary rocks which there overlie the andesites, no such feature appears to favour a diversion from its presumed west-east course at the eastern end of Glen Devon. The sudden abandonment of a generally west-east course for one to the southeast, at Tormaukin, suggests that the river may have been captured by a smaller stream, a tributary of the Sorrow, which appears to have been continued eastwards beyond its present valley (Fig. 7). To effect such a diversion, this stream must have had some advantage over the Devon. This can hardly have been one of size, but it is possible that at this period the Upper Devonian sedimentary rocks had not been stripped from the western parts of the Plain of Kinross, while along the course of the Devon, the andesites may have lain at a higher level, and have been already exposed. Such an effect could well arise from irregularities in the surface on which the younger rocks were deposited. The Sorrow and its tributaries may have been able to adjust themselves to changes in base-level more rapidly than the Devon, and being thus at a slightly lower level than the main stream at the point of capture, were able to effect the diversion. The broad valley above the ravine of Glen Dey running north-south between the South Queich, at Myrehaugh, and the Devon, may have been developed in a similar fashion, and have carried the Queich to the Devon until the cutting of Glen Queich by meltwaters renewed the earlier outlet. It may be significant that the first capture postulated is along a NW-SE line - i.e. in alignment with the Glen Queich fault and certain other valleys which may be similarly structurally controlled (Fig. 4).

Following diversion the Devon probably took up a generally southeastwards course across the Plain of Kinross, but in this area few traces of the pre-glacial drainage remain.

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III. The Morphological Evolution of the Kinross Ochils

The name Kinross Ochils has been applied to the area lying east of the Mellock-Lendrick col, and south of the main west-east watershed of the hills. This area lies almost entirely within the county of Kinross, and is drained southwards to the Plain of Kinross by a number of small streams. It shows many contrasts with the Glen Devon area, and, indeed, with the hills as a whole. Between the col and the spur along which the road from Milnathort to Path of Condie climbs the hills the streams occupy relatively broad and shallow valleys, within which small benches and facets appear to be evidence of stages in valley development (Fig. 9). The interfluves are lower than those to the west of the col, and do not carry such extensive benches. There is a noticeable fall in level from the col to this area, and in the same way the Innerdouny Hill - Slungie Hill ridge rises steeply some 200-400 feet above it. East of the Milnathort-Path of Condie road there is only a short slope between the watershed and the low ground of the Plain of Kinross, and valleys are poorly developed.

The southerly drainage of the Kinross Ochils was probably more marked pre-glacially than it is at present. In the southern part of the area the drainage pattern is largely determined by a series of meltwater channels running from west to east, and diverting the drainage from the hills in this direction (Fig. 12). Thus the Lee Burn now joins the Warroch West Burn by a spill-way, and may previously have been a tributary of the Cloon Burn.

The Warroch West itself may have used the col across which the spillway is cut in order to join the Cloon - slope facets forming an earlier valley appear to continue from the Warroch West valley into the Cloon valley by way of the Col (fig. 7).

The highest benches on the interfluves in this area fall mainly between 1250' - 1350' O.D., and are described as "1200' - 1300' benches" on Fig. 9. That on the Lee-Warroch West interfluve appears to be continued by a spur from Mellock Hill west of the Lee Burn. A shallow col links this area with the South Queich valley, and the bench may be traced across this to Third Hill without any marked discontinuity. It seems probable, therefore, that the 1200' - 1300' benches in the Kinross Ochils correspond to the 2nd Devon valley stage. On the lower interfluves further east a separate erosion surface appears to have developed, between 1100' - 1200' O.D., which may correspond to the 3rd Devon Valley stage. (1st Valley stage, Fig. 9.)

From these benches steeper slopes descend to the valley floors, interrupted in places by lower benches. These can sometimes be traced upstream until, near the valley heads, the 2nd Valley Stage forms the present valley. This is well-illustrated in the Warroch West Valley, where, at ca. 1100' O.D., the headwaters occupy a wide hollow with gently sloping sides, which can be followed downstream above a relatively shallow post-glacial incision, into benches at 1000' - 1050' O.D. on Hog Rig (37/039058) and Warroch Hill (37/048059). Corresponding benches and slopes occur in the Warroch East valley, and may be continued further eastwards in the broad bench between Arlick Hill and the small Craigow Burn, which descends to ca. 950' O.D. A third valley stage is traceable from the upper Warroch West Burn into the Cloon valley, and again appears in the Warroch East valley. The most recent stage of which clear traces remain is well-developed in the Warroch East valley, and in the bench, on which the farm of Upper Warroch stands, at 800' - 900' O.D. A narrow valley, below which the West Warroch spillway has been cut, may also belong to this stage: if so, it would appear that the West Warroch had adopted its present course prior to glaciation. Further south, the gently sloping summit surfaces of Downeriand Drumgarland Hill may represent this fourth valley stage, at, or a little above, 800' O.D.

Four valley stages may thus be recognised in the area drained by the Warroch streams, all closely related to these streams. At higher altitudes, less extensive, more isolated benches may be evidence of still earlier stages in the development of the landscape. The southerly direction of the drainage of this area may have been even more marked pre-glacially than it is at present, and suggests that the streams were tributaries of the Devon, before this adopted its present course. The various valley stages described above might, therefore, be expected to correspond to those already established in Glen Devon. However, the relatively low level of the Kinross Ochils is such that only the small, high-level benches on the north of the area appear to correspond to the best-developed Devon valley stages - i.e. to the second and third stages. The valley stages that are well-developed may be of the same age as the poorly represented, later, valley stages in Glen Devon. No reliable correlation can, apparently, be established between the two areas, although it is possible that the 4th Warroch stage, and the broad valley at ca. 750' O.D. near Nether Auchtinsky, may be of similar age, developed when much of the Plain of Kinross had been reduced to ca. 700' O.D. - a surface that may now be represented only in isolated hills, such as H oad Hill (734' O.D.) near Drum.

There appears to be a relationship between the contrast of the Kinross Ochils and Glen Devon, and that of the Plain of Kinross and the Ochil Hills as a whole. Both the Warroch area and the Plain of Kinross are developed on similar rocks to the hills as a whole, yet both show relief forms contrasting in varying degrees with the rest of the hills. The explanation for this contrast does not appear to lie in differences in lithology, and differences in erosional history might therefore be expected to provide an explanation. However, there seems to be nothing in the history of the area, as this is indicated by the evidence in the higher parts of the hills, to bear out this explanation. The Devon most probably followed a southeasterly course across the Plain of Kinross throughout much of the period when this was opened up, and may have contributed to its development as a broad lowland. This development would almost certainly be reflected in a widening of the tributary valleys, and might therefore explain the characteristics of the Warroch area. It leaves unexplained the sudden change from the narrow valley of Glen Devon to the three and a half mile wide lowland. If the Devon were in fact responsible for the production of the Plain of Kinross a more gradual narrowing of its valley upstream might be expected. A large tributary, possibly the fore-runner of the Burn of Sorrow may have joined the Devon below the entrance to Glen Devon, butit seems unlikely, from the size of its catchment area, that this could have been larger than, or even as large as, the main stream.

The presence of Upper Devonian sedimentary rocks in the Plain of Kinross (Fig. 2), lying unconformably on the andesites, suggests that much of the denudation that produced the lowland took place prior to the deposition of the sedimentaries. A considerable thickness of rocks younger than the Lower Devonian may have covered both the Plain of Kinross and the area east of the Mellock-Lendrick col at the time that the high-level valley benches of the Devon were formed, and may only have been removed as the various valley stages of the Warroch streams were developed Remnants of early Devon valleys may have been destroyed as the sedimentary rocks were removed, as was suggested above; this must also have had the effect of reducing the depth of the valleys east of the Mellock-Lendrick col, in that there was, in this area and in the Plain of Kinross, a much lesser thickness of resistant rock in which valleys could be developed than elsewhere in the hills.

East of the Milnathort - Path of Condie road no large valleys have been developed, many streams occupying spillways running east and southeastwards. There are, however, one or two shallow depressions, not now occupied by streams throughout their length, which may represent the pre-glacial drainage of the area, and which also have a southeasterly direction. The eventual destination of streams using these early valleys may have been the Devon, but it seems equally probable that some at least may have joined the Eden through the broad gap separating the Ochils and the Lomond Hills. The width of this gap suggests that it is of considerable age, but it would appear to owe its existence to the relative ease with which the Upper Devonian strata could be removed, by streams of subsequent origin, rather than to represent an initial consequent element in the development of the landscape.

IV. The Development of the Hillfoots Valleys

Description of the Area

The Hillfoots valleys are those of the streams draining southwards from the Blairdenon Hill - Whitewisp ridge to join the River Devon in the lower part of its course (Photograph 9). From west to east these streams are the small Logie Burn; the Menstrie Burn with its four important left-bank tributaries; the Balquharn Burn (Photograph 10); the Alva Burn, with two large tributaries, the Strabanster and the Glenwinnel; the small Silver Burn, a close neighbour of the Alva, and whose valley may for many purposes be regarded as part of the Alva valley, the Tillicoultry Burn, with two large tributaries, the Daiglen and the Gannel; the Harviestoun Burn; and the Dollar Burn, for much of its length known as the Burn of Sorrow, until joined by the small Burn of Care.

In many ways the Hillfoots valleys resemble those tributary to Glen Devon, but there is reason to believe that the streams occupying them have only recently joined the Devon. At Crook of Devon the river abandons a southeasterly course across the Plain of Kinross and turns sharply westwards, cutting deep gorges below a surface formed almost entirely by glacial deposition. As Geikie observed, these gorges must be of post-glacial origin,[1.] and there appear to be no traces of earlier valleys that may be attributed to the Devon in this area. It is therefore probable that pre-glacially the Hillfoot streams joined the Forth independently of the Devon, which continued

PHOTOGRAPH 10. THE BAIQUHARN VALLEY.
(Photograph by Aerofilms, Limited.)

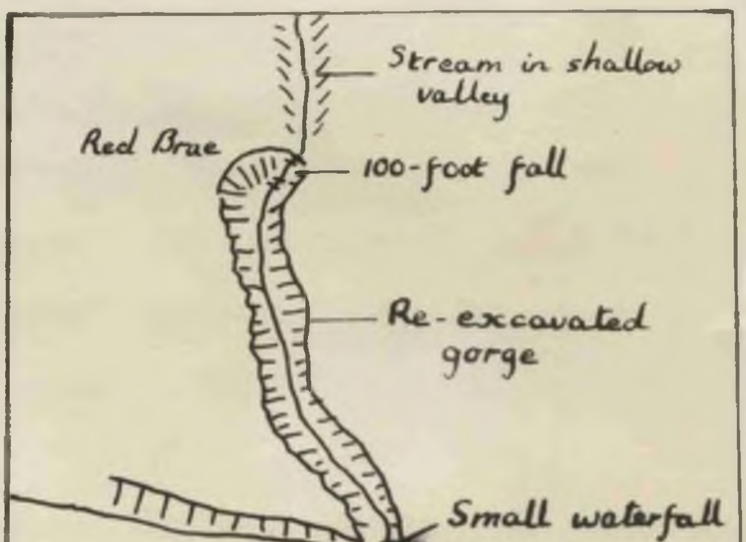
southeastwards across the Plain of Kinross.

The Evidence of Early Stages of Development

The valleys are all deeply cut and V-shaped, with few traces of early stages in their development remaining. The Ochil Main surface is present on the interfluves, where it is sometimes interrupted by trap-featuring, becoming more extensive where the interfluves join the main west-east watershed. Between Blairdenon Hill and Ben Buck it can be traced into the area around the Devon headwaters. Throughout the Hillfoots area it is gently undulating, contrasting strongly with the deeply cut valleys. Few traces of the shallow valleys, associated with the surface about the Devon headwater, occur in this area. As a result, it has a lower range of relief, some 200 feet as opposed to 400 feet north of the watershed. The inner edge varies in height, from 1800' O.D. to 1900' O.D. The outer edge is well-defined, on the Balquharn-Alva and Alva-Tillicoultry watersheds ending abruptly at the precipitous scarp face, at heights of ca. 1675' O.D. Elsewhere, the edge is set back slightly from the scarp, and small, lower, benches intervene. This is the case east of the Tillicoultry valley, where the surface is present on a spur sloping gently from ca. 1800' to 1675' O.D. A slightly steeper slope continues to 1500' O.D., and may form one of the few extensions of the surface below 1600' O.D. in this area. Separating it from the scarp-face is a succession of steeper slopes and small benches.

Most of the Hillfoots valleys are of particularly steep-sided

Photograph 11. THE RED BRAE.
Boulder-clay infilling of a tributary of the Menstrie Valley.



"X" marks the point from which the photograph was taken.

form and show few valley benches. Such as there are occur mainly at the mouths of the valleys, as indicated by the letters A - H in Fig. 8. They vary in height, but examples are found in nearly all the valleys between 1250' - 1300' O.D; in all but the Alva at ca. 1000' O.D. and in all but the Tillicoultry at 800' O.D. There are in addition smaller, lower benches, at heights varying from 300' - 600' O.D., in comparable positions at the edge of the gorges that have resulted from the hang of the valleys above the Lower Devon Valley.

All the Hillfoots valleys resemble each other strongly in certain important respects, although they may differ in many minor details. Each is divisible into two sections - a lower, in which the stream may descend as much as 700 - 800 feet in a distance of less than a mile, by a succession of waterfalls and gorges, and an upper, in which the gradient is much reduced, and the valley more open, while the stream flows between steep banks of boulder-clay (Photograph 4). Some modification of this pattern occurs in the Menstrie valley, which is much wider than those to the east - some two miles, as compared to the Alva and Tillicoultry valleys which are for much of their length less than one mile wide - and the only one with extensive valley benches. Here the lower, gorge, section is less extensive, the stream descending some 300 feet only. Upstream, the valley is wider, although the stream itself occupies a deep, narrow trench cut in rock, boulder-clay being absent until a point near the head of the valley is reached. The broad col that forms the head of this valley has already been discussed.

The Menstrie tributary streams are of some interest, reproducing on a smaller scale the features found in the larger valleys. Each joins the main stream by a series of narrow but deep gorges, and upstream occupies a small incision into boulder-clay. An important feature of these valleys is that they provide evidence of earlier gorges, which have been filled with boulder-clay, now being removed (Photograph 11).

The Alva Valley as a Type Example

The characteristic features of the Hillfoots valleys are well displayed in the Alva valley, which provides some evidence for their dating, and which may be regarded as a type example. For much of its length the valley sides rise steadily and steeply from the floor to the watershed, with a gradient (as measured between surveyed contours on the 1/25,000 map) frequently of 1 in 3, and occasionally less. These slopes are usually grass covered, but characterised by small terracettes, bare rock appearing mainly near the mouth of the valley, where it is probably partly due to ice-action, and partly to the considerable downcutting that has here taken place. Boulder-clay occurs mainly in the upper part of the valley, where it forms sloping terrace-like features on either side of the stream (Fig. 10, Photograph 12).

At high levels certain benches apparently representing early stages in valley development may be traced. Gentle slopes above approximately 1600' O.D. are almost certainly parts of the Ochil Main Surface, and are shown as such on Figs. 8 and 10.

Photograph 12. THE UPPER ALVA VALLEY.
The steeply sloping upper surface of the infilling is probably due to the downward movement of boulder-clay on the valley sides.

Below this are the slightly steeper slopes forming the 1st Valley Stage (Stage C, Fig. 8) best-developed between 1500' - 1600 O.D. about the headstreams, but descending to ca. 1400' O.D. on the spur between the Alva and the Strabanster, and re-appearing at a similar height in the flattish spur of Big Torry, near the mouth of the valley, and in The Nebit, between the Alva and Silver valleys. The 2nd Valley stage appears as gentle slopes between 900' - 1000' O.D. between the Alva and the Strabanster, and descends to 700'-800' O.D. at the mouth of the valley (E on Fig. 8). Here it continues along the scarp face into the Silver valley, where a deep gorge has been cut immediately below it (Fig. 10).

Intermediate between these two stages, on the eastern side of the Silver valley, are gentle slopes between 1250 - 1350' O.D. (D on Fig. 8). These appear to have no continuation upstream in either the Alva or Silver valleys, but can be traced eastwards into the Tillicoultry valley.

Below these remnants of early valleys, which are presumably of considerable age, the Alva and its tributaries have cut narrow, flat-floored and steep-sided trenches into the boulder-clay occupying the upper parts of the valley. In one place immediately upstream of the Strabanster confluence, the Alva occupies a short, narrow gorge, apparently the result of the plugging of an earlier valley by boulder-clay, which has forced the stream to adopt a new course. Downstream, the Alva continues to occupy a narrow trench, some 25 feet deep, walled with boulder-clay at the point where the infilled section of the valley appears to lie. Beyond this point, boulder-clay disappears except for occasional isolated patches, and the sides of the trench, in which bare rock is frequently exposed, became 75-100 feet high. The flat valley floor ends as the stream descends over a small fall at 700' O.D: below this point the incision becomes more V-shaped. Small benches, however, continue the flat-floored section, and together with it, form a distinct valley stage which will be referred to as the "Strabanster stage". Above the second of the gorges forming the lower part of the Alva valley this stage is at 500' O.D., and falls to approximately 300' - 400' O.D. near the mouth of the valley. Here, however, the inaccessibility of the small benches renders accurate determination of their heights difficult.

The Dating of the Gorge Sections

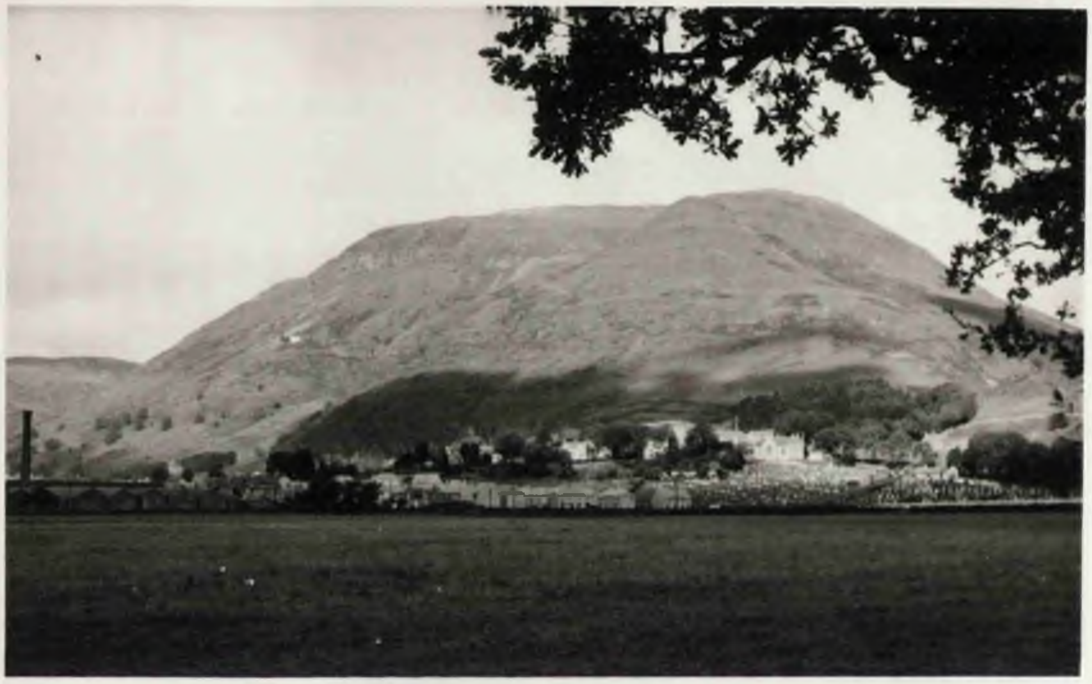
On one of the Strabanster benches stream gravels occur, consisting of rounded and sub-angular pebbles, some of Highland origin (26/885981). These are overlain by angular hill-wash debris. Although the exposure is not more than 18 inches high, it appears to indicate that the Alva flowed at the Strabanster level after the final withdrawal of the ice-fronts from the area, while climatic conditions were still too cool for the establishment of a vegetation cover capable of preventing hill-wash. The Highland constituents of the gravels were probably washed out of boulder-clay in the valley, as is the case of the numerous Highland pebbles and boulders upstream. It would thus appear that, on the disappearance of the Pleistocene ice-sheets, the Alva was between 200-300 feet above its present level at the mouth of its valley, and that the deeply-cut gorges below the Strabanster level are of very recent origin. However, the presence of small patches of boulder-clay within the Strabanster stage incision upstream suggests that an older incision may have been plugged by glacial deposits, and re-excavated as soon as normal drainage was re-established. Although no evidence of a similar boulder-clay infilling has been found in the various gorges, it is possible that they were also cut in a pre- or inter-glacial period, plugged with glacial deposits and recently re-excavated. The infilled ravines of the Menstrie tributaries suggest that this may well have been the case, and some further evidence may be provided by the presence of some thirty feet of what appears to be deeply weathered rock, exposed in a quarry in the side of the lower section of the Tillicoultry valley (26/912975). The yellowish colour of this rock contrasts strongly with the blue of the unweathered rock. Elsewhere in the hills only a very shallow layer of rock has been weathered, suggesting that weathering as deep as that at Tillicoultry could not have been produced in post-glacial time.

The lower section of the Alva valley is formed of a series of gorges and ravines through which the stream falls rapidly, from approximately 600' O.D. at the 1st Fall (Fig. 10) to 100' O.D. where the lowest gorge ends at the big alluvial fan at the mouth of the valley. This descent is by a number of falls,

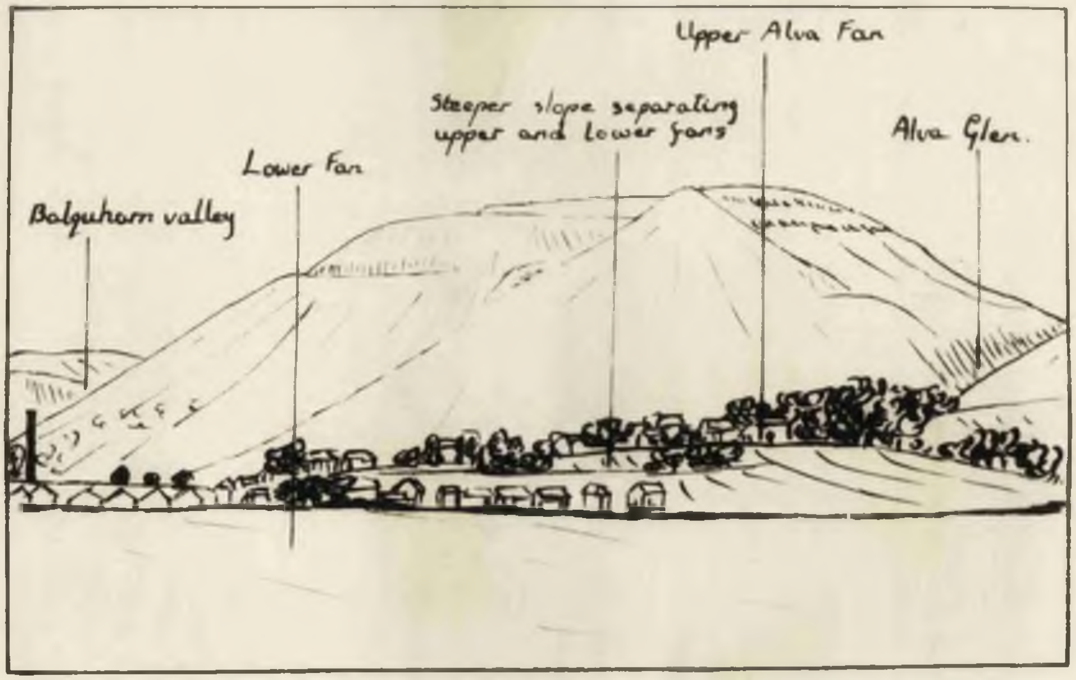
Photograph 13. ALVA GLEN.

of varying size, separated by reaches of less steep gradient. The three falls marked on Fig. 10 are among the largest: each forms the head of a distinct section of the valley. Thus the 1st Fall marks the sudden descent of the stream into its lower valley. Large, circular caverns have been hollowed out by the falling water in a less resistant agglomerate; below these the stream continues in a narrow gorge. On the valley sides above it the Strabanster stage is clearly traceable. This first gorge ends in the 2nd Fall, some 75 ft. high, at ca. 400' O.D. forming the head of a more open, V-shaped ravine, through which the stream flows relatively quietly for some distance (Photograph 13). In turn, this section ends as the stream enters the lowest gorge at the 3rd Fall, at approximately 250' O.D. Through this the stream descends by a number of falls and lesser gorges, the last of which has been cut considerably below the level of the apex of the alluvial fan.

The Alva fan has two parts - an upper, level-surfaced fan rising to 200' O.D., separated from a lower, gently sloping fan by a steep slope (Photograph 14). All the Hillfoots fans are regarded by Dinham and Haldane as deltas,[2.] and the form of the upper Alva fan supports this view. It seems possible that the gently sloping floor of the ravine section, ending at ca. 250' O.D., was continued to the apex of the fan, and that the stream flowed at this level when the Lower Devon Valley was occupied by a Late-Glacial lake or sea. Some credence is given to this view by the pipes supplying water to the burgh of Alva, which, leading from a small barrier at the end of the ravine



Photograph 14. ALVA FAN.



section, descend with a gentle gradient to the apex of the fan and appear to represent the level below which the longest gorge was cut. This later incision may well be entirely of post-glacial origin, formed as the Alva attempted to adjust itself to the base-level provided by the present River Devon. The lesser gorges within this last section may possibly be related to stages by which the present base-level was established.

While these stages can be established, and even roughly dated, in the Alva valley, the identification of corresponding stages in neighbouring valleys is uncertain. Few benches can be traced from one valley to the next along the scarp face, and the only basis of correlation appears to be height above sea-level. Because of this, the letters A-H are used in Fig. 8 to indicate the sequence of stages in individual valleys only.

The Development of other Hillfoots Valleys

On spurs in the Menstrie valley there are several distinct benches of relatively gentle gradient at heights between 1250' - 1500' O.D. These may represent one or more early stages in the valley development. Steep slopes separate these from remnants of a wide valley at 700' - 900' O.D. (A on Fig. 8), best developed between Dumyat and Myretoun Hill. Below these, at least two narrower valleys can be traced, at 300' - 400' O.D. (B on Fig. 7) and 200' O.D. above the deep trench now occupied by the stream. This incision, steep-sided, narrow but often flat floored, and not usually more than 100 feet deep, is for much of its length developed in rock. At its upper end, near the entry of the highest of the four left-bank tributaries, however, it is continued in boulder-clay, and may therefore be of recent - i.e. post-glacial origin. The tributaries join the main stream by way of a series of deep slot-gorges, above which on the Third Inchna Burn is the boulder-clay infilled section exposed in the Red Brae (26/844993).

For most of the length of the trench the Menstrie Burn descends steadily, falls and steep gradients being limited to the last 200 yards above the small Menstrie fan into which the stream is only slightly incised. In spite of the small size of this gorge section, it may nevertheless correspond to the incision of the Alva below the level of its delta.

Few traces of valley benches occur in the Balquharn valley and none below 600' O.D. (Photograph 10). Here the gorge section is again very short, although in situation is exactly comparable to that of the Alva. The difference in length may be due to the difference in size of the two streams, the Balquharn having insufficient volume to have incised itself as deeply as has the Alva.

The Silver valley is closely associated with the Alva Valley. It is separated from the larger valley only by The Nebit (1438' O.D.) and valley stages established in the Alva valley can be traced into the Silver valley (Fig. 10). The Silver Burn is the shortest of the Hillfoot streams - so short and small in volume that it looks incapable of having produced the large valley in which it flows. This valley is connected by a broad col, at ca. 1200' O.D., with the Glenwinnel tributary of the Alva, and the alignment of the upper part of this stream with the col, and the Silver Burn strongly suggests that the Glenwinnel formed the original head of the Silver Burn (Fig. 10 and Photograph 9). There appears to be little evidence, however, indicating how a diversion from such a line might have taken place. The col between the two streams suggests that the diversion occurred when the combined stream flowed at, or a little below, 1200' O.D., but the floor of the col has apparently undergone many changes. The sides of the valleys incised below it indicate that it was at some stage cut considerably below its present level, and then infilled by glacial deposits, possibly as much as 100 feet deep. More recently a shallow meltwater channel has been cut across it.

The bend by which the Glenwinnel reaches the Alva is so sharp as to suggest that a small tributary of the latter may have succeeded in capturing the more easterly stream. There seems to be no reason for supposing that the Alva had any advantage over the Glenwinnel-Silver stream, however, except in that its valley is developed along a fault-line (Fig. 2), and falls in base-level might be more rapidly reflected along the Alva and its tributaries than along the neighbouring streams. Alternatively, it is possible that the diversion may have been due to the development of a large meltwater channel between the Alva and Glenwinnel-Silver valley. The steep-sided narrow form of the ENE-WSW section of the Glenwinnel valley is not out of keeping with such an origin, but the presence of boulder-clay within this section indicates that the development of such a channel must have taken place prior to the last glaciation of the area. It seems probable that the direction of flow through a spillway between these two valleys would have been from west to east, and that the Glenwinnel would continue to join the Silver following the disappearance of the ice, although the development of a corram divide might have caused it eventually to join the Alva. With renewed glaciation of the area, however, and the plugging of the Glenwinnel-Silver col, the former spillway might then offer the easier route for the Glenwinnel stream.

For a short distance south of the col, the Silver is incised below thick banks of glacial deposits. The form of these, with their gently sloping upper surfaces passing smoothly into the floor of the shallow spillway cut across the col, suggests that they were formed as a large alluvial fan. Exposures of the material show, however, that it is unsorted. Further downstream, the valley is largely free of thick glacial deposits, and of a narrow V-shape, with smooth grassy sides. This section is terminated by a small fall, marking the head of the gorge section of the valley, at ca. 800' O.D. By no means as deep as that of the Alva, this section is nevertheless impressive, the stream falling 400 feet in little more than 1/4 mile. At 400' O.D. the gorge ends, opening out on to the scarp face. Here, for a few yards the stream occupies no well-developed valley, and can be crossed without any scrambling into and out of, steep-walled gorges. Below this point it once more enters a gorge, but this is much smaller, being probably nowhere more than 50 feet deep. By this narrow incision the stream descends to its fan at the foot of the scarp. It seems clear that at least three well-marked stages of valley development are present even in the short Silver valley:- 1) An upper, relatively open section, partly infilled near its upper end with the glacial deposits associated with the Glenwinnel col. This may be the same stage as that represented by the bench assigned to the Lower Alva valley stage on the south flank of The Nebit (Fig. 10). 2) A narrow, more deeply cut, gorge section, as much as 150 feet deep in places, ending abruptly half-way up the scarp-face. Its formation was clearly related to a base-level considerably above the level of the floor of the present Lower Devon Valley. Below this section the narrow incision of 3) appears to be the result of the attempt by the stream to adjust itself to the present base-level. The contrast between the Alva and Silver gorges lies chiefly in the failure of the Silver to continue its incision into the middle section of its valley, following the fall to the present baselevel, to give a deep gorge comparable to that of the Alva. This presumably reflects the difference of the volumes of the two streams; it is possible that the middle section may have been formed while the Glenwinnel was still tributary to the Silver, and that the small size of the lower gorge reflects the stream's reduced erosive power after the diversion of the Glenwinnel.

High above the Silver gorge, at 1250'-1350' O.D., a gently sloping bench may be traced into the Tillicoultry valley, by way of a narrow bench along the scarp face (D. Fig. 8). A similar feature appears on the east side of the Tillicoultry valley, but there appears to be no upstream continuation in either the Daiglen or Gannel valleys. It is noticeable that nearly all well-developed benches are confined to a small area near the mouth of the valley, above the steep walls of the gorge section. Thus two small benches occur at ca. 1000'-1100' O.D. (F. Fig. 8) while below them, at 400'-600' O.D., a rather more extensive flattening has been partly destroyed by quarrying. This last may be represented upstream by a flattening on the Daiglen-Gannel interfluve, at 800'-900' O.D., but the correlation is not certain. Below these benches is the deep incision now occupied by the Tillicoultry Burn; it is not clear whether the bench at the mouth of the valley represents the level at which the stream flowed immediately prior to the development of the gorges, or whether another stage intervened. Steep, but not precipitous, grassy slopes above the almost sheer walls of the gorge suggests that the latter was the case.

Within the Dollar valley, spurs from the Tarmangie-Whitewisp ridge are flattened between ca. 1500'-1600' O.D. These may be related to the rather lower spurs from Commonedge Hill, terminating in Hillfoot Hill (1448' O.D.) and Seamab Hill (1442' O.D.), possibly representing a stage when the Burn of Sorrow followed an easterly course to join the Devon in the Plain of Kinross, and corresponding to the early Devon Valley stages. No similar benches are developed on the south side of the Dollar valley, the slopes from King's Seat Hill descending smoothly, except on the long spur ending in Bank Hill (26/955992), and here modifications by ice and meltwaters have been so severe that the original form must have been largely destroyed. Bank Hill itself, however, is an extensive flattening of the spur, between 1050'-1150' O.D.

The small Burn of Care occupies a narrow incision below an extensive valley bench (G, Fig. 8). This is partly blanketed by glacial deposits, but appears to have been formed as a wide valley, rising gently from 800' O.D. in the south to 1200' O.D. at its upper end. East of the Care it is continued by a bench below Hillfoot Hill, and on the south side of the Burn of Sorrow by a less extensive flattening. The reasons for this widening when the valley occupied by the larger stream remained narrow, are not clear. It may have been favoured by the fault running into Glen Quey, but, even so, would appear to represent an important stage in the development of the Dollar valley, possibly corresponding to a widespread opening out of the lowlands. It is not improbable that at this time the Sorrow still flowed east, and was affected by an opening out of the Plain of Kinross.

A later stage appears in the col between the lower slopes of Hillfoot Hill and Gloom Hill (26/965992). The col is between 50-100 feet deep, but this depth has been increased by the development of a shallow channel across it, at the time when an ice front across the site of the present Dollar gorge prevented the Sorrow and Care from draining southwards. Gloom Hill is at at approximately 700' O.D., and it seems probable that the col behind it preserves a section of the valley of the Sorrow before this abandoned its eastward course. East of Gloom Hill a broad depression between Law Hill (26/9799) and the main mass of the hills may mark the continuation of this valley, although it has been lowered to less than 600' O.D., and its continuity with the Gloom Hill col has been broken by the development of the Kelty valley in the glacial deposits which cover most of the area (Fig. 11). The diversion of the Sorrow from this course must have taken place prior to the last glaciation of the area, if not earlier, for the presence of thick deposits of boulder-clay within the gorge section of the valley, near Castle Campbell (26/961993) indicates that a pre-existing ravine was filled with glacial deposits and is now being re-excavated.

On the western valley side, relatively gentle slopes descend to 500' O.D., ending abruptly above the Dollar gorge. These gentle slopes continue westwards along the scarp foot, decreasing in height, and traceable as far as Alva. Near the Dollar Burn they may be remnants of a valley formed soon after the diversion of the Sorrow from its easterly course. Below them, the valley sides descend steeply, passing into the often precipitous walls of the gorge, through which the stream descends in a series of falls. At 300' O.D. this section of the valley ends, the stream descending more gently in a flat-floored valley between steep banks of glacial sands and gravels, before emerging on to its alluvial fan at 200' O.D.

Possible Causes of the Hillfoots Incisions

The great incision of all the Hillfoots streams in the lower parts of their valleys is clearly indicative of a sudden change in base-level - a change which apparently had effect prior to the last glaciation affecting the area. No other part of the hills shows evidence of a change of such magnitude, although along the northern scarp face, overlooking Strath Earn, most streams are incised to a lesser degree. The depth of the incised sections of the valleys and the height of benches, apparently representing the older, slightly wider valleys below which the present gorges were cut, above the floor of the Lower Devon Valley, suggests that base-level fell by some hundreds of feet - possibly by as much as 300 feet or more. It seems unlikely that this was due to any widespread rise of the land relative to the sea, especially as the area so affected is of limited extent. A purely local change of base-level may therefore be postulated.

One of the most striking features of the Hillfoots gorges is their association with the Ochil Fault. Each of the streams affected by the change in base-level ~~xxxxxx~~ crosses the line of the fault at or near the point where it emerges from the hills into the Lower Devon Valley. The impressive scarp face clearly testifies to the influence of the fault on the landscape, and the possibility that recent movements may have caused the incision of the streams must be considered. Such movements were never envisaged by Geikie, who regarded the scarp face as a fault-line scarp, due solely to the contrasts in rock hardness revealed by denudation.[3.] Later, however, in 1924, Davison compiled a catalogue of earthquakes with epicentres in Britain,[4.] and noted that the western end of the Ochils, in particular the Hillfoots area, had experienced some 200 earthquakes between 1736 and 1924. Of only a small number of these - some twelve to fifteen, was there sufficient evidence to enable the epicentres to be plotted, but from these few it appeared that the shocks originated along a line traversing the immediate neighbourhood of the Hillfoots towns, running approximately N 77°E. This corresponds to the Ochil Fault, and would appear to indicate that slight movements have taken place along it up to the present day. However, the seismic evidence suggests that the fault responsible for the shocks should hade to the north, while the geological evidence, based on exposures of the fault plane, indicates that the Ochil Fault hades to the south, at an angle of ca. 70°.[5.] Haldane has attempted to reconcile these two conflicting pieces of evidence, noting that a northerly hade would indicate that the Ochils were thrust over the coalfield to the south. This seems unlikely, on general grounds, and in view of the southerly hade of associated faults in the coalfield. In conclusion, Haldane suggests that "Either the

Ochil Fault is normal near the surface of the ground, and steepening its hade passes into a reversed fault at no great depth; or the fracture indicated by the earthquakes is not the Ochil Fault, but another - possibly one hitherto undetected because it is too small, or because it meets the plane of the Ochil Fault before reaching the surface; or lastly simultaneous movements along the Ochil Fault and the series of N.N.W. presumably pre-Carboniferous faults in the Old Red lavas north of the Menstrie-Alva segment may combine to produce a resultant seismic effect like that which is actually observed".[6.] There can thus be no certainty that very recent movements have taken place along the fault.

For part of its course, at the extreme western end of the hills, the fault traverses the flat-surfaced deposits of the so-called 100-ft. and 25-ft. Raised Beaches, running several hundred yards south of the scarp face at Airthrey. The fault and the scarp face do not exactly coincide until the neighbourhood of Alva is reached. This, as well as demonstrating that the fault and the scarp face are not as closely associated as might be supposed, also appears to indicate that no movement sufficient to dislocate the surface of the flat carse-lands has taken place since the Raised Beach period, in Late-Glacial and Post-Glacial times.

There can be less certainty about the stability of the area during the Pleistocene period. No case of dislocation of glacial deposits by movement along the Ochil Fault is known, but it seems unlikely that deposits of any but the latest glaciation remain in the area, while the incision of the Hillfoots streams was apparently initiated prior to this glaciation. Before this incision, the streams may have emerged from their narrow, upland valleys into broader valleys developed in a lowland surface formed of Carboniferous strata. The benches above the gorges suggest that such a surface may have risen to 400'-500' O.D. at Dollar, to 300'-400' O.D. at Alva, and to only 200'-300' O.D. at Menstrie. If the present hang of the valleys is due to movement along the fault, such movement does not appear to have been uniform throughout the area. It does not, however, seem necessary to postulate any movement in order to explain the incision.

East of Dollar there is a rise from the floor of the Lower Devon Valley, here at ca. 100' O.D., to a surface, largely covered with glacial deposits, which over a wide area ranges between 400'-500' O.D., rising to 600' O.D. and over against the foot of the Ochils and in various isolated hills. The broad valley north of Law Hill appears to form part of this surface; eastwards it merges with the Plain of Kinross. It is continued westwards along the scarp foot by the narrow bench described above; this descends to 300'-400' O.D. at Tillicoultry and here it is not difficult to envisage the valley of the Tillicoultry Burn opening out at the level of this bench prior to the development of the modern gorge. At Dollar the bench, and the surface which it continues are formed on the andesites, but at Tillicoultry it is cut entirely on Carboniferous strata. It continues towards Alva, becoming narrower and decreasing in height, until it disappears at 200'-300' O.D. east of the Silver valley. In this Tillicoultry to Alva section no exposure has been found revealing the material of which the bench is formed its similarity of form to the section east of Tillicoultry suggests that it is solid and not built of glacial deposits. Throughout its length such deposits are banked more or less thickly against the lower edge of the bench, making it virtually impossible to determine the height of this with any accuracy, although it appears to be at approximately 200' O.D. in the west, rising to 300'-400' near Dollar.

South of the Lower Devon Valley, the scarp foot bench is paralleled by the Clackmannan Plateau, developed on Carboniferous strata, which descends from 400'-400' O.D. in the east near the Cleish Hills, to 100'-150' O.D. in the west at Tullibody. It seems probable that both the bench and the Plateau are parts of a surface which extended across the site of the Lower Devon Valley to the foot of the Ochils, and in which the Hillfoots streams cut broad valleys before they were obliged to incise themselves in response to a lowered base-level. Neither the scarp foot bench nor the Clackmannan Plateau continue the whole distance to the western extremity of the Ochils, but traces of the same surface may remain in the line of crags, developed on an intrusive sill, running between the Ochils and the Campsies, on one of which Stirling Castle stands. The crag and tail form of these shows that their presence is largely due to the action of ice on a resistant rock: preglacially the sill may have formed only a minor feature in the landscape, and the summits of the crags may therefore approximate to the pre-glacial surface. In the south, King's Park rises to 219' O.D; the Castle Craig rises to ca. 250' O.D. and the Abbey Craig to ca. 300' O.D. Further west, Craig Forth rises to 202' O.D. The pre-glacial surface may thus have ranged between 200'-300' O.D. across the Stirling Gap. Flowing at the level of the lowest of its pre-incision valleys, the Menstrie Burn could have continued on to such a surface from the Ochils without any appreciable break in its long profile, while further west the 200' O.D. valley benches of the Allan Water might similarly have been formed when the Forth passed through the Stirling Gap at ca. 200' O.D.

While the possibility of movement along the Ochil Fault being responsible for the considerable change in base-level testified to by the gorges of the Hillfoots streams cannot be discounted, it seems that there is some evidence of a pre-glacial surface in relation to which the valleys above the gorges may have been developed, and which in part at least remains at the height of these valleys. The lowering of base-level resulting in the incision of the streams may therefore be due to severe denudation of parts of this surface, and, in particular, to the development of the Lower Devon Valley. No evidence has been found which suggests that this valley existed pre-glacially, but there is in the area ample evidence of the severity of glacial erosion, and this may have been of great importance in the development of the present landscape. The line of crags already described, in the Stirling Gap, are some measure of the intensity of ice-action in the gap, and the appearance of the scarp face of the Ochils, with boiler-plated and roughened rock surfaces suggests that glaciation continued to be severe as the ice moved eastwards (Fig. 12). The steepness of the scarp-face may also be in some measure due to over-steepening by ice moving along it. Further evidence of the severity of glacial erosion may be provided by the deep "Buried Channel" underlying the Lower Devon Valley. This, thought by Cadell to be of fluviatile origin,[7.] is revealed by numerous borings to comprise two basins separated by a low ridge, which, together with the apparent steepness of its sides and depth below sea-level, suggest that it may in fact have been gouged out by ice (Fig. 13). It seems probable that the Stirling Gap and the western end of the Ochils may have been an area of considerable ice congestion, as ice from the Upper Forth and Teith valleys converged on the narrow opening, and was unable to escape freely because of the presence in the Lower Forth Valley of ice from the Southern Uplands and Western Highlands, moving eastwards on the south side of the Campsies. Under such congested conditions, considerable erosive power would be developed, and ice forced eastwards along the southern face of the Ochils might be fully capable of lowering the surface of the Carboniferous strata until the Devon trough was gouged out, and of over-steepening the scarp face itself, until, on the waning of the ice-sheets, the Hillfoots valleys were left hanging several hundred feet above the floor of the Lower Devon Valley, and the streams immediately commenced the cutting of their impressive gorges. The repetition of this process in successive glaciations might result in the distinct evidence of repeated falls in base-level found in all the valley.

Movements may have taken place along the Ochil Fault in Tertiary times and may have influenced the deeply-cut nature of the valleys. No definite evidence of such movement appears to exist, however, and it seems unnecessary to postulate it, as the deep, narrow form of the valleys is characteristic of the whole of the Western Ochils, and probably reflects changes in base-level of more than local significance.

Summary

While various stages in valley development may be found in the individual Hillfoots valleys, not all of which can be related to those in neighbouring valleys, it is possible to distinguish a few major phases apparently affecting the whole area. Thus, the Ochil Main Surface was developed throughout the area, with shallow valleys comparable to those still remaining north of the Blairdenon Hill - Bencleuch watershed. It was succeeded by a period in which wide, fairly shallow valleys were again formed, but at lower altitudes. Best developed in the Alva and Menstrie valleys, traces of these remain above 1250'-1350' O.D. They may possibly be equated with the high level Devon valley benches above Glen Devon. After the period in which these valleys were formed, falls in base-level appear to have been of greater magnitude, succeeding each other more rapidly, with the consequent formation of deeper, narrower valleys. More stable conditions may again be represented by the well-marked benches at ca. 1000'-1100' O.D. in the Dollar and Tillicoultry valleys. There are no benches at these heights in the Alva and Menstrie valleys; they may correspond to the equally well-marked benches, in similar positions at the valley mouths, between 700'-900' O.D., but this is a considerable difference in altitude, and two separate stages may be represented. Further falls in base-level resulted in the continued development of deep, narrow valleys up to the beginning of the Pleistocene glaciations, by which time the larger valleys had probably been lowered to 300'-400' O.D. At the close of the glacial period, and possibly during interglacial periods, a change in base-level appears to have resulted in a great and rapid incision of the streams - an incision that has still not progressed a great distance upstream. While this may be due to movement along the Ochil Fault, it seems more probable that it was more simply the result of over-steepening and overdeepening by ice moving along the scarp face.

No major changes in the drainage pattern of the Hillfoots area appear to have taken place, although the Sorrow may have been diverted from an easterly course to the Plain of Kinross. This diversion, apparently effected before the development of the lower gorge section of the valley, may nevertheless have been due to the action of a stream draining to the lowered scarp-foot valley in an early interglacial period, and so working to a lower base-level than the Sorrow. In the Alva valley, the Glenwinnel stream may have been diverted to the Alva from an earlier course in which it joined the Silver Burn. On the whole, however, it seems probable that the Hillfoots streams rapidly became too deeply incised in their valleys for any diversions to be effected.

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V. The Morphological Evolution of the Area Draining to Strath Earn

The larger part of the Central Ochils, together with a small area of the western hills, lying east of Glen Eagles, is drained by a number of streams whose waters eventually reach the Earn. This area shows many contrasts with the Western Ochils. Throughout the Central part of the hills valleys tend to be wider and less deeply cut; there is a more pronounced development of valley benches, but the evidence of glaciation is also more abundant, and in some places the surface appears to have been considerably modified by the passage of ice. The most extensive drainage system is that of the Water of May, but, while this gathers together a number of smaller streams (Fig. 6) it has not developed a valley comparable to that of the Devon, and, like most other streams of the area, occupies a relatively deep and narrow incision below the gentle slopes of a series of older, higher valleys.

Stages in the Development of the Landscape

On Fig. 9 the main upland surfaces and valley benches in the whole of the Central Ochils are shown. Throughout the area certain valley stages may be traced by well developed benches of low gradient. Below these other stages appear to have been of shorter duration, and are represented by more steeply inclined benches and facets of the valley sides.

The highest, and therefore oldest upland surfaces in this area are found along the main west-east watershed, and on the secondary watershed separating the Coul and Pairney valleys from that of the Dunning Burn. The Ochil Main Surface appears to extend eastwards from the Western Ochils to Corb Law (1558' O. D.) (37/003092) and Innerdouny Hill, descending to approximately 1500' O.D. Its edge is marked by a descent, usually appreciably steeper than the slopes comprising the surface, of some 50 to 100 feet, to a second, gently undulating surface, extending along the crest of the Innerdouny - Slungie Hill ridge, and from Corb Law to Muckle Law (27/986094) and Craig Rossie (27/984122). Described as the "Simpleside" surface from its development in the neighbourhood of that hill, it has a height range of some 150 feet from 1300' O.D. to approximately 1450' O.D. In places it appears to be formed of two minor surfaces, at 1300'-1350' O.D. and 1400'-1450' O.D., but the gentle slopes separating the two, and the unity of the surface as contrasted with the surrounding valleys, suggest that it should be regarded as one major feature. The total height range, together with the prevalence of gentle slopes, falling towards the surrounding valleys, suggest that it is of sub-aerial origin. Moreover, it appears, in at least one instance, in the Coul valley as a valley bench.

Between the Simpleside surface and the more continuous valley stages are certain benches described on Fig. 9 as "1200'-1300' benches". These on the whole are not extensive, or numerous. The most extensive is found on the narrow ridge north of the upper May valley, running northeastward from a remnant of the Simpleside surface forming Cock Law (37/032103). It is clearly separate from the Simpleside surface, and equally clearly above the highest valley stages that can be traced for any distance. The gentle slopes of the 1200'-1300' benches suggest that they are remnants of an undulating landscape, possibly of low relief, developed in response to a slight fall in baselevel below that obtaining when the Simpleside surface was formed.

The development of the landscape from this stage until the onset of the Pleistocene glaciation appears to have been by the cutting of successive valley stages, none of which succeeded in destroying its predecessors entirely. The highest of these valley stages (1st Valley Stage, Fig. 10) is of limited extent, and occurs only in the West Central area, forming gently sloping spurs usually between 1100'-1200' O.D. It is perhaps best developed in the Coul and Pairney valleys, where relatively extensive benches of gentle slope occur on nearly all spurs between 1100'-1250', falling towards the stream, and apparently representing very broad, shallow valleys some 300-500 feet above the present streams. This 1st Valley stage appears also at the head of the May valley, and on spurs above the Chapel Burn; here it is separated by steep slopes of 100-200 feet from the Simpleside surface.

Benches and slope facets apparently representing two later valley stages can be traced for most of the length of the upper May valley. These are rarely separated by more than 50 feet in altitude. The 2nd Valley Stage forms the remarkably wide head of the May valley - an area sloping gently towards the May, but surrounded by a ring of steeply rising hills. A narrow gap, about half as wide as the floor of the depression, is used by the May on its way eastwards. Other gaps, of similar width but varying depth, lead to the Dunning and South Queich valleys. That leading to the Dunning valley has almost certainly been modified by the movement of ice through it. On its northern side the Dunning Burn rises in a valley head resembling that of the May on a smaller scale, in its gently sloping, wide floor, and at much the same altitude (1000'-1100' O.D.). In view of this resemblance it seems probable that the same stage is represented in both valley heads.

Traced downstream above the Water of May, the 2nd Valley Stage descends to 950' O.D. above Path of Condie (37/075116) and rises again up the Chapel and Slateford valleys. At their heads it passes into a gently undulating surface along the main watershed of the hills, at heights of 1000'-1100' O.D. Long spurs run northwards from this ridge between tributaries of the May and the Farg, and along these the 2nd Valley stage surface once more decreases in height, falling to 973' O.D. in Arlick Hill (37/099104). Along the May-Farg watershed small groups of low, flat-topped hills at ca. 900' O.D. may also belong to this stage. These hills - for example; Berry Hill - are much broken by shallow channels and depressions, apparently the result of glacial action. West of the Water of May, the Clevage Hills have a similar form, and have also been attributed to the period of the 2nd Valley Stage.

Extending from both the Berry Hill area and the Clevage Hills are long, broad spurs on which an erosion surface with a remarkably low relief range has been developed. Over distances of a mile or more this does not usually rise much above 850' O.D., or fall below 750' O.D. It is not particularly smooth - it has been much broken by ice-action and the formation of meltwater channels, and its nature is therefore probably best seen at a slight distance. Thus, from the summit of Culteuchar Hill, the spurs on which it is developed appear to represent a very broad, shallow valley of the Water of May. This impression is strengthened as the surface is traced into benches in the various tributary valleys and finally into the upper valley of the May itself, occurring immediately below the benches of the 2nd Valley stage, and apparently forming a 3rd Valley Stage. It can also be traced into the Dunning Valley, by way of a broad depression between the Clevage Hills and the watershed north of the Water of May, remaining between 800'-900' O.D. In the Coul and Pairney valleys it may be represented by one or two small benches, but there is no direct connection between these valleys and those further east, and the various valley stages can only be established by reference to their position in relation to higher benches and the Ochil Main Surface.

Frequently there is no very clear line of demarcation between the 2nd and 3rd valley stages where these cover wide areas on the May-Farg watershed, although it is usually possible to separate them in the valleys of the West Central area. In view of this, and of their marked contrast with both earlier and later valley stages, none of which now forms a widespread erosion surface, they may be grouped together and described as the "Ochil Lower Surface", comparable to the Ochil Main Surface in its unity, although most probably comprising two or more minor stages of landscape development. This surface appears to represent a lengthy period during which this East Central part of the hills was reduced to a gently undulating landscape close to the base-level then obtaining, rising towards the main west-east watershed and the higher parts of the hills, but falling near the streams to form broad, shallow, valleys. East of the Farg it may be continued in the broad, smooth areas at and above 800' O.D., around Beins Law (879'O.D.), Binn Hill (908' O.D.) and Dumbarrow Hill (843' O.D.).

Later valley stages occupy a much more restricted area, hardly penetrating the May valley above Path of Condie, and found usually in the lower parts of the Dunning, Pairney and Coul valleys. They are, however, better developed in the area drained by the Farg and its tributaries. A broad valley through which the Slateford Burn flows in the upper part of its course, at ca. 800' O.D., forms a 4th Valley Stage, which can be traced downstream above the Water of May, falling to

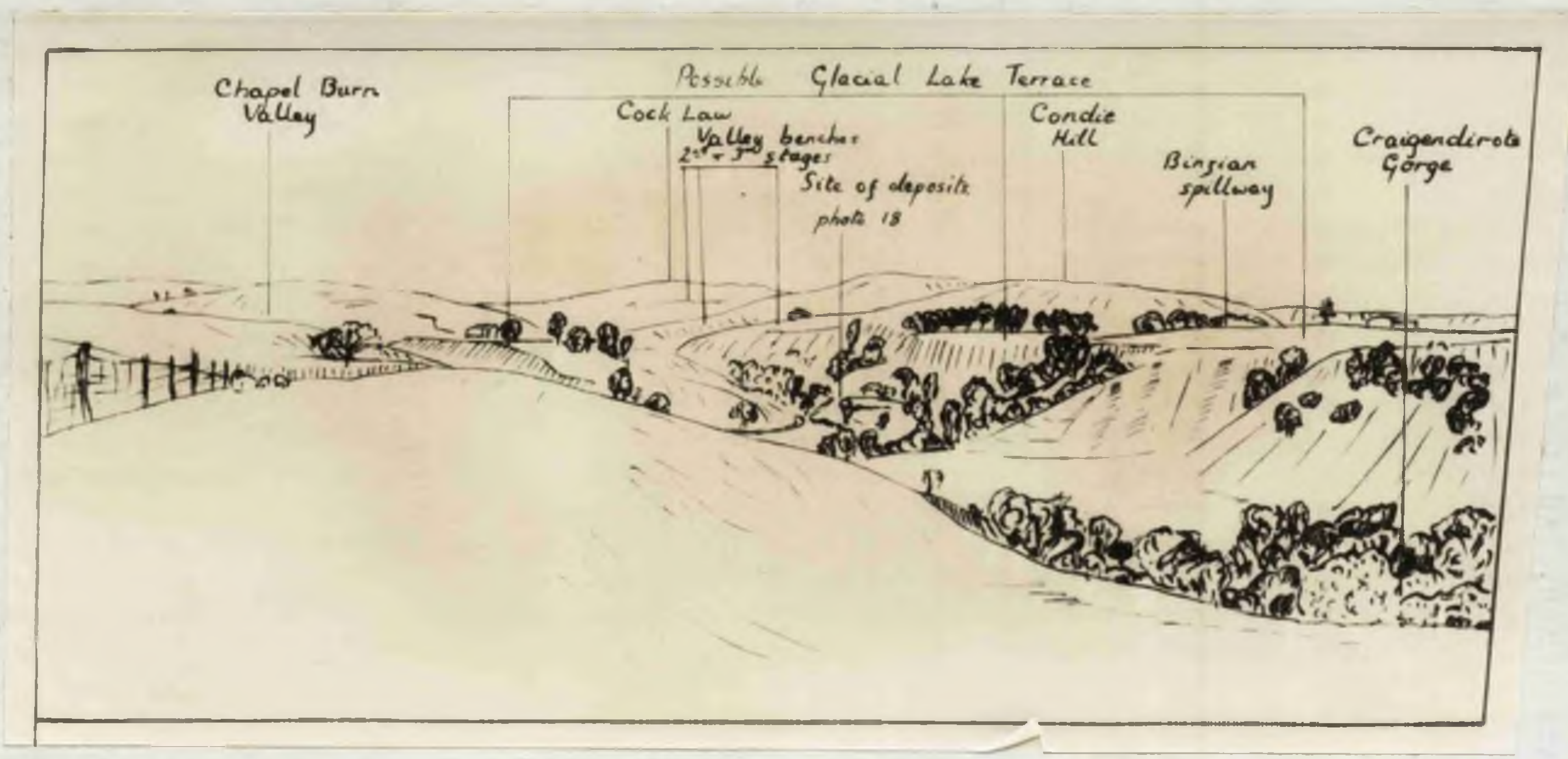
700' O.D. in spurs above the Kelty Burn. Drumfinn Hill (37/083164), a long, flat-topped hill rising to 634' O.D. and overlooking the sudden westward bend of the May, may represent this stage further downstream. It can also be traced from the Slateford Burn southeastwards through a dry valley to a small stream which now finds its way by a succession of spillways to the Farg (Fig. 10). It seems probable that pre-glacially this stream must have joined the Slateford valley by way of the dry valley.

The 4th Valley Stage does not extend far up the Dunning valley, but broad benches between 600'-700' O.D., immediately succeeding those of the 3rd Valley Stage appear to represent it. That to the west of the Dunning Burn continues for some distance westwards, but does not extend beyond Craig Rossie, and there seems to be no certain corresponding feature in the Coul and Pairney valleys. Neither is there any continuation eastwards along the edge of the hills from the May to the Farg valley. In the latter, however, broad benches on the spurs between the Farg tributaries, occurring immediately below the Ochil Lower Surface appear to belong to this stage. These benches, for example those on which the farms of Eastertown (37/126112) and Fordel (37/130121) are situated, are often remarkably even, their almost flat surfaces being interrupted only by occasional glaciated knobs of rock. They lie mainly between 700'-800' O.D. falling below 700' O.D. only in the north, near Balmanno Hill (37/141145). East of the Farg one

Photograph 15. THE MAY VALLEY.
Looking upstream from the Craigendirots gorge.
(Explanatory diagram facing p. 90.)

or two similar spurs running westwards from Beins Law may also belong to the same stage, but this area has not been studied in detail. However, the very gentle slopes of the benches suggests that they were formed very close indeed to base-level. Apart from those near Balmanno Hill, none shows any marked fall down-valley.

In the May valley a 5th stage can be traced in various small benches, occasionally passing into the present-day valley floors of some of the tributary streams. This appears to have a steeper gradient than the preceding valley, falling from 600'-700' O.D. near Path of Condie to 400'-500' O.D. near Binzian (37/074152). The exact height of some of the benches apparently belonging to this stage is difficult to determine, as pre-glacial lakes appear to have been formed in the lower parts of the valleys converging on Path of Condie, and a considerable thickness of glacial and lacustrine deposits may overlie the rock cut benches (Photograph 15). Those further downstream do not appear to have been affected to so great an extent. The same stage can be traced westwards to the Dunning Burn in broad benches along the foot of the northern edge of the hills, between 400'-500' O.D., but does not appear to extend upstream into the Dunning valley at all. West of the Dunning Burn, occasional small benches along the hill-foot may belong to the same stage. In the Farg valley a second series of benches with only slight variations in height, between 600'-650' O.D., may represent this 5th Valley Stage. Like the preceding



Explanatory diagram for Photograph 15.

stage, it is mainly confined to spurs separating the Farg tributaries, but may also be present in the flattish spurs and hill tops of the triangular area between the Farg, the Eden and the Morton Burn, a small tributary of the Eden.

The Early Drainage Pattern of the Eastern Hills

A 6th Valley Stage appears to be well-developed in the Farg valley, where it forms gently sloping benches between 300'-500' O.D., above the deep incision now occupied by the Farg in its lower course. This stage can be traced upstream, the distance between it and the stream decreasing until, near Glenfarg, it appears to form the modern valley, at ca. 1150' O.D. There are some traces of an intermediate stage intervening between the 5th and 6th stage, but these are not well-developed west of the Farg. In the area east of the river, however, shallow dry valleys occur at 500'-600' O.D., 50-100 feet above the Farg and Eden but below the surfaces apparently belonging to the 5th stage. They have an open V-form, and while they may have been modified during Pleistocene times, they appear to have been developed as normal stream valleys. The largest, containing Newton of Balcanquhal (37/158107) is drained at either end by small streams leading to the Eden in different parts of its course. It is joined from the northwest by the smaller Arngask valley, drained at its northwestern end to the Farg, but at its southeastern end falling to the Balcanquhal valley. Both valleys have every appearance of being the remnants of an older drainage system, disrupted relatively recently.

Some indication of the nature and extent of this drainage system may be given by certain streams west of the Farg and the Eden. Thus the Eastertown March and Lochelbank streams curve southeastwards, and appear to be heading for the Arngask valley. However, they join the Farg and drain northeastwards. Further south, the small Lossley Burn occupies a broad shallow valley which could quite conceivably have formed the head of the Balcanquhal valley, prior to the development of the valley occupied by the Eden headstream. At Arngask (37/140108) a shallow col leads into the Arngask valley, exactly opposite the upper west-east section of the Farg valley, but now some 75 feet above its floor. It seems possible that these streams may have converged on the Balcanquhal valley, and continued eastwards to join the Eden, by way of a bench at ca. 500' O.D., on which Corrinzion stands (37/169107). Such a drainage system is shown in Fig. 6. The present divide between Earn and Eden drainage, running westwards from Beins Law north of the Balcanquhal valley, may have been continued to Berry Hill across the narrowest part of the present Farg valley. To the north of it the Farg would have had a smaller catchment area than at present, but possibly favoured by a shorter distance between its source and ultimate base level, may have been able to extend its course by headward erosion more rapidly than the streams draining to the Eden could lower themselves into the andesites, and so was able to divert these streams. Further south, another tributary of the Eden may have been in a position to divert the Lossley Burn, by virtue of having a course over the more easily eroded sandstones between the Ochils and the Lomond Hills. However, there seems to be no evidence indicating without doubt the pre-glacial direction of drainage through the Farg-Eden valley; the present drainage appears to be determined by the development of spillways and a common divide in Pleistocene times, and it is possible that the disruption of the east-flowing streams indicated by the Arngask and the Balcanquhal valleys may be due largely to the action of the Lower Farg.

Outside the Farg area the 6th Valley Stage is not widespread. The Baiglie valley appears to belong largely to this stage, but many bare rock surfaces, and low, rounded hummocks, indicate that it has been much modified by ice. In the Dron valley, small benches above the narrow gorge known as Ram's Heugh may represent the same stage. It may also be present in the low plateau, between 200'-250' O.D., in the parish of Forgandenny, extending into the May valley in the benches on either side of the river at Ardargie House (37/075159).

Recent stream incisions and their possible cause.

Most of the streams of the Central Ochils occupy deep, narrow incisions below the relatively open valleys formed by the benches described above. In some cases it can be seen that the streams are re-excavating earlier ravines, which have been filled with glacial deposits. An example of this may be seen in the May valley, at Path of Condie, where the stream occupies a narrow, flat floored trench, in part walled entirely by fluvio-glacial sands and gravels (Photograph 15). Elsewhere, gorges have been cut in the solid rock. This sometimes appears to be the result of a slight diversion of the stream from an earlier course, as in the case of the May at Craigèndirots, shortly below Path of Condie, where an earlier, infilled valley may lie a short distance north of the present stream. Along the northern edge of the hills, however, from Auchterarder eastwards, all the streams joining the Earn descend 200-300 feet or more through narrow ravines and gorges. These may vary in length from a few hundred yards to more than a mile. As in the case of the Hillfoots streams, their association with the abrupt northern slope of the hills is very evident, although this is nowhere as precipitous and upstanding as the southern scarp face. Unlike the southern scarp, however, the northern is associated with a known fault line for only a short distance - from approximately West Dron (37/126159) eastwards (Figs. 1 and 2). Movement along this line can hardly be invoked to explain all the incisions. The alternative explanation, suggested for the Hillfoots incisions, may, however, also apply in this case.

Strath Earn, like the Lower Forth Valley, was most probably occupied during Pleistocene times by a powerful glacier fed from the upper Earn and other Highland valleys, as well as by ice moving up Strath Allan. While the appearance of the East Central Ochils indicates that much of this ice moved south-eastwards across the hills, the steep, roughened scarp face suggests that some was unable to surmount the barrier, and moved eastwards along it (Photograph 1). This may have gouged out the floor of Strath Earn, much as the Clackmannan Ice appears to have lowered the floor of the Lower Devon Valley, destroying the pre-glacial surface, and effectively lowering the base-level of the streams draining northwards. The nature of the pre-glacial lowland may be indicated by the low plateau of Forgandenny and various small benches along the scarp foot, from 200-300 feet above present sea-level, and by the broad, smooth benches, between the same heights, on either side of the ravine in which the Farg now flows (Fig. 3). West of Auchterarder this surface may remain relatively unchanged, apart from a certain amount of glacial deposition, and appears to have been gently undulating, over much of its area ranging between 200'-300' O.D., but rising to nearly 500' O.D. along the Allan-Earn watershed, and probably falling below 200' O.D. near the Earn.

Minor Changes in the Drainage Pattern.

Apart from what appears to have been the major change in the drainage pattern in the eastern part of the Central Ochils, several minor changes have also taken place. These have chiefly affected the Water of May. After leaving the gorge of Craigendirots this stream flows in a northerly direction for some three miles, then turns sharply westwards soon after entering a gorge 50-100 feet deep near Ardargie House. After flowing westwards for a little over a mile, it again turns sharply on leaving the gorge, and takes up a northerly course (Fig. 3). It seems unlikely that these abrupt changes in course are an original feature of the stream. They appear rather to reflect relatively recent events diverting the May from an earlier course. Such a course may well have continued the present north-flowing section of the stream upstream of the gorge, across the low ground beyond Ardargie House to Forgandenny. No certain traces of an early valley along this line remain, but it is possible that if one existed it was utilised by one of the several spillways running north and northeastwards from the May.

The Ardargie gorge, like those found on nearly all the streams draining to the Earn, appears to be of post-glacial origin, no traces of a glacial infilling having been found within it. It may reflect a fall from the pre-glacial base-level, and probably also the changing sea-level of Late- and Post-Glacial times. In passing through it, the May falls some 150 feet, flowing between near-precipitous walls of rock rarely more than 50 yards apart. The association of the westward bend of the stream with the head of the gorge section suggests that the diversion may be very recent indeed, and due to the capture of the May by a small stream initiated as the ice-fronts retreated from the area. North of the gorge, however, a low spur running westwards from Drumfinn Hill indicates that the pre-glacial Water of May also turned westwards, occupying a broad, shallow valley, only some 50 feet deep. Moreover, the succession of spillways running across the line of the stream, from southwest to northeast, developed as the ice-front retreated, and decreasing in height westwards, show that there was already a westward slope as the drainage was re-established, and it is probable that the May merely took up its pre-glacial course once more (Fig. 15). The association of gorge and elbow bend would appear to be purely accidental. No evidence bearing on the reason for a pre-glacial diversion seems to remain: between the Water of May and the Dunning Burn the various small streams probably bear little relation to any draining the area prior to glaciation.

The second bend of the May, to take up a northwards course, does not appear to have any great significance. This part of the stream is obviously of very recent origin, and the northerly course is probably simply the result of adjustments to the form of the glacial deposits over which the stream flowed on emerging from its gorge.

It is possible that the May has itself played the part of a pirate stream in the area of its headwaters. Here, as was described earlier, a relatively broad valley is connected to the Dunning valley by a low col. Although this has almost certainly been modified by ice, it may indicate that the Dunning Burn once rose some distance further south than at present, and drained from the main west-east watershed of the hills. It may have continued to do so until the 2nd Valley Stage, as benches belonging to this stage appear to be traceable from the May to the Dunning valley through the col, but was then deprived of its headstreams by the encroachment of the May. Such an encroachment might have been favoured by the structural weakness whose existence is suggested by the direction of the upper May valley (Fig. 3).

Further west, the Coul and Pairney burns appear to have suffered some diversion as a result of glacial interference with the drainage pattern. The Coul Burn, which for the first two miles of its course flows northwestwards through a broad, straight valley, suddenly makes a right-angled bend into a narrow, V-shaped breach in the valley side, and joins the Pairney Burn. The valley it has abandoned continues northwestwards, now occupied by the Cloan Burn, which is separated from the Coul only by a low corrom divide. It seems clear that the Coul originally occupied the whole broad valley, but when a retreating ice-front lay across the mouth of the valley a spillway was formed by water escaping to the Pairney valley. On the disappearance of the ice the Coul Burn continued to use the spillway, and a small corrom divide was developed at the point where the Cloan Burn reached the floor of the main valley,

At the point where the Pairney Burn emerges from the hills at the foot of Craig Rossie it also is diverted eastwards through a short spillway. The line of its pre-glacial course is not clear, owing to the abundant glacial deposits and numerous meltwater channels along the edge of the hills (Figs. 11 and 15) but may have continued the line of the valley within the hills northwards, across the site of

Easter Coul (27/971128). The stream now emerges into a broad shallow flat-floored valley at the farm of Pairney (27/977131). This also appears to have been a meltwater channel, leading eastwards, but the development of a corrom divide, as described by J.B. Simpson,[1] has resulted in a further sharp bend, this time to the west. The Cloan Burn also enters a meltwater channel on leaving the hills, and turns eastwards on its way to join the Ruthven Water. Both the Cloan and Pairney burns are deeply incised on the lower parts of their valleys, these incisions being into and below boulder-clay, and apparently of post-glacial origin. They appear to reflect the lowering of the meltwater channels through which the streams eventually flow.

<u>Summary</u>

It seems probable that the original drainage pattern of the Central Ochils consisted of a number of rather small streams draining north and south from the main west-east watershed of the hills. Of these, only the Water of May - Chapel Burn stream seems to have developed an extensive drainage basin, collecting together a number of smaller streams. In contrast to the Western Ochils, where much of the run-off is collected in an interior drainage basin - that of the Devon - the streams of the Central Ochils flow directly away from the hills to join trunk streams in the surrounding lowlands. Those flowing southwards probably joined the Devon in its course across the Plain of Kinross. Those flowing northwards now join the Earn, but as Linton has pointed out, there are reasonsfor believing that the course of the Earn below Crieff is of post-glacial origin, and that pre-glacially it may have followed the broad valley now occupied by the Pow Water north of the Findo Gask ridge.[2] If this were indeed the case the Ochil streams in the later stages of their development must have been separated from the Earn by this ridge, and may have combined to form a large tributary of the main river, following much the same course as the present Ruthven Water and Lower Earn. It is possible that such a stream formed part of the initial drainage pattern of the area, the excavation of a broad valley parallel to that of the much larger Earn being facilitated by the trough-faulting which has dropped the crest of the Ochil anticline.

In the extreme east of the area, a number of small streams may have drained to the Eden, a secondary watershed branching from the main ridge, and crossing the present Farg valley. This may now be represented, east of the Farg, by the high ground about Bein's Law.

There appear to be few traces in the Central Ochils of the stages in the development of the landscape established in the western hills. The Ochil Main Surface appears only in one or two small areas, forming the highest summits. Below this, rather more extensive remnants of upland surfaces suggest that for a lengthy period falls in base-level were slight, and that a gently undulating landscape was formed.

These remnants - the Simpleside Surface and the benches at 1200'-1300' O.D. - may correspond to the high-level valley benches of the Devon. It is noticeable that all these upland surfaces are confined to the West Central area of the hills, apparently not continuing beyond the Water of May - Chapel Burn line. In the East Central area a much more extensive upland surface has been developed at lower altitudes - the Ochil Lower Surface - represented in the West Central area only by relatively narrow valley benches. The Ochil Lower Surface appears to be rather more even than the Main Surface, apart from numerous irregularities due to glaciation. This tendency for lower erosion surfaces to be smoother than those at higher levels is again apparent in the broad benches in the May valley, and in those in the Farg valley with their remarkably low relief range and absence of any marked gradient. Neither the Ochil Lower Surface nor any of the later stages can be traced into the Western Ochils. There is no obvious correspondence between them and the narrow, limited benches found in Glen Devon and most of the Hillfoot valleys below the wide, high-level valley benches. It is possible, however, that traces of the same stages may occur in the Menstrie valley and in the much more extensive surfaces on either side of Strath Allan.

As in the case of the Hillfoots Valleys nearly all those draining to the Earn have been affected by a very recent rejuvenation. No cases have been found of the re-excavation of infilled ravines, and it would thus appear that the incision of the streams is entirely of post-glacial origin, reflecting an appreciable fall from the pre-glacial base-level. Such a fall has affected too wide an area to be attributed to movements of the fault which margins the hills from West Dron eastwards, and may be due to glacial erosion of Strath Earn.

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2. Linton, D.L. Some Aspects of the Evolution of the Rivers Earn and Tay. _S.G.M._ _56_, 1940, p. 8 and Fig. 3, p. 77.

4.

The Pleistocene Period: the effects of glaciation on the Ochils.

I. Superficial Deposits.

The Ochils must have been surrounded, and probably covered, by ice during the successive glaciations of the Pleistocene period, all of which presumably contributed to the modification of the pre-glacial landscape. In most instances, however, it is not possible to distinguish the effects of earlier glaciations from those of the latest, to which most of the deposits and glaciated surfaces must therefore be attributed.

Fig. 11, showing the distribution of boulder-clay, gravels and alluvium has been compiled from various maps of the Geological Survey. Except for small areas in the Lower Devon Valley, which are mapped on the scale of 1.10560 these are mainly unpublished, and in the case of 1" sheets 39/48, are not wholly reliable. No recent survey has been made, and the distributions shown can only be regarded as approximate. Field work suggests that for most of the area the picture is not greatly distorted, but in certain parts needs revision.

Boulder-clay is the most extensive glacial deposit in the area, mantling the lower slopes of the hills, and occurring above 1500' O.D. in only a few places. On the whole a relatively thin deposit, it probably represents the ground moraine of the last ice sheet to cover the larger part of the hills, and the term boulder-clay is not inappropriate. Numerous exposures, chiefly in the valleys of the Western Ochils, where the deposit forms a partial infilling, show that it contains unsorted, angular or subangular boulders and pebbles, varying in diameter from one to two inches to over three feet. The matrix is usually clayey, but varies in texture and in places is course and gritty. It also varies in colour, from a vivid red in the west, reflecting a high proportion of material derived from Strathmore, to a dark chocolate-brown within the hills, where the local andesites are more important. The included pebbles and boulders are remarkably uniform in type throughout the area. Most common are fragments of the local rocks, but schists, granites and gneisses of Highland origin occur frequently. Fragments of Devonian sandstone, usually small and angular, are found more often in the western and northern parts of the hills than in the south and east. Carboniferous rocks from the area south of the Ochil scarp are found in, and to the east of, Lower Glen Devon.

Where boulder-clay occurs as a valley infilling it may be as much as 100 feet thick, or even more. It may have accumulated partly by direct deposition from the ice, but occasional bands of sand and gravel suggest that a certain amount of melting out and water-sorting took place under the ice; under peri-glacial conditions material from the valley sides may also have been added, although there are no clear indications that this took place. The streams are deeply incised into and below the infilling, and occupy narrow trenches whose flat floors are littered with boulders washed out of the deposit. The sides of the trenches are steep, numerous arcuate scars and piles of debris indicating their unstable nature and the frequency of slipping. In many valleys a terraced appearanco is given by the flat or gently undulating upper surface of the infilling. (Photographs 4 and 12)

An indication of the extent and depth of ice-cover in and around the Ochils may be given by the upper limits of boulder-clay. The unpublished drift map of the area covered by sheet 39 shows it extending to variable heights around the Blairdenon-Bencleuch ridge, from 1600' O.D. to 2250' O.D. and might suggest complete over-running of the hills. It seems doubtful, however, whether the highest of these occurrences are true boulder-clay. In the memoir on sheet 40 Geikie noted that "As the deposit" (i.e. boulder-clay) "is traced upwards into the higher valleys of the Ochils it becomes loose and earthy, and then resembles the ordinary moraine-stuff of local glaciers."[1.] The contrast between the higher and lower occurrences probably deserves even greater emphasis, for the former show few of the characteristics of the latter. In each case in which boulder-clay is mapped above approximately

1650' O.D., the material exposed consist of frost-shattered and weathered fragments of the underlying rock. No rock of non-local origin has been found in the exposures. Nothing, in fact, except the appearance from a distance of certain scars on Grodwell Hill (27/912013) above the Glenach Burn, suggests that the deposits are boulder-clay. The highest supposed area of boulder-clay, on the shoulder of Bencleuch, is not exposed. Its site, although in part ill-drained, does not differ notably from adjacent drift-free areas. On the whole, it seems unlikely that boulder-clay occurs as high as the map suggests.

A wide area around the Devon headwater is apparently free of boulder-clay. Although peat covers much of the surface, it is not usually more than six feet thick, and in most places has been eroded so that the base is visible. Rotted fragments of bedrock underlie the peat. Occasionally pieces of schist may also be found, but these lie on the surface, and are not embedded in boulder-clay. Larger erratic blocks occur throughout the hills, the majority below the certain upper limits of boulder-clay, but a notable exception is a block of granite (6' x 4' x 3') on the summit of Scad Hill at 1921' O.D. (27/939021)

No moraines are marked as such on the drift map, although both within and around the hills are various sand and gravel accumulations, apparently indicating stages in the disappearance of ice from the area. The material forming them is in most cases water-sorted, which may account for their non-recognition as moraines.

Spreads of fluvio-glacial gravels occur in the lowlands surrounding the Ochils, extending into the hills along some of the valleys. These deposits appear to have originated in a number of ways. East of the Allan-Earn watershed they take the form of a spread of outwash gravels, probably deposited by meltwater where drainage was unimpeded, as suggested by J. B. Simpson.[2.] West of the ridge the gravels are disposed in terraces, and kettle holes occur, apparently reflecting the former existence of a pro-glacial lake and dead ice masses. In the Plain of Kinross rudimentary terraces occur in places, together with eskers and other depositional forms. Westwards these gravels pass into a more continuous spread at Muckart. At Airthrey and Bridge of Allan a wide gravel ridge and terrace appear to have been deposited in the Late-Glacial sea, and later modified by wave-action as the area began to regain its original level. Owing to their mode of deposition they are mapped as Raised Beaches by the Geological Survey.

Two Raised Beaches are generally recognised in this area - the 100-Foot and 25-Foot. As these terms are rather generally regarded as unsatisfactory, in view of the wide height range of the features they describe, and are particularly so in this instance, the terms Late- and Post-Glacial, will be substituted.

Late-Glacial has been used by Simpson,[3] M'Callien[4] and by Lacaille[5] to describe the deposits formed when glaciers both in the Highlands and the Midland Valley extended into the sea; various nomenclatures have been suggested for the so-called 25-Foot Raised Beach, but as there seems to be no general agreement on which is most satisfactory, Post-Glacial has been used to indicate deposits formed when ice had completely disappeared from the Midland Valley, and when a renewed submergence took place following the emergence of Early Post-Glacial times.[6] There are traces of beaches at intermediate levels, apparently representing stages in the withdrawal of the sea from the maximum encroachment of Late-Glacial times, but these are not usually extensive.

The Late-Glacial Raised Beach deposits are thought to be, in part at least, the result of direct deposition from an ice-tongue, as in the case of the Airthrey gravels. No sections exist in these, but they probably originated in the same manner as similar features south of Stirling i.e. by deposition at the snout of a glacier occupying the Upper Forth Valley, into the Late-Glacial sea.[7] The alluvial fans at the mouths of the various Hillfoots valleys are also assumed to have been initiated, if not entirely formed, as deltas at the same period.[8] In Strath Earn gravel terraces near Forgandenny may represent this Raised Beach.

The Post-Glacial Raised Beach deposits are of an entirely different character. They form the carse-lands of the Forth and Lower Devon valleys, and of Strath Earn. Probably estuarine deposits, they consist largely of fine clay and silts, resting in places "on a beach or platform cut back laterally into the underlying deposits."[9] Their inner limit is found at or near the 50-foot contour, and from this they extend down towards the present sea-level. A bed of peat, at 15'-20' O.D. occurs in the deposits, and is thought to indicate a sea-level at least as low as that of the present day, intervening between the Late- and Post-Glacial levels.[9]

Alluvial deposits are not extensive in the area. Where they occur within the hills they are usually associated with the present floodplains of the larger streams, and particularly with the Devon. Occurrences at higher levels, mapped as terraces by the Geological Survey, are probably associated with meltwater streams and pro-glacial lakes. The smaller streams descend too rapidly to deposit alluvium, and their valley floors are usually littered with coarser material washed out of the boulder-clay. Outside the hills alluvial deposits are partly associated with present-day streams, but may also mark the sites of pro-glacial lakes. Thus, in the Plain of Kinross, Loch Leven is surrounded by alluvium marking its former extent, and other smaller lakes also appear to have existed. In Strath Allan the Allan Water flows for much of its length over the imperfectly drained floor of a former lake.

Peat occurs over much of the higher parts of the Western Ochils, as a thick but eroded deposit. It appears to be the result of climatic and drainage factors, being confined mainly to the relatively broad, gently sloping watersheds and valley heads about the headwaters of the Devon and Hillfoots streams, at and above 1500' O.D. At lower altitudes it is usually found in particularly favourable, ill-drained areas - for example, on the alluvial deposits of Glenquey Moss (27/985035) and Strath Allan (Fig. 11). The eroded nature of all the high peat mosses strongly suggests that they were initiated under more favourable climatic conditions, and that under present conditions they are rapidly being destroyed.

Solifluxion deposits or "head" do not appear to be common in the Ochils, although, as already suggested, it seems probable that the boulder-clay infilling of many valleys may have been augmented by similar material washed from the steep valley sides. There are no exposures showing clear evidence of this, but the irregular edge of the infilling against the valley sides, and the slope towards the stream incision, may perhaps be the result of solifluxion. (Photograph 12) That material is still moving down the valley sides is evidenced by terracettes, which cover many of the steeper hillsides.

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II. The Glaciation of the Ochils.

In his book, "The Scenery of Scotland",[1] Geikie includes a map showing the main trends of movement of Scottish ice, from centres of dispersal in the Highlands and Southern Uplands. The suggested movement over the Ochils is in a N.W.-S.E. direction. This is supported by the direction of striations, and by the types of erratics found, a high proportion of which originated in the Highlands. On the assumption that smooth, rounded landforms were the result of moulding by ice, Geikie believed that the Scottish hills, including the Ochils, were completely buried. Although rounded landforms are now recognised as the result of normal sub-aerial denudation, and although Geikie's description is couched in terms of one major glaciation only, the view that the Ochils were completely buried by a N.W.-S.E. moving ice-stream has never been re-examined. Charlesworth, in discussing the kane-moraine of southern Scotland remarks that when ice lay to 1000' O.D. against the Lomond Hills "the equally high Ochil Hills ...... were apparently buried beneath this extraneous mass."[2] Simpson, however, in discussing the Perth Readvance, implies that the Ochils were not, at that period, buried, but were surrounded by glaciers from the Upper Forth, Teith, and Earn valleys.[3]

The relief of the Midland Valley suggests that while the hill masses within it may have been completely over-run at the period of maximum glaciation, the main lines of movement must have been along the broad lowlands, in a generally easterly or south-easterly direction along the Kilsyth, Forth, Teith and Earn valleys. Glaciers, with their sources in the Highlands to the north and west, might be expected to remain in these valleys when, with the onset of milder conditions, ice had disappeared from the intervening hills, Two of these ice-streams, in the Upper Forth and Teith valleys, must have converged on the relatively narrow Stirling gap between the Campsie Fells and the Ochils. The Forth glacier in particular may well have been of considerable size, occupying the whole of the lowland between the Campsies and the Highland edge, and serious congestion must have been caused by the narrowness of the outlet to the Lower Forth valley east of Stirling - so much so that some ice appears to have been forced up Strath Allan. In Simpson's view, this was the Teith ice.[3] The western end of the Ochils shows ample evidence of the erosive power resulting from the congestion.

On Fig. 12 an attempt has been made to show areas in which glaciation has appreciably modified the surface - i.e. where the movement of ice over the hills has produced a roughened, broken surface, or oversteepened slopes. (Dumyat, photograph 1) Bare rock surfaces, in some cases forming smooth, low knolls, and in others precipitous crags, appear to indicate the areas in which erosion was most severe. The small crags at the summits of certain of the hills in the Western Ochils have not been included; the situation and appearance of these suggests that they are the result of frost-shattering - in some cases still in progress, as is evidenced by the accumulations of fragments in screes - rather than of moving ice. As the map suggests, the western end of the hills and the southern scarp face appear to have been much modified by the passage of ice. Dumyat, isolated from the main mass of the hills by the Menstrie valley, has been so much modified that it appears as a rock drumlin, with a precipitous southern face and a long, gently sloping tail to the north-east. On the opposite side of the Menstrie valley, Myreton Hill has a similar, but less extreme, form. Bare rock surfaces and oversteepened slopes continue eastwards along the scarp face, and to some extent into the mouths of each of the Hillfoots valleys, becoming less marked towards the east. Beyond Dollar they are replaced by the smooth, if sometimes steep, slopes typical of the high Western Ochils.

Further evidence of the intensity of erosion in this area may be provided by the "Devon Buried Channel." First described by H.M. Cadell, in "The Story of the Forth"[4.] this underlies the Lower Devon Valley from Airthrey to Dollar, and was discovered by means of borings in connection with the coal-mining of the area. It is a deeply cut and narrow trench, completely infilled with sands, gravels and carse deposits.

Near Menstrie its floor lies 336 feet below sea-level. In Cadell's view, it was formed by the Devon at a period when sea-level was some hundreds of feet below that of today, and, together with similar channels in the Carron and Forth valleys, formed part of a complete river system. On Fig. 13 the positions of boreholes in the Lower Devon Valley are marked, with contours showing the depth of rock-head below sea-level. Since Cadell wrote, the number of boreholes has been greatly increased, and it now appears unlikely that a connected system of buried valleys exists. In a reconstruction of such a system, Cadell shows the Devon channel curving sharply south at Blairlogie, to join a similar channel below the Forth. While boreholes are few in this area, some do exist, and there is none in which any great depth of superficial deposits has been found. Nor are there any in the Forth Valley between Stirling and Kincardine showing depths greater than 115 feet, and between these points a fair number of bores has been put down. It seems unlikely that a deep buried channel could have been missed, if in fact one does exist. This suggests that the Devon and Carron channels are quite separate, and unconnected with the isolated deep bore off Bo'ness, where rock-head is 675 feet below sea-level. (Fig. 13)

Dinham and Haldane put forward what appears to be a more satisfactory explanation for the Devon Buried Channel - namely, that it is of glacial origin.[5] The steep-sided form of the valley, and the apparent existence of a ridge at Alva, dividing it into two elongated basins, (Fig. 13) offer support for this hypothesis. The steepness of the sides is comparable with that of the Ochil scarp, which indeed appears as an extension of the northern side, and which shows every sign of having acquired its present form as a result of ice action. Cadell dismissed a glacial origin for the Buried Channel as improbable, on the grounds that no boulder-clay occurred in it, and thought it to be a pre-glacial valley filled with river sands and gravels. There appears to be no valid objection here; in more recent borings boulder-clay has been found. In some cases boulder-clay appears to lie above sands and gravels; this may indicate, as was suggested earlier, that the trench was formed prior to the last glaciation.

A problem is presented by the lack of evidence of any continuation of the trench. There are no records of deep superficial deposits near Dollar, and it may be that here it peters out, corresponding to the disappearance of signs of severe glaciation on the scarp face, and probably to a lessening of congestion in this area as the ice was able to spread over the hills. At the western end of the trench, near Airthrey, Dinham and Haldane suggest a continuation between the Abbey Craig and the Ochils, linking with a possible overdeepening of the Upper Forth Valley.[5]

On the whole, a hypothesis suggesting a glacial origin appears to offer a more satisfactory explanation for the trench than one involving a fall in sea-level to some 600 feet below that of today. The necessary erosive power might result from the congestion of ice, first in passing through the Stirling Gap, and then within the Lower Forth Valley, where the Upper Forth ice must have encountered a massive glacier from the Kilsyth valley, and must have been forced eastwards along the Ochil scarp face. Evidence of this eastwards trend is given by the direction of striations over the Clackmannan Plateau.

Near Dollar, the steep slopes marking the edge of the Ochils begin to trend northeastwards, and the hills themselves become lower. Heavily glaciated surfaces become rare, suggesting that here the ice was less congested. In part this was probably due to movement into Glen Devon by way of the Core valley and Glen Quey as well as by the entrance to the main valley itself, and also into the embayment of the Kinross Ochils. It is possible that the Cleish Hills, although eventually over-run, may have served to split the massive ice-stream that had advanced over the Clackmannan Plateau, enabling part of it to expand into the Plain of Kinross. For convenience, this ice-stream, moving along the Lower Devon Valley and into the Plain of Kinross, will be referred to as Clackmannan Ice. It appears to lose its identity near the eastern side of the Plain of Kinross, probably merging with a more powerful stream crossing the Ochils from the north-west. This must have produced some congestion in the Plain, so that, while outlets to the Howe of Fife and the Firth of Forth existed, some ice appears to have been forced across the Lomond Hills by the heavily glaciated valley below the West Lomond.

On the north side of the hills, Simpson, citing the evidence of the rock types found in the boulder-clay, suggests that Strath Allan formed an outlet for ice from the Teith and upper Forth Valleys.[3.] Strath Allan itself does not show signs of severe glaciation, and probably offered an unobstructed route for some distance at least. The Glen of Kinpauch and Glen Bee, however, are marked by rocky knolls, and separated by a low, rather roughened col at just over 1250' O.D. Pre-glacially it can have been little higher, but it appears probable that ice began to move into the hills at this point. Further east is the impressive trench of Glen Eagles, with precipitous sides rising 800-900 feet above the flat floor, strangely out of keeping with the V-shaped valleys more typical of the Ochils. (Photographs 6 and 7) As Linton noted,[6.] it possesses all the features of a glacial trough, and was most probably formed by ice moving into the hills, and breaching the watershed at a point where a low col had previously existed - a process of which Glen Bee may represent an early stage. In the case of Glen Eagles the erosive power of the ice may have been greater, as the result of congestion caused by the entry of a glacier from the Knaik valley, and the obstruction of the outlet to the east by the presence of a major glacier in Strath Earn. Thus some Strathallan ice may well have sought an alternative outlet by Glen Eagles, forcing a way through into Glen Devon, to join ice already entered from Glen Bee, and possibly augmented by local ice. Linton does not appear to envisage the passage of ice entering Glen Eagles into Glen Devon, remarking that "It found no way through,"[7] but the glaciated sides and trough form of Glen Eagles continue southwards beyond the rock step and moraine, regarded by Linton as terminal, and it is difficult to imagine that ice moving through Glen Eagles could have done other than enter Glen Devon. How far ice continued to move eastwards down the main valley is not altogether clear. The valley sides are in places roughened (Fig. 12) but the presence of Clackmannanshire ice at the lower end, as indicated by Carboniferous erratics, must have impeded movement beyond Tormaukin. (27/998042)

East of Glen Eagles glaciated surfaces, boulder-clay and outwash gravels show that ice moved into the Coul and Pairney valleys; in neither case does it appear to have had sufficient erosive power greatly to modify the surrounding watersheds. The occurrence of boulder-clay in shallow cols across the watershed north of Glen Devon (Fig. 11) shows, however, that some ice succeeded in crossing them. Still further east, beyond the screes and precipices of Craig Rossie - probably the result both of ice-action and frost-shattering - glaciated surfaces, as shown on Fig. 12 become more common, reflecting the decreasing height of the hills, and their failure to form a complete barrier to the Strathearn Glacier. The effects of this become more and more marked towards the east, notably in the area south of West Dron Hill, (37/115150) and about Berry Hill. Movement seems to have been particularly strong in the larger valleys, to such an extent that what were probably pre-existing cols have been considerably modified. Thus a steep-sided, flat-floored trench connects the Dunning and May valleys, possibly representing a stage intermediate between the relatively slight glaciation of the Glen Bee col and the severe modification of Glen Eagles. Similarly, ice appears to have moved through the col at the head of the Chapel Burn, and the same may be true of one or two cols further east. The evidence in most of the Central and Eastern Ochils points to movement from the northwest, and suggests that the Strathearn Glacier was more powerful than that to the south of the hills, apparently extending to the main west-east watershed and even overriding it without opposition. The disposition of spillways near Innerdouny Hill, however, indicates that Clackmannan Ice completely overspread the area south of the relatively high section of the watershed between Innerdouny and Slungie Hill. Along the northern edge of the hills, eastward from Craig Rossie, the glaciated, oversteepened slopes and truncated valleys suggest that, while the main mass of ice moved southeastwards, some - possibly the lower layers of the glacier - was diverted northeastwards.

While in the Central and Eastern Ochils there was no serious barrier to ice movement, the situation in the western hills must have been rather different. North of Glen Devon boulder-clay reaches only to 1600' O.D., at which height ice could not have covered much of the higher parts of the hills. However, as this height is reached on the south side of Wether Hill (27/924059) the watershed must have been overrun, and a rather greater thickness of ice may be assumed. In the Hillfoots area boulder-clay certainly occurs higher - at least up to 1800' O.D. Here its presence in the valleys suggests that it is a remnant of a wider spread, and that the interfluves may have been ice-covered also. Support for this view is given by the evidence of glaciated surfaces in some areas. Thus, the outcrops known as "The Cloves", (27/875003) in the Alva valley, are apparently glaciated, while the steepness of the valley sides may also owe something to ice-action. It is probable that ice moved not merely over Dumyat, but also, if less strongly, over the higher ridges. The Balquharn and Alva valleys may have received ice from both ends - from the Lower Devon Valley, and at their heads by means of the slight cols that separate each of the minor interfluves from the higher west-east watershed. Ice may have entered the Sorrow valley at its upper end from the Gannel valley. A small rock step exists near the head of the Glen of Sorrow, over which the stream descends by a series of small falls, and which, together with the roughened valley sides, appears to point to the movement of ice down-valley.

North of the Blairdenon-Bencleuch ridge is the drift-free area of the Devon headwaters. Not only is boulder-clay apparently absent from the watersheds, where it could be present but hidden by peat, (although this seems unlikely) but there are no traces of it in the valleys - the Broich valley is the first in which it appears. The thickness of ice which must have obtained both to north and south should have been adequate to cover at least the larger part of this area, yet there are no traces of such a cover. Nor is there any boulder-clay in or east of the low col between Sauchanwood Hill and Core Hill. This rises to little above 1400' O.D., and ice might certainly be expected to have moved into it, especially as the presence of ice in the immediate neighbourhood is indicated by boulder-clay in Glen Anny. The explanation may lie in the fairly low relative relief of the area, coupled with high absolute relief. With the lowering of the snow-line that must have accompanied the onset of

Photograph 16. THE SUMMIT OF BENCLEUCH.

glaciation, a local ice-field may have developed. Although of small extent, such a field might nevertheless have been able to feed small valley glaciers, joining the more powerful ice-streams of external origin, and might have been of sufficient thickness to prevent the external ice from advancing over the area. If this explanation is accepted, then the occasional erratics found here must be regarded as deriving from an earlier glacial period when the area was covered by ice of external origin, and of which all other traces have vanished, or are at any rate indistinguishable from those of the latest period.

While, as already noted, certain writers have thought the Ochils to have been completely buried by ice, there appears to be some reason for doubting whether this was in fact the case, at any rate during the latest glacial period. Ice reaching to at least 2000' O.D. would be necessary to cross the Hillfoots ridges, and at this level nearly all the Ochil summits would have been covered. Bencleuch, however, rises to 2363' O.D., and is distinguished from all the others by the presence of large, somewhat rounded or subangular boulders lying on the summit. (Photograph 16) The edges of the outcrop from which they are derived are also rounded. While outcrops occur on several adjacent hills - on Andrew Gannel (2175+' O.D.), the Law (2094' O.D.) and Tarmangie Hill (2117' O.D.) they are all angular and frost-shattered. It is therefore suggested that the Bencleuch boulders owe their form to climatic conditions probably warmer and wetter than those of today, under which chemical weathering would be more intense and would produce rounded forms. It seems unlikely that such conditions obtained post-glacially - if they had, similar boulders might be expected elsewhere in the hills. An interglacial period may have provided the necessary conditions; if so, the presence of these boulders must indicate that ice never overran the summit after their formation, for they could hardly have remained there under moving ice. They may thus have much the same origin and significance as the larger tors considered by Linton to be indicative of unglaciated areas.[8.]

It may be noted that there are no corries in the Ochils. The valley heads are of two types - shallow hollows in the upland surfaces, or deeper, with steep sides flaring away from a narrow floor. None shows any sign of the plucking of the sides and hollowing of the floor consequent on ice-accumulation, although snow presumably collected in them. There appears to be no basis for Charlesworth's description of the Ochils as "possibly crowned by small corrie glaciers."[2.]

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5.

The Waning of the Ice-Sheets.

In this section the evidence for stages in the retreat of the various ice-fronts has been examined. An attempt has been made to describe the gradual emergence of different parts of the hills from the ice-cover in chronological order, but it does not seem possible to adhere to a strictly chronological order and at the same time to trace the movements of individual ice-fronts in a logical manner. The hills have therefore been subdivided, and different areas considered in turn, beginning with one which appears to have been ice-free at an early date, tracing the stages by which the ice-front concerned withdrew from it, and the changes in drainage pattern through the period. Another area, which appears to have become ice-free soon after the first, has then been considered, and related to the first where possible, this procedure being followed also with the remaining areas.

I. General Considerations.

The probable sequence of events by which the Ochils were freed from ice is indicated by various types of field evidence, in particular by meltwater channels, and by glacial and fluvio-glacial deposits, but the general trends may also be deduced from general considerations. It may be assumed that the climatic amelioration leading to the waning of the great ice-sheets and glaciers was reflected at an early date by a rise in the position of the snowline. Such a rise would in all probability lead to the disappearance of any local ice field within the Ochils. At the same time, the increased ablation would result in some slight shrinkage of the glaciers surrounding, and penetrating into, the hills, although these glaciers, with sources in the north and west, might not be greatly affected by the actual raising of the snowline for some time. The effect of the disappearance of local ice, with the shrinkage of the external ice-masses, would be to leave the higher parts of the hills ice-free. Drainage in these areas, augmented by glacial meltwater, must obviously have been obstructed by the presence of ice in the valleys, and the resultant meltwater channels or spillways may be expected to give some indication of which were the first ice-free areas, and of the pattern of retreat of the various ice-fronts from the hills.

The Blairdenon-Bencleuch ridge and the area around the Devon headwaters were probably among the first areas to emerge from the ice - if indeed, they had ever been completely covered. Very few meltwater channels exist here, possibly because of the small area involved. Only one example of a possible spillway has been found in the highest area. A shallow but steep-sided valley cuts the col between Bencleuch and Andrew Gannel Hill (27/919006) just above 2000' O.D. Its floor is covered with peat, and there is no indication of the possible direction of flow through it. If it is indeed a spillway, its height suggests that it must belong to a very early stage of deglaciation.

Meltwater channels in the Ochils do not generally appear to have been associated with pro-glacial lakes. Few deltas appear to have been formed and there are few areas of lacustrine deposits. It seems probable, therefore, that most spillways debouched onto ice, the meltwater escaping either through or over the glaciers, and that their deposits are now indistinguishable from other types of glacial debris. If this was indeed the case, many spillways must indicate fairly closely the height to which the ice reached at the time when they were formed. Certain channels have a one-sided form - i.e. one wall is appreciably lower than the other, or may be entirely absent. Such channels appear to have developed so close to the ice edge that one wall was completed or formed of ice.

II. The South Central Hills.

It is probable that, after the high southern watershed area of the Ochils, the rather lower northern watershed became ice-free. Certain cols at valley heads between Glen Eagles and John's Hill (37/002081) have apparently been modified by meltwaters, being rather more sharply cut than might be expected as a result of normal, subaerial denudation. All are at high levels - above approximately 1400' O.D. - and are short, with no very marked fall, suggesting that they carried meltwaters from the edge of one ice-mass to that of another - from ice in the Coul valley to Glen Devon. (e.g. 1a & b Fig. 14) Between Sim's Hill and John's Hill a slightly deeper spillway, (2)* approaching 100 feet in depth, appears to have been cut by water draining from the Coul valley to one of the South Queich tributary valleys. It must have been superseded by Corb Glen, (Fig. 14) one of the more impressive spillways in the Ochils, which drains to the May valley. Nearly 200 feet deep, it breaches a col whose original height was probably not much below 1400' O.D., and appears to have formed the major outlet for water from the Coul valley for a long period. At first possibly leading onto ice, it continued

* Except where otherwise indicated, numbers referring to meltwater channels in the following pages are those shown in Fig. 14.

in use as the May valley became ice-free, and, together with those from a tongue of ice occupying the col between the Dunning and May valleys (3) the meltwaters using it probably developed the sharply incised trough now occupied by the Water of May.

East of Innerdouny Hill, the relatively high ridge to Slungie Hill was probably also ice-free at an early date - possibly at much the same time, or very shortly after, the watershed north of Glen Devon. Spillways at high levels - i.e. above 1200' O.D., were developed near Innerdouny Hill, indicating that the broad col between the May and South Queich valleys must have remained ice-filled for a long period. Fluvio-glacial gravels in the South Queich valley between Fanny Hill and Myrehaugh (37/012052), containing andesite and Highland pebbles, but apparently none of Carboniferous rocks, suggest that a lobe of the Strathearn Glacier occupied the col and extended some distance down the South Queich valley. Further east, beyond the ridge from Innerdouny Hill to Lendrick Hill, the area drained by the Warroch streams was probably occupied by Clackmannan Ice, the Innerdouny Hill-Slungie Hill ridge serving as a barrier to the Strathearn Glacier. Spillways in this part of the Ochils appear to reflect differences in the rate of shrinkage of the two ice-masses.

The Black Law spillway (4) was probably one of the earliest to develope. A relatively shallow channel, about 15 feet deep only, it leads from the South Queich valley, with an intake at ca. 1325' O.D., into the valley of the Lee Burn. Here, at a height of ca. 1225' O.D., the channel divides, one branch, presumably the older, continuing eastwards into the Warroch West valley, while the other at a slightly lower level, turns south down the Lee valley, probably reflecting a change in the position of the ice-front. The rejuvenation, consequent on the opening of the lower outlet, is now marked by a small step, three to four feet high, in the floor of the channel a short distance upstream. Neither branch has a very clear termination; the meltwaters using this spillway may have escaped onto ice lying at about 1200' O.D. At much the same time, when ice in the upper South Queich valley reached to approximately 1300' O.D., a col between John's Hill and Lamb Hill appears to have been used as a spillway, and is slightly modified by meltwaters (5). It leads from the May valley into that of the South Queich: it may have carried waters escaping from the Coul valley by way of Corb Glen.

Further east along the Innerdouny Hill-Slungie Hill ridge other high-level spillways must similarly have developed in the early stages of deglaciation. Thus, between Coalcraigy Hill and Head's Hill, a shallow spillway (6) crosses the ridge at a little below 1400' O.D., leading from the May valley. Unlike these north of Glen Devon, however, it continues as a well-marked channel down to approximately 1100' O.D. Near its upper end a one-sided channel branches from it, hanging slightly above its floor, and runs obliquely downhill to ca. 1200' O.D. (7).

These channels appear to represent two stages - an early one, when the oblique channel (7) was cut alongside ice lying well up in the head of the Warroch East valley, and a later one, when the ice-front had withdrawn southwards, but meltwaters continued to cross the ridge from ice lying at a high level in the May valley. Also belonging to an early stage is a broad but shallow channel, with no obvious fall, between Head's Hill and Slungie Hill, at ca. 1300' O.D. (8).

North of Innerdouny Hill, two shallow spillways at a lower level, leading from the valley of a tributary of the May to the South Queich valley, can have developed only after a shrinkage of the ice. One trenches the flat summit of the Muckle Rig at a little over 1250' O.D., (9a) the other (9b) at just over 1200' O.D., is rather a slightly modified col than a true spillway. These channels are separated by only a few yards, and must have been virtually contemporaneous. The same may also have been true of two spillways entering the May valley on its northern side (10a & b). Both lead from the valley of the Thorter Burn, a tributary of the Dunning Burn, at a height of ca. 1300' O.D., and descend as deeply cut, steep-sided channels to approximately 1200' O.D. They suggest that the Strathearn Glacier may have decreased in thickness steadily from north to south - lying at over 1300' O.D. on the northern slope of the hills, descending to possibly 1200' O.D. in the May valley - to which it had access by way of the col at the head of the Dunning valley, as well as by the lower May valley itself - and probably thinning still more rapidly in the South Queich valley.

These high spillways must inevitably have been abandoned as the ice edges shrank away from the Innerdouny Hill-Slungie Hill ridge, and meltwater drainage then appears to have taken place in a generally west-east direction across the spurs running from it. Thus a number of shallow channels cross the long ridge running south from Slungie Hill to Arlick Hill (37/063055). The highest of these (14) has no marked fall, crossing the summit of Corse Hill at ca. 1100' O.D., and suggests that ice may have been at much the same level on either side of the ridge when it was formed. A short distance northwards the col between Corse Hill and Black Hill may have been covered by ice, for a second channel has been cut across it (15), with an intake some 20 - 30 feet lower. This has a steeper gradient, descending to ca. 1050' O.D. as a shallow but clearly cut trench, some 10 - 15 feet deep. It appears to be continued to 950' O.D. as a one-sided channel, suggesting that ice still lay to these heights on the east side of the ridge. A further spillway (16) across Arlick Hill, with an intake at ca. 950' O.D. presumably developed later, but has a very slight fall and an outlet but little lower than its intake. This may reflect a fairly rapid shrinkage of the ice west of the ridge, possibly because it was thinner than that to the east, which apparently remained at much the same level over a longer period.

North of the Innerdouny Hill-Slungie Hill ridge other spillways crossing spurs between tributaries of the May, and falling eastwards, indicate a smiliar shrinking of Strathearn ice away from the ridge, and the drainage of meltwater along the ice-margin. (22a - f, Fig. 14) There seems to be no comparable sequence across the Innerdouny Hill-Lendrick Hill ridge, at the western side of the area drained by the Warroch streams, although the various hills along it are separated by relatively low, broad cols. One of the earliest spillways in the area, (4) crosses one such col between Innerdouny Hill and Mellock Hill, at ca. 1300' O.D. Further south, the col between Mellock Hill and Carmodle is crossed by a very shallow channel a little below 1200' O.D. (11). There is no trace of the development of spillways intermediate between this and the magnificent trench Glen Queich, cut across a col which could not have been above 1000' O.D. although there are cols which would appear to offer outlets. The existence of these apparently unmodified cols suggests that the cutting of Glen Queich commenced very soon after the Carmodle spillway developed, probably as a result of a shrinkage of the Clackmannan glacier.

Glen Queich is undoubtedly the finest spillway in the Ochils. A narrow, steep-sided trench 300 feet deep for much of its length, it is nearly two miles long, and for about half this distance absolutely straight, following a fault-line. (Photograph 5)

Commencing at Myrehaugh at ca. 775' O.D. it is in fact a part of a more extensive system of meltwater channels (see Fig. 14) by which water from Glen Devon was carried to the Plain of Kinross, where the outlet at Carnbo (37/053032) is below 600' O.D. The form of the channel suggests that there were two main stages in its development. The lower 100 - 150 feet of its walls are very steep, and frequently precipitous, while the upper walls are somewhat less steep, although still at a high angle. These contrasting slopes are confined to the straight section of the channel, the higher part of the channel apparently not continuing along the line of the glen below Braughty Hill. These upper slopes do, however, continue into a channel running eastwards south of Broadhead (12), which now hangs 150 feet above the floor of Glen Queich. The intake has been lowered to ca. 850' O.D., probably from an original height of nearly 1000' O.D. This channel turns abruptly between Cloon and Braughty Hill, the change in direction being marked by a sudden descent over a small cliff. Below this point the channel is known as Keerie Glen, and is a narrow, steep-sided V-shaped valley some 200 feet deep. The sudden deepening and change of form of the channel clearly reflects the discovery of a new, lower outlet by the water using it, consequent on a change in the position of the ice-front. Keerie Glen now opens onto a broad, smooth-floored valley in which the farm of Braughty stands (37/041038). This valley is drained by two streams, one joining the South Queich, the other the North Queich, but appears to have been used by meltwater flowing eastwards to the spillway now occupied by the Golland Burn (21). Although Keerie Glen hangs a few feet above the valley floor, it must have been the disappearance of ice from this valley that caused its rejuvenation. Also hanging above the Braughty valley, but by 50 - 100 feet, is another broad, smooth-floored valley, now drained southwards by the Cloon Burn (13). This stream has made a narrow incision into glacial deposits, and the valley appears to have been used by meltwater draining first northwards, then eastwards by a narrow channel occupied by the Lee Burn, and finally southwards by the continuation of this channel, occupied by the Warroch West Burn. It is possible that this circuitous route may have been used by meltwater using the Keerie Glen prior to its rejuvenation.

The Lee-Warroch channel appears at first to have led meltwater eastwards into the Warroch East valley, over the bench on which the farm of Upper Warroch stands, at ca. 800' O.D. (37/053051). The Warroch East valley is broader than its neighbours to the west, and its floor is covered with relatively extensive deposits of sands and gravels. Particularly in the southern part of the valley, these deposits have an almost flat surface, and it is possible that a pro-glacial lake existed here. Further outlet for the meltwater must have been over or alongside the ice, possibly by the shallow Ledlation channel (17)

This one-sided spillway, 10 - 15 feet deep, descends from approximately 800' O.D. to 750' O.D. running obliquely down the hillside, as if cut alongside an ice mass decreasing in thickness eastwards. As the ice-margin retreated, uncovering lower cols, the Drumgarland spillway developed (18a) being lowered from approximately 750' O.D., and causing the abandonment of the Ledlation channel. The Drumgarland spillway now appears as a straight, flat-floored channel about 100 feet deep, cut partly in rock and partly in gravels. It seems to have had two outlets (18b & 18c) before the present one was developed, each probably reflecting a change in the position of the ice-front. All the outlets, however, are at much the same level, opening onto a flat-floored area of the Plain of Kinross, at 500' O.D. This area is partly margined by steep banks of sands and gravels, 15 - 20 feet high, and may mark the site of a pro-glacial lake.

The Lee-Warroch channel seems also to have been affected by the retreating ice-front, and to have been extended slightly to join the Drumgarland spillway. The present incision of the Lee-Warroch channel probably reflects the downcutting of the larger spillway. With the continued retreat of the ice-margin, a new spillway was developed between Shiel and Downeri (19) across a col whose original height was probably 800' O.D. This presumably replaced the Lee-Warroch channel as a route for meltwater from Glen Queich and Keerie Glen, resulting in the rejuvenation of Keerie Glen, while the Lee-Warroch spillway carried only the Lee and Warroch West streams. For a time it may also have carried the Cloon Burn, but the development of a corrom divide turned this southwards, where the descent to the Downeri spillway resulted in the incision of the stream into the glacial deposits flooring its valley.

The lower end of the Downeri spillway is cut some 20 - 30 feet below a smooth-surfaced area of fluvio-glacial sands and gravels, lying between the Golland Burn and the North Queich. These are terraced, and extend from 600' O.D. to nearly 750' O.D. An exposure at a height of ca. 625' O.D. (27/804044) shows sands and fine gravels in beds dipping gently eastwards. It seems probable that these were deposited by meltwaters using the Downeri spillway, possibly in a small pro-glacial lake. The two terraces must have been formed when the meltwaters continued eastwards by the Drumgarland spillway. Later, a withdrawal of the ice-front probably resulted in the development, as a spillway, of the present North Queich valley (20) and the lake must have been drained. For a short time the Downeri spillway was apparently continued by a shallow depression to the North Queich channel, but this must have been abandoned after a short time in favour of the right-angled channel (21) now occupied by the Golland Burn. The curious course of this channel may be due to its having developed partly along the line of a pre-glacial valley, the lower part of which still remained blocked by ice, causing the meltwater to turn northeast and join the North Queich as before.

Further west similar withdrawals of the ice-front must have permitted the development of lower Glen Queich, and the abandonment of Keerie Glen. It is possible that for a time both outlets were in use simultaneously, but that the incision consequent on the use of the relatively low level valley from Braughty to the Downeri spillway progressed more rapidly up Glen Queich, leaving the intake of the Keerie Glen hanging.

The final stages in the development of Glen Queich - the lowering of its floor to its present level, and its extension beyond the hills into the glacial and fluvio-glacial deposits of the Plain of Kinross - must have resulted from a withdrawal of the edge of the Clackmannan Ice at least as far south as the line of the South Queich below Carnbo. With this withdrawal meltwater could escape southeastwards, and the Downeri spillway must have been abandoned. The form of the deposits into which the spillway was cut, spreading southeastwards from the mouth of Glen Queich, suggests that they may have accumulated in part at least as an alluvial fan. Only one exposure of the material has been found; this is situated in a small gully close to the hill foot (37/039033) and shows unsorted pebbles, mostly rounded or subangular, up to three to four inches in diameter. No traces of bedding were distinguished. The surface of the deposits has been terraced. The higher of these terraces, on which Braughty stands, continues into the Downeri spillway, and was probably formed by the meltwaters using it. A steep slope ten to twelve feet high separates this terrace from the lower, which appears to have been formed by streams spreading fanwise from Glen Queich. Thus there are traces of a channel running eastwards between Downeri and Cairn Hill (37/048036) while on the opposite side of the South Queich a better developed channel (25) is cut into the remnants of the higher terrace. The incision now occupied by the South Queich may have been developed on the line of a further channel. Such radiating channels may well have been associated with the development and dissection of an alluvial fan.

The narrow, flat-floored and steep-sided valley now occupied by the South Queich between Glen Queich and Carnbo may have been initiated by meltwaters, and so reflect a further change in the position of the ice-front, but may equally well be the work of the South Queich, which is a large stream apparently quite capable of producing such a valley. Meltwaters using the spillway in the later stages of its development may have continued southeastwards to join one of the lakes in the Plain of Kinross, but the details of the route followed are not clear, owing to the later development of the Pow Burn spillway (26) which truncates the alluvial fan at Carnbo, and along which the South Queich drains eastwards.

For much of its history Glen Queich appears to have formed an outlet for waters from Glen Devon, and for at least part of its development may also have carried meltwaters at first from a lobe of the Strathearn Glacier occupying the upper South Queich valley, and later from the May valley when this lobe had disappeared. It seems probable that the thick gravel deposits in the upper South Queich valley, found mainly between the Fanny Burn and Myrehaugh, were deposited as the snout of the Strathearn lobe withdrew, meltwaters from it possibly being dammed temporarily near Myrehaugh until Glen Queich was lowered sufficiently to allow free drainage. As the ice margin withdrew the present South Queich valley was cut into the gravels, producing terraces between 900'- 950' O.D. some 100 feet above the present valley floor at Myrehaugh, but decreasing in height upstream. On the freeing of the col between the May and South Queich valleys meltwaters appear to have escaped across it to the South Queich valley, cutting the Deaf Knowes spillway (24). The original height of the col was probably not above 1050' O.D., and the spillway has been cut 50 feet below it. At its lower end it passes imperceptibly into the floor of the South Queich valley, indicating that the water using it continued without obstruction down the valley, and may have contributed to the cutting of the steep-sided, flat-floored valley through which the South Queich flows on its way to Myrehaugh. It is not clear whether meltwaters continued to use the Deaf Knowes channel virtually until the South Queich valley was lowered to its present level at Myrehaugh, or whether two small falls giving a total descent of some ten feet a short distance upstream of Myrehaugh (Lamb Linn, 37/014057) mark the change from the true spillway section of the valley to a section in which the flat floor is due to the action of the South Queich alone. In either case, it seems probable that water from the May valley used this route for a very long period, and that the Clackmannan Ice was shrinking rapidly while the Strathearn Glacier still extended far into the hills.

Water from Glen Devon reached Glen Queich chiefly by way of the Whiterigg spillway (22) a narrow and deeply cut channel curving round Down Hill (37/001037) to reach the broad valley 50 - 100 feet deep, now drained southwards by the Glendey Burn, but which at its northern end passes without break into the floor of Glen Queich (23). The flat floor and steep sides of this Dey valley show clearly that it has been modified by meltwaters, and it is equally clear that the meltwaters flowed northwards towards Glen Queich. The Glendey Burn has cut a deep and narrow ravine on its way southwards to join the Devon, partly in rock and partly in glacial and fluvio-glacial deposits. The smooth upper surface of these deposits, 150 feet above the confluence of the Glendey and the Devon, forms a terrace which slopes steadily northwards, passing into the unincised section of the valley floor near the outlet of the Whiterigg spillway, and sweeping on to Glen Queich. It seems clear that the southward flow of the Glendey Burn is a relatively recent development, resulting from the development of a corrom divide near Myrehaugh, and probably encouraged by the gullying of the glacial deposits into which the Devon began to incise itself at the southern end of the valley.

The Whiterigg spillway passes into the Dey valley with no marked break, suggesting that meltwaters were using it when the Dey terrace was formed. Yet the intake of the spillway, a little above 800' O.D., is at least 50 feet higher than the terrace, and it might be expected that the spillway would be abandoned as soon as the Dey valley became ice-free. A possible explanation is that while Glen Devon waters used the Whiterigg spillway a lobe of the Clackmannan Ice occupied the Dey valley, meltwaters from it joining those from Glen Devon and continuing to Glen Queich. When this lobe eventually disappeared Glen Devon water may have used the Dey valley for a short time, but if so, does not appear greatly to have modified it.

The spillways just described, together with Glen Queich, form an extensive system by which water from the central and western parts of the hills, unable to escape freely because of the presence of glaciers to the north and south, made its way gradually eastwards to the Plain of Kinross, which, if not entirely ice-free, cannot have been so completely ice-covered as areas further west. In the Plain, numerous flat, sometimes ill-drained areas, floored with sand and silt, diversified by mounds of sands and gravels, and margined with more or less well-developed terraces of gravel, point to the existence of pro-glacial lakes, into which the various meltwater channels drained. The shrinking of the ice-mass which occupied the area appears to have been marked along the eastern slopes of the Ochils by much the same features as those noted between Glen Queich and Arlick Hill. Meltwater channels tend to drain eastwards and southeastwards (e.g., 27a, 27b, 27c), but a less complicated system appears to have developed in the east than in the west, probably reflecting the shorter slope from watershed to lowland, and the absence of large embayments. Fluvio-glacial gravels are commonly banked up thickly against the lower slopes of the hills, probably as a result of deposition from ice waning more or less in situ. These gravels sometimes form rough terraces, not usually continuous for more than 200 - 300 yards.

The meltwater channels of the area are not usually more than fifteen to twenty feet deep, and are usually partly or wholly one-sided. These features suggest that they were not used for long periods. The largest of them, the Holeton channel (27a), commences near Craigow (37/089064) a little below 700' O.D., and runs eastwards for two miles, descending steadily until it opens out onto a flat area near Netherton, (37/131061) at 425' O.D. This flat is in part edged by steep banks ten to fifteen feet high, and its appearance strongly suggests that it is the site of a pro-glacial lake. The course of the Holeton channel, with its descent of over 200 feet and its partly one-sided form, may well mark the position of the ice-front at the time at which it was formed, and the Netherton lake may have been at or very near the snout of the glacier. Large, rounded, hummocks, 25-30 feet high, near Nether Tillyrie (37/115059) may be morainic deposits of much the same age.

Other meltwater channels, with lower intakes, emerge onto flat areas similar to that of Netherton. Immediately north-east of Milnathort there is some evidence of two probable lake levels, one at 425'- 450' O.D. forming a terrace above the lower, which is represented by a flat or very gently sloping area with an outer margin at 400' O.D.

Although field investigations in the Plain of Kinross have not been extensive, there appears to be evidence of a series of pro-glacial lakes, now represented by flat, ill-drained areas in places edged by steep sand and gravel slopes. While some of these areas may be kettle holes, the way in which the bounding slopes are in places broken by the entrance of meltwater channels points to their having been occupied by lakes. The highest of these lakes appear to have been in the west, receiving meltwaters from the Drumgarland, North Queich and

South Queich channels, at a height of ca. 500' O.D. These are unlikely to have been very extensive, and must have been held between the hills and ice covering the greater part of the lowland. Similarly, lakes at slightly lower levels, such as that at Netherton, may have had only a small extent. No traces of extensive lake flats at heights above 400' O.D. have been discovered. At and below 400' O.D. the wide, flat or gently sloping areas around Loch Leven may well indicate former extensions of that lake. Lacustrine deposits mapped by the Geological Survey and margined by a slight rise indicate a fairly recent lake level of 360' O.D., nine feet above that of today.

The possibility of extensions of Loch Leven to the 400 - foot level raises a problem concerning its outlet. At present it is drained by the River Leven through the broad, flat, depression between Bishop Hill and Benarty, lying entirely below 375' O.D. On the northeast, however, a smaller depression, in part occupied by the River Eden, leads to the Howe of Fife. A lake at a level of 400' O.D. could apparently have drained by this route. The higher Netherton lake almost certainly did so. It is possible, therefore, that the present outlet was blocked - presumably by ice - when a lake level of 400' O.D. obtained at the northern end of Loch Leven. The absence of any flats at the 400-foot level below Bishop Hill offers some support for this hypothesis. The ice mass effecting the blockage may still have been attached to the main glacier, or may have been detached and stagnant.

III. The North Central Hills.

North of the Innerdouny-Slungie Hill ridge the Ochils appear to have been largely overrun by the Strathearn Glacier. The evidence of the South Central part of the hills suggests that this was sufficiently powerful for a lobe to extend some distance down the South Queich valley. East of Slungie Hill the appearance of the col at the head of the Chapel valley, broad and steep-sided, indicates that another lobe may have extended through it, while the broken surface of the watershed as far east as Tillyrie Hill (37/105081) suggests that ice may have moved strongly over it to enter the Plain of Kinross. Crossing this watershed are a number of spillways which, like those crossing the Innerdouny Hill-Slungie ridge, fall southwards. It seems probable that, like the other parts of the major watershed, this part became ice-free before the areas to north and south of it, and that for some time the ice to the north of the ridge remained at a higher level than that to the south.

The highest spillways east of the Chapel valley col lie south of Dochrie Hill (37/082083) at approximately 1050' O.D. These are short, with no great difference in the height of their intakes and outlets. (Fig.14,28a & b) It is possible, therefore, that they were used at a very early stage of deglaciation, when ice on both sides of the ridge remained at similar heights. A third channel (29) shows a considerable difference between the heights of its intake and outlet, its intake being at ca. 1050' O.D., while its outlet is slightly below 900' O.D. Further east a channel between Tillyrie Hill and Holeton Hill (37/108082) is similar, falling from ca. 1025' O.D. to below 900' O.D. (Fig. 15, 1). Both these channels descend as steep, dry gullies down the southern slope of the hills; their steep-sided, flat-floored form is that of a spillway, but it is possible that they have been modified or extended by water from snow melt on the watersheds.

One other small channel leads southwards at a high level from the watershed (Fig. 15, 4). This leads from a flat, ill-drained peaty area at approximately 1025' O.D., and descends to only 1000' O.D. The appearance of the flat at its intake suggests that ice lying north of the watershed may have dammed a lake within a small rock basin at the head of the Slateford valley. On the northern side of this basin another spillway at a slightly lower level appears to have developed as the ice-front retreated (3)[*] resulting in the abandonment of (4). This lower channel leads northwards to the Miln valley, a tributary of the Slateford valley, descending to ca. 950' O.D. It is difficult to envisage how this could have formed an efficient outlet for meltwaters, as it seems probable that the

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[*] Except where otherwise indicated, numbers referring to meltwater channels in the following pages are those shown in Fig. 15.

lake was in part dammed by ice in the upper Slateford valley, and ice extending so far up the main valley must necessarily have extended into the tributary valley also. Escape westwards to the Chapel valley seems improbable, as spillways below the level of (3) drain from the Chapel valley to the Miln valley across the col between Baulk Hill and Whitehill Head (5a & b), suggesting that this col was ice-filled when the higher spillway was in use. The only outlet would appear to have been by way of the ice itself.

Further east, another channel of spillway form at a high level leads northwards from the watershed (2). This is aligned with the Holeton channel (1) both being developed along a fault-line. While this may have carried water impounded by ice, as its form suggests, it seems probable that the development of the steep sides, ten to fifteen feet high, but not continuous throughout its length, was facilitated by the structural weakness, and that water from melting snow in the relatively wide area drained by the Strawearn Burn through the channel also contributed to its growth.

East of Holeton Hill, the watershed decreases in height, only small areas rising above 800' O.D. Shallow cols across it have been deepened by meltwaters moving southeastwards. Thus the little Langside spillway (7) was developed between the Glendy and Lossley valleys, at ca. 775' O.D. It does not appear to have been used for long, and as it does not extend far into the

Lossley valley, may have functioned when ice remained at a relatively high level on both sides of the ridge. The Birniehill spillway, (6), although probably initiated at much the same period as the Langside, must have continued in use when much of the Glendy valley was ice-free, and when the Golloch valley was being used, and deepened, by meltwaters. The Birniehill spillway is a steep-sided, V-shaped valley nearly 100 feet deep, narrow at its upper end but widening southeastwards where it merges with a pre-existing valley. Because of this, it is difficult to decide precisely where the spillway ends, but the valley does not appear to be modified by meltwaters below 600' O.D. No evidence has been found of the route followed by the meltwaters on leaving the spillway, and this may have been over ice occupying the Plain of Kinross.

The Golloch valley appears to be of pre-glacial origin, but modified by the movement of ice over this part of the hills, and also by meltwaters. These developed a flat-floored and shallow channel leading to the Glendy valley and the Birniehill spillway. At its upper end it is joined by a broad but similarly shallow spillway from the Strawearn valley (8), and must have carried water from this valley at a time, when its lower end was blocked by ice. A lobe of ice that dammed the Strawearn valley must, of necessity, have closed the lower Glendy valley also, and water from this must also have escaped by the Birniehill spillway.

The arrangement of spillways in this area suggests that two ice-fronts existed - one retreating northwestwards towards the May valley, the other north and northeastwards towards the lower Farg valley. The continued retreat of the May ice-front, beyond the Slateford-Strawearn watershed, led to the development of a system of spillways to carry off the water which must have been impounded against that watershed. Thus the small Temple Hill spillway (9), some twenty feet deep, at a height of 800' O.D., drained southwards, probably at first by the Golloch valley, but later, eastwards, as the Strawearn valley became ice-free. At much the same time, the Strawearn valley may have received water from shallow channels across the spur east of Temple Hill (e.g. 10).

The Birniehill spillway was probably abandoned at about the same time as the Golloch channel, the floor of the latter continuing without an appreciable break into that of the former. Near the intake of the spillway the floor of the Glendy valley is so flat as to suggest the existence of a lake, probably dammed by ice in the lower Glendy valley. The height of the intake - 685' O.D., as given by a benchmark - indicates the probable level of the lake before the retreating ice-front allowed it to drain northeastwards: earlier it must have risen to a higher level. In the lower Glendy valley between Shuttlefold (37/122094) and Glendy Mill (37/124098) a similar flat area of the valley floor, just below 600' O.D. through which the Glendy Burn meanders slightly, may mark the site of another lake.

For a short time this may have been sufficiently extensive to have been drained by the Birniehill spillway, but this must have been abandoned as the Farg valley became ice-free. The flat-floored section has developed at a point where the width of the Glendy valley is slightly increased: immediately downstream of Glendy Mill the valley narrows slightly, and the stream is incised some ten to fifteen feet in the boulder-clay flooring it. The lake may have remained after the disappearance of the ice in the valley because of an irregularity of the glacial deposits, or may have extended downstream as the ice-front retreated.

The shrinkage of the ice occupying the Farg valley and its tributaries must eventually have resulted in the abandonment of the Temple Hill spillway (10) and in the development of the Craigfarg and Blair spillways. (11 & 12) These two appear to have formed a route by which water from ice in the Slateford valley crossed the pre-glacial watershed to reach the Farg valley. The Craigfarg channel, with an intake at ca. 825' O.D., probably carried water direct from the May ice-front, as well as that contributed by two sets of marginal channels on either side of the Shirend tributary valley of the Slateford valley. (14a & b, 15a & b) The first of these (14a) at approximately 900' O.D., has a somewhat lower wall on its northeastern, down-valley side, and appears to have developed marginal to ice lying in the main valley. The second (14b) is at a slightly lower level, and appears to have developed as the ice shrank. Both lead towards a broad but sharply cut channel (13) which in turn joins the Craigfarg channel. On the opposite side of the valley 15a and b appear to have developed in a similar fashion to 14a and b, but are some fifty feet lower, and lead directly into the Craigfarg channel. None of these marginal channels, although usually sharply cut, with steep sides and flat floors, is more than fifteen feet deep.

As far as the intake of the Blair spillway, which hangs fifteen to twenty feet above its floor, the Craigfarg channel is not deeply cut, increasing in depth from about fifteen feet to 25 - 30 feet. Beyond the Blair spillways it deepens rapidly, becoming a ravine in its descent to the Glenfarg Reservoir, where it is about 100 feet deep. On its eastern side under Blair Hill (37/107104) there are remnants of a bench which appears to fall towards the northerly branch of the dual intake of the Blair channel. The other branch, also at ca. 775' O.D., appears to continue the line of the upper Craigfarg spillway. It seems probable that the lower Craigfarg spillway is developed along the line of a pre-glacial valley falling northwards, but that movement of meltwaters in this direction was prevented by the presence of ice. Water from this ice may have escaped to the Blair spillway, cutting the bench under Blair Hill, while water from the Slateford valley reached the Blair spillway by the upper Craigfarg channel and the southern intake. The eventual disappearance of the ice in the Craigfarg and Farg valleys must have allowed meltwaters to abandon the Blair spillway, and to continue northwards along the whole length of the Craigfarg channel.

The Blair spillway swings round Blair Hill to join the Farg valley at a point about half a mile below the reservoir. For some 500 yards below its intake it is a broad, flat-floored valley of gentle gradient with steep walls fifty feet high. At West Blair (37/110102) however, there is a sudden descent of twenty to thirty feet, beyond which the spillway continues as a deep and narrow valley, falling rapidly to 550' O.D. at its outlet in the Farg valley, where it hangs four to five feet above the valley floor. Benches near its outlet, at 575' - 625' O.D. appear to mark the height of the outlet when the upper part of the channel was formed. Two smaller channels enter from the north at West Blair and a short distance further east (16a & b), the first descending from ca. 825' - 775' O.D., the second from 800' - 750' O.D. Both appear to have carried water from north of Blair Hill, and are 25 - 30 feet deep. Both were apparently abandoned some time before the main channel fell out of use, the first hanging fifteen to twenty feet above the broad upper part of the channel, the second hanging over fifty feet above the lower, deeply incised section.

The Farg valley for about a mile below the reservoir - and possibly, to judge from early Ordnance Survey maps, in the section occupied by the reservoir - has a marked spillway form,

Photograph 17. THE FARG VALLEY.
Looking east (downstream) from above Gllenfarg Res.

with a flat floor and steep, often rocky sides. (Photograph 17) Near the entrance of the Glendy valley these characteristics vanish, and the valley has a normal, if steep-sided and narrow, form. These contrasts most probably result from the effects of glaciation and of meltwater drainage on the pre-existing valley system. The pre-glacial watershed between the May and Farg drainage was probably continued from Blair Hill to Berry Hill across the present Farg valley. This area bears much evidence, in broken, irregular surfaces, of the intensity of ice-action, and ice moving eastwards from the May valley may have overriden and partially breached the watershed. Later, as the ice-fronts retreated, water was probably impounded against the watershed, and escaped over it, cutting a spillway (17) and deepening the valley beyond. This modification did not extend to the part of the valley already sufficiently large to accommodate the meltwater stream. There is some evidence, in the presence of small benches immediately below the reservoir, at 600' - 650' O.D., 50 - 70 feet above the valley floor, of an early high level of the spillway, probably corresponding to the upper level of the Blair channel.

It is possible that the higher level may have been associated with a pro-glacial lake in the Farg-Eden valley, extending into the upper Farg valley. There appear to be few deposits pointing to the existence of such a lake, only one small area between Glenfarg (37/134105) and Edenhead (37/136100) in the Farg-Eden valley having the ill-drained appearance of a lake flat, in addition to that already described in the Glendy valley. A short distance north of Glenfarg, however, a small meltwater channel leads from the Eastertown March spur down the side of the Farg valley. Although nowhere more than twenty feet deep, this is sharply cut, and ends high above the valley floor, at 600' O.D. No delta associated with it has been recognised, but the coincidence of the height of its outlet with the height of the benches in the Blair and Farg spillways suggests that it may have entered a lake at or near 600' O.D.

Such a lake could only have existed in the Farg-Eden valley if both ends were blocked by ice. Such barriers may have been provided by the Strathearn Glacier on the north, and by ice in the Plain of Kinross on the south. An outlet is offered by the Arngask valley. A shallow, open pre-glacial valley, this appears to have been modified by meltwaters at its upper end, where a 30-foot deep spillway (19) leading to the broad Balcanquhal valley has been cut through a col whose original height was probably not above 600' O.D. Beyond it, the Balcanquhal valley does not appear to have been modified by meltwaters, but may have held a shallow lake, the waters eventually draining to the Howe of Fife. At its eastern end the valley of the Morton Burn has a spillway form (20) but is at a lower level, and therefore was probably not used until a later date.

The evidence of the rejuvenation of the Farg and Blair spillways points to the abandonment of the Arngask outlet for one much lower. This was probably the result of the shrinkage of ice in the Plain of Kinross, which permitted the development of the Eden spillway. Although not one of the largest spillways in the Ochils, being not more than fifty feet deep, this must have carried the drainage of an extensive area. It descends from the lake flat south of Glenfarg, at a height of 450' - 475' O.D., to ca. 350' O.D. in the broad vale between the Ochils and the Lomond Hills. At its lower end benches suggest that it may have had an earlier, higher, outlet at ca. 400' O.D. At both levels the vale into which it drained must have been ice-free, and it may have functioned at the time when the Holeton and other channels in the Plain of Kinross drained into the Netherton lake, which, draining northeastwards, may have joined the meltwaters using the Eden spillway, the combined waters continuing into the Howe of Fife.

While the Eden spillway was in use, the lower Farg valley must have continued to be blocked by ice. Although the deeply cut Glen Farg is sometimes regarded as a spillway, it is more probably a recent stream incision, and there seem to be no grounds for Simpson's statement that this valley functioned from south to north as an overflow channel.[1] The present River Farg appears to follow a northerly course solely as a result of the formation of a corrom divide at the point where it enters the Farg-Eden valley. Its pre-glacial valley must certainly have fallen from south to north, but, as is indicated by benches high above the river, 150 - 200 feet above its present level. The deep, narrow incision below these benches is probably comparable to that of the Hillfoot streams in their lower courses - that is, due to a lowering of base-level by ice scouring out the less resistant sedimentary rocks, brought against the andesites along the east-west fault-line. On a smaller scale, the incision of the Farg is reproduced by all the streams draining to Strath Earn from Auchterarder eastwards.

The withdrawal of the ice-front in the lower Farg valley does not appear to have been accompanied by the development of any very extensive system of spillways. Some small channels probably developed alongside the ice, but much of the water escaping from it probably had a more or less unobstructed outlet southwards to the Eden valley. Benchmarks along the road on the valley floor south of Paris Bridge (37/138115) indicate a gentle southerly slope towards Glenfarg, the highest benchmark (37/136115) at 454' O.D. being not much more than a foot below the divide at Glenfarg.

The spillways which lead into the lower Farg valley are small and shallow, probably never carrying large volumes of meltwater. Their lower ends usually merge with the floors of the valleys into which they lead, indicating that when the spillways were in use these valleys were probably ice-free, and that the meltwaters drained away freely. The two channels crossing the spur between the Farg and Baiglie valleys, however, start and finish high up on the valley sides. (33a & b). Both may have opened out onto ice in the Farg valley. The higher of the two (33a) at 600' O.D., may have been abandoned when the col between the Baiglie and Fildie valleys became ice-free, and was used as a meltwater channel. (34) From an initial height of approximately 600' O.D. this was lowered to 531' O.D. (height of spot height on the road through the col). In its turn, it was probably superseded by the lower of the two channels crossing the spur into the Farg valley, at ca. 475' O.D. In the Farg valley itself, the Pottiehill channel (35) cuts across a small spur, and has been lowered to ca. 450' O.D. from an initial height of approximately 500' O.D. Leading southwards, it may have developed marginal to ice in the Farg valley. Similar channels occur at varying heights on the eastern side of the valley.

There seems to be no evidence showing definitely whether the Farg was diverted northwards immediately after the disappearance of ice from its lower valley, or whether some time elapsed before this took place. The dimensions of the gorge - some three miles in length and 250 feet in depth at its lower end - may, however, be due to the augmenting of the Farg by meltwaters from the May valley, which must have escaped for some time by the Farg spillway, and may therefore indicate that the river was diverted at an early date. The large fan at the mouth of Glen Farg, apparently in part deposited as a delta in the Late-Glacial sea (Fig. 16) suggests that the diversion took place not later than the Late-Glacial period.

With the withdrawal of the ice-front from the lower Farg valley the Ochils east of the May valley were probably ice-free, although ice may have remained close to the northern edge of the hills, in Strath Earn.

Much of the wide watershed between the lower May and lower Farg valleys must have become ice-free during the time that the Craigfarg, Blair and Farg spillways were in use, leaving ice only in the two main valleys and in Strath Earn. While this watershed area has an irregular, confused surface, with a great number of small depressions, and low, glaciated hills, it is nevertheless possible to recognise certain more important lines of meltwater drainage. As shown in Fig. 15, nearly all the meltwater channels have a NW - SE trend, and appear to have drained from one shallow valley head to the next, marginal to the retreating ice-edge. The valley heads were probably occupied by lakes - one such is shown on Fig. 15 an enlargement of the present Pitkeathly Loch (37/019145). Other, smaller, examples, are still recognisable as flat, ill-drained and peaty areas.

The great number of meltwater channels makes it inadvisable to consider them in detail, but it may be noted that, on the whole, they decline in altitude from NE to SW - i.e. they must have been formed in response to changes in the position of the ice-edge in the May valley, rather than of that in Strath Earn. The highest and therefore probably the earliest, are the numerous shallow channels crossing the area around Berry Hill - e.g. (28), at ca. 825' O.D., leading to the Eastertown March valley. This must have been superseded by the Deuglie channel (29), cutting sharply across the watershed at 800' O.D. These two channels appear to have preceded the Farg spillway as routes for meltwaters from the upper Farg valley.

It seems probable that, while the edge of the main Strathearn Glacier may have withdrawn fairly rapidly from the May-Farg watershed, it must have remained for some long time along the northern edge of the hills, where its thickness must have been greatly increased. Because of this, streams normally flowing northwards down the scarp-face must have been obstructed, and diverted eastwards into neighbouring valleys until an outlet could be found. A number of spillways have been developed across watersheds separating such streams, apparently marginal to ice lying along the scarp-face. They are not so arranged as to suggest a more or less continuous system of meltwater drainage from the May to the Farg valley, but appear to have developed independently. A few, which open out high up on a valley side, may have led onto ice;

one such is the Mundie channel (41) which, lowered from 900' O.D. to 850' O.D. opens out in the West Dron valley, about 100 feet above the valley floor. Others may have developed close to the ice-front, and have led to ice-free areas. Thus, a channel at ca. 650' O.D. (36) leads from the Dron valley to the Fildie valley, which probably offered an unobstructed outlet. Later, water from the Wood valley appears to have reached the Dron valley by way of a spillway at 500' O.D. (37). The outlet of this, however, is 50 - 100 feet above the valley floor, suggesting that the valley was partly blocked by ice when the channel functioned.

Near Glenearn Hill (37/107155) a number of meltwater channels, falling mainly eastwards or southeastwards, were apparently developed by water from the Strathearn Glacier. Their positions, however, appear to have been controlled by the withdrawal of the ice-edge in the May valley. Thus three channels (38a, b, c) are cut at successively lower altitudes from north to south across that section of the watershed between Pitkeathly Loch and Culteuchar Hill (37/096152). The first of these commences at ca. 950' O.D. near the summit of Glenearn Hill, apparently carrying water from a small valley on its western side to the somewhat larger Pitkeathly valley on its eastern side, where the outlet of the spillway is at ca. 800' O.D. Only a part of the second channel now remains, hanging 20 - 25 feet above the third. It appears to have drained into the Pitkeathly lake, where its outlet is at ca. 775' O.D. It seems probable that its intake occupied the same position as that of the third channel, and that it carried water from the edge of the Strathearn Glacier. A movement of the May ice-edge must have allowed a new outlet to develop at a slightly lower level, with the result that the earlier channel was in part abandoned. The latest channel of the series appears to have received water by a small spillway north of Culteuchar Hill (42) which, at ca. 875' O.D., drained from the Culteuchar valley, and must have been abandoned when the ice along the scarp-face shrank sufficiently to allow meltwaters to use a col between Westhall Hill (37/095158) and Culteuchar Hill.

The Pitkeathly lake appears to have received much of the water carried by the various spillways of this area. It probably fluctuated somewhat in size, and a number of outlets seem to have been utilised. Amongst these are the 15 - 20 foot deep channels crossing the watershed to the Kelty headstream, and apparently forming part of a system draining southeastwards. (26a, b, c). For a time, however, possibly, to judge from the heights of the intakes, between the periods when 26b and c were in use, a small channel leading to the Pitkeathly valley was used (39). At present the marshy area occupied by the former lake is subdivided into a number of shallow basins by low ridges. The more northerly of these drains to the Wyllie valley, while those to the south, including Pitkeathly Loch, are drained by a tributary of the Kelty Burn.

Meltwaters from the Strathearn Glacier which did not reach the Pitkeathly Lake, but used spillways nearer the scarp face in escaping from the hills, have not always left complete records of the routes followed. One such example, noted above, is that of the spillway between the Wood and Dron valleys (37). Similarly, the first Glenearn Hill channel (38a) leads into the Pitkeathly valley at 800' O.D. Water using it may have continued eastwards to the adjacent Wyllie valley by a further channel across the watershed at 800' O.D. There seems to be no further trace of its course. As the outlet of the spillway ends some fifty feet above the Wyllie valley floor it seems unlikely that water was able to escape freely down the valley, but must have continued into or over the ice itself. Further west, in the Culteuchar valley, a meltwater channel draining eastwards appears to have developed marginal to ice occupying the valley (43). This leads to a deep gully cut in the col between Westhall Hill and Culteuchar Hill, occupied only by a very small stream. It seems probable that this gully, which descends the scarp face for nearly 200 feet, to 600' O.D., was used by meltwaters. As the lower end is some 400 feet above the floor of the Dumbuils valley, at the foot of and parallel to the scarp, it seems probable that the meltwaters escaped onto ice occupying the valley.

The shrinkage of the ice occupying the lower Farg valley and of the main Strathearn Glacier must have been accompanied by a similar shrinkage in the May valley. The arrangement of spillways across the spurs separating the upper May, Chapel, Slateford and Woodside valleys suggests that a lobe of the Strathearn Glacier occupied the main valley, extending into the tributaries. The headstream area of the May, about the Common of Dunning, was probably occupied by a separate tongue of ice, entering by the col at the head of the Dunning valley, and for a time extending across the watershed into the South Queich valley.

The lobe of ice in the lower May valley also appears to have extended across the major watershed. Between Slungie Hill and Dochrie Hill the existence of a spillway (Fig. 14,30) cutting across the Chapel valley col at 1000' O.D. points to the presence of ice in the col for some little time after its disappearance from the watersheds. This spillway extends as a shallow but well-marked channel, occupied by the Craigow Burn, and not usually more than twenty to thirty feet deep, to the 750-foot contour on the south side of the col. Its position is such that it could not have developed except when ice lay at a high level in the Chapel valley, while its southern extension indicates that it still functioned when ice in the Plain of Kinross had fallen to a relatively low level. It would appear to have functioned almost until the development of the Holeton channel (Fig. 14, 27a) the intake of which, just below 700' O.D., is quite near to the outlet of the Craigow spillway. There does not appear to have been any connection between the two.

At the head of the Chapel valley, at Stronachy (37/069086) a flattish area apparently formed of fine silts (exposed only in the banks of the Chapel Burn) may mark the site of a small lake. On its northern side it is bordered by two or three large mounds, 20 - 30 feet high of rather angular gravel, consisting mainly of local rocks. Although there is no good exposure of these gravels, the form of the mounds and their situation suggests that they may have been deposited at the margin of the ice occupying the Chapel valley, which formed a barrier to the normal drainage of the valley, and was responsible for the lake. Although the flat at Stronachy is nearly 100 feet below the intake of the Craigow spillway, it is possible that this was the outlet of the lake. Similar lakes may have existed temporarily in all the valleys converging on Path of Condie as the ice-fronts gradually withdrew down-valley, although, except in one or two areas, no evidence of such lakes in the form of lake-flats and shore features has been recognised. With the obstruction of the normal drainage lines, however, and the development of a meltwater drainage system from valley to valley, the existence of small lakes at the snout of each lobe of ice seems highly probable.

The positions of the spillways linking the May valley and its tributaries indicate that during the later stages in the withdrawal of the ice-fronts, if not during all, a continuous system of meltwater drainage existed, by which water impounded in the upper May valley was able to escape from valley to valley until it could cross the watershed into the relatively ice-free Farg valley. Thus the long spur between the May and Chapel valleys is notched by a series of spillways ranging in height from 1100' O.D. to 750' O.D. (22a - f, Fig. 15) The highest of these (22a, b) must have developed at an early stage; both enter a valley tributary to the Chapel valley, the first at ca. 1100' O.D., the second at ca. 1050' O.D. Water using them may eventually have escaped by the Craigow spillway. The lower members of this series are all below ca. 950' O.D. and were probably associated with channels leading from the Chapel valley to the Slateford valley. The absence of a spillway across the spur at an intermediate level may reflect the shrinkage of the ice over the Common of Dunning, allowing meltwaters to escape for a time by the Deaf Knowes spillway, at 1000' - 1050' O.D.

Three spillways cross the watershed between the Chapel and Slateford valleys, two by way of a col between Baulk Hill (37/077092) and Whitehill Head (37/077102). The first of these (5a) descends from 1000' O.D. to 900' O.D., probably succeeding the Craigow channel as a route for meltwaters from the Chapel valley; the second (5b) descends from 900' O.D. to ca. 825' O.D., and may have received water from the spillways crossing the May-Chapel interfluve at comparable heights. This seems to imply that a lake at a level of about 900' O.D. may have existed in the Chapel valley; it is possible that the presumed lake flat at Stronachy was associated with such a lake, as well as with one draining southwards at a higher level. A similar pro-glacial lake may have developed in the Slateford valley, receiving water from the two Whitehill spillways. During the time that the first of these was in use meltwaters may have continued to the Craigfarg channel, but it seems probable that it fell out of use as the outlet of the second Whitehill channel was lowered to 825' O.D., and that some alternative outlet was found.

The third spillway crossing the Chapel-Slateford watershed is the broad Struie channel (23). This is 30 - 40 feet deep, and has been lowered a little below the 700-foot contour. It probably received water from the lowest of the spillways leading into the Chapel valley. At its lower end the form of the ground suggests that a gently sloping fan was deposited, but no exposures of the material forming this feature have been found. On the opposite side of the Slateford valley, the Craighead spillway (24) cut not more than twenty feet below the 700-foot contour falls towards the Woodside* valley and may mark the route followed by the meltwaters from the Struie channel. From this valley the Farg spillway offered a route eastwards. The rejuvenation of the Blair spillway, which must have been abandoned for some time, indicates that the Farg lake had disappeared by this period, and that ice may have disappeared completely from the Farg valley.

On the north and east sides of the May valley, the retreat of the ice-edge produced series of spillways across the spurs separating the tributaries of the Kelty Burn and the upper Farg. Here, however, the very gentle slope of the spurs led to the development of many small, shallow channels, within a small height range, draining lakes of whose existence there is ample evidence in the form of flat, ill-drained areas. Thus, two small channels at ca. 900' O.D. run W - E across a small spur of Culteuchar Hill (25a & b), the lower of the two (25b) being further south, while a number of channels cross the spur running S.W. from West Dron Hill

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* This valley is not named on Ordnance Survey maps. It contains a small tributary of the May, flowing W.N.W. from an arm of Glenfarg Reservoir near the farm of Woodside. (37/094113).

(26a - f), at successively lower altitudes towards the southwest. The highest of these (26a) is at ca. 925' O.D., the lowest (26f) is slightly below 800' O.D. Apart from the first, which is thirty feet deep, none is deeply cut; each appears to have been abandoned in favour of one at a slightly lower level. All must have served to drain the Pitkeathly Lake into the valley of the Kelty Burn. A further series of small spillways (27a - c), between 800' O.D. and ca. 775' O.D., probably carried this water to the upper Farg and Dron Burn valleys. From here, further escape may have been by way of the Deuglie channel (29) and later by the Farg spillway (17).

At a later stage, the two Auchengownie spillways were developed, (30a & b), with intakes between 675' - 700' O.D., and at ca. 650' O.D., respectively. Both lead into a broad, flat-floored valley linking the Woodside and upper Farg valleys, from a small tributary of the Woodside valley. At its head the valley is connected to the Kelty valley by a low col, whose height is indicated by a benchmark at 679' O.D., some ten to twelve feet above the lowest point. It is possible that these two spillways were developed by water from a small lake in the lower Kelty valley, reaching them by way of the col. The flat valley floor just below 600' O.D. at Craigencat, offers some evidence of a former lake, but, as in other cases, no shore-lines have been recognised.

A small spillway, north of Craigowny Hill (31) leads into the Kelty valley, descending from 750' O.D. to 700' O.D., and may have led into a lake, but there appears to be no delta or alluvial fan at its outlet. The flat floor of the valley into which the Auchengownie spillways lead, together with the presence in it of alluvium, suggests that they entered a lake, which was probably dammed by ice in the Woodside valley, and drained by the Farg spillway. This lake may have had a level of approximately 650' O.D. when the higher Auchengownie spillway (30a) was developed, this being the height of the spillway outlet. Its level appears to have fallen slightly by the time the second Auchengownie spillway was developed.

The continued shrinkage of the ice in the May valley must have caused the abandonment of both Auchengownie spillways. The smooth, almost flat surface below which the May and its tributaries are incised at Path of Condie, however, suggests that the lake into which they drained extended into the area vacated by the ice. (Photograph 15) The relatively narrow incisions occupied by the streams are over 100 feet deep at Path of Condie. Their upper walls are usually formed of glacial deposits, while bed-rock appears nearer the stream. The form of the valleys as a whole suggests that the pre-glacial valleys were V-shaped, but not quite as deeply cut as these of today, except

Photograph 18. THE MAY VALLEY AT PATH OF CONDIE.
Sand and gravel deposits at the outlet of the Binzian valley. The flat surface marks the site of the pro-glacial May lake.

possibly in the case of the May valley, where glacial deposits extend to and possibly below the present valley floor. These valleys were infilled by glacial deposits, which in places appear to be at least 100 feet thick. An exposure in the Woodside incision (37/086121) shows that here the lower parts of the infilling are of boulder-clay. There are few clear exposures near the top of the incision walls, owing to slumping of the material, but here it appears to be of clay and silt, without any boulders, while fine gravels form a thin layer about one foot deep at the top. On the north side of the May, opposite Path of Condie (37/076119) there is a very clear section of bedded sands and gravels, partly obstructing the valley floor, and dipping gently towards the stream. (Photograph 18) Only some 30 feet of sands and gravels are exposed, as a result of undercutting by the May, but they appear to extend to the lip of the incision. They almost certainly testify to the existence of a lake, into which vast quantities of material were deposited from an ice-front and from tributary spillways, the Path of Condie gravels forming a delta at the lower end of a spillway leading from the Binzian valley (44b).

In its early stages this May lake probably had a level a little above 600' O.D. There are no well-marked shore-lines, but at Path of Condie a spot-height, at 608' O.D. on the Milnathort road, lies very close to the margin of the former lake floor. A later level of approximately 575' O.D. is indicated by a small bluff at this height, again at Path of Condie, and by the height of the intake of the Farg spillway. Benchmarks along the valley floor, now hidden by the reservoir, show a very gentle fall eastwards from 572' O.D. to 563' O.D. At this level the lake may have extended sufficiently far north to become continuous with that in the Kelty valley.

Throughout the period when the upper May valley was being freed from ice, it appears to have received meltwaters from the north, by spillways across the Cock Law-Condie Hill ridge. These probably carried water from ice lying close to the ridge, but most are shallow, and do not appear to have been used for long. A channel immediately west of Condie Hill, however, 25 - 30 feet deep descending from ca. 925' O.D. to 900' O.D. (44a). Its height suggests that it may have functioned when spillways 22c and d were cut on the south side of the valley. It must have been abandoned when a withdrawal of the ice-front allowed a spillway to develop east of Condie Hill. (44b). This is considerably lower, with an intake at 700' O.D. It is at most not more than 20 feet deep, but appears to have led into the May lake extending southwards as the lake level fell, ~~and~~ probably being responsible for the sands and gravels at Path of Condie. Meltwaters using it may have derived from ice in the Dunning valley, reaching it by way of the Binzian valley. The form of the steep-sided trench of the Binzian valley, whose floor is some 30 - 40 feet below the intake of the spillway, suggests that when the May ice-front withdrew northwards, it continued to be used by meltwaters from ice in the Dunning valley.

North of the Binzian valley, a number of spillways developed, leading from the northern edge of the hills to the May valley. The relatively high area of the Clevage Hills in some ways resembles the area around Berry Hill further east, and like it, is crossed by shallow channels, apparently formed at an early stage in the disappearance of ice from the surrounding area. These channels do not appear to continue into the surrounding valleys, and may have led only on to ice. The same may be true of certain small channels, crossing a broad spur running northeast from the Clevage Hills, at a lower level - ca. 725' O.D. (45a - c). The largest of these, (45c), has been lowered below the 700-foot contour at its upper end, and continues as a broad, but shallow channel, fifteen to twenty feet deep, to the 600-foot contour. It is possible that it drained into the May lake as this extended northwards.

The northward expansion of the May lake probably continued as the ice-front retreated northwards, until an outlet replacing the Farg spillway was established. This was provided by the Drumfinn spillway (46a) which, with its eastern side nearly 100 feet higher than the western, appears to have commenced as a one-sided channel a little below 600' O.D., and was eventually lowered to ca. 450' O.D. at its intake. At its outlet it has been lowered to 300' O.D., and opens into the Dumbuils valley about 100 feet above its floor. In the Dumbuils valley, running along the foot of the scarp and cutting off the 200' - 300' O.D. plateau on which Forgandenny is built from the main mass of the hills, a small area of alluvium (Fig. 11) points to the previous existence of a lake. This may have remained until relatively recent times - a farm in the valley is named "Lochend". There is apparently no evidence that this lake was present when the Drumfinn spillway functioned: it seems more probable that the valley was occupied by a mass of dead ice. The presence of such ice might also account for the direction of one of the spillways succeeding the Drumfinn channel, (46d), which, in passing the western end of the valley appears to pass a much more direct route than the one it follows.

While the Drumfinn channel was in use the ice-front in the May valley must have lain in a S.W. - N.E. direction across the valley from the high ground near the Clevage Hills to that across which the spillway is cut. Subsequent spillways indicate that further withdrawal was in a northwesterly direction. The first of these (46b) is small, and also leads to the Dumbuils valley. Its intake is at ca. 450' O.D., but has been little lowered, and the channel was probably soon abandoned as the retreating ice-front freed the lower ground to the west. A series of shallow channels with a S.W. - N.E. alignment, usually beginning on the south side of the present Water of May and continuing across the site of the deep gorge that it now occupies must then have been initiated. (46c - j) By this time the May lake was probably drained, and the incision of the May and its tributaries begun. Meltwaters from the Corb Glen and Common Burn spillways (2 and 3 on Fig. 14), both of which continue without a break into the flat-floored steep-sided trench of the upper May valley probably assisted the stream in its incision. At the lower end of its valley the May waters must have joined with meltwaters to form the series of SW - NE meltwater channels. This may explain the more deeply cut and better defined nature of the parts of those channels north of the gorge, where they may be 30 - 35 feet deep, as compared with 15 - 20 feet further south.

The highest of the series (46c), begins at nearly 500' O.D., and descends gradually to 300' O.D. at the edge of the May incision. Its meltwaters probably then turned north along the course of the stream, until the lower section of the channel (46d) offered a route northwards. Later, a lower intake developed, at approximately 350' O.D., but the outlet remained unchanged. Further movements of the ice-front appear to have allowed more northerly intakes to develop, at much the same height. (46f - g) These are linked to the lower part of the channel by a steep bluff, suggesting that for part of this distance a one-sided channel was formed against the ice-edge. The lower part of the channel is joined by a short channel from the west (46h) which appears to be a pre-glacial valley slightly modified by meltwaters, possibly from the ice-margin. This hangs slightly above the main channel, which was eventually deepened to ca. 250' O.D. at the edge of the May gorge, and continues northeastwards, past the western end of the Dumbuils valley, to open out onto a gravel terrace at Forgandenny. The height of this terrace is indicated by a spot height at 147' O.D. near the spillway outlet, and slopes gently northwards. It may have been built up in part by material deposited at the outlet of the spillway, but this is by no means certain.

Two lower spillways were developed further west. The higher of these (46i) does not appear to have had a southerly extension, but commences slightly above 200' O.D. at the edge of the May gorge. The lower channel (46j) commences at ca. 175' O.D., and is continued across the gorge. Both open out onto a gravel terrace at approximately 150' O.D. There is some suggestion that a fan has been deposited at the outlet of the lower channel, but the presence of a scrubby birch wood makes the interpretation uncertain. There does not appear to be a fan at the outlet of the higher channel, and it is possible that it continued below the level of the terrace, but again, the evidence is not clear.

Further, west, the Durning and Coul valleys may have been occupied by ice for a longer period than the May and Farg valleys. Both the Corb Glen and Common Burn spillways appear to have functioned when the ice-front had almost completely withdrawn from the May valley. This implies that ice still reached a high level in the Dunning and Coul valleys at the time, although its front may have been retreating steadily. In both valleys sections of the valley floor a little below the intakes of the spillways are flat-surfaced, and covered with gravels. These are particularly well-exposed in the Coul valley (27/991081) where they appear to be outwash gravels deposited in a pro-glacial lake. A similar lake may have existed at the head of the Dunning valley. These lakes were presumably drained by the two spillways, continuing to exist until alternative outlets were available. In the case of the Dunning valley, this may have been provided by the Balquhandy spillway (1, Fig. 16) leading to the Binzian valley, at 900' O.D. Corb Glen must have continued in use until the big Coul spillway (2)[*] was developed; there are reasons to believe that this occurred only a short time before the ice-front withdrew from the mouth of the Pairney valley.

While meltwaters in the Coul valley were escaping by Corb Glen, those from the Pairney valley found a route eastwards across the ridge ending in Craig Rossie. A spillway 100 feet deep leads into the Banekist valley (3), commencing at ca. 1225' O.D., and ending at 1100' O.D. Below this the valley does not appear modified by meltwaters, which may have escaped over the

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[*] Except where otherwise indicated numbers referring to meltwater channels in the following pages are those shown in Fig. 16.

ice.

Further shrinkage of the ice in this part of the hills is reflected by a number of spillways, most being found crossing the watershed between the Dunning Burn and its smaller, western neighbours. There are few traces of meltwater drainage eastwards from the Dunning valley, apart from the Balquhandy spillway, and the slightly modified col leading to the Binzian valley. It is possible that, once the higher parts of the valley were freed, the ice-front retreated westwards on a N - S or S.W. - N.E. line, as was the case at the mouth of the May valley, and the Dunning Burn was rapidly able to re-establish a northerly, unobstructed course. The relatively broad valley leading northeast from the Dunning Burn at Newton of Pitcairns (4) may represent a stage in this process.

Various channels lead into the Dunning valley from the west. At an early stage, probably when the Common Burn spillway still functioned, meltwaters from the tributary Thorter valley crossed Skymore Hill by a shallow channel, ten to fifteen feet deep. (5) With an intake at 1250' O.D., and descending to 1200' O.D., this must have superseded the two channels at the head of the valley. (10a & b, Fig. 14) Other shallow channels were developed, at successively lower altitudes, leading from the Scores valley, the highest at ca. 1225' O.D., the lowest at ca. 925' O.D. (Fig. 16, 6a - c) At lower altitudes, the Kippen valley (7) may have been modified by meltwaters moving eastwards, but it seems probable that a northward drainage was rapidly established. Only one channel leads into the Scores valley from the west. This is the deeply-cut Rossie Law spillway (8) commencing at 900' O.D. and ending at ca. 850' O.D. As in the case of the channels leading out of the valley, there is no evidence of the route followed by the meltwaters on leaving the spillway, and they may have escaped over ice. A similar situation may have arisen at a later date, when three smaller channels developed across benches at 600' O.D. at the mouth of the Banekist valley. These probably formed one channel, marginal to the Strathearn Glacier (9). No trace of a fan or delta has been found at its lower end, nor is there any evidence that meltwaters escaped down the hillside to the floor of Strath Earn.

In the Coul valley small meltwater channels across the spurs separating the left-bank tributaries of the Coul Burn descend towards the head of the valley. They appear to represent stages in the shrinkage of the lobe of the Strathearn Glacier occupying the valley. The highest, (10) at ca. 1300' O.D., must have contributed to the water escaping by Corb Glen; lower channels, (11, 12a, b) at ca. 1150' O.D., 1100' O.D. and ca. 875' O.D. respectively, can only have developed when Corb Glen had been abandoned, and the ice-front had retreated sufficiently to allow the cutting of the Coul spillway. This channel probably resulted from the deepening of a col not much below 900' O.D. and was eventually lowered to 700' O.D. No spillway that could have functioned at the same time crosses the ridge east of the Pairney valley, and it is probable that the meltwaters escaped down the deeply-cut Pairney valley itself. A series of spillways (13a - c) cutting the steep slope below Craig Rossie, near the mouth of the valley, may have been used as successive outlets for these meltwaters. All three channels lead to the broad Pairney spillway, (14) the first two descending steeply, a feature which suggests that they may have developed close to the snout of the Strathearn Glacier, where its surface descended rapidly to its margin. The highest channel has its intake on a small bench at 800' O.D., and descends as a steep, wide, gully, ending 100 - 200 feet above the floor of the Pairney spillway, and may therefore have led onto ice. It was abandoned before it had had time to extend completely across the bench at its upper end.

The intake of the second channel (13b) is some 400 feet below the first, which suggests that the Strathearn Glacier was diminishing rapidly in thickness at this point. There are signs that a channel similar to the first began to develop at an intermediate altitude, but was soon abandoned. The second Craig Rossie spillway descends almost to the level of the floor of the Pairney spillway, by way of a steep, 50-foot high rock step half-way along its length, and by a steep gradient. It hangs 20 - 30 feet above the floor of the larger channel, which

Photograph 19. SPILLWAYS NEAR CRAIG ROSSIE.

must have been lowered to its present level of ca. 250' O.D. during the cutting of the lowest of the Craig Rossie spillways. (13c) This is still occupied by the Pairney Burn, which may have assisted in keeping the 50-foot high cliff, that forms its northern wall, clear of debris. It is joined from the west by a less deeply cut channel (15) which appears to have carried to it waters from some distance further west. (Photograph 19)

The Pairney spillway, into which the Craig Rossie spillways lead, is a broad, but shallow channel, for much of its length not more than 15 - 20 feet deep. It extends eastwards to the Dunning Burn, and like the lower course of the latter, is cut below the gravels covering the floor of this part of Strath Earn. It is now occupied by only a small stream, the Pairney Burn having been diverted westwards by a corrom divide, as described by J. B. Simpson.[1.]

Ice must have continued to lie across the mouth of the Coul valley until after the development of the lowest of the Craig Rossie spillways, and the Coul Burn continued to join the Pairney Burn even after its disappearance, as it still does. A corrom divide obstructs the Coul valley just north of the entrance to the Coul spillway, and the lower part of the valley is occupied by the small Cloan Burn. Both the Cloan and the Pairney Burns are incised in their lower courses, reflecting the down-cutting of the meltwater channels into which both lead, and, not improbably, some glacial lowering of the floor of

Photograph 20. KINCARDINE GLEN.

Strath Earn.

A series of meltwater channels with a generally S.W. - N.E. trend cross the lower ground north of this part of the Ochils, apparently developed as the ice-front withdrew from the Coul and Pairney valleys. The first three of these (16a - c) are nowhere more than 15-20 feet deep, and usually have smooth, grassed-over sides, although in one or two places bare rock is visible. All lead from the edge of the fourth in the series, the deeply cut Kincardine Glen (Photograph 20) their intakes becoming successively lower towards the north. The first of the series (16a) is short, hanging slightly above the second, and any eastward extension it may have possessed has presumably been deepened at a later date, and now forms part of the second. This, commencing at ca. 350' O.D. is in part one-sided, and occupied by the Cloan Burn. It may initially have continued to the lowest of the Craig Rossie spillways, but this section (15) was probably abandoned as the ice-front retreated, and a northerly outlet, to the Ruthven valley, became available.
The intake of the third in the series is probably not much lower than that of the second, and has an outlet also at much the same level - namely, at, or very slightly below, the 200-foot contour.

As described above, these three channels lead from the edge of Kincardine Glen, and do not appear to be continued on the further side. It is probable, therefore, that they are early outlets of the larger channel, developed as the margin of the

Strathearn Glacier withdrew northwestwards, retiring towards the narrower Highland part of its valley. Kincardine Glen itself is an impressive trench, for much of its length 100 - 150 feet, deep cut in Devonian shales and sandstones. It leads from Strath Allan where it breaches the moraine-crowned ridge closing the valley at its eastern end, to the valley of the Ruthven Water. The height of the ridge prior to the cutting of the spillway was probably 450' - 475' O.D., the intake has since been lowered a little below 400' O.D. It appears to have formed for a long period the outlet for an extensive lake in Strath Allan (see Fig. 16) although it was probably initiated when only a very small part of that valley was ice-free. Over two miles long, Kincardine Glen ends at the point where the Lochy Burn joins the Ruthven Water, at 200' O.D., but beyond this point the Ruthven valley is flat-floored and steep-sided, and may well have been modified by the waters using Kincardine Glen. It is joined from the northwest by several shallow channels - e.g. (17), apparently developed as the northwestward retreat of the Strathearn Glacier was continued.

The valley of the Lochy Burn is more open than that of the Ruthven Water, and less modified by meltwaters. It may be a survival of the pre-glacial drainage pattern, and probably remained ice-filled when Kincardine Glen was initiated.

A number of sub-parallel ridges run in a N.W.-S.E. direction along the lower, eastern part of the watershed between Strath

Allan and Strath Earn, in the area known as the White Muir. From 10 - 30 feet in height, they are formed of ill-sorted, rounded pebbles and boulders, some of the latter as much as two feet in diameter. There are some traces of bedding, as in an exposure at Loaninghead (27/926098), and the appearance of the ridges, both on the ground and in air photographs, suggests that meltwaters were important both in their initial formation, and in producing some later modifications. Together with Kincardine Glen and its associated meltwater channels, these ridges appear to mark the parting of the Strathallan and Strathearn glaciers. Thereafter, the waning of the Strathearn Glacier ceased to affect the Ochil Hills, although meltwaters from it probably continued to contribute to the thick fluvio-glacial deposits of lower Strath Earn for some time.

<u>References</u>:-

1. Simpson, J.B. The Late-Glacial Readvance Moraines of the Highland Border West of the River Tay. p. 638.

IV. Lower Strath Earn, and the Perth Readvance.

As shown in Figs. 11 and 17, the floor of lower Strath Earn below 200' O.D. is extensively terraced. These terraces have been variously interpreted. On 1" maps of the Geological Survey (sheet 48, published 1893, and sheet 47, published 1888) the edge of a 100-foot marine terrace is marked (presumably the inner edge, although this is not stated) extending some distance west of Dunning, while below this are three river terraces, the lowest being the modern flood plain and two lower marine terraces, at 45' - 50' O.D., and 9' - 12' O.D. More recently, an unpublished map shows the area of the 100-foot marine terrace to be covered with fluvio-glacial gravels. In 1933, J.B. Simpson published a map in which these gravels are described as "surface morainic deposits"[1] and considered that the part of the deposits east of Crieff and below the 200-foot contour formed an outwash plain, deposited by glacial streams following the withdrawal of the Strathearn Glacier from the maximum of the Perth Readvance.[2] Apart from commenting that they "are partly marine, partly fluvio-glacial, and partly fluvial, and they certainly cannot be attributed to a single origin"[3] he made no attempt to describe or account for the terraces. Yet their extent is such that they can only be regarded as major features of the landscape, and the study of the Late-Glacial and post-glacial history of the area can hardly be complete unless they are taken into consideration.

The first, and highest, of the terraces is best developed east of the Dunning Burn, and will be referred to as the "Dunning Terrace". It has a smooth surface, often nearly flat, but trenched by a number of steep-sided flat-floored valleys. Exposures in the valley sides show that, between the Dunning Burn and the Water of May, it is developed in sands and gravels. One such exposure in the Dunning valley (37/022155) shows some stratification of the deposits, sands alternating with beds and lenses of fine gravel. The inner edge of the terrace is followed for much of its length by the Dunning-Green of Invermay road, along which benchmarks range between 145' O.D. and 159' O.D. (Fig. 17) From this margin the terrace slopes gently to an outer edge usually at 100' O.D., but occasionally higher, (115' - 120' O.D.) and is separated from lower terraces by a steep descent of 20 - 25 feet. Low mounds in places interrupt the terrace surface: these are shown on Geological Survey maps as boulder-clay, rising through the gravels to heights of 160' and 171' O.D.

East of the Water of May the Dunning terrace continues at much the same height as to the west, but gradually narrows, and is apparently absent at Newton of Condie. (37/076182) It reappears at Forgandenny, where the gravels of which it is formed are exposed in a small gully (37/087186) and where a meltwater channel opens onto it. (146d, Fig. 15; Fig. 17). Between the Green of Invermay (37/051163) and Kildinny (37/067176) two further spillways open onto the terrace (146i, j. Fig. 15) which is backed by a well-marked rise at ca. 150' O.D. There is not such a well-marked inner edge at Forgandenny, but near the spillway outlet benchmarks give the height of the terrace as 141' - 147' O.D., descending gently to 129' O.D. near the outer edge. East of Forgandenny the terrace appears to continue for a short distance, but in doing so apparently passes onto an area of boulder-clay, still remaining between 120' - 140' O.D. (Fig. 17) No exposure of this boulder-clay, mapped by the Geological Survey, was noted during fieldwork in this area.

A number of lower terraces are recognisable, falling into two major groups. In the western part of the area two terraces occur between the Dunning Terrace and the present floodplain, both mapped as river terraces by the Geological Survey. In the eastern part of the area a further two terraces are mapped as of marine origin. Of the two terraces succeeding the Dunning Terrace, the first is the Forteviot Terrace, so named because of its development near the village of Forteviot, and like the higher terrace developed on sands and gravels. Various benchmarks show that its inner edge is probably a little above 70' O.D.; its outer edge is usually followed by the 50-foot contour. A steep slope some 10 feet high separates the

Forteviot Terrace from the Henhill Terrace, which everywhere appears to be developed on alluvium, and at its outer edge is but little above the present floodplain, at about 35' O.D. This terrace is best developed near the farm of Henhill (37/048171) where it extends in an unbroken stretch of about one mile from the edge of the Dunning terrace at 100' O.D. northwards to the Earn floodplain at 36' O.D. Below it the May has cut a narrow floodplain, and it seems probable that this extension of the terrace is largely due to the activity of the Water of May.

The two marine terraces further east are also well-marked and distinct. The upper forms a narrow fringe along the edge of the higher ground, with an inner edge a little above the 50-foot contour. Its surface is very level, the outer edge being at 47' O.D. near Dron, and apparently at a similar height elsewhere. While no exposure of the material forming this terrace was noted in the field, it is considered by the Geological Survey to be formed of gravels. An interesting feature of the section between Kintillo (37/133174) and Dron is its dissection by a number of small gullies, running roughly perpendicular to the terrace edge, and opening onto the lower terrace. This lies seven to ten feet below the flat surface shown in Fig. 16 as the 45 - 50-Foot Raised Beach, and forms an extensive area of flat land several miles in length, falling from ca. 40' O.D. at its inner edge to 25' - 30' O.D. above the floodplain of the Earn. At Kintillo a recent excavation showed that there the Terrace is formed of almost pure sands, containing very few pebbles, and at least fifteen feet deep. The height and appearance of this deposit suggest that it is comparable to, and contemporaneous with, the carse-lands of the Forth and Lower Devon valleys.

In addition to the better-developed terraces, described above, there are a number of smaller terraces, whose relation to each other and to the main terraces is not always clear. This is in part due to the lack of information as to their composition. All are higher than the 45 - 50-Foot Raised Beach, and are usually developed close to the 100-foot contour. Hence, on Fig. 17, they have all been grouped together under the heading "Possible Raised Beach at ca. 100' O.D." Of these Terraces those most resembling the lower Raised Beaches are formed of gravels, in particular that which commences at the Farg fan at Aberargie (37/165158). The fan has been terraced at two levels, the higher of which, between ca. 125' - 150' O.D. corresponds in height to the Dunning Terrace. Below this the second Terrace lies between 100' O.D. and 68' - 70' O.D. It can be traced beyond the area shown on Fig. 17 as a well-marked feature extending to Abernethy and even further east. To the west of the Farg there is no obvious continuation, although some distance away at Dunbarney (37/113187) a tongue of gravels is flattened between the same heights. In the neighbourhood of Dron another terrace rises slightly above the 100-foot contour, descending at its lower edge near Newbigging (37/152156) to 83' O.D. The appearance of this suggests that it is similar in origin to the Aberargie Terrace, but no exposure showing its composition was seen during fieldwork, and it is shown to be boulder-clay covered on Geological Survey maps. It is not possible in this or in most other cases to find a well-marked cliff feature at the back of the possible 100-Foot Raised Beach: the terraces are usually at the scarp foot and hill-wash debris has accumulated. It does seem possible, however, that the various terraces noted above, and particularly that at Aberargie, may represent beaches formed in fluvio-glacial gravels at a time when sea-level was temporarily stationary between the maximum of the Late-Glacial sea and the Post-Glacial sea. Evidence of a similar intermediate level has been noted on the south side of the Ochils, near Stirling.

The form and composition of the Dunning Terrace suggest that it was indeed formed as an outwash plain, as Simpson believed,[1.] the sands and gravels being deposited close to sea-level from a retreating ice-front. At Forgandenny and Kildinny material may also have been added by the meltwaters using the spillways which open onto the Terrace at these points. There seems to be little definite evidence in this area of the height of sea-level at this time. In Simpson's view, during the Perth Readvance the Strathearn Glacier advanced into the Late-Glacial sea between Crieff and Forgandenny,[4.] and did not withdraw until this sea-level was already falling. The height of the upper terrace of the Farg fan, however, suggests that this may have been formed as a delta with a sea-level of approximately 150' O.D. There is no evidence that the readvancing Strathearn Glacier extended so far east, and this figure may therefore represent the maximum level of the Late-Glacial sea in this area. The possible Raised Beaches at ca. 100' O.D. may mark a period between this sea and that responsible for the formation of the 45 - 50-Foot Raised Beach: it is possible that the Dunning Terrace was formed during much the same period.

Between Kildinny and Forteviot a narrow terrace between 100' O.D. and ca. 110' O.D. has been cut below the Dunning Terrace. This has a well-marked edge near Kildinny, where it descends to deposits of the 45 - 50-Foot Raised Beach, but is separated by only a slight break from the Forteviot Terrace near Forteviot. It has been shown on Fig.17 as part of the possible 100-Foot Raised Beach. Clearly of later date than the Dunning Terrace, it may represent an incursion of the Late-Glacial sea into the area vacated by the Strathearn Glacier - an incursion which was limited in extent by the continued fall of that sea-level relative to the land. Alternatively, it may have been formed as a river terrace related to the 100-Foot Raised Beach further east, but this seems unlikely in view of the absence of any similar terrace elsewhere between the Dunning and Forteviot Terraces.

The Forteviot and Henhill terraces appear to have been formed by the Earn and its tributaries in response to falls in base-level, and to correspond to the two Raised Beaches further east. The Henhill Terrace was almost certainly formed at the same time as the lower Raised Beach. Its lower parts correspond closely to the level of the beach, and the two are separated by only a short stretch of modern flood-plain. Moreover both have been formed below the 45 - 50-Foot Raised Beach, as may be seen near Broombarns and Farmhall (37/074187 and 37/084191). The Forteviot Terrace, lying above the Henhill Terrace, would appear to correspond to the 45 - 50-Foot Raised Beach by virtue of this fact: in addition the lower limit of the terrace appears to agree closely with the upper limit of the beach.

The above interpretation of the Earn Terraces as forming a sequence corresponding to a gradual fall in sea-level is at variance with the interpretation put forward by Simpson, who considered the fall from a high, Late-Glacial sea-level to have been very rapid, possibly reaching a level below that of the present day while ice still remained in Lower Strath Earn. This conclusion was based on the evidence of certain valleys cut in the gravels, which he regarded as overflow channels. These descend to the 50-foot contour, and may have been cut below this level, but are infilled by "post-glacial marine and estuarine deposit." As they are close to the limit of the postulated readvance it would appear that these channels "must have been completely deprived of water as soon as the ice retired a very little further, and so could have functioned only over a short period of time ....."[5]

It is unfortunately not entirely clear which channels Simpson regarded as near the limit of readvance, but from the map accompanying his article, it would appear that these were (a) one of the two spillways opening on to the Dunning terrace near Kildinny; (b) a dry valley midway between Forteviot and Kildinny; and (c) two similar valleys between the Dunning Burn and the Water of May, one of which joins the Garvock Burn, while the other lies slightly further north. The first of these four valleys may be dismissed from the present discussion, as it appears to be misplaced on Simpson's map, where it is shown as continuing across the Dunning terrace. Fieldwork has revealed no such continuation. The remaining three certainly indicate a sudden fall in sea-level, if in fact they are meltwater channels. This, however, seems unlikely. Apart from the difficulty in envisaging the deposition of the gravels west of the Water of May between 100' - 150' O.D. when the base-level for meltwater streams was possibly below 50' O.D. immediately east of Forgandenny, the form of the channels is not altogether in agreement with an origin as overflow channels. In each case the head of the channel is a very slight depression in the smooth surface of the terrace, and has no continuation in the direction in which the ice-front may be assumed to have retreated. Nor are these valleys mapped by Simpson unique - there are many similar examples fretting the terrace edges, including that of the 45 - 50-Foot Raised Beach between Kintillo and Dron. Most of these have a direction or position quite out of keeping with an origin as channels cut by meltwaters from the Strathearn Glacier.

The gullies can only have been formed as, or after, the Forteviot Terrace and the 45 -50-Foot Beach were developed. They may have been cut by streams which have disappeared owing to a fall in the water-table of the gravels - a result of the falling base-level - or their formation may have been associated with solifluxion processes under peri-glacial climatic conditions. Evidence from other areas suggests that Strath Earn was probably affected by a period of very low sea-level, and the peat underlying clays near Forgandenny, mentioned by McCallien,[6.] may be direct evidence of that sea-level, but it seems unlikely that this followed the high-level Late-Glacial sea quite as rapidly as was envisaged by Simpson.

It is not clear to what extent the Perth Readvance affected the Ochils. The meltwater channels in the Lower May valley, associated with the Dunning Terrace, appear to have been used, and were possibly formed, as the Strathearn Glacier finally melted. There seems to be no evidence, however, indicating which, if any, of the various spillways further west

were also used or initiated at this period. Some disruption of drainage in the Coul, Pairney and Dunning valleys must have occurred, but no certain traces of this have been noted.
Both the Coul and Corb Glen spillways, however, show some signs of two phases of downcutting, in that their upper slopes are at a steep angle and grass-covered, while the lower 50 - 100 feet are markedly steeper and in places cliff-like. It is possible that the lower slopes may mark renewed use of the channels during the Perth Readvance, but the evidence is by no means definite, and elsewhere the Perth Readvance seems to have left no traces that can be distinguished from those of the previous withdrawal.

References:-

1. Simpson, J.B. The Late-Glacial Readvance Moraines of the Highland Border West of the River Tay. p. 638.
2. Simpson, J.B. op.cit. p. 636.
3. Simpson, J.B. op.cit. p. 634.
4. Simpson, J.B. op.cit. p. 635.
5. Simpson, J.B. op.cit. p. 640.
6. McCallien, W.J. Late-Glacial and Early Post-Glacial Scotland. Proc. Soc. Antiquaries of Scotland, vol. 71, 1937. p. 200.

V. The Western Ochils, and the Later Stages in the Development of the Devon.

In the Western Ochils, higher and with valleys more deeply cut than in the Central Ochils, deglaciation must inevitably have followed a pattern differing in several respects from that so far described. The main watersheds north and south of Glen Devon appear to have become ice-free at an early stage, as suggested above, while ice remained to the north, in Strath Allan, extending into Glen Devon by way of Glen Bee and Glen Eagles, and to the south, where Clackmannan Ice reached the Plain of Kinross, but also occupied lower Glen Devon, entering the South Queich valley by way of Glen Dey. The disposition of the valleys tributary to Glen Devon would appear to lend itself to the development of pro-glacial lakes, dammed by the ice in the main valley, and connected by series of spillways, as was apparently the case in the May valley. In fact, however, only a few spillways occur, and these show little or no relation to each other, although they do appear to mark a gradual shrinkage of the Glen Devon ice. (Fig. 16)

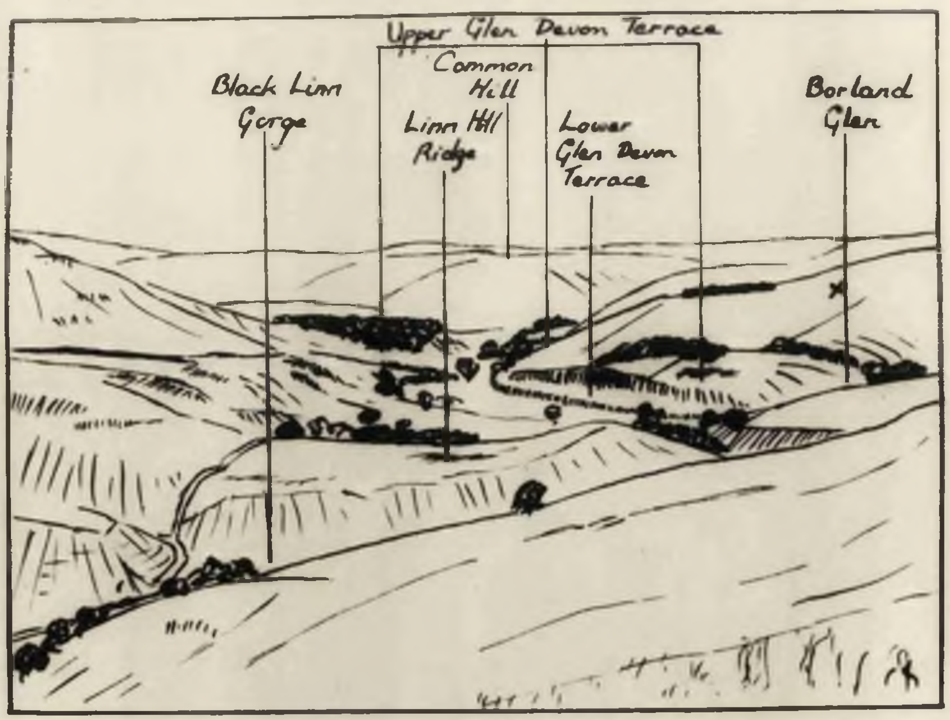
The highest of these spillways is a small, shallow channel, not more than ten feet deep, entering the Frandy valley from the Broich valley, at ca. 1400' O.D. (18) The position of its outlet is uncertain, owing to the incision at its lower end of a tributary of the Frandy Burn. A second spillway leads out of the Frandy valley, also apparently at ca. 1400' O.D. This is Darn Cleuch, (19, Fig. 16, also Fig. 18) which crosses the watershed south of Ben Shee as a shallow channel, but deepens suddenly and descends steeply for approximately 100 feet down the side of Glen Sherup. It ends in a small, flat-surfaced terrace or bench 300 feet above the valley floor. There is no exposure in this feature, but its form is that of a small delta, and it is possible that the spillway led into a lake at ca. 1300' O.D. The apparent agreement of the height of the intake of this channel with that of the spillway leading into the Frandy valley suggests that this also may have held a lake, at a higher level. Apart from the spillways, there is no other evidence of pro-glacial lakes in these two valleys, nor does there appear to be any outlet for a Glen Sherup lake. Several small benches occur, however, at the mouth of this valley, north of Innerdownie, and, while they are apparently of structural origin, may have been used as one-sided spillways by waters escaping to Glen Devon.

A spillway similar to Darn Cleuch crosses the narrow neck of the spur terminating in Ben Trush, north of Glen Devon, at ca. 1300' O.D. (20) It, too, is deeply cut on one side of the watershed only, and apparently carried water from a relatively high level in the Eastplace valley to one some fifty feet lower in Borland Glen. A col leading to the Lamb valley, a tributary of the South Queich, may have offered an outlet for water from Borland Glen when this spillway was in use.

Two more deeply cut spillways occur on either side of the entrance to Glen Eagles, falling from west to east. (20 & 21) Both appeared to have been lowered from ca. 1300' O.D. The Common Hill channel (21) is ten feet deep at its intake, but deepens downstream, descending by way of a small rock step to approximately 1250' O.D. A small stream is now slightly incised into its floor at its lower end, so that the exact position of its outlet is uncertain. It may have carried water from the edge of ice in upper Glen Devon. On the east side of Glen Eagles, the Goat (22) has been lowered a few feet below 1250' O.D., and is a steep-sided channel, fifty feet deep throughout its length, its flat floor somewhat encumbered by debris from the bare rock walls. It descends to ca. 1200' O.D. in the Hillkitty valley. (Photograph 8) The close agreement in height between these two channels suggests that they may have functioned at much the same time. It is even possible that water continued from one to the other, across the ice that must have occupied Glen Eagles.

Only one spillway was developed marginal to Glen Devon ice at a lower level. This is the Black Hill channel (23) leading from Glen Sherup at ca. 1100' O.D. Some twenty to thirty feet deep, it appears to open into the valley of the Whitens Burn (Fig. 18) but this is unmodified by meltwaters, and the spillway may be continued down to the 1000-foot

Photograph 21. GLEN DEVON.
Looking west from Down Hill.



"X" marks the point from which Photograph 22 was taken.

contour by a one-sided channel, leading into the little valley of the Black Burn. (Fig. 18) This also does not appear to be modified by meltwaters, and the channel, therefore, may have led into a small lake held against the ice-margin, draining across the ice to the area from which the ice-front had withdrawn.

The Whiterigg spillway (22, Fig. 14) must have provided the major outlet for Glen Devon meltwaters throughout the period when Clackmannan Ice blocked the mouth of the valley. Cutting across a spur whose original height was probably about 1000' O.D., the intake of the spillway has been lowered to 800' O.D. A short distance further south is the entrance to the Dey valley, about 100 feet below the intake of the spillway. Clearly, this must have been in some way obstructed when the spillway was in use. Such an obstruction was probably provided by a lobe of Clackmannan Ice - the presence of this ice in the Dey valley is indicated by coal and other Carboniferous rocks in the fluvio-glacial gravels. The Whiterigg spillway may therefore have developed near the point where Clackmannan and Glen Devon ice began to separate.

More information on the position of these two ice-fronts as retreat commenced is provided by the thick gravel deposits of Lower Glen Devon. (Photographs 21 and 22) Described on the Geological Survey map as fluvio-glacial, their surface form suggests that they are also morainic deposits. Near Tormaukin

Photograph 22. GLEN DEVON.
Looking downstream from Ben Trush.
(Explanatory diagram facing p. 204.)

(27/997043) they form a ridge 150 - 200 feet high, swinging across Glen Devon in an arc terminating in Linn Hill above the Black Linn gorge. (Fig. 18) At its highest point this ridge rises to 899' O.D., in a steep slope from the valley floor. It seems probable that this slope has been given its present form in part at least by the undercutting of the river. Downstream there is no comparable slope, and the undulating crest of the ridge passes into the rather uneven surface of the gravels which continue downstream from it, as far as Yetts of Muckart and beyond. These gravels appear to fill a pre-glacial valley of the Devon, which is now partially re-excavated, and rise to ca. 900' O.D. on the western valley side. In places their upper surface is smooth, and a small terrace is present at ca. 750' O.D. north of Rab's Burn. (Fig. 18) Apart from this terrace and the gullies cut by a few small streams in response to the downcutting of the Devon, the surface of the gravels appears to have been relatively unmodified since their deposition. The Linn Hill ridge also closes the entrance to Glen Quey, except where it is broken by the Glenquey Burn, and here the descent to Glenquey Moss from the crest of the ridge is a matter of four to five feet only, the Moss being above the level of much of the ridge.

The gravels are on the whole rather coarse, boulders up to a foot in length being intermingled with finer material, in a matrix that is in parts sandy and in parts clayey. In some

Explanatory diagram for Photograph 22.
"X" marks the point from which Photograph 21
was taken.

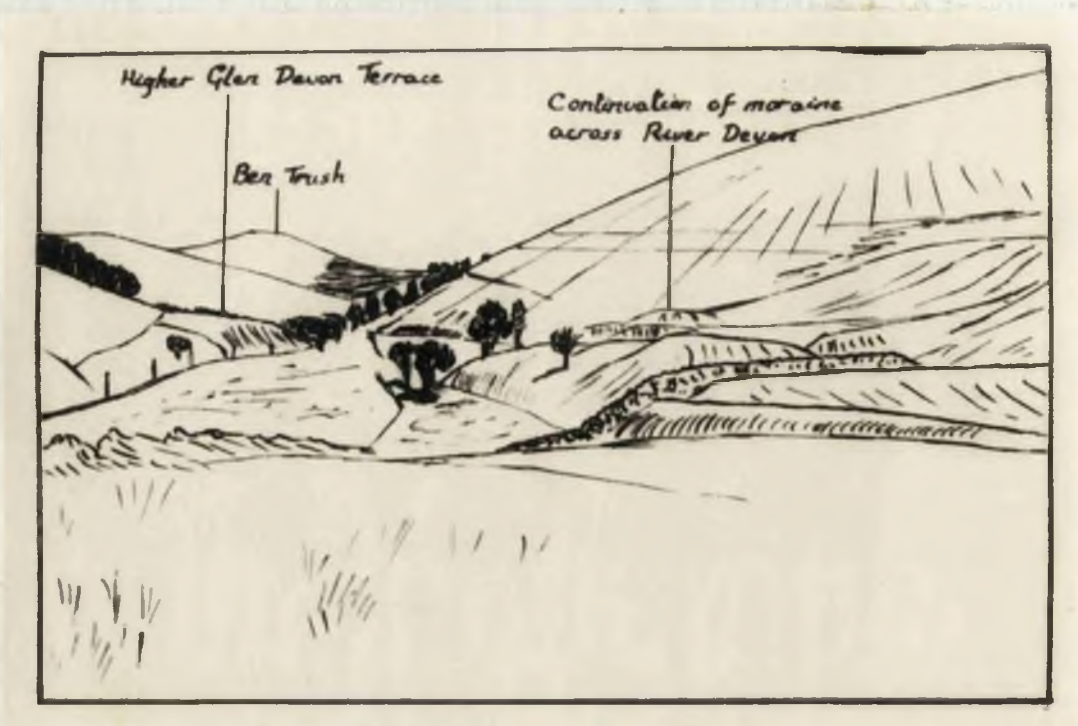
exposures, notably in the sides of How Cleuch, traces of bedding may be noted. The boulders and pebbles are chiefly of local origin, but some of Highland origin have been found. Carboniferous rocks also occur south of the Howcleuch Burn; none have been found in the Linn Hill ridge, but this may simply reflect the smaller number of exposures. It seems probable that the gravels were deposited as the edges of the Clackmannan and Glen Devon ice began to shrink away from each other, under conditions of rather restricted drainage. The Linn Hill ridge may have been formed as a morainic ridge at the snout of the lobe of ice which occupied Glen Devon, or, more probably, as other features in the valley suggest a gradual melting of dead ice, as a kame around a mass of dead ice lying in upper Glen Devon.

The gravels and probably the ice behind them appear to have formed a dam across the entrance to Glen Quey, giving rise to a lake whose presence is now indicated by the flat peaty surface of Glenquey Moss. Reaching a level only a few feet short of 900' O.D., this lake appears to have received meltwaters from a large spillway at the head of the valley, draining away from the Dollar valley. (Fig. 16, 24) Near the farm of Glenquey an exposure in the side of the flat-floored trench occupied by the Glenquey Burn, and cut some fifty feet below the Moss surface, reveals sands with occasional beds and lenses of gravel, dipping gently downstream. (27/983032) It seems probable that the lake was at least partly infilled by the material carried in the meltwaters, which may eventually have left Glen Devon by the Whiterigg spillway. As this was lowered, the lake may have been drained, and the spillway feeding it extended across its floor to form the large trench occupied by the Glenquey Burn, but there is no certainty of this, as the Glen Quey Reservoir hides any connection between the spillway proper and its possible extension.

On the northern side of Glen Devon, a small terrace is mapped by the Geological Survey on the spur between the Hall Burn and Borland Glen (Fig. 18), using the same symbol as for Glenquey Moss, which is mapped as a river terrace. The terrace appears to be at the same height (ca. 900' O.D.) as the Moss, but there seems to be no exposure showing its composition. Also at much the same height in Borland Glen itself (27/993053) is a section showing some six feet of fine stratified gravels in a silty matrix overlying much coarser and apparently unstratified material. It seems probable that a pro-glacial lake existed on this side of Glen Devon also, into which the Creich Burn deposited materials derived from higher up its valley. The close correspondence between the terrace level and that of Glenquey Moss suggests that the Glenquey lake may have extended across Glen Devon as the two ice-fronts became increasingly separated.

Narrow, discontinuous terraces line Glen Devon for much of its length between Glen Quey and Glen Eagles. The highest of these, the Eastplace Terrace, commences at the mouth of the Eastplace valley, where it is continuous with the valley infilling, and descends from 900' O.D. to ca. 850' O.D. in the Borland Glen. (Fig. 18) The floor of Glen Devon in this section is just below 700' O.D. The terrace appears to have no upstream continuation, nor is there any corresponding feature on the opposite valley side. The other two well-developed terraces are found, however, on both sides of the valley. The higher is most extensive at the entrances to tributary valleys, where it appears to merge with the valley infilling. It increases in height above the river, from 15 - 20 feet near Glendevon Reservoir to 50 - 60 feet at the entrance to Borland Glen. The surface of the individual terrace remnants is usually smooth, and slopes gently towards the outside edges, although that at the entrance to Glen Sherup is rather more undulating. (Photograph 8) The outer edge appears in many places to have been steepened by the undercutting action of the Devon or its tributaries, but elsewhere its steepness may be an original feature. Both this terrace and that below it are apparently formed of fluvio-glacial gravels, although exposures are not common, and none is clear enough to show whether the gravels are stratified. The Lower Glen Devon Terrace is more uniform in appearance than the Higher, and of greater extent. It appears to have been formed at the expense of the higher terrace, and is in turn

Photograph 23.   GLEN EAGLES LATERAL MORAINE.



being cut away by the Devon, the sinuous line of its outer edge clearly corresponding to past and present meanders. Its gradient is much the same as that of the present flood-plain; the terrace is ten to twelve feet above the river for most of its length, and its surface in any given locality nearly flat.

The Lower Glen Devon Terrace continues some distance into Glen Eagles, but does not appear to be represented in Glen Devon above the entrance to Glen Eagles. The two valleys are separated by a long ridge running eastwards from the foot of Common Hill to the Devon, and apparently continued across the river by a line of low mounds along the valley side. This ridge is at approximately the same height as nearby parts of the Higher Terrace, but differs from them in form and composition. Broadest at the foot of Common Hill, it narrows eastwards, and has an uneven surface of small hollows and ridges. (Photograph 23) A number of exposures occur above the Devon, which occupies a narrow channel between the ridge and the southern valley side. In one of these (27/950050) boulders up to 4 feet in length are included with smaller examples in a completely unsorted deposit. They suggest that the ridge may be a moraine, deposited laterally to a tongue of ice extending into Glen Devon from Glen Eagles. Upstream of the ridge in Glen Devon a terrace similar to the Higher Terrace but of coarser material continues from the moraine on the north side of the valley, suggesting that dead ice may have lain in the valley when the moraine was formed, the terrace being formed as the ice melted out. On the south side of the valley is a rather lower terrace, with a remarkably level surface. The composition of this is unknown: it may be a lake terrace formed when ice had disappeared from Glen Devon, but before the river had cut through the ridge completely.

The terraces east of Glen Eagles may have had more than one mode of origin. Their development in fluvio-glacial gravels suggests that these gravels were deposited as a valley train, and the terraces formed, by meltwaters from a retreating ice-front. The Eastplace Terrace, higher and less well-developed than the others, may, however, be a kame-terrace, formed by deposition from a mass of dead ice. The Higher Glen Devon Terrace, with its steep outer edge which is not always related to the Devon but may be an ice-contact slope (Photograph 21), may have had a similar origin. This seems very probable on the southern valley side, near the entrance to Glen Quey, where it is represented by isolated hillocks. An interesting feature elsewhere is the continuity of the terrace surface with that of the infilling of the tributary valleys, which suggests that a rough grading of the surfaces was effected. Unfortunately the absence of adequate exposures makes it difficult to decide the exact relationships of these features. The terrace edge was undoubtedly modified on the disappearance of the ice by meltwater streams depositing the gravels forming the Lower Glen

Devon Terrace. Only the lower terrace continues into Glen Eagles, and it seems probable that this indicates the passage to an active glacier, adequately supplied from ice in Strath Allan.

The deposition of the gravel train, and the destruction of the Higher Glen Devon Terrace, appear to have continued as the Glen Eagles ice-front gradually retreated northwards. A moraine was formed at the point where Glen Eagles suddenly deepens, probably reflecting the increased thickness of the glacier, and therefore the lower efficiency of ablation in causing the front to retreat. There seemed to be no evidence that this moraine represents a readvance. As long as the ice-front remained in this position meltwaters must have escaped by way of Glen Devon, but when retreat recommenced, and an alternative outlet was found, the formation of the gravel train must have ceased, all further down-cutting, and the development of the present flood-plain at the expense of the lower terrace, being entirely due to the Devon.

There seems to have been no parallel retreat of an ice-front in Glen Devon west of Glen Eagles. Indeed, as noted in connection with the terraces in this part of the valley, it seems more probable that the ice had stagnated or had even completely disappeared before the Glen Eagles ice had withdrawn from Glen Devon. Stagnation in this part of the valley, on theoretical grounds, seems not improbable. The two main routes by which ice entered Glen Devon were the col at Glen Bee, and Glen Eagles. Of these, the first is 400 feet higher than the second, and ice may well have ceased to use the Glen Bee col when it could still extend some distance into and through Glen Eagles. Ice in Glen Devon, between Glen Bee and Glen Eagles, might thus be cut off from its source and would stagnate, while Glen Eagles ice continued to be active.

Along the watershed north of Glen Devon and west of Glen Eagles the probability that ice remained at a high level in Strath Allan and in Glen Eagles after its disappearance from Glen Devon is indicated by a number of spillways. Four of these run north-south across the watershed, two between Craigentaggart Hill (27/906056) and Wether Hill, one at the head of Glen Bee, and one between the upper valley of the Devon and Glen Anny. (25-28, Fig. 17). There are also one or two shallow meltwater channels crossing the broad bench immediately west of Glen Eagles (eg. 29); these appear to have carried water from the main glacier in Strath Allan round the edge of the Glen Eagles lobe, to escape by deep gullies in the side of the valley, probably developed near the snout of the glacier. Of the first four channels, three clearly lead into Glen Devon; the highest (25) may have done so, but its floor now falls gently to both north and south, the centre of the channel being raised by the development of peat. Some fifty feet deep, this spillway cuts through a col whose original height was probably 1500' O.D., between two small valleys, neither of which appears to be modified by meltwaters. Like the channels across the watershed east of Glen Eagles, it may thus have functioned at an early stage of deglaciation, the meltwaters it carried escaping over ice lying at a high level on both sides of the watershed.

A short distance further east the second of this series of spillways (26) links the Damakellis and Dow valleys. This is more spectacular than the first, with steep, rocky walls, and a narrower floor, although it is of the same depth. A spot height at 1419' O.D. near its intake suggests that this is slightly above 1400' O.D. The col across which the spillway is cut was therefore at approximately 1450' O.D., and it is possible that its development caused the abandonment of its near neighbour. There seems to be no obvious reason for such a development, however, unless it be that the col was occupied by ice while the higher channel was cut.

The Dow spillway clearly descends southwards, its floor falling fairly steeply towards the head of the Dow valley, which appears to have been much modified by meltwaters. The spillway opens into a broader, but still steep-sided channel, margined on its western side by a bench twelve to fifteen feet above the floor. Small rock knobs rise from the floor to similar heights, and an incision by meltwaters into what was a shallower, more open valley, is suggested. (Photograph 24)

Photograph 24. THE DOW SPILLWAY.

This section of the valley is ended by a rock step ten feet high about 50 yards downstream. Below it the valley has near-vertical sides, and a flat floor, for a further 50 yards, before a second step marks another descent. Beyond this the valley continues to descend steeply with the same trench form, until its lower parts are drowned by the Glendevon Reservoir, and its relation to the floor of the main valley is hidden. The development of this valley form must almost certainly be due to meltwaters, for the present Dow Burn is a small stream, which has not succeeded in cutting more than a small notch into the rock steps. These appear to mark changes in the level to which meltwaters drained, and if so, show that ice in Strath Allan remained at a fairly constant level, possibly damming a small lake at ca. 1400' O.D., while ice in Glen Devon was decreasing in thickness.

The third of the spillways entering the Devon valley is that between Sauchanwood Hill and Core Hill. (27) Its intake is at ca. 1400' O.D., the channel being here not more than ten feet deep, but descending rapidly to the floor of the Devon valley approximately 100 feet lower, and becoming thirty to forty feet deep. The river, which is here small, but swiftly flowing, has lowered its bed not more than one or two feet below the level of the spillway floor. There is a distinct contrast in the valley form above and below the entrance of the spillway. Upstream the Devon is incised a few feet into

Photograph 25. LOWER GLEN BEE.

the floor of a V-shaped valley about 100 feet deep. Downstream the floor is very flat, while the sides are steep, and the valley as a whole has a spillway form. These characteristics disappear at a twelve foot high waterfall, near the entrance of Greenhorn Burn. (27/894042) It is clear from the virtual continuity of the spillway floor with that of the Devon valley that the latter must have been ice-free when the spillway functioned, and that it was not even occupied by a lake, but offered an unobstructed route eastwards for the meltwaters. For what distance downstream this continued to be the case is uncertain: below the waterfall what appears to be a recent incision of the Devon has destroyed any continuation of the meltwater-modified section of the valley. There may, however, have been a connection between this and a smooth-surfaced bench in lower Glen Bee, some 15 - 20 feet above the Devon.

This bench continues a short distance up Glen Bee, but rapidly becomes indistinguishable amongst the numerous rock knolls developed over much of the western side of the valley. These are probably due in part to the action of ice over-riding the col at its head, as earlier suggested, and possibly also to meltwaters from an ice-front halted on the watershed. (Photograph 25) The Glen Bee spillway has been cut below these knolls and the bench. (28) It is the lowest of all the spillways entering Glen Devon, with an intake at 1250' O.D. The actual col between the Glen of Kinpauch and Glen Bee does not appear to have been lowered more than a few feet by meltwaters, but immediately south of it there is a steep descent of some 15 - 20 feet to the floor of a steep-sided, flat-floored channel. This falls steadily towards the Devon, and is cut 10 - 12 feet below the bench described earlier. The Devon, which is here rather below 1100' O.D, is incised a few feet below the lower end of the spillway. In this case, as in that of the Sauchanwood Hill spillway there can have been no ice in this part of upper Glen Devon at the time the spillway functioned. On the northern side of the watershed, however, ice must have remained up to at least the 1250-foot contour.

Owing to the existence of Glendevon Reservoir it is impossible to know whether or not the Dow spillway also functioned when Glen Devon was ice-free, but this seems probable, as the reservoir is unlikely to be more than sixty feet deep at the point where the Dow Burn enters it. The three spillways may have been nearly contemporaneous, although the Dow channel was probably initiated first, showing as it does, evidence of falls in the level to which it drained. The Sauchanwood Hill and Glen Bee spillways do not appear to have been affected by similar falls in base-level, although the incision of the Devon, possibly augmented by meltwaters from the Glen Anny spillway, below the bench in lower Glen Bee may have been caused by such a fall occurring either before the Glen Bee spillway was developed, or in its early stages of development. Ice may have continued to occupy the Glen of Kinpauch - Glen Bee col while the Dow and Glen Anny channels were developed, but seems unlikely to have extended far into Glen Bee. Meltwaters from this ice may have helped to produce the broken terrain that characterises much of the valley. The height of the Glen Bee spillway intake suggests that it was the latest of the channels leading into Glen Devon. In view, however, of the fact that it leads from the Glen of Kinpauch, a tributary of Glen Anny, and that both valleys must have been dammed by ice at the same time, it is possible that, for a short time at least, the Sauchanwood Hill and Glen Bee spillways functioned simultaneously.

The height of the Glen Devon terraces, apart from the Eastplace Terrace, indicate that they were formed after the Whiterigg spillway had been abandoned. This can only have been due to a withdrawal of the Clackmannan ice-front. For a time the Dey valley may have provided an alternative outlet at least fifty feet lower for Glen Devon water, and the development of the Higher Glen Devon terrace was probably related to this level. The Glenquey lake was probably drained as the Whiterigg spillway was cut below 900' O.D., and with the disappearance of the lake, the Linn Hill ridge may have functioned as a barrier to drainage from further west. The River Devon now occupies a gorge 100 feet deep at the extreme northern end of the ridge, and is incised about twenty feet into the underlying rock. It seems probable that here the course of the river lies slightly to the north of its infilled valley, and has been superimposed upon the old valley side. The rim of the gorge is followed by the 800-foot contour - some fifty feet above the level of the Higher Glen Devon Terrace. This suggests that the gorge may have been initiated as a spillway by water from the stagnant ice with which the development of the Eastplace Terrace and adjacent parts of the Higher Terrace appears to be associated. Further downcutting must have been performed first by the meltwaters from the retreating Glen Devon-Glen Eagles ice-front, and later by the Devon alone, and must reflect the abandonment of the Whiterigg spillway for lower outlets. Downstream from the Black Linn gorge the river may have been less restricted, the Rab's Burn terrace possibly being formed when the Dey valley was used as an outlet.

The evidence by which the stages in the disappearance of ice from Glen Devon may be traced seems to be rather limited in amount. It would appear, however, that the ice, which, to judge from the extent of boulder-clay, filled the valley completely, even covering the high-level benches, gradually decreased in thickness until it occupied only the narrow, deeply cut glen and the equally narrow tributary valleys. This shrinkage is attested by only a small number of spillways, notably by those on either side of Glen Eagles, but may have been accompanied by some development of small pro-glacial lakes. Further shrinkage within the narrow valleys is likewise associated with but few spillways. The final stages in the disappearance of ice have left more evidence. The thick gravel deposits of the lower parts of Glen Devon appear to have accumulated as the Glen Devon and Clackmannan ice-fronts separated, and to have dammed back a small lake in Glen Quey. In part these gravels and the terraces lining the valley upstream of them may have developed by deposition from stagnant ice. This was almost certainly the mode of formation of the Eastplace Terrace, and not improbably of the Higher Glen Devon Terrace below it. With the disappearance of the stagnant ice, however, the meltwaters from the Glen Eagles ice-front were probably responsible for the development of a valley train. The gravels forming the Lower Glen Devon Terrace appear to have been deposited in this way. West of Glen Eagles, upper Glen Devon was probably occupied by stagnant ice, cut off from its source when Strath-Allan Ice was unable to surmount the col at Glen Bee, even when Glen Eagles ice was still active. A small lake may have existed until the Devon cut through the moraine formed across the entrance to upper Glen Devon. Several spillways show that when upper Glen Devon was ice-free, Strath Allan must have remained ice-filled.

During all the later stages in the deglaciation of Glen Devon meltwaters must have escaped by way of the Whiterigg spillway, until the rather lower Dey valley was freed by a withdrawal of the Clackmannan ice-front. The lowering of these outlets was accompanied by the lowering of the Black Linn gorge, and therefore by the development of the Lower Terrace and its later destruction.

Further retreat of the Clackmannan ice-front must have left the entrance to Glen Devon unobstructed, allowing the Devon to follow approximately its pre-glacial course over the gravel deposits, at a level considerably above that of the present valley floor. It is unlikely that the river was able immediately to take up its present course southeastwards from Yetts of Muckart. Here it now occupies a broad valley cut into the extensive gravel deposits which cover the lowlands flanking the hills. Terraces have been developed in these gravels. The surface of the highest terrace, from Middleton Fossoway (37/036021) eastwards, is poorly drained and remarkably flat. It occupies a triangular area between the Ochils and White Hill (37/042018) passing at its apex into the Pow spillway (26, Fig. 14), at 568' O.D. This channel is nowhere more than fifty feet deep, and is cut across a col originally probably not much above 600' O.D. It seems probable that the Devon entered a small pro-glacial lake on leaving the hills, into which sands and gravels were deposited, and from which waters escaped by the Pow spillway to one of the lakes of the Plain of Kinross. A terrace can be traced upstream from the former lake flat for a short distance into Glen Devon, rising to ca. 650' O.D. but does not appear to be continued beyond the gorge through which the river flows at Nether Auchlinsky (37/001026). On the western side of the valley the terrace occurs only between Nether Auchlinsky and Yetts of Muckart, which may indicate that the ice-front lay along a line between Yetts of Muckart and White Hill.

The Nether Auchlinsky gorge appears to be of similar origin to the Black Linn gorge, in that it seems to have developed where the river has left its pre-glacial line and has been superimposed across a buried spur. About 100 feet deep, only the upper 20 - 30 feet of the sides are in unconsolidated material, the lower parts being cut in rock. In contrast to the Black Linn gorge there is here no waterfall, the river flowing through the gorge with no apparent increase in gradient. Both above and below the gorge a wider valley has been developed by the removal of glacial and fluvio-glacial deposits from the pre-glacial valley.

A second terrace has been formed ten to fifteen feet below the first upstream of Yetts of Muckart and thirty to forty feet lower southeast of Fossoway. (37/017019) This could only have developed on the abandonment of the Pow spillway and the retreat of the ice-front to allow the river to continue southeastwards from Glen Devon. On its eastern side a shallow channel running from Fossoway to Drum (37/046006) separates this terrace from the edge of the first, while west of the river it merges into a gently undulating surface of apparently unmodified glacial deposition. In height it falls from ca. 600' O.D. to below 500' O.D. near Crook of Devon - a gradient rather greater than that of the modern floodplain, which is 20 - 30 feet below the terrace at Fossoway, but only four to five feet lower at Crook of Devon. Beyond Crook of Devon the terrace passes into a broad, shallow valley occupied by the Gairney Water and leading southeastwards to Loch Leven. It seems highly probable that the Devon continued along this valley at the time the lower terrace was formed. The slope of the terrace suggests it may have developed as an alluvial fan, comparable to that at the lower end of Glen Queich, and that the shallow channel at its eastern side may have been formed by a distributary. It is possible, however, that this channel represents a temporary course of the Devon, followed before the Clackmannan ice-front had withdrawn west of the present river.

At Crook of Devon the undulating surface with which the terrace merges on its western side appears to approach close to the river, which has cut back its edge to give a bluff ten to twelve feet above the modern floodplain, and six to eight feet above the terrace. The river breaks through this bluff in a shallow gorge, abandoning its former southeasterly course and flowing in a generally westerly direction. The gorge, never more than ten feet deep, but 400 yards long, opens out onto a lower floodplain, margined by two terraces, and terminated by the descent to the impressive Rumbling Bridge gorge, through which the river falls over 100 feet in a distance of not much more than 300 yards. This sudden change of course has been explained in at least two ways. To J. Wynfield Rhodes it appeared due to capture by a stream working back along the line of the Ochil Fault.[1] Valid objections to this hypothesis were advanced by D.L. Linton, who pointed out that the Devon follows the Ochil Fault only in a general way,[2] but the chief objection would appear to lie in Rhodes' complete failure to appreciate the post-glacial age of the drainage in this area - a fact of which A. Geikie, writing in 1900, was fully aware.[3] Linton himself suggested that the present course of the Devon is due to "a very recent diversion at the margin of a stagnant portion of the last ice-sheet"[2] This seems unlikely in view of the absence of kames or other features associated with stagnant ice, and the existence of the broad, southeast trending valley.

It seems clear that the diversion of the Devon took place after the formation of the second terrace, when the bluff on its western side had already developed. The river itself cannot have produced the breach in this bluff, but must have been diverted through it after its formation. Such a diversion might result from the capture of the Devon, not on the lines envisaged by Rhodes, but by a small west-flowing stream initiated on the surface of glacial deposition. This stream may have had some slight advantage over the Devon, in that in crossing the area of the lower floodplain to Rumbling Bridge (36/016994) it was probably 20 - 30 feet below the level of the Devon at Crook of Devon. The breaching of the bluff may not, however, have been due entirely to what must have been only a small stream. On either side of the lower floodplain flat terraces about ten feet above the river offer some support for a suggestion by Geikie that a small lake was formed upstream of Rumbling Bridge.[3.] This he considered to have been dammed by the low rock ridge against which terraces and floodplain terminate in the west. It seems unlikely that the ridge did function as a dam, if only because it is absent north of the river, but a small lake may well have formed in a hollow left by the retreating ice-front, being dammed by that ice-front for a short time, and overflowing across the higher ground at its eastern end to the Devon. In doing so a channel would be cut which may later have been utilised by the pirate stream.

The further withdrawal of the Clackmannan ice-front probably opened a lower outlet for the lake at its western end. There can have been no drainage to the Lower Devon Valley, which must have remained ice-filled, and for a time meltwaters from the ice and drainage from the ice-free area must have followed a more circuitous route to Loch Leven than that offered by the Devon, but one at a lower level. This may have been provided by the broad, flat-floored valley overlooked by Aldie Castle. (Fig. 17) So flat and poorly drained is this valley at the foot of the Cleish Hills that no watershed can be discerned between the Pow Burn, draining northeastwards to the Gairney Water, and the Gairney Burn, draining northwestwards to the Devon. Margined as it is at its eastern end by flat-surfaced gravels, it seems probable that it may have held a mass of dead ice, later replaced by a lake. This lake may have been responsible for the apparent erosion of the gravels, recorded in the Summary of Progress for 1926.[4.] Such a lake, possibly a little above the present level of the floor, at ca. 410' - 415' O.D., may have received water from the Clackmannan Ice and drained to the Plain of Kinross.

There seems to be no evidence to show when, in relation to other events in the area, the Devon was diverted westwards. It must have been very recently indeed, possibly not occurring until the withdrawal of the Clackmannan ice-front had proceeded so far that a lower outlet than the Aldie valley had been found for meltwaters, and the pirate stream had a fairly rapid descent between Rumbling Bridge and the Lower Devon valley. The fall in base-level on diversion appears to be responsible for the development of the present floodplain above Crook of Devon; its effect can certainly be traced as far upstream as the gorge at Nether Auchlinsky. The removal of glacial deposits from the section of Glen Devon between this gorge and the Black Linn is probably due to the combined effects of the series of falls in base-level as the river found successively lower outlets following the abandonment of the Whiterigg spillway.

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VI. The Hillfoots Valleys and the Lower Devon Valley.

The withdrawal of the Clackmannan glacier from the mouth of Glen Devon must have been accompanied by a decrease in its thickness further west, and by a shrinkage of its margin away from the valleys and scarp face of the Hillfoots area. As in Glen Devon, this shrinkage did not lead to the development of an extensive system of spillways by which meltwaters could drain from one valley to another as the ice-margin gradually withdrew. The absence of such features is probably due to the height and steepness of the scarp face. The spurs separating the various valleys extend for some distance southwards at or above 1700' O.D., and are crossed by several shallow depressions, rarely more than a few feet deep, which may have carried meltwaters at an early stage of deglaciation, when the watersheds had just emerged from the ice. The descent from the relatively level surfaces of the spurs to the Lower Devon Valley, however, is sudden, even precipitous, and once the level of the ice had fallen below that of the spurs, escape for meltwaters across the spurs would probably become impossible, and must necessarily have taken place across, or into, the glacier itself.

Of the spillways that were formed, few are associated with deltas or alluvial fans, and it is therefore probable that most debouched onto ice at a slightly lower level than that in the valleys from which they lead.

What appears to be one of the earliest spillways in this area commences high up on the side of the Alva valley, at ca. 1700' O.D. (25) This is not more than 20 - 30 feet deep, with steep sides, and a narrow, rather uneven floor, in which large hollows (? potholes) are filled by peat. At its lower end the channel deepens and descends steeply by a rocky ravine, aptly known as the Rough Knowes, to the 1500-foot contour in the small valley of the Wood Burn. It has no apparent connection with the adjacent Tillicoultry valley, although it is possible that a one-sided channel developed along the spur between the two, but is now indistinguishable from the many small structural benches on this slope. The spillway appears to mark a remarkable difference in the level of ice on the two sides of the Alva-Tillicoultry watershed, for which there is no obvious reason. It is possible that the meltwaters entered a lake at ca. 1500' O.D., in spite of the absence of any depositional features. Two overflow channels lead out of the Tillicoultry valley, both having been lowered at their intakes to ca. 1550' O.D., (26 & 27) and may have served to drain a lake into which the Rough Knowes spillway led. The existence of two such channels, however, rather suggests that both drained from the ice-margin and that the coincidence of height is accidental.

One of these spillways (27) cuts across the spur separating the Tillicoultry valley and the smaller Harviestoun valley. At its intake this channel is shallow, several low bosses of rock apparently marking a division of the meltwaters using it into several small streams, but deepens rapidly until it is 30 - 40 feet deep at its outlet, a few feet above the floor of the Harviestoun valley. No corresponding spillway leads from this valley, and meltwaters may therefore have escaped across the ice that must have extended into it. The second channel (26) leads from the head of the Gannel valley to the Glen of Sorrow, where it ends at ca. 1510' O.D. Some ten feet deep at its intake, it deepens suddenly after a distance of about 50 yards, but never becomes more than 25 - 30 feet deep. It now ends above a narrower valley apparently developed by the Burn of Sorrow, and not by meltwaters, which may have destroyed an extension of the spillway. A small bench on the south side of the stream may be a remnant of this extension.

Water entering the Dollar valley by this route may eventually have contributed to the cutting of the Glenquey spillway (24), but no connection has been traced between the two, and the Gannel channel may well have been abandoned before the lower channel was developed. As described earlier, the meltwaters using the Glenquey spillway appear to have contributed to the infilling of the Glenquey lake, one of the few instances in the hills where a spillway is associated with a depositional feature. Cutting across a col whose original height must have been at least 1250' O.D., the Glenquey spillway is nearly 200 feet deep at its intake, where a flat alluvial area at 1100' O.D. may mark the site of a small lake, and appears to have served as the major outlet for water from the Dollar valley for a considerable time. Benches, both above the intake, and near the Maiden's Well, at the head of Glen Quey, some 50 - 75 feet above the present floor, and the steeper, more rugged appearance of the lower 50 feet of the spillway walls, as contrasted with the smoother, grass-covered upper slopes, suggest that it was cut in two stages. In the first stage, the spillway probably drained into the Glenquey lake. The second stage may reflect the draining of the lake, the down-valley extension of the spillway, and its possible incision into the floor of the former lake.

Although there is a long and relatively gentle slope southwards from Hillfoot Hill, up to which the ice must have lain while the Glenquey spillway functioned, no channels were developed across it, by which meltwaters might have escaped as the ice-edge retreated. By the time the only other channel leading from the Dollar valley was formed with an intake at approximately 645' O.D., the Sorrow and Core streams must have reappeared, and were probably beginning to incise themselves into the glacial deposits partly filling their valleys. This channel, to the north of Gloom Hill, (28) is not more than fifteen feet deep, and appears to be more a temporary channel of the Dollar Burn than a true overflow channel. Ice across the mouth of the valley must have prevented the streams from taking up their pre-glacial route from the valley, and obliged them to flow eastwards, along the postulated line of their original course, by the broad depression north of Law Hill. This is floored with fluvio-glacial sands, and a shallow channel leading to the Cowden Burn may mark the temporary line of the Dollar Burn. There is, however, no connection with the Gloom Hill channel, possibly owing to the later development of the Kelty Burn, draining in the opposite direction.

Several small meltwater channels enter the Dollar valley across the long spur running east from King's Seat Hill. (26/936997) The highest has an intake at 1500' O.D. (29a), and, running along the hillside as a partly one-sided channel, must have developed alongside the ice-margin. It ends at ca. 1300' O.D., in the much broken area known as the Banks of Dollar, similar to the head of Glen Bee, with numerous shallow, but sharply cut channels and low rock bosses, apparently cut by meltwaters from ice lying close up to the spur. One or two of these channels descend almost to the level of the valley infilling, here at approximately 1000' O.D., and must have been used when the Glen of Sorrow was almost, or completely, ice-free. A larger channel, (29b) with an intake at ca. 1150' O.D., also seems to have been used at this stage, and an alluvial fan, descending from 1000' O.D., at its apex to 900' O.D. at the edge of the Sorrow incision, appears to have been laid down at its lower end.

Spillways in similar positions to these just described are found at the mouths of other Hillfoots valleys. Thus, a small channel at ca. 1400' O.D. enters the Harviestoun valley (30), while another enters the Tillicoultry valley across the spur separating it from the Wood valley (31). The intake, at ca. 1100' O.D. is only four to five feet deep, but the channel deepens rapidly as it descends to a small bench at 1000' O.D. A similar, but smaller spillway enters the Balquharn valley (32) at 800' O.D., while a less steeply sloping channel, some fifteen feet deep, enters the Menstrie valley at 600' O.D. on its western side, across a spur from Dumyat (33). The direction of all these channels suggests that they carried water from the ice margin into the valleys concerned, which, if not ice-free, were at least not filled by ice reaching to so high a level as that along the scarp face. They may have been occupied by lobes of the main glacier, the surface of these lobes falling rather rapidly to their margins. In these circumstances small pro-glacial lakes may have developed, into which spillways and streams from ice-free areas drained. The absence of spillways leading from the valleys, suggests that such lakes may have drained by channels in or over the ice.

Positions of the Clackmannan glacier along the scarp face may be marked by certain marginal overflow channels running between small valleys or embayments in the southern face of the hills. East of Dollar, two broad but not deeply cut channels (34a & b) may have been formed by meltwaters accumulating in a small valley head, draining eastwards to a similar embayment by the first channel, which descends from ca. 1300' O.D. almost to 1250' O.D., and continuing eastwards by the second spillway, at 1250' O.D. Another similar, but smaller, channel occurs at 1100' O.D. below King's Seat Hill, (35), and is unconnected with any other channel. The absence of such channels elsewhere along the scarp face appears to be a result of the steepness of the slope, as was suggested earlier, and it is notable that those above described occur where the steepness and degree of glacial roughening lessen.

There is some evidence that the three eastern Hillfoots valleys (Menstrie, Balquharn, and Alva) were entered by ice from the northwest at their upper ends, and this is reflected in the development of meltwater channels as these valleys were freed from ice. Thus, in the Alva valley, the spur separating the main valley from the Strabanster valley is crossed by a spillway (36) leading from the upper, NE - SW part of the Alva valley, known as Birken Glen, at ca. 1600' O.D., to the Strabanster valley, where it opens out at ca. 1300' O.D., at the level of the valley infilling. At least the head of the Strabanster valley must then have been ice-free when the spillway functioned, yet ice in the main valley must have been almost 500 feet thick. It is difficult to envisage this situation arising if the Alva valley were entirely occupied by a lobe of ice from the south, which must have decreased in thickness towards the valley head. It might have arisen, however, if the northern part of the valley, at least, had been entered by ice from Glen Tye, over the broad col at 1700' O.D. north of Bengengie Hill. As the ice-sheet thinned, this ice may have been cut off from its parent glacier by the emergence of the watershed, but remained, to some extent protected from ablation, in the deep and narrow upper Alva valley, blocking the normal drainage of Birken Glen, and causing it to develop the spillway to the Strabanster valley. The shrinking back of the margins of the dead ice, and of any lobe of the Clackmannan glacier occupying the lower Alva valley, may have left the Strabanster valley virtually ice-free at this period.

A spillway 25 - 30 feet deep at 1200' O.D., crossing the col between the Glenwinnel and Silver valleys, (37) suggests that such a lobe of Clackmannan Ice may indeed have occupied the lower Alva valley, as it could only have developed if the lower Glenwinnel valley were obstructed. The floor of the channel is continued without a break by the surface of the infilling of the Silver valley, which slopes gently down to ca. 1100' O.D., forming a distinct terrace on either side of the stream incision. This is ended by a steeper slope on the downstream side, beyond which, although boulder-clay is present on the valley sides, no terraces have been developed. Exposures in the terrace are poor, and the material in them appears unsorted, but the form of the feature suggests that a delta or fan was built up at the outlet of the spillway, possibly on top of boulder-clay already in the valley. At the time the fan was formed, the Silver valley was probably blocked by ice, which must also have extended into the Alva valley.

The Silver spillway is cut in boulder-clay, which appears to plug an older, deeper valley. As was suggested in considering the evolution of the Alva valley, this may be part of a continuous Glenwinnel-Silver valley, and the present lower Glenwinnel valley may have been developed as a spillway. If so, this must have been prior to the last glaciation, for boulder-clay in the valley indicates that the last ice to affect the area moved through it.

The disappearance of ice from the Balquharn valley was not accompanied by the development of spillways. Like the Alva valley, it may have been entered at its head by ice, which was eventually cut off from the main glacier, and stagnated in situ. Meltwaters from this ice may have been able to escape over the Clackmannan Glacier. These entering the tributary Lethen valley, by the big Myreton Hill spillway, (38) must also have escaped in this way; the unmodified form of the lower Lethen valley does not suggest that meltwaters were able to continue down it to reach an ice-free Lower Devon Valley.

Of all the Hillfoots valleys, the Menstrie valley must have been most open to ice advancing from the west and northwest, and it seems probable that a large ice-stream moved down it. With the increased ablation that ended the glacial period, this glacier appears gradually to have decreased in thickness, and a number of marginal channels were developed, particularly on the eastern valley side. These are cut across the broad spurs separating the tributaries of the Menstrie Burn - the Crunie Burn, and the three Inchna Burns - and most appear to have contributed to the water using the Myreton Hill spillway, so escaping to the Balquharn valley. This spillway, crossing a spur from Colsnaur Hill, which must here have been no lower than 1250' O.D., is about 100 feet deep. From an intake at approximately 1150' O.D., it descends to the 1000-foot contour in the Lethen valley.

Spillways which cross the watershed separating the Menstrie valley from Glen Tye and the upper Wharry valley show that water entered the valley across this ridge. These channels are mostly shallow and all below 1500' O.D. Their gradient is usually slight, and they appear to have been used when the valleys on either side of the ridge were filled with ice to much the same level. One or two, however, are more deeply cut, e.g. (39a) which commences as a shallow, flat-floored channel some ten to twelve feet deep, but which descends from ca. 1450' O.D. to approximately 1300' O.D. The Balloch (39b) is more deeply cut, flat-floored and nearly 100 feet deep. With an intake just above 1250' O.D. it descends gently to approximately 1200' O.D. at the head of the Crunie Burn, where the valley floor is covered by gravels, probably deposited by the meltwaters.

The water entering the Menstrie valley by these spillways probably found its way southeastwards, either over the ice or by some of the marginal channels. The highest of these has an intake at ca. 1450' O.D., crossing the spur between the 1st and 2nd Inchna Burns. (40) It opens out at 1250' O.D., and may have been used in the early stages of the development of the Myreton Hill spillway. There seems to be no channel at a similar level further west. A number of shallow depressions, sometimes overlooked by a line of low crags, may have been formed by meltwaters, but do not appear to have been used for long. The lowest of these are best developed, and as much as ten feet deep. It has proved difficult to map and determine the height of these channels with any accuracy, owing to the absence of features which can be identified on the map. The lowest, however, appear to lie between 1100' - 1200' O.D., and form a series leading from the Crunie valley to the Myreton Hill spillway (41a, b, c.).

On the west side of the Menstrie valley a few marginal channels were developed, but here there are no tributary valleys, and therefore no reason for the development of any series comparable to those on the opposite valley side. The highest, at 1000' O.D. (42) crosses a spur between two shallow embayments; others occur at 800' O.D. (43) and 760' O.D. (44). These last are particularly short, cutting across very small spurs or bosses of rock, and are only six to seven feet deep.

Below Myreton Hill, some small spillways lead out of the Menstrie valley, between 600' - 700' O.D. (45) There is no clear evidence of a succession of spillways which might have developed as the Myreton Hill spillway was abandoned, but the hillside has been so much roughened by ice-action that meltwaters may well have used the various depressions and gullies without any traces of this now being apparent.

The absence of spillways lower than those described may reflect the increasing steepness of the valley sides, below about 1000' O.D. on the east, and 800' O.D. on the west. Moreover, after the cutting of the lowest channels, on the western valley side, drainage may have been able to take up its present pattern as the ice-front retreated northwestwards. A gully on the western side of the Menstrie Burn, with a NW - SE direction, may have been cut by meltwaters near the snout of the glacier, and the deflection of the lower 2nd and 3rd Inchna and Crunie Burns, towards the lower end of the main valley, may have a similar cause. As the ice finally withdrew, meltwaters appear to have used the broad col at the valley head, at 729' O.D., (46) drainage by way of the Wharry Burn to the Allan Water probably being prevented by the presence of ice to the west. These meltwaters may have contributed to the cutting of the Menstrie gorge.

A number of spillways, mostly shallow, cross the long ridge running westwards from Dumyat. The highest, immediately west of the summit, (47) has developed along a fault-line, which has also been picked out by later stream erosion, so that from its highest point, at 1140' O.D., the channel falls to 600' O.D. on the scarp face, and to 700' O.D. in the opposite direction in the Menstrie valley. There seems to be no evidence as to which way meltwaters flowed through it. Further west, however, channels at 900' O.D. have a definite, if slight fall to the southeast, and probably carried meltwaters from the ice-edge in the Menstrie valley to that of the Clackmannan glacier.

By the time that the Menstrie valley and the area west of Dumyat had become ice-free, the Clackmannan glacier had probably ceased to exist, only the Upper Forth glacier remaining over and around the western end of the hills. This must have prevented the Wharry Burn from draining freely westwards, with the result that, together with meltwaters from the ice-front, it followed alternative courses. For a time it may have escaped by the Menstrie valley, a lake possibly developing in its valley. The last traces of this remain in well-marked terraces surrounding a flat-floored hollow near the farm of Lynns, (27/815011) which end against an apparently morainic ridge on their western side. Later a small spillway ten to twelve feet deep at 600' O.D. may have carried meltwaters to the Logie valley (48). The outlet of this spillway is high above the valley floor, and the lack of modification of the valley by meltwaters suggests that it may have been ice-filled when the spillway functioned.

There seems to be no evidence bearing on the position of the snout of the Clackmannan glacier as the various Hillfoots valleys became ice-free. In view of the considerable hang of these valleys above the deep trough underlying the Lower Devon Valley, it is probable that ice may have remained in this to a considerable thickness, even when normal drainage had been established, in some, if not all, the tributary valleys. At an early stage, meltwaters may have drained eastwards from the ice-front by the Aldie valley; with the emergence of lower ground to the west, however, this must have been abandoned, and spillways developed across the Clackmannan Plateau. (49 & 50). As the ice-front withdrew westwards meltwaters were probably impounded against the rising ground at the eastern end of the Lower Devon Valley - forming a lake in which material from the ice-front was deposited, contributing to the infilling of the Devon trough. This lake probably first drained by the Dollarbeg spillway (49) cut across a col initially a little below 300' O.D., and lowered at its intake to 259' O.D. As the ice-front withdrew further west a lower outlet was developed at Coalsnaughton (50). This channel is not more than 15 - 20 feet deep, and has been lowered to 213' O.D. at its intake. Both of these spillways can be followed to the Black Devon valley, where a broad, flat, alluvium-covered part of the valley floor appears to have held a shallow lake at ca. 200' O.D. (Fig. 16) From this meltwaters could probably escape easily to the Forth by one of the broad, shallow and peat-filled depressions among the drumlins of the plateau.

At the eastern end of the Lower Devon Valley there is a gradual ascent from the floor of the valley, at about 100' O.D. to the 450' - 500' O.D. surface between Yetts of Muckart and Crook of Devon. On the whole, this rising ground has been apparently but little modified since the retreat of the ice-front from it. Its surface is largely formed of sands and gravels, usually smooth, but in places diversified by low ridges which may have been formed as the ice-front halted temporarily. The Devon and its tributary, the Cowden Burn, have become deeply incised into this surface, but it seems clear that the Devon has followed the centre line of a broad valley formed as the ice-front retreated. Small terraces have been formed in the valley of the Cowden Burn; these may be related to the Lower Devon lake, but do not appear to be continued downstream above the Devon. It is possible, however, that the spread of fluvio-glacial gravels between Vicar's Bridge (26/986980) and Dollar, descending from 200' O.D. to 150' O.D. may have been deposited by the Devon in the lake.

The edge of these gravels has been cut away by the meanderings of the river across its floodplain, which ends at Vicar's Bridge, where the river emerges from a gorge $1\frac{1}{2}$ miles long and from 25 - 50 feet deep. This gorge appears to mark the final incision of the river in adjusting itself to the present sea-level, and is largely cut in rock. It ends against a dolerite sill, over which the river plunges 70 - 80 feet in Cauldron Linn. (36/004988) Above the fall the Devon flows through a deep but open valley. It is possible to trace the extension of this valley downstream above the gorge, and into the Cowden Valley, where the stream flows for some distance at its level before descending through a short ravine to join the Devon. Intervening between the terrace remnants and the gorge, this valley appears to have been developed, mainly in glacial deposits, in response to a base-level intermediate between that of the Lower Devon lake and the present day. Small terraces on its floor, near Muckart Mill, (26/992986) and two nick points in the Cowden ravine may indicate a further intermediate base-level.

On the south side of the floodplain below Vicar's Bridge near Boghall (26/977973) a short trench, of the dimensions of the gorge, has been cut across a small spur. This is described on Geological Survey maps as an old river gorge. It seems probable that the river flowed over gravels close to the southern valley side prior to its incision, and on the fall of base-level became superimposed across the small spur. In meandering across and extending its floodplain the river must eventually have abandoned the short gorge section.

West of Dollar, fluvio-glacial deposits are found almost exclusively on the northern valley side, where they are banked against the scarp face. They do not appear to be terraced, although in a few places the surface is almost flat. Above the Devon, they are usually terminated by a steep slope, clearly produced by the river in meandering across its floodplain. At Cunninghar, east of Tillicoultry (26/925972), the valley is almost completely closed by a ridge, rising 50 - 60 feet, above the river, and according to C.H. Dinham and D. Haldane, ranging from 80' - 180' O.D.[1] A sandpit reveals that the ridge is formed largely of bedded sands, dipping eastwards at an angle of 10°, with occasional beds and lenses of gravels. In part the surface of the ridge has a slope of much the same angle, but near the Devon has clearly been undercut, and the slope is here much steeper. As was suggested by Dinham and Haldane, this ridge appears to have been formed by deposition at the snout of the Clackmannan glacier, as this was temporarily halted in its westward retreat. The sands are obviously waterlaid, and provide additional evidence of the presence of a lake in the eastern end of the Lower Devon valley. At its northern end, the ridge, increasing in height, curves slightly westwards, and large boulders, including Highland erratics, apparently banked up against the scarp foot, suggest that it is continued to the mouth of the Tillicoultry valley by a lateral moraine.

On the south side of the Devon, near Alva, a gravel pit formerly existed, in what appears to have been a remnant of a ridge similar to the Cunninghar kame. (26/898962) Unfortunately, this has been destroyed in the extension of a colliery tip-heap. It may have represented another halt in the westward withdrawal of the Clackmannan glacier. There appears to have been no further halt until the snout of the Forth glacier lay in the Stirling Gap, and the Raised Beach deposits of Airthrey (26/812966) and Bridge of Allan were formed. Throughout the retreat of the ice-front from the Lower Devon Valley, the now buried trough must have received the silts, sands and gravels, with which it is partly filled. In a number of borehole records gravels and sands are recorded beneath fine clays and silts, apparently Raised Beach deposits, and these appear to have completed the filling of the trough.

The Airthrey and Bridge of Allan Raised Beach is thought to have been formed in much the same manner as the similar, but better developed, beaches south of Stirling - namely, by deposition at the snout of a glacier occupying the Upper Forth valley during the period of the so-called 100-Foot or Late-Glacial sea.[2.] Although no exposures are known, the nature of the soil at Airthrey indicates that it is developed on gravels. The gravels in turn appear to lie on boulder-clay, which projects through their flat surface to form low hills. A lake in a long depression across the Airthrey deposits is thought to owe its existence to this boulder-clay, although it may have originated as a kettle-hole. The level of the beach rises from 100' O.D. at its outer edges, to 150' O.D. against the steep scarp-face. Here a wave-cut notch was observed by Maclaren, at an estimated height of 155' O.D.[3.] It has not proved possible to locate this with any certainty, and it is therefore impossible to decide whether the notch is in fact wave-cut, or merely an overhang produced by the weathering of a less resistant lava-flow. However, a benchmark on the inner edge of the terrace, slightly further west (28/807969) is at 149' O.D. and indicates that its formation may indeed have been associated with a sea-level of approximately 150' O.D.

That section of the Raised Beach on which Bridge of Allan is situated is margined by a slope some fifty feet high, descending steeply from the 100-foot contour to the carse-lands below, but a lower terrace occurs between the edge of the Raised Beach at Airthrey and the carse. The inner edge of this terrace is 20 - 25 feet below the higher Raised Beach - i.e. at ca. 75' O.D., and a similar descent separates it from the carse. It is largely confined to the western side of the deposits, but may be present as a very narrow fringe on the eastern side also. It appears to represent a fall in sea-level to ca. 75' O.D.

The carse, descending almost imperceptibly from 50' O.D. at the base of the Airthrey and Bridge of Allan terraces towards the Forth, contrasts with these in being formed of fine clays, in some places laminated. These appear to have been formed under estuarine conditions, probably similar to those obtaining in the Forth today. They lie on a wave-cut bench, of boulder-clay or even of rock,[4.] a fact which suggests that some considerable destruction of the higher Raised Beaches may have taken place. This may account for the almost complete absence of the 75-Foot Beach on the eastern side of the Airthrey deposits, when it may have been more exposed to attack than on the western side. The 50-Foot Raised Beach extends up the Lower Devon valley as far as Cunninghar; there seems to be no trace of a 75-Foot Beach. It also extends up the Upper Forth valley, indicating a considerable withdrawal of the ice-front, and may be described as Post-Glacial.

The presence of peat under the Carse Clays but above the red clays of the so-called 100-Foot Beach,[5.] at 15' - 20' O.D. is regarded as evidence of a fall in sea-level at least to that of the present day, prior to the development of the Post-Glacial Raised Beach.[6.]

Each of the Hillfoots streams has formed an alluvial fan at the point where it emerges onto the floor of the Lower Devon Valley. (Figs. 11 & 18) These are regarded as "deltas of gravel laid down in the sea of the 100-ft. Raised Beach" by Dinham and Haldane.[7] From the evidence of the Airthrey and Bridge of Allan beaches this sea appears to have risen to a level of ca. 150' O.D. The Hillfoots fans, however, do not show any close association with this level while certain contrasts between the four eastern fans, formed by the Dollar, Tillicoultry, Silver and Alva streams, and the three western ones, of Balquharn, Menstrie and Blairlogie, also suggest that the explanation put forward by Dinham and Haldane is over-simplified.

Apart from the obvious contrast in size, apparently due to differences in stream size, the apices of the eastern fans are nearly 100 feet higher than those to the west, in every case rising to the 200-foot contour. The Balquharn fan rises a few feet above 100' O.D., those of Menstrie and Blairlogie to 100' O.D. This difference does not altogether agree with the suggestion that all were formed with a sea-level of ca. 150' O.D. There is also a significant difference in the form of the fans. Near its apex, the Alva fan is very gently sloping, descending to ca. 150' O.D., where there is a much steeper slope to a lower level, at or a little above 100' O.D. From this, the fan continues to slope gently down towards the Devon. The Alva Burn is deeply incised to one side of the upper fan, less deeply into the lower. Similar features are also found in the Silver fan, and may be evidence of two distinct stages of development. In no other fans are such features so well-marked, although there is a slight flattening near the apex of the Tillicoultry fan, and also, at a much lower level, near that of the Balquharn fan.

It is suggested that the eastern fans were initially formed as deltas, either in the Late-Glacial Sea, or, in view of the agreement between the height of these fans and that of the intake of thè Coalsnaughton spillway, in the Lower Devon lake. The low altitude and simple form of the western fans is difficult to reconcile with a deltain origin. The flattening of the Balquharn fan might indicate deposition in a sea-level of over 100' O.D., but extensive excavations in this fan have revealed an almost complete lack of water-sorting of the material of which it is formed. Coarse boulders and pebbles, mostly rounded, are closely packed, with some sand in the interstices. Bedded sands and finer gravels, dipping towards the outer edge, occurred in only one or two places. The whole suggested dumping of the material by a torrential stream, certainly not under deltain conditions, the rare, small areas of sands possibly marking more permanent courses of the distributaries. Anòther objection, possibly less valid, to the hypothesis that the western fans were formed as deltas is the small size of the Menstrie fan. Yet the Menstrie Burn has a catchment area at least as large (approx. 10 sq. km.) as these of the Alva, Tillicoultry and Dollar Burns, and a long, deep gorge has been re-excavated since the disappearance of the ice.

The contrast in the form of the western with the eastern fans is such as to suggest that the former developed as true alluvial fans - that is, by deposition on a land surface. This would imply that they were not developed until after the Late-Glacial period of high sea-level and possibly not until after the Post-Glacial period. There appear to be two possible explanations for this. Ice may have remained in that part of the Lower Devon valley between Alva and Airthrey, until sea-level had fallen, a lake continuing to exist in the eastern part of the valley; alternatively, the development of these fans may have been hindered by wave-action. It seems unlikely that ice would have remained in this section of the valley throughout the Late-Glacial period without providing more evidence of its presence than the mere absence of the alluvial fans. In view of the evidence that the Post-Glacial Raised Beach deposits rest on a wave-cut platform, however, it seems possible that wave-action may have been adequate to prevent the formation of deltas in this area. The western fans may thus be of relatively recent origin, compared to the larger eastern fans.

The various Hillfoots streams have all become incised into their respective fans near their apices, apparently reflecting the fall to the present day sea-level. This is particularly marked in the Alva and Silver fans. None of the fans are being extended today, although the way in which the Devon swings to the south side of the valley opposite each of the larger fans, and the development of small gravel cones where each of these streams enters the river, suggests that deposition continued until very recent times, and might still occur but for the artificial control and straightening of the streams.

There seems to be no evidence as to the distance to which the Late-Glacial sea extended up the Lower Devon Valley. Apart from the alluvial fans, there are no features which can be certainly attributed to deposition at this time, nor are there any wave-cut features. At Dollar, stratified clays have been recorded at approximately 100' O.D. overlain by the material forming the alluvial fan, (26/956977) and may have been laid down in this sea, but may equally well have been deposited in the Lower Devon lake.[8.] The only possible barrier to the incursion of this sea as far as Dollar is the Cunninghar ridge, and at its present height this would be unlikely to be very effective. There is no evidence that it was ever much higher than it is today and the sea may therefore have extended to Dollar. The valley above the Vicar's Bridge gorge of the Devon may have been formed at this period. On the fall in sea-level, the Devon must have developed the narrow breach by which it now crosses the ridge, and commenced the formation of its floodplain upstream. Later, the Post-Glacial sea apparently extended as far as the Cunninghar ridge, but no further. It is unlikely that wave-action was strong east of Alva, this part of the valley probably being well-protected by the Clackmannan Plateau, so that little or no modification of the eastern fans and the Cunninghar ridge was effected. With the withdrawal of this sea, the Devon must have been able to continue its course westwards, as a sluggish, meandering stream. It still retains this nature, and old cut-off lakes can be traced, but it is now largely confined between levees.

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8. Dinham, C.H. and Haldane, D. — op. cit. p. 210.

VII. The disappearance of ice from Strath Allan

The spillways leading into western Glen Devon show that ice remained at a high level to the north of the hills in Strath Allan after it had disappeared from Glen Devon, and possibly after the edge of the Clackmannan Ice had withdrawn some distance from the mouth of the valley. Few traces remain, however, of the stages by which the Strath Allan ice shrank from this high level. The slopes from Glen Anny to Glen Eagles appear to be free of marginal overflow channels, although meltwaters must surely have accumulated in these and smaller valleys. In the absence of such channels, it can only be assumed that these meltwaters, and streams draining from the hills, found ways of escape through the ice itself. Possibly the shrinkage was too rapid for the cutting of spillways to keep pace with it. One small spillway, ten to twelve feet deep (51), enters Glen Anny across the ridge separating it from Sheriffmuir, but, at ca. 1300' O.D., this was probably contemporaneous with the Glen Bee spillway, and is unlikely to represent a later stage.

No other meltwater channels are found in the Ochils proper; some, however, are found across the adjacent lower ground of Sheriffmuir. Here the Burn of Ogilvie, and the Buttergask Burn occupy sharply cut, flat-floored trenches, partly in rock and partly in boulder-clay (52a and b).

Running in a SSW-NNE direction, and commencing in broad, shallow hollows between 800' - 900' O.D., these may be to some extent guided by pre-glacial valleys, but their form and the way in which they are cut indifferently in rock and glacial deposits, suggests that they were developed as meltwater channels marginal to ice in Strath Allan, running down to the ice-front. Tributaries, particularly of the Burn of Ogilvie, descend the hillslopes in a northwesterly direction, and are then suddenly diverted northeastwards, as if further progress in the original direction had been prevented by a mass of ice. Further west, a large number of channels with a similar direction have been developed - i.e. running obliquely down the sides of the strath giving the slopes an undulating form (e.g. 52c - f). These are all shallow, and appear to have been used for short periods only, the ice-front possibly retreating more steadily than when the two larger channels were formed.

On the opposite side of Strath Allan there are further channels of the same type (53a - c). The Muckle Burn occupies a fifty-foot deep trench, largely cut in boulder-clay, of most convincing spillway form (53a). Here there seems to be no trace of an earlier valley which might have guided the stream - the spillway runs along the hillside, the ground on its southern side falling steadily away from the lip of the trench. It is clear that this could only have developed if drainage southwards down the slope was prevented by the presence of ice. To the south of the Muckle Burn, the valley of the Lodge Burn (53c) appears to represent a later stage, when the ice-front had retreated some distance. Narrow sections of the valley alternate with relatively broad, shallow sections, around which small lake terraces are developed, and it seems probable that a series of small pre-glacial lakes were linked by short spillways.

These spillways in the western part of Strath Allan, appear to point to a more or less steady retreat of the ice-front in a southwesterly direction. Few meltwater channels are found in eastern Strath Allan and here evidence of the manner in which ice disappeared from the valley is mainly provided by extensive gravel deposits. Much of the floor of this part of the strath is covered with ridges and mounds of fluvio-glacial deposits (Figs. 11, 16), with no very obvious order in their disposition. Some, as east of Blackford and south of A9, run along the length of the valley, others appear to be transverse to it. Air photographs suggest that some ridges are the result of the dissection of a wider mass of gravels by meltwater channels, apparently draining towards the valley floor; others appear to be unmodified depositional features. An exposure in a gravel pit immediately east of Blackford (27/902093) shows fine sands and gravels, but is not clear enough for the dip of the bedding to be ascertained.

West of Blackford, the Allan Water follows an artificial course across the flat floor of its valley. On either side of it rise gravel terraces, from which, in places, ridges run towards the river, dividing the valley into a number of sections. One of these is occupied by the peat of Shelforkie Moss, another by the small lake of Carsebreck; and a third, nearer Blackford appears to have contained a peat moss, but is now largely reclaimed. The form of these big hollows, and the existence of similar depressions further away from the Allan - e.g., that containing the Rhynd lakes - suggests that they may be large kettle-holes, formed as masses of ice, detached from the main glacier, melted out <u>in situ</u>.

The terraces line the sides of Strath Allan for almost the whole of its length. They vary somewhat in height, but are consistently formed of gravels, and, as is indicated by a number of benchmarks, the most continuous and best-developed has an outer edge ranging within a few feet of 420' O.D. Its height above the valley floor increases from about twenty feet near Blackford to 50-70 feet near Kinbuck. In places smaller terraces are found, at or below 400' O.D. Many of the ridges of eastern Strath Allan are flat-topped, again at a height of ca. 420' O.D., although at Blackford at least one ridge rises to 454-456' O.D.

In 1925, J.W. Gregory discussed the Strath Allan gravels in his catalogue of the Scottish kames.[1] He regarded their present form as resulting from the dissection of a much wider sheet of gravels - in fact, an enormous fan deposited by streams from the Ochils. In support of this he included an analysis of the origin of pebbles found in a section near Blackford, which he considered indicated "that the bulk of the material came from the Ochils".[2] The analysis is as follows:-

Old Red Sandstone lavas	36%
Old Red Sandstone	22%
Old Red grits and conglomerates	10%
Highland schists	22%
Quartz (probably mainly from Old Red Sandstone conglomerate)	10%

It is a little difficult to see how 36% can be regarded as "the bulk of the material". Apart from this, Gregory's conclusions do not appear to be supported by field evidence. Although some ridges are undoubtedly due to dissection, others seem to be equally clearly unmodified. Nor is there any trace of a rise of the surface of the gravels towards the streams that are supposed to have deposited them, and it seems improbable that these generally small streams would be capable of forming a fan several miles in extent, while the larger Hillfoots streams were unable to form fans of a comparable size.

The explanation, suggested by J.B. Simpson[3] to account for the contrast between the Strath Allan deposit and those of Strath Earn,-namely, that the former were laid down under conditions of restricted drainage, whereas the latter were deposited by meltwaters draining away freely - appears to be more satisfactory. The consistent height and the form of the terraces and ridges, suggests that as the ice melted, a lake developed. This was probably dammed at its eastern end by the ridge across which Kincardine Glen is cut, the big spillway undoubtedly being formed by the outflow from the lake. At first, the level of the lake was probably rather above 450' O.D., falling as the outlet was lowered, and the highest terrace, near Blackford at 454'-456' O.D., may have been formed in this early period.

The importance of the 420-foot terrace appears to indicate that the lake remained at this level for some time, and extended at least as far southwest as Kinbuck. The present watershed between the Allan and Earn drainage, a short distance west of the intake of Kincardine Glen, at Muiralehouse (27/917097) is a low rise at 419' O.D. separating what appear to be two shallow kettleholes. It seems, therefore, that after the 420-foot terrace was formed, a new outlet was found for the lake after which its level may have fallen more rapidly, and the smaller, less continuous lower terraces were formed. This new outlet can only have been to the southwest, more or less along the line by which the Allan Water leaves the site of the former lake. Here, at Kinbuck, the terraces on either side converge, and between them the valley is almost closed by a slightly lower ridge, rising to 412' O.D. Although when seen from upstream the valley appears to be closed by a terminal moraine, convex to the south, the appearance is deceptive. The Kinbuck ridge is formed of sand, the bedding, according to J.B. Peach, in a note on the manuscript 6" Geological Survey maps of the

Photograph 26. GLACIAL DEPOSITS AT DUNBLANE.

area, dipping at an angle of 20° Unfortunately the direction of dip is not stated, but it seems probable that the sands were deposited as a delta at the snout of the glacier damming the lake at this southwestern end. As this ice-front retreated, th lake must have extended southwards until an outlet was found leading to the Forth.

The fluvio-glacial deposits of Strath Allan continue south of Kinbuck, as far as Dunblane, forming an extensive terrace between 300' - 400' O.D. From this rise rounded mounds and low ridges, some as much as 50-60 feet high - notably the Knock of Barbush, which reaches to 369' O.D. This last mound has bee almost completely destroyed by the extension of a sand-pit, whi exposed a face of sands, with some fine gravel, almost 80 feet high. Beds exposed in 1955 appear to be dipping north, but Gregory remarked that "the false-bedding dips N., as if the material had been laid down on a surface rising to the S."[4] Beyond Dunblane, the sands and gravels continue westwards, along the Stockbridge valley* towards Doune forming a chaotic belt of ridges and mounds.

Gregory's interpretation of these deposits around Dunblane resembles that which he put forward for the Strath Allan gravel "The Dunblane drift hills have been carved out of a deltaic fluvio-glacial sheet". The Allan is considered responsible for

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* This name has been applied to the short through valley carrying the road from Doune to Dunblane, and in part occupied by the Ardoch Burn.

formation of this particular delta, when it reverted to a western outlet after a period during which it flowed east by Kincardine Glen.[5] There seems to be no more justification for this view than for assuming that the Strath Allan gravels were close to the Ochil streams. The kames about Dunblane show no signs whatever of having been carved from a "deltaic fluvio-glacial sheet". Their rounded form appears to be rather the result of deposition, along a retreating ice-front (photograph 26) and contrasts strongly with the sharper lines developed where the Allan Water has cut a gorge through the deposits.

It seems probable that the ice which occupied Strath Allan came from the Teith valley by way of the Stockbridge valley- a conclusion which Simpson reached on the basis of the content of the gravels[6] and that, later, the ice-front retreated along the same line, depositing the moraince ridges of Dunblane and the Stockbridge valley. As the direction of the retreat changed, from southwards to westwards, a route was opened by which the Allan Water could reach the Forth, draining the lake in its upper reaches. For a short time ice may still have remained in the Allan valley, so that the drainage from the lake may have followed a slightly more easterly course than that of the Allan Water, along the line of the Scouring Burn, shown on Fig 11 by a band of alluvium. This cannot have been used for long, however, for the form of the valley does not appear to be modified, and the Allan must rapidly have been able to take up its present course. A small spillway south of Dunblane (54) may mark a temporary channel of the river, but, at 250' O.D., may equally well mark the route followed by meltwaters before the valley was sufficiently free of ice to permit the Allan to join the Forth.

The cutting of the gorge in which the Allan now flows, from Kinbuck southwards, appears to be related to the fall from the high, Late-Glacial sea-level to that of the present day. The more open valley above the gorge in the lower part of the Allan valley was almost certainly developed with this sea as base-level, and passes into the Late-Glacial Raised Beach, to which the river probably contributed material.

Strath Allan and the "Perth Readvance"

In describing the sands and gravels of Strath Allan Simpson appears to have envisaged a complete withdrawal of ice from the valley, followed by a readvance - the "Perth Readvance" during or after which the gravels were deposited. This, however, seems to be a rather unnecessary extension of the facts. There seems to be no evidence of a readvance in Strath Allan itself, and the actual evidence of readvance in Strath Earn is 'confined' to three sections, all of which lie within the area that would be occupied by the Strath Earn Glacier.[7.] The gravels which are found in Strath Allan can be explained on the assumption that they were deposited as the ice finally retreated, and there seems to be no need to postulate an extensive readvance to account for them. Ice could have remained in Strath Allan during the Perth Readvance; the ice-front may here have been stationary, or may have readvanced slightly, but it seems quite possible that the Strath Earn Glacier alone may have been able to readvance any appreciable distance.

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1. Gregory, J.W. The Scottish Kames and their Evidence on the Glaciation of Scotland. Trans.Roy.Soc.Edin., vol. 54, 1926, pp. 395-432.
2. Gregory, J.W. op.cit. p. 420.
3. Simpson, J.B. The Late-Glacial Readvance Moraines of the Highland Border West of the River Tay. Trans.Roy.Soc.Edin. vol. 57, 1931-33, p. 636.
4. Gregory, J.W. op.cit. p. 421.
5. Gregory, J.W. op.cit. p. 422.
6. Simpson, J.B. op.cit. p. 635.
7. Simpson, J.B. op.cit. p. 639.

6.

Post-glacial changes in the landscape

Inevitably, post-glacial times in the general sense (as distinct from the term when used to distinguish Post-Glacial from Late-Glacial Raised Beaches) must have overlapped with glacial times, in that not all areas of the hills became ice-free at the same period. Thus, the Water of May gorge was probably initiated, and possibly deeply cut, while ice still surrounded the western end of the hills. Many of the post-glacia changes have already been discussed, in connection with the withdrawal of the various ice-fronts, but, when considered together, some measure of the amount of modification since the melting of the ice-sheets is given.

By far the most obvious change in the landscape, and the one which is found throughout the hills, is the incision of almost every stream into the glacial deposits with which the valleys were to some extent filled. This has resulted in the development of narrow, flat-floored and sometimes deep trenches, walled by steep and unstable slopes of boulder-clay. At the bottom of the trenches, streams meander over a floor littered with boulders from the sides. In some valleys, the streams have cut down to the underlying rock, and are flowing at what may be the pre-glacial, or possibly inter-glacial, level. A number of impressive gorges have also been developed, which can be grouped in two categories. There are those, like the two Devon gorges in Glen Devon, the May gorge at Craigendirots, and numerous smaller examples throughout the hills, which are essentially the result of a failure of the stream to strike the line of its pre-glacial course. In these cases, both upstream and downstream of the gorge the stream occupies a relatively open valley from which glacial deposits may have been largely, if not entirely, removed, while slightly to one side of the gorge a plug of such deposits appears to mark the position of the older valley. Such gorges do not necessarily imply a change in base level, causing a rejuvenation of the stream, although this may be a contributory factory. Gorges of the second category do appear to indicate a marked change in base level, probably not due to any change in sea level, but to the exposure of certain over-deepened valleys as the ice-fronts withdrew. Thus the Hillfoots streams were left hanging above the Lower Devon Valley, and cut the deep gorges in their lower valleys. The Rumbling Bridge gorge of the Devon and the smaller gorges cut by the streams breaching the northern scarp face probably developed in the same way. Late- and Post-Glacial changes in sea-level have also undoubtedly contributed to the cutting of these gorges; the Vicar's Bridge gorge of the Devon, the May gorge below Arngask House and Glen Farg may be partly due to these falls in base-level. It is clear, however, that more than one factor may have been involved in the development of any one particular gorge.

The thick infilling in many valleys is probably in part of post-glacial development. It seems unlikely that boulder-clay was deposited by the ice only on the valley floor, and not on the sides, although the melting out of the ice probably resulted in a thicker deposit here than elsewhere. The slightly uneven surface of the infilling, rising up the valley sides, suggests that material may have moved down the sides to add to that in the valley bottom.

Numerous examples of scree development are found throughout the hills, particularly along the steep slopes of the southern scarp face, for example on Dunyat, on Craig Rossie, and in Glen Eagles. None of the individual screes is of great dimensions, but most are clearly still being augmented by the addition of material from the crags above. At higher altitudes, however (i.e. above approximately 1700' O.D.) patches of scree can be found which are not associated with any rock outcrop, and which occur on relatively gentle slopes, not usually exceeding 8°. These may well have developed under peri-glacial conditions. Small but distinct stone polygons and stripes appear on certain of these screes, but in most cases they appear to be in the process of being covered by vegetation.

The extensive peat mosses of the Western Ochils may also have been developed with a climate differing from that of to-day, under cooler and wetter conditions. Nowhere does the peat appear to be in process of formation: it is everywhere being eroded, and stands up in hags in all stages of destruction. No remains a former tree cover have been discovered in the peat; although there is a local tradition that the hills were wooded until relatively recent times, it seems probable that trees never extended on to the windswept uplands now covered by peat. Modern woods, mainly coniferous, extend to 1200' - 1300' O.D., and are confined mainly to the Central and Eastern parts of the hills.

7.

Summary and Conclusion

1. Introduction

In the preceding pages the length of the section on the events of Pleistocene times might suggest that this period was of greater importance in the development of the landscape than the much longer preceding period. This is by no means the case. The bulk of the landscape as it now appears must have been formed prior to the Pleistocene period, and compared to this the modifications due to glaciation are minor. They are, however, numerous, and very fresh, therefore relatively easy to interpret and describe, whereas in the case of the earlier phases of development the details are not easy to decipher and have remained on the field maps, only the broader outlines being described. Moreover, it is necessary in the course of fieldwork to examine the Pleistocene features with some care, in order to decide which facets in the landscape must be rejected from the point of view of establishing the early phases of development. The process is essentially one of stripping away the less relevant detail, but since this detail is often the most immediately obvious thing in any given section of the landscape, it is necessary to describe it and its mode of origin at length, if only to establish that it does belong to a relatively minor phase of development.

II. Mid-Devonian Denudation

The landscape of the Ochil Hills appears to reflect not only the events of Tertiary and more recent times, when the land-surface of Britain is generally thought to have developed, but also a much earlier period of denudation, when the newly arched Lower Devonian rocks were worn away prior to the deposition of the Upper Devonian sedimentaries. The form imposed on the anticline at that period, although much modified, seems to be still discernable in the present landscape, and may have had far-reaching effects on the development of certain parts of that landscape. The Plain of Kinross, a lowland developed on the andesites, probably owes its existence to this Mid-Devonian denudation, and the usually steep edge of the hills, bounding the plain on its northern side, may have originated at the same time. It seems probable that here the andesites were deeply buried by younger and possibly less resistant strata, and that this may account for a number of puzzling features, amongst them the contrast between the width of the plain and the narrowness of the Devon valley in the hills, and the probable diversion of the Devon from a west-east course at Tormaukin (pp. 46-47). It is also possible that Mid-Devonian denudation may explain the existence of broad relief zones within the hills, to which the names Western, West Central and East Central Ochils have been given, and which do not appear to owe their existence either to structural features or to the processes of erosion that can be recognised in other land-forms of the hills. Most of the erosion surfaces probably continued across the andesites on to the younger strata which must have covered them to a far greater degree than is to-day the case. Successive falls in base-level would result in the incision of the streams and the stripping of the younger strata from the uneven Mid-Devonian surface. Further falls in base-level, below that obtaining to-day, would presumably result in a further exposure of this surface over the Plain of Kinross.

III. The Influence of Geological Structure and Lithology

While the early denudation of the andesites may have established certain of the broad outlines of the Ochil Hills, it seems clear that the landforms are chiefly the result of denudation in relatively recent times. That this nevertheless involved a very long period is indicated by the influence on the land forms of certain structural features. This is most obvious in the coincidence of the edge of the hills for some distance, both to north and south, with important east-west trenching faults, and in the association of the hills with the andesites. On a smaller scale, within the range individual hills and ridges correspond to more resistant intrusions, while the alternation of lava, tuff and agglomerate is illustrated by trap featuring on certain slopes and ridges. The drainage pattern, with which the development of these slopes and ridges is intimately associated, also shows some adjustment to structure. This is apparent in the S.W. - N.E. alignment of certain valleys throughout the hills (Fig. 4). Although few mapped structures other than the main Ochil axis have this trend its persistence is such that it should probably be regarded as reflecting a significant structural weakness.

IV. Early Phases of Drainage Evolution

There are a number of valleys whose direction does not appear to be controlled by the underlying structure (Fig. 7). The most important of these is that of the River Devon, following a generally west to east course. A number of its tributary valleys appear to be similarly independent of structure. The well-developed valley benches high above the Devon suggest that it is one of the original elements in the drainage pattern of the area. There is some evidence that it was initially a longer stream, with a source beyond the present western limits of the Ochils and that instead of leaving the hills along its present course, it continued eastwards beyond Tormaukin and across the Plain of Kinross, possibly reaching the sea along the line of the River Leven. This early Devon probably occupied a rather narrow drainage basin, receiving small tributaries from north and south: these may be represented by some of the modern tributaries and by the south-flowing streams of the Kinross Ochils.

The direction and continuity of the watersheds bounding the early Devon drainage basin, in particular of that on its northern side, point to the existence of other west to east flowing streams on either side of the Devon, to which the Hillfoots streams and those descending to Strath Earn were tributary. These streams were probably the predecessors of the Forth and Earn; the apparent ability of their tributaries to behead the Devon and open out the lowland of Strath Allan suggests that they were larger and more powerful than the Devon, although the development of their valleys was undoubtedly favoured by the less resistant strata surrounding the Ochils.

V. Later Phases of Drainage Evolution

A number of changes in the drainage pattern within the hills can be recognised. The majority of these appear to be the result of various formsof glacial interference, but there are some instances in which a stream has apparently been diverted as a result of piracy, usually along a line of structural weakness. Thus, the Water of May appears to have extended its valley headwards until it was able to divert the headwater of the Dunning Burn. In the Western Ochils two cols aligned with the Grodwell Burn may be evidence of the disruption of an early tributary of the Devon along S.W. - N.E. lines. In the Hillfoots area a small tributary of the Alva may have been able to divert the upper reaches of the neighbouring Silver Burn, forming the Glenwinnel Burn. Of more importance is the probable diversion of the Devon from its west-east course at Tormaukin. This appears to have been more complex than the others noted, possibly involving piracy by two tributaries of a stream flowing eastwards to join the Devon in the Plain of Kinross.

A complete reorganisation of the drainage pattern may have taken place in the East Central and Eastern Ochils. Here a number of dry valleys on the east side of the Farg-Eden valley, aligned with tributaries on the western side of that valley, point to the disruption, mainly by the Farg, of a number of streams flowing eastwards to join the Eden in the Howe of Fife.

VI. Earlier Phases of Denudation Chronology

Except for very short reaches near their sources all the streams in the Ochils occupy more or less deeply incised valleys below widespread upland surfaces (Fig. 3). Two major surfaces are recognisable, apparently representing long periods during which base level changed but little. The highest, the Ochil Main Surface, occurs mainly in the Western Ochils, where it ranges from ca. 1900' O.D. to 1500' O.D., and is present only in small areas along the watersheds in the West Central Hills. It is not represented at all in the East Central Hills, where the Ochil Lower Surface is developed over large areas. This lower surface has a smaller height range, occurring mainly between 800' - 1000' O.D., but rising to 1100' O.D. in the West Central Hills, where it is represented by narrow valley benches. It has proved impossible to trace this surface into the Western hills, largely because of the way in which the Western and Central Hills are separated by high N - S trending ridges running from Craig Rossie to Lendrick Hill, and rising abruptly from the lowlands. Traces of one or two intermediate upland surfaces are found on the watersheds of the West Central hills.

The development and partial destruction of these erosion surfaces appear to be the result of the attempts by the Devon and its tributaries, and of the tributaries of the Earn and Forth, to adjust their valleys to an intermittently falling base-level. The form of the surfaces, their height, range and their close association with the development of the streams now incised below them seem all to afford strong evidence of their sub-aerial origin. Nowhere does there appear to be any trace of a cliff-line, or of a constant height for the inner edge of a surface, which might indicate a marine origin, although such features could hardly be expected to remain recognisable over the long period that must have elapsed since the surfaces were formed, and through the glaciations of the Pleistocene period. The drainage pattern, however, does not appear to be such as might have arisen with a falling sea-level and a coast line that fell away from the Ochils to the surrounding lower ground. Rather does the present pattern seem to be consistent with an origin on a land-surface - possibly a newly emerged sea-floor - at a level above that of the highest point of the Ochils, and with an adjustment to the underlying structure as this was exposed.

It seems probable that, as was suggested by Bremner[1] and Linton,[2] the early drainage of this part of Scotland consisted of west-east trunk flowing streams, initiated on a surface sloping gently eastwards. The Earn, Devon and Forth appear to have been members of such a system. There seems to be no evidence in the Ochils which would indicate the nature of the surface on which the Devon first developed: this was probably high above the present summit levels, and erosion surfaces may have been developed from it which are now only represented by these flat summits between 2000' O.D. and 2200' O.D. Below these the Ochil Main Surface was probably developed during a long period in which base-level changed only slightly. That part of it drained by the Devon must have formed a broad shallow valley, of which traces remain on a number of the highest spurs.

The two lower Devon valley benches were probably developed in response to rather greater falls in base-level, which further east may have resulted in the formation of such intermediate surfaces as the Simpleside Surface, by streams draining to the Earn. Probably near the end of this period the Devon was deprived of its headwaters, but still continued eastwards beyond Tormaukin (p. 37).

VII. Later Phases of Denudation Chronology

The later history of the Devon appears to have been controlled by a series of more rapid falls in base-level, as a result of which valley deepening proceeded more rapidly than valley widening. Small valley benches, none of any great extent, remain as evidence of these stages, during one of which the river probably adopted its present course south-eastwards from Tormaukin. It is surprising that in the Central Hills, the Ochil Lower Surface appears to have been formed during a period of relative standstill, which must have coincided with the deepening of the Devon valley. This surface is, however, represented in the upper May valley, above Path of Condie, by narrow benches similar to those in Glen Devon, and it is therefore possible that at the time of its formation both valleys appeared as narrow upland glens opening out abruptly on to wide lowlands, the contrast being a further result of the uneven surface on which the Upper Devonian and younger rocks were deposited. In the case of the Devon, the equivalent of the Ochil Lower Surface may have been developed entirely on such younger rock, above the level of the present Plain of Kinross, but possibly still preserved in the moors of the Cleish Hills.

The later development of the landscape seems to have been controlled by a further series of falls in base-level, producing wide, shallow valleys in the Central hills, but a continuing incision in the Western hills. The reason for this may lie to some extent in the fact that most of the valleys of the Central Hills are drained by tributaries of a much longer and more powerful stream than the Devon (i.e. the Earn). Throughout the Ochils, however, there is clear evidence of a period of deep incision, during which many valleys were lowered to at least their present level, immediately prior to glaciation and their plugging with glacial deposits.

Although the Ochils are now isolated from all neighbouring hill masses by the broad lowlands which surround them, it seems probable that the erosion surfaces so well-developed within the hills continued across the less resistant strata in which the lowlands are developed, to merge with similar surfaces in these neighbouring hill-masses, and that some correlation with these surfaces is possible. Such correlations can only be tentative, however, in view of the distances involved and the lack of detailed research on the uplands concerned. On the basis of form and height the Ochil Main Surface may be equated with the widespread upland surface of the Eastern Grampians, named by Fleet[3.] the Grampian Lower Surface and, as shown on his map, ranging between 1400' - 2000' O.D. Above this surface monadnocks such as Mt. Battock rise in much the same way, if to higher altitudes, as Bencleuch rises above the Ochil Main Surface. The Ochil Lower Surface may correspond to Fleet's Grampian Valley Benches.

No evidence bearing on the age of the upland surfaces has been found in the Ochils. Although Geikie considered certain dykes across which the surfaces have been cut, to be of Tertiary age, more recent geological opinion relegates them to Permo-Carboniferous times. There appear to be no Tertiary deposits which might aid the dating - such deposits would be unlikely to survive the glaciation of the area. If the surfaces do correspond to the Grampian Lower Surface and Valley Benches, however, they are parts of large surfaces which on general grounds may well be of mid or late Tertiary age.

VIII. Pre-glacial and Inter-glacial Aspects of the Ochils

Prior to glaciation the Ochils may have had a form similar to that of to-day, rising high above broad surrounding lowlands. The steep scarp faces may have been present, although they were probably not as precipitous as they are to-day. Most of the valleys must have had their present narrow V-shape, although it is unlikely that many streams flowed through deep gorges similar to those now found in a large number of valleys. The entry into the zones of less resistant rocks surrounding the hills was probably marked by a sudden widening of the valleys, and an abrupt decrease in the height of the watersheds. Apart from the development of the numerous spillways, it is probable that the greatest changes from the pre-glacial form are to be found in the surrounding lowlands, which may have been open river valleys as much as 200-300 feet above their present level.

It is not clear to what extent erosion in interglacial times has influenced the landscape. The gorges of certain of the Hillfoots streams appear to have been initiated at that time (p. 61) but elsewhere there seems to be no way by which pre- and inter-glacial landforms can be distinguished.

IX.I. The Ochils in Relation to Pleistocene Ice-Streams

The Ochils were clearly modified in various ways by ice during Pleistocene times. Most of these modifications appear to be related to the last glaciation of the area, and only in a few instances does it seem possible to recognise traces of earlier glaciations. It is possible that the pattern of glaciation and deglaciation was much the same during each glacial period, being controlled largely by the broad relief features of the area. Glaciers from the various Highland valleys appear to have emerged into the lowlands, moving generally eastwards. The Upper Forth valley was probably occupied by a powerful glacier moving through the Stirling Gap. The narrowness of this gap, and the presence of a second major ice-stream in the Lower Forth Valley must have resulted in considerable congestion forcing some ice northeastwards into Strath Allan, while the deep buried trough underlying the Lower Devon Valley was probably gouged out by ice forced eastwards along the Ochil scarp face. Congestion probably eased further east, as ice moved into the hills, but that in Strath Allan may have been unable to escape freely, owing to the presence of a third major ice-stream in Strath Earn. Diffluent streams may therefore have developed, pushing into Glen Devon by way of Glen Bee, and, to an even greater extent, by way of Glen Eagles. The Strath Earn Glacier apparently succeeded in over-running the hills completely, and moved southeastwards across them to reach the Plain of Kinross and Howe of Fife.

A small local ice-cap may have developed over part of the Western Ochils, but most of the modifications of the hills due to glaciation can probably be attributed to the gradual expansion of the large ice-streams of external origin. At the maximum of glaciation the hills may have been completely ice-covered, with the possible exception of the summit of Bencleuch. The western hills show few signs of strong ice-movement, however, except in relatively limited areas, and here the thickness of ice may not have been great. The most powerful of the ice-streams, to judge from the way in which it penetrated the hills, and the lateness with which it receded, was probably the Strath Earn Glacier.

X. The Phenomena of Deglaciation

The climatic improvement which led to the disappearance of the various glaciers appears to have resulted first in the emergence of the highest watersheds of the Ochils from the cover of ice, and so in the separation of this cover into a number of lobes of ice, extending from the trunk glaciers surrounding the hills into the larger valleys. The rise of the snowline probably caused the disappearance of the small Ochil ice-cap, and deprived ice in Glen Devon of one of its sources. Amounts of meltwater were probably at first small, so that only shallow spillways were developed at high levels, but as ablation continued and wider areas became ice-free the amounts of water unable to escape by the normal drainage lines must have increased, and some very large spillways were formed, together with complex series of channels apparently reflecting stages in the withdrawal ofthe ice-edges. Small pro-glacial lakes may have developed in some areas, but on the whole there is little direct evidence of such lakes, and it seems probable that meltwater streams not infrequently found outlets through or over the ice itself.

The dispositions of the various meltwater channels, and of deposits of fluvio-glacial origin in certain areas, give some indication of the pattern of retreat of the ice-fronts. Thus the Clackmannan ice appears to have been most rapidly affected by the climatic improvement, and had probably diminished considerably in thickness and extent while Strath Earn ice still extended far into the hills, and even lay south of the main watershed in certain valleys. One of the most extensive systems of marginal meltwater channels in the Ochils, along the borders of the Plain of Kinross, appears to mark later stages in the shrinkage of the Clackmannan ice, which may have eventually stagnated in this area, giving rise to kettle-holes and thick fluvio-glacial deposits. Further west, in the Lower Devon Valley, this ice-front may have retreated more steadily.

Ice in Glen Devon appears to have diminished more rapidly than that either to north or south of the hills; it may in part have stagnated as it was cut off from its external sources, and valley side terraces were probably formed by deposition from stagnant ice. The Glen Eagles ice-front appears to have retreated steadily, however, meltwater from it depositing a valley train. It seems clear that the western end of the valley was ice-free while ice in Strath Allan still reached a high level on the north side of the hills, and it is possible that the whole valley was ice-free when Clackmannan ice still lay near its entrance.

In the Central Hills the lobes of the Strath Earn Glacier occupying the various valleys probably shrank only slowly. That in the Farg valley appears to have left few traces of the stages of retreat, but in the May valley numerous spillways mark the different positions of the ice-edge (Fig. 15) and probably linked shallow pro-glacial lakes in the tributary valleys. A somewhat larger lake may have existed later near Path of Condie where the tributaries converge, like the earlier lakes draining to the Farg valley, which must have become ice-free before that of the May. In turn, the May valley was probably virtually ice-free while the Dunning and Coul valleys were still occupied by ice.

Along the northern edge of the hills the shrinkage in the valleys was accompanied by a similar shrinkage of the main glacier, and by a gradual retreat of the ice-front. Near the entrance to the May valley this front appears to have run S.W. - N.E., but probably retreated westwards, and continued to do so until, near Auchterarder, the direction changed to northwesterly as the ice front withdrew towards the Highlands. The areas vacated by the ice were probably rapidly occupied by the waters of the Late-Glacial sea, which may have risen to 150' O.D. Before this sea reached its maximum level the Strath Earn Glacier appears to have readvanced into it. The ensuing retreat probably took place as sea-level was falling, and the extensive fluvio-glacial deposits of Lower Strath Earn may have been deposited close to sea-level.

At the time of the Perth Readvance Clackmannan ice, or more properly, the Upper Forth Glacier, appears to have been stationary in the Stirling Gap, the extensive fluvio-glacial deposits in this area being thought to have been deposited at the snout of the glacier, in the Late-Glacial Sea, which seems to have risen to ca. 150' O.D. in this area also. The Readvance may therefore have affected only the Strathearn Glacier; ice in Strath Allan, apparently forced into this valley because of the congestion at the Stirling Gap, may have remained stationary.

Later, ice in Strath Allan appears to have stagnated, and a large lake eventually developed, draining first eastwards to Strath Earn, and later southwestwards to the Forth as the ice-fronts retreated further (pp. 255-259).

The stages in the deglaciation of the Hillfoots valleys and the Lower Devon Valley seem to be virtually impossible to relate to events in other parts of the hills, largely because few connections exist either between the Hillfoots valleys themselves, or between them and other areas. The hang of these valleys above the Lower Devon Valley is such that they may well have been ice-free when ice still remained in the main valley. On the evidence at present available it seems only possible to say that at the time of the Late-Glacial high sea-level the area was probably ice-free, the Airthrey gravel deposits being thought to have been deposited at the ice-front in this sea. Certain of the Hillfoots fans may also have been formed at this time, or may have been initiated in a pro-glacial lake.

Following the period of Late-Glacial high sea-level both Strath Earn and the Lower Devon and Forth valleys may have been affected by a fall in sea-level to at least its present level. This fall may have been intermittent, to cause terracing of the earlier marine deposits at various levels, at 75' O.D. at

Airthrey, and possibly at 100' O.D. in Strath Earn. The succeeding rise in sea-level in Post-Glacial times appears to have been responsible for the extensive flat lands of these valleys, sometimes described as the 25-foot Raised Beach, but in this area rising almost to the 50-foot contour. In Strath Earn the changes in sea-level appear to have been reflected in the formation of river terraces upstream.

XI. Conclusion

The stages by which the landscape of the Ochil Hills attained its present form are three. First may be placed the period in Devonian times when the andesites were given the irregular surface which, as it was exhumed from its covering of younger rocks, had far-reaching effects on later denudation. This later denudation, in Tertiary times, was the second stage. During it the present drainage pattern was established, and the present landscape was gradually carved from the buried and roughly shaped andesite mass. Finally the third stage includes Pleistocene and more recent times, when the processes of the Tertiary period were interrupted, the hills modified in various but usually minor ways.

Considered in relation to the wider area of which they are part, the Ochils appear to provide much evidence of the stages by which the Scottish lowlands were given their present form. It is possible to envisage the upland surfaces recognised in the Ochils as having continued across the lowlands, and being later gradually destroyed as the lowlands were opened out. The traces of the early drainage pattern, preserved in the resistant andesites, together with the associated watersheds, appear to throw some light on the initial drainage pattern of the area, and of its mode of origin. Similarly, the Ochils and their immediate surroundings hold information on the various ice masses which covered the area in Pleistocene times, their origin, probable thickness and eventual disappearance.

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3. Fleet, H. Erosion Surfaces in the Grampian Highlands of Scotland, pp. 91-94. Rapp. de la Comm. pour la Cartographie des Surfaces d'Appl. Tertiare. Union Geog. Int. Paris 1938.

APPENDIX

Methods of Field Work

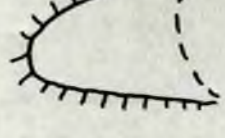
The greater part of the work recorded in the preceding pages is based on fieldwork carried out chiefly in the summer months of 1954 and 1955. This involved the detailed mapping and interpretation of the land-forms of the hills over an area of 550 sq.km. on the scale of 1:25,000, while of this area some 60-70 sq.km., mainly comprising the Hillfoots valleys and the Lower Devon Valley, were mapped on the scale of 1:10560. The areas covered on these two scales are shown in the accompanying diagram.

Field-mapping was based on the assumption that the significant facets of the landscape could be shown by the mapping of the breaks of slope separating them from adjacent facets. Thus, in the case of a valley bench, the convex break of slope at its outer edge was shown on the map by a a distinctive symbol, and the concave break at its inner edge by another. (A).

A

Bench

Map



Ideally, the hatching on the line marking the convex break could probably be continued to the next concave break, thus eliminating the need for a special symbol for this feature, but in practice, when the distance between the two breaks might be several hundred feet, this method seemed to obscure an undue area of the map. Arrows were sometimes inserted on the various facets to indicate a slope, especially if this was not adequately shown by contours.

It was found possible to map most of the area using the two basic symbols in various combinations, with the addition of a few others for certain commonly occurring features. Thus meltwater channels were shown by a special symbol, designed to mark the steep sides and sharp breaks of slope bounding them.(B).

B

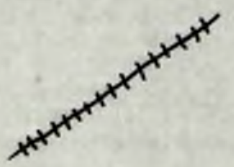
Spillway

Map

Direction of hatching indicates probable direction of flow.

Gorges cut in rock were shown by simple hatching perpendicular to the line of the stream, (C^1), and deep incisions by small streams into glacial deposits by a variant of this symbol (C^2).

$\underline{C^1}$



Gorge, rock-cut

$\underline{C^2}$

Incision in
glacial deposits

The boundary of various types of glacial deposits against the solid rock of a valley side was in some cases marked by an irregular, wavy line, but was only marked in a few areas where it appeared to be of special interest. Exposures of importance were noted on the map by a serial number and a description entered in the field note-book under that number. Bare, roughened rock surfaces apparently indicating severe glacial erosion were shown on the map by the letters R or r, indicating heavy or slight roughening. Most other information was noted either briefly on the map or in greater detail in a field note-book, supplemented by sketches and photographs.

The relation of the various valley benches to each other was indicated either by the use of initial letters or by rough shading. Owing to the considerable distances involved and the inaccessibility of some areas it was not usually possible to trace each stage the whole length of a stream in a single period of three or four consecutive days' field work based on one centre, and correlations in the field were not complete.

Heights

No attempt was made to determine heights by means of an aneroid barometer. Particularly during the summer of 1954, although to a lesser extent in that of 1955, barometric conditions were far from stable, and high winds and the passage of fronts must have rendered most readings suspect. Moreover, even though a large number of bench marks are scattered through the hills, over most of the area it was extremely difficult to locate points at which the instrument might be checked, except for trigonemetrical points on the summits of a number of widely-spaced hills. In view of these difficulties heights were determined with reference to Ordnance Survey contours and bench marks. Throughout the area surveyed contours are at intervals of 100 feet up to 1000' O.D., and thereafter at 250-foot intervals. The 50-foot contour is everywhere surveyed, as is the 450-foot contour in Kinross-shire. On the 1:25,000 sheets sketched contours are interpolated at 25-foot intervals, and provide a basis for estimating the heights of benches and other features. It has been concluded from this work that these contours are more valuable in estimating height than is generally realised, and that they may be very accurate in areas where their interpolation was aided by lines of bench marks. The conclusions reached by Col. H.A.L. Shewell on the relation between contours and estimates of heights are interesting in this connection.[1] Col. Shewell states that the standard error of height estimation, as a percentage of the contour interval, varies from 17% with perfect contours to 37% with an error of 1/3 of the interval (the maximum error that he considers). With a contour interval of 25 feet the probable maximum error in estimation would therefore be not more than 8-10 feet. An error greater than this would seem to be quite permissible in estimating the heights of the valley benches at high levels, which are undoubtedly somewhat altered from their original height. In practice, it seems probable that the error might be reduced by reference to bench marks, where these are available. Greater accuracy might be desired in the case of certain terraces of recent date, in particular of those of possible marine origin, and as there was insufficient time for such accurate heights to be obtained, use was made of 6-inch maps, including those of the 1st Edition, which give the heights and positions of a large number of bench marks. It was found that the distribution was such that, particularly in the Central Hills and the surrounding lowlands, the heights of most terraces, and of various other features, was very accurately given. This fact was used in the preparation of Fig. 17.

Throughout the hills the 25-foot contours were found to be excellent form lines, very few features indeed not being indicated by them. The features not shown were usually small meltwater channels, although it was noted that in several of the larger channels the direction of slope was inaccurately shown. Thus in the Dey valley the terraces above the incision of the Glendey Burn are shown with a definite southern slope, and the Whiterigg spillway apparently hangs slightly above the valley floor. Such errors presumably result from the attempts of the draughtsman to rationalise the contours on the basis of the drainage pattern, in areas where the original hachured maps offered no assistance. In only two areas were major errors in the contours discovered, namely, on the slopes above Sheriffmuir, where a fairly well-developed bench is not indicated, and in the Devon valley above Cauldron Linn, where the gorge is shown to continue upstream of the fall.

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Synopsis: The Geomorphology of the Ochil Hills.

Jane M. Soons.

Rising steeply above the lowlands drained by the rivers Allan, Earn, Forth and Leven, the Ochil Hills are essentially a watershed area, formed of resistant Devonian andesites, and have withstood denudation better than the surrounding lowlands. As a result their landforms still retain traces of the development of the area from a period, probably in middle or late Tertiary times, when an upland surface of low relief was formed at the level of the present hill summits. The appearance of this surface suggests that it is of sub-aerial origin, and that its later destruction resulted from the action of streams in deepening their valleys in response to falls in base-level. The initial drainage pattern of the area of which the Ochils form part was probably one of west-east flowing streams, but this pattern was modified as structural weaknesses were revealed, offering opportunities for river capture. There is also some evidence that certain features in the landscape are the result of a Devonian period of denudation of the andesites, the landscape then formed having been exhumed from a cover of younger rocks. Because of the inequalities of this landscape, sedimentary rocks may have extended over some parts of the range until relatively recent times, and this may account for the absence of evidence of some stages in the development of the present landscape in these areas.

The western and central parts of the hills show several contrasts. While the Ochil Main Surface may have developed across both, its destruction in the western area was largely associated with the development of deep, narrow valleys, whereas in the central area more open valleys were formed, a a widespread lower erosion surface is present. Throughout t hills, however, there is evidence that a period of downcutti took place immediately prior to glaciation, during which the valleys were deepened to approximately their present level.

During the Pleistocene period the hills appear to have been almost completely covered by ice of Highland origin. The movement of this ice modified certain areas, leaving their surface broken and causing minor changes in the drainage pattern, while everywhere the soil cover was remove The steep scarp slopes both to north and south of the hills may have been emphasised by the movement of ice along the valleys at their foot, overdeepening these and causing the valleys of streams draining to them to be left hanging some distance above their floors.

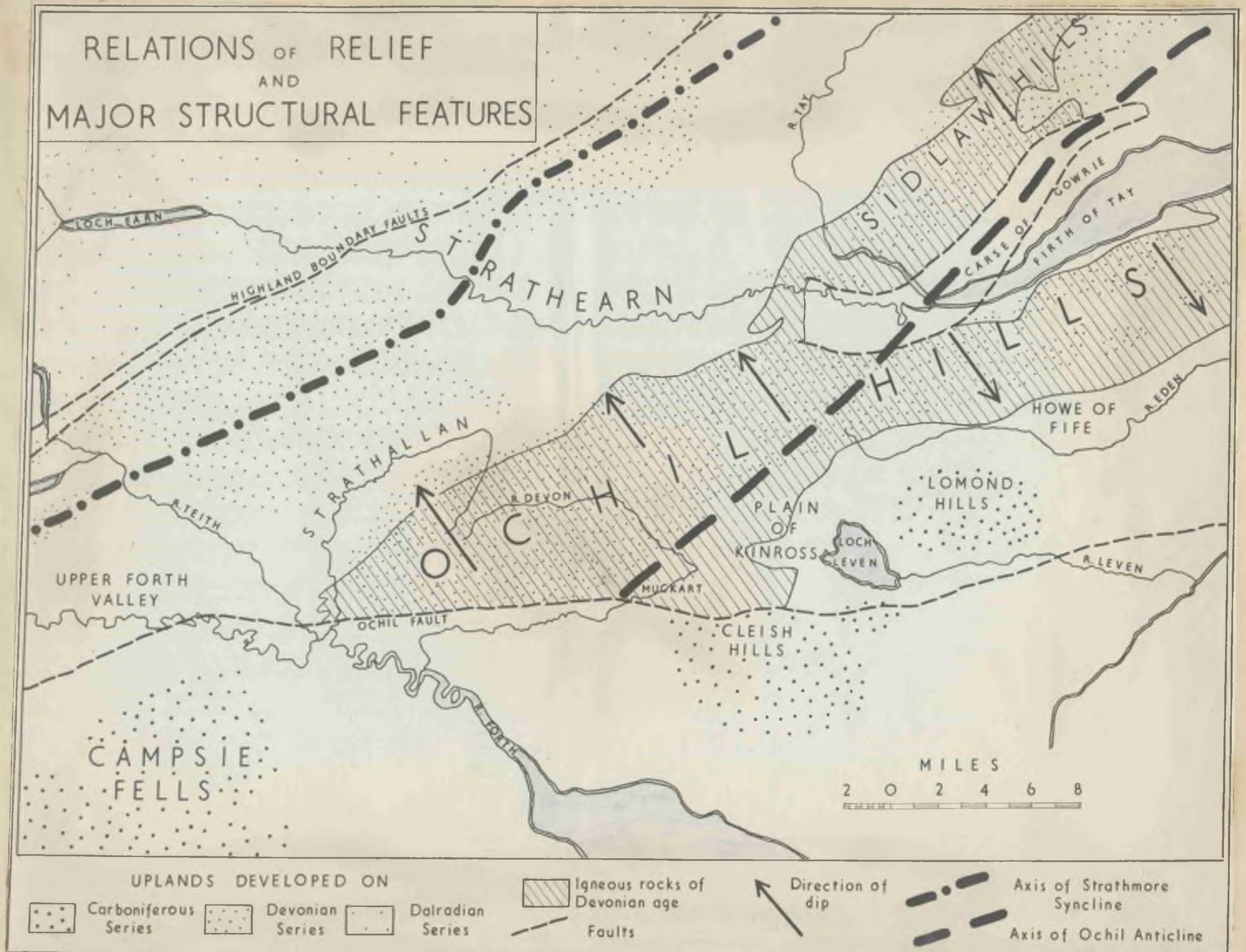
During the withdrawal of the various ice-fronts the re-establishment of the pre-glacial drainage pattern was for a time prevented, and a considerable number of spillways was developed, forming a temporary drainage system. These, together with fluvio-glacial deposits, make it possible to reconstruct the way in which the fronts withdrew. In the hills the pre-glacial drainage pattern was largely re-established, but in the surrounding lowlands thick glacial deposits have often masked the pre-glacial pattern, and the present drainage is of post-glacial origin. In the lower parts of Strath Earn, and in the lower Forth and Devon valleys the retreating ice-fronts were followed by an incursion of the sea, to give Raised Beaches of varying extent and at varying levels. In Strath Earn river terraces may be associated with these levels, and the fall from the Late-Glacial high sea-level seems to be marked by the incision of many streams into the rock underlying the glacial deposits over which they flowed, to produce gorges of varying extent.

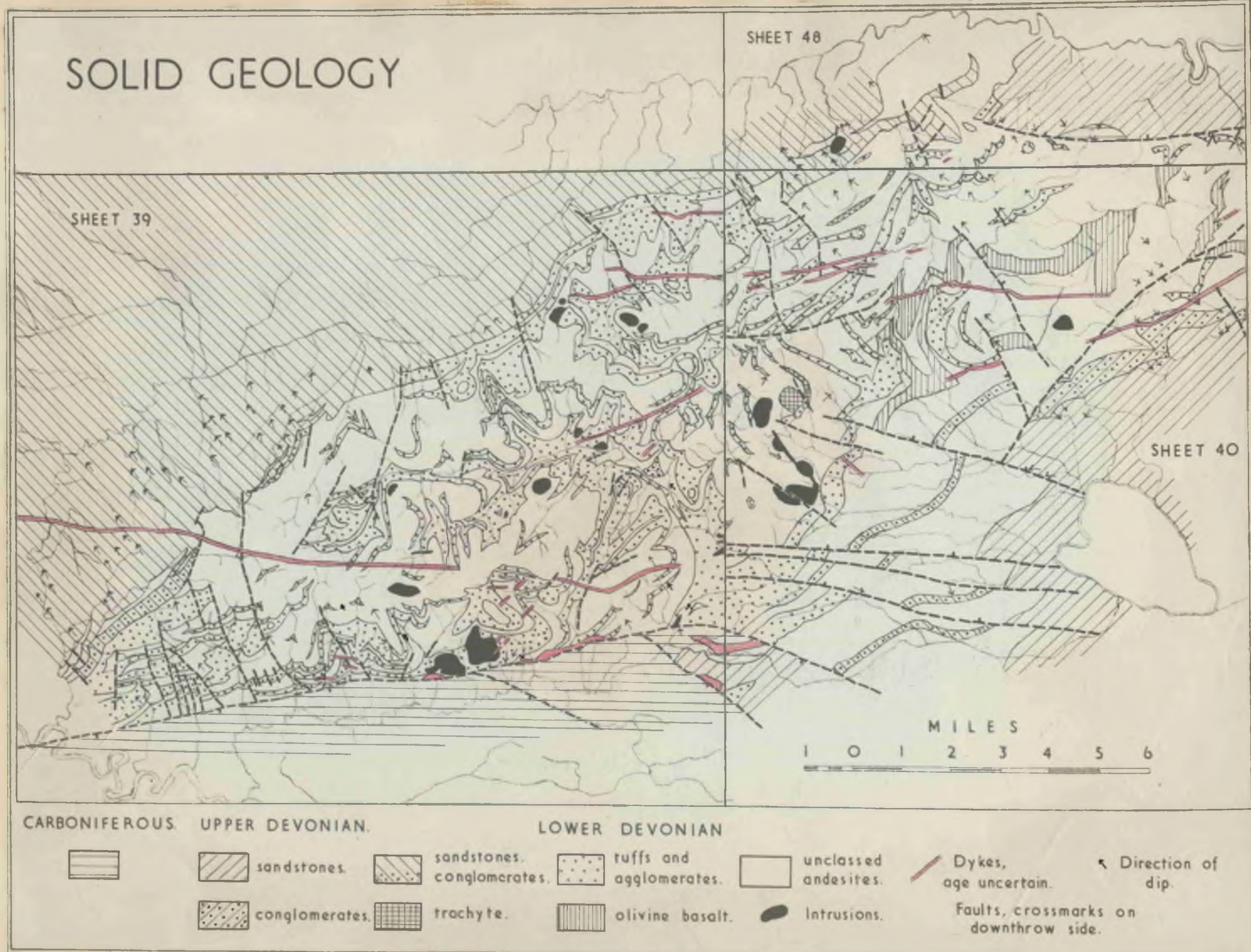
The Geomorphology of the Ochil Hills

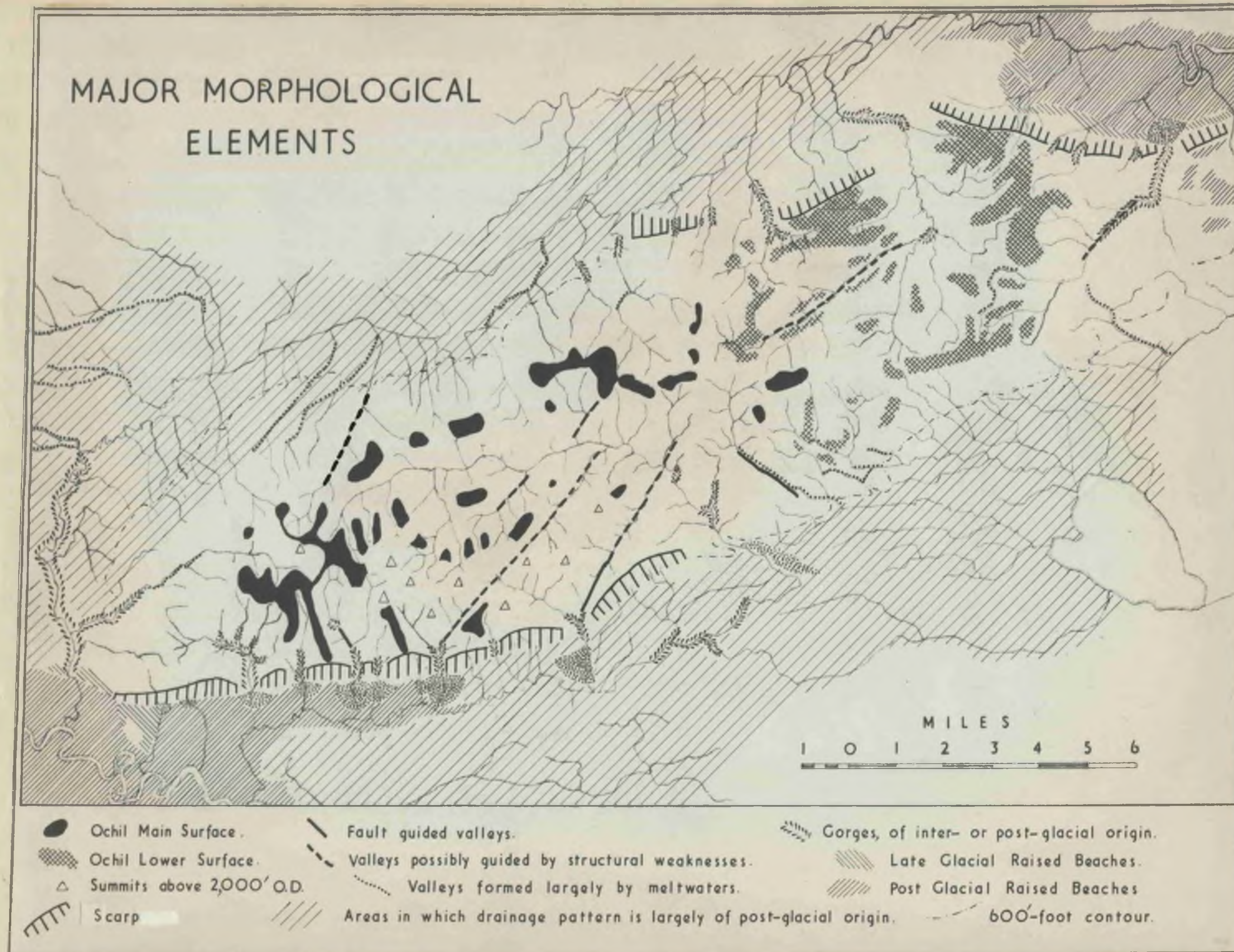
List of Maps

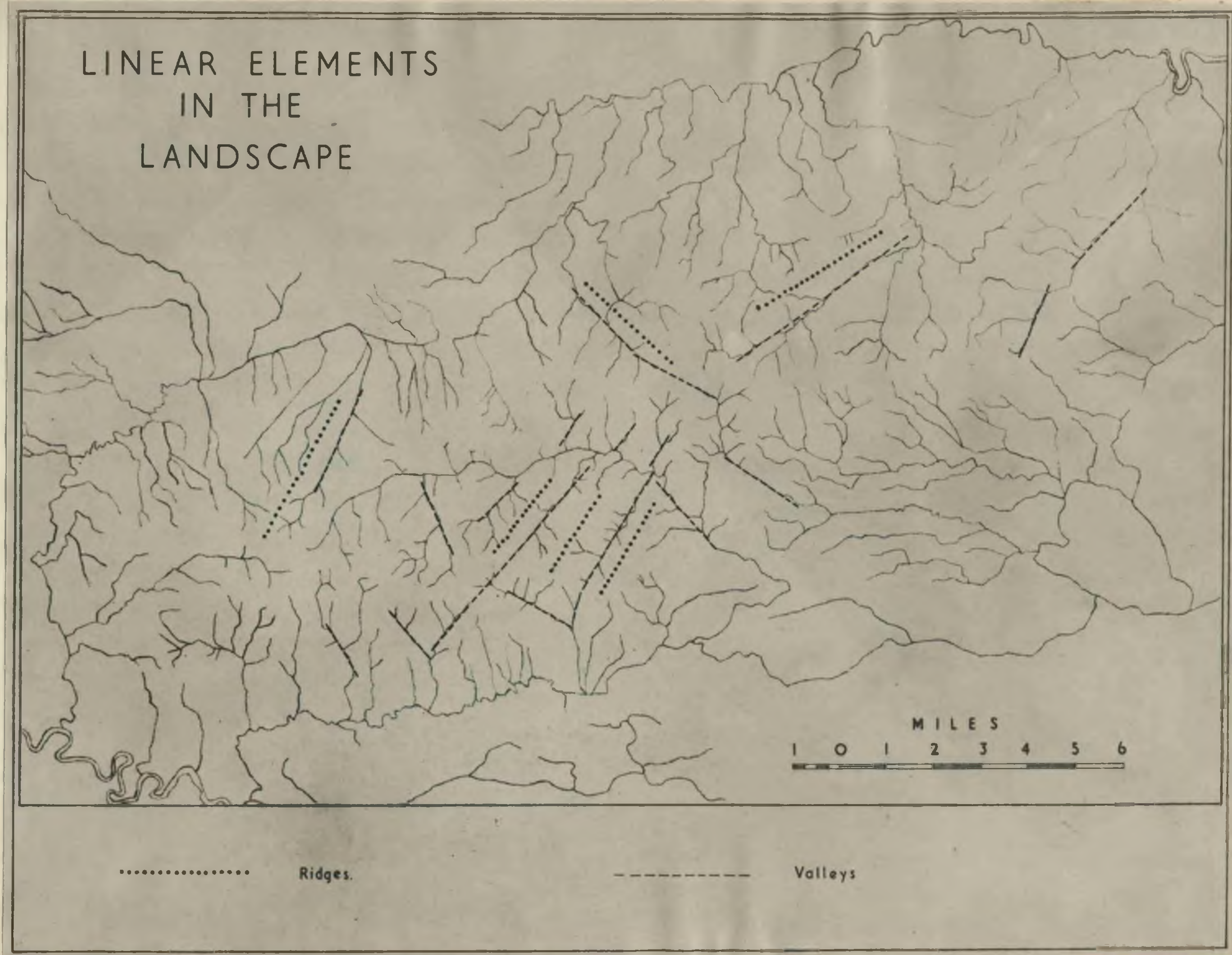
1. Relations of Relief and Major Structural Features.
2. Solid Geology.
3. Major Morphological Elements.
4. Linear Elements in the Landscape.
5. Relative Relief.
6. Drainage Pattern and Watersheds.
7. Possible Early Drainage Pattern.
8. Western Ochils: Ochil Main Surface and Valley Stages.
9. Central Ochils: Upland Surfaces and Valley Stages.
10. Alva Valley.
11. Superficial Deposits.
12. Glaciated Areas.
13. The Devon Buried Channel.
14. Meltwater Channels and Related Features in the Southern Ochils.
15. Meltwater Channels and Related Features in the Northern Ochils.
16. Terraces in Lower Strath Earn.
17. The Western Ochils: Meltwater Channels and Related Features.
18. Glen Devon.

The relevant 1" Ordnance Survey maps, sheets 6[illegible], 64 and 69, will be found at the back of this folder.


RELATIONS OF RELIEF AND MAJOR STRUCTURAL FEATURES
LOCH EARN
HIGHLAND BOUNDARY FAULTS
STRATHEARN
R. TAY
SIDLAW HILLS
CARSE OF GOWRIE
FIRTH OF TAY
OCHIL HILLS
HOWE OF FIFE
R. EDEN
STRATHALLAN
R. DEVON
R. TEITH
PLAIN OF KINROSS
LOCH LEVEN
LOMOND HILLS
R. LEVEN
UPPER FORTH VALLEY
MUCKART
OCHIL FAULT
CLEISH HILLS
R. FORTH
CAMPSIE FELLS
MILES
2 0 2 4 6 8
UPLANDS DEVELOPED ON
Carboniferous Series
Devonian Series
Dalradian Series
Igneous rocks of Devonian age
Faults
Direction of dip
Axis of Strathmore Syncline
Axis of Ochil Anticline


SOLID GEOLOGY
SHEET 48
SHEET 39
SHEET 40
MILES
1 0 1 2 3 4 5 6
CARBONIFEROUS
UPPER DEVONIAN.
sandstones.
conglomerates.
sandstones. conglomerates.
trachyte.
LOWER DEVONIAN
tuffs and agglomerates.
olivine basalt.
unclassed andesites.
Intrusions.
Dykes, age uncertain.
Direction of dip.
Faults, crossmarks on downthrow side.

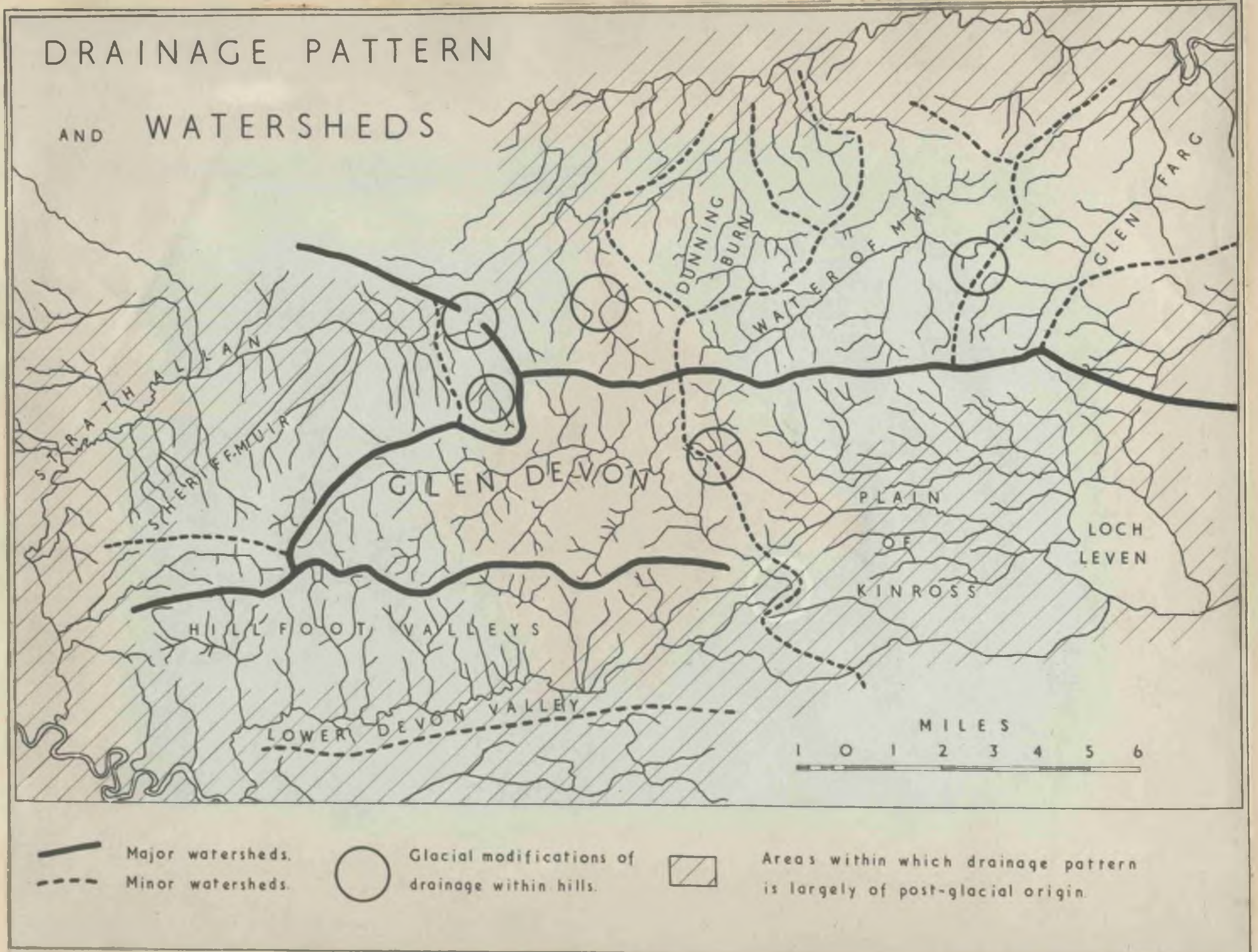

MAJOR MORPHOLOGICAL
ELEMENTS
MILES
1 0 1 2 3 4 5 6
Ochil Main Surface.
Ochil Lower Surface.
Summits above 2,000′ O.D.
Scarp
Fault guided valleys.
Valleys possibly guided by structural weaknesses.
Valleys formed largely by meltwaters.
Areas in which drainage pattern is largely of post-glacial origin.
Gorges, of inter- or post-glacial origin.
Late Glacial Raised Beaches.
Post Glacial Raised Beaches
600′-foot contour.

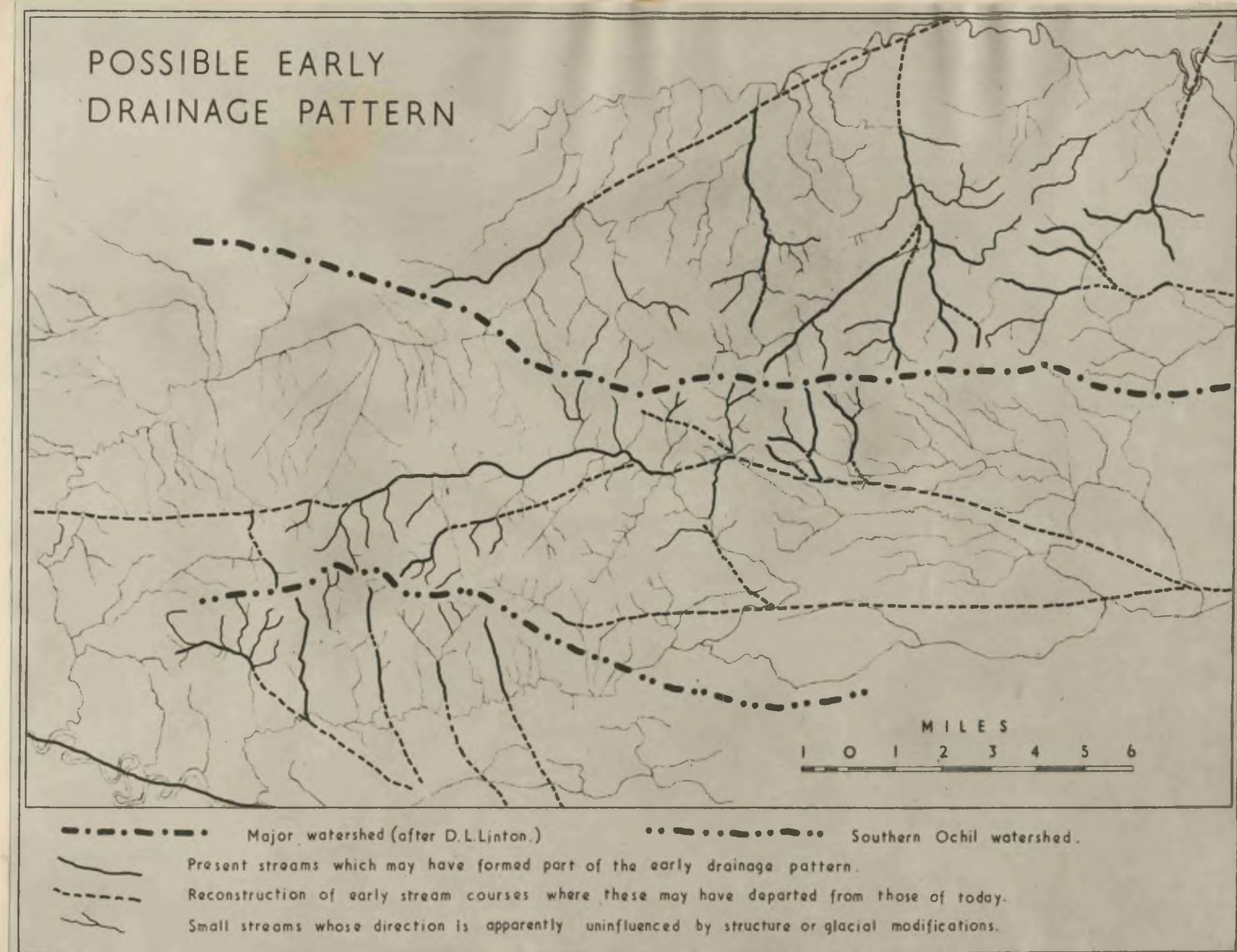

LINEAR ELEMENTS
IN THE
LANDSCAPE
MILES
1 0 1 2 3 4 5 6
Ridges.
Valleys

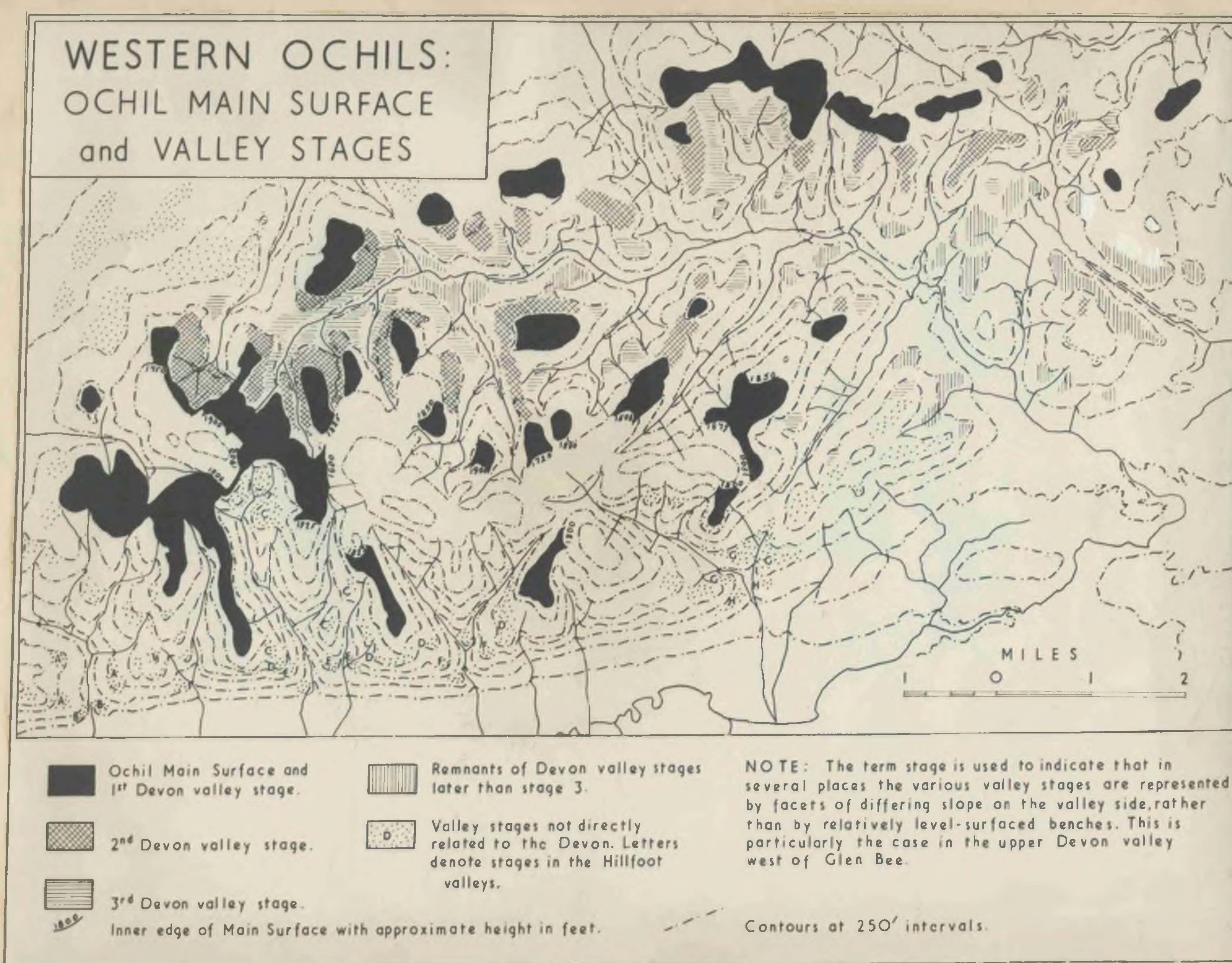
RELATIVE RELIEF

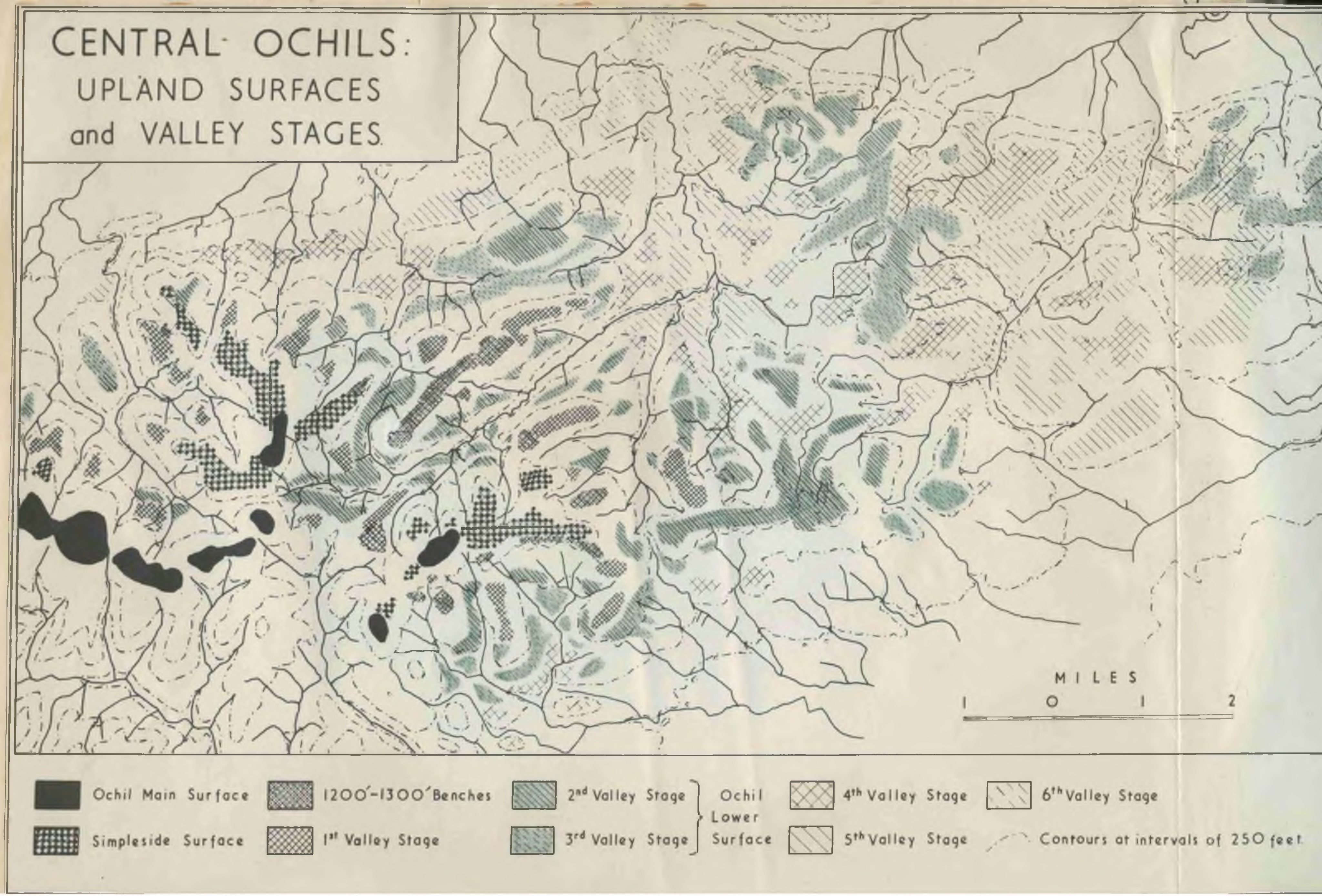
Over 750 feet. | 500–749 feet. | 250–499 feet. | Under 250 feet

Relief values measured between highest and lowest points in squares of 4 km² based on National Grid lines.

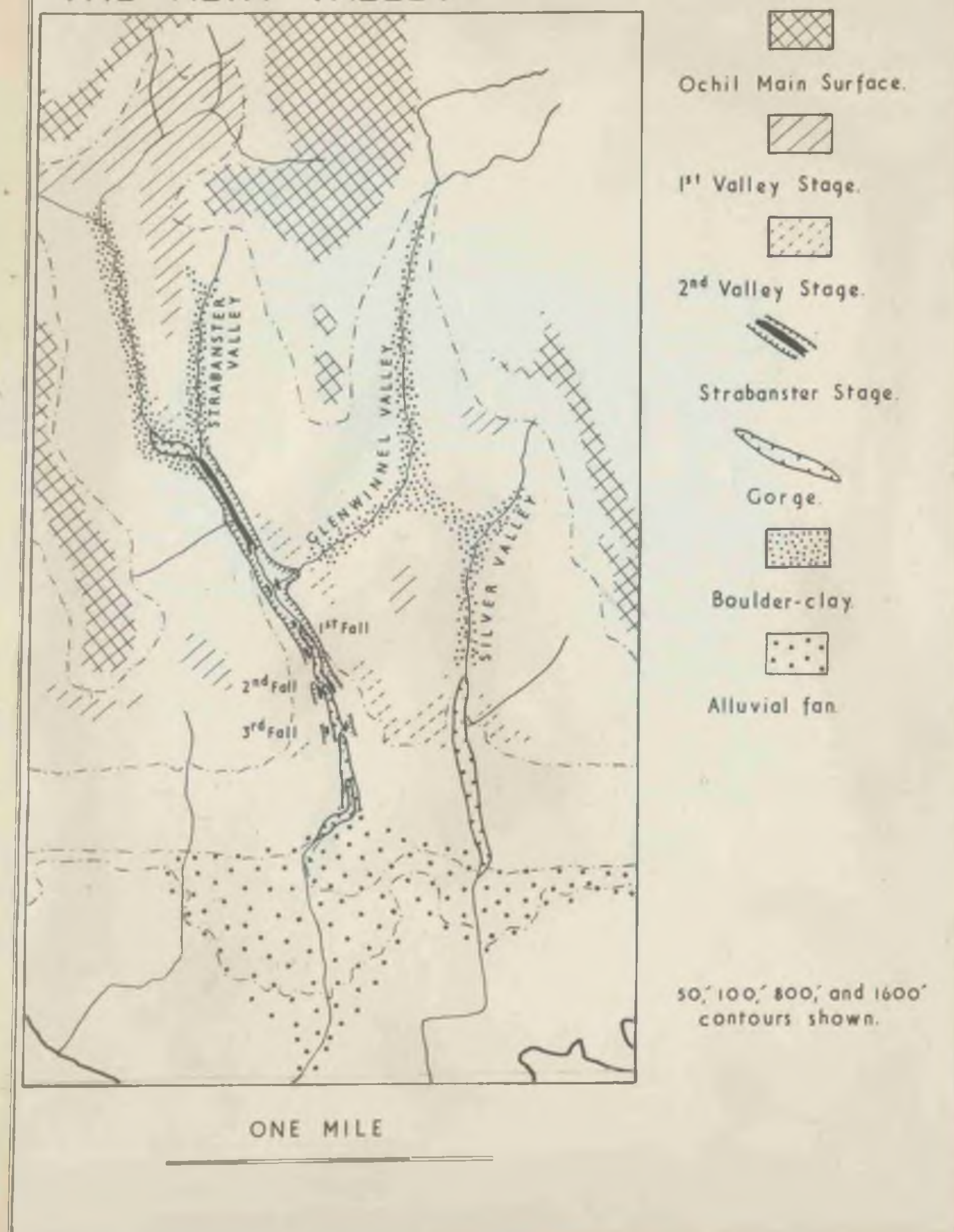

DRAINAGE PATTERN
AND WATERSHEDS
STRATHALLAN
SHERIFFMUIR
DUNNING BURN
WATER OF MAY
GLEN FARG
GLEN DEVON
PLAIN OF KINROSS
LOCH LEVEN
HILLFOOT VALLEYS
LOWER DEVON VALLEY
MILES
1 0 1 2 3 4 5 6
Major watersheds.
Minor watersheds.
Glacial modifications of drainage within hills.
Areas within which drainage pattern is largely of post-glacial origin.


POSSIBLE EARLY
DRAINAGE PATTERN
MILES
1 0 1 2 3 4 5 6
Major watershed (after D.L.Linton.)
Southern Ochil watershed.
Present streams which may have formed part of the early drainage pattern.
Reconstruction of early stream courses where these may have departed from those of today.
Small streams whose direction is apparently uninfluenced by structure or glacial modifications.


WESTERN OCHILS:
OCHIL MAIN SURFACE
and VALLEY STAGES
MILES
1 0 1 2
Ochil Main Surface and 1st Devon valley stage.
2nd Devon valley stage.
3rd Devon valley stage.
Remnants of Devon valley stages later than stage 3.
Valley stages not directly related to the Devon. Letters denote stages in the Hillfoot valleys.
Inner edge of Main Surface with approximate height in feet.
NOTE: The term stage is used to indicate that in several places the various valley stages are represented by facets of differing slope on the valley side, rather than by relatively level-surfaced benches. This is particularly the case in the upper Devon valley west of Glen Bee.
Contours at 250′ intervals.

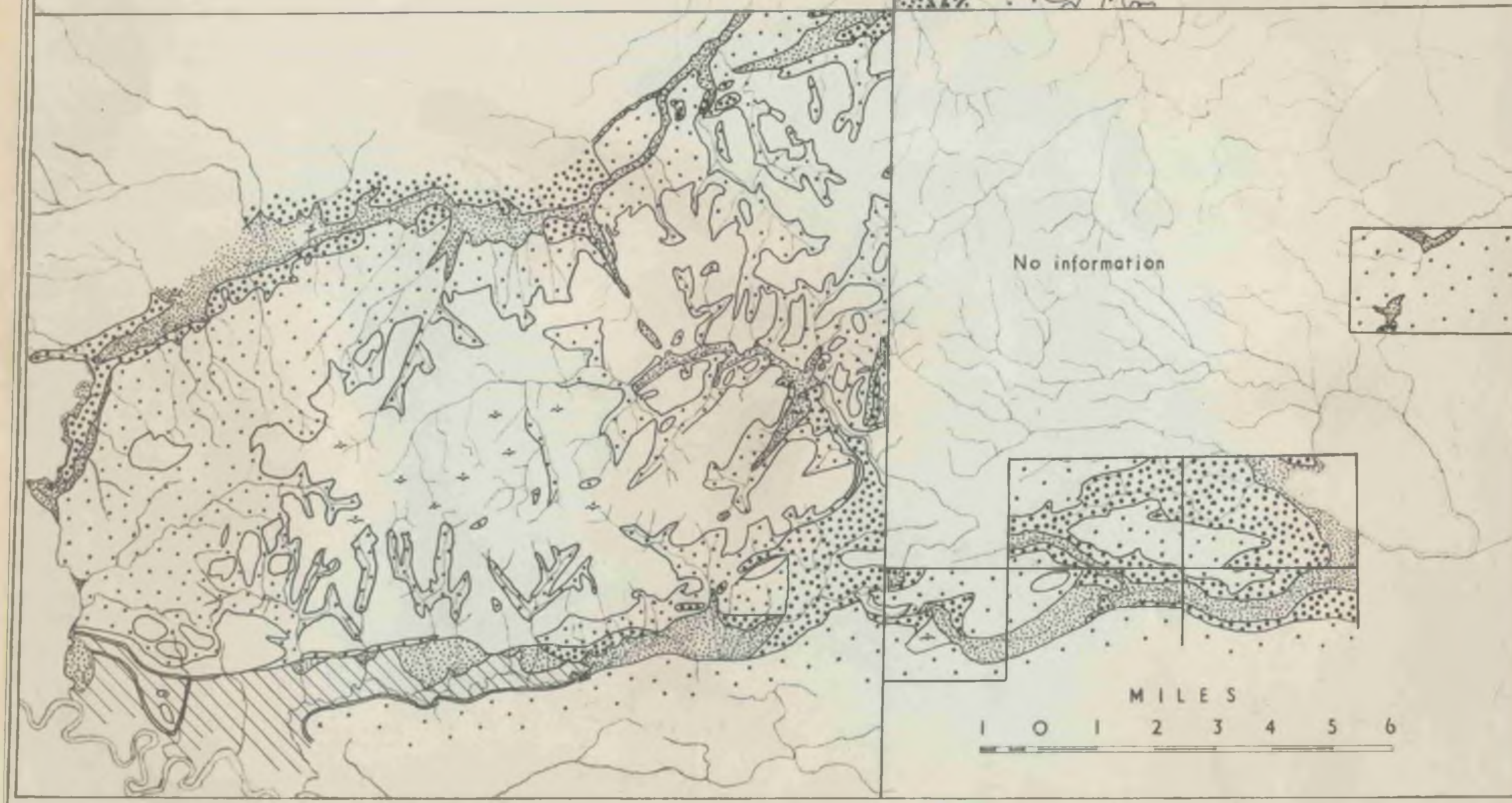

CENTRAL OCHILS:
UPLAND SURFACES
and VALLEY STAGES
MILES
1 0 1 2
Ochil Main Surface
Simpleside Surface
1200′–1300′ Benches
1st Valley Stage
2nd Valley Stage
3rd Valley Stage
Ochil Lower Surface
4th Valley Stage
5th Valley Stage
6th Valley Stage
Contours at intervals of 250 feet

THE ALVA VALLEY



SUPERFICIAL DEPOSITS

BASED ON GEOLOGICAL SURVEY MAPS



SOURCES OF INFORMATION

Sheet 39 based mainly on 1-inch manuscript map. Lower Devon Valley based on 1-inch (solid) and 6-inch published maps.

Sheet 48 as 39; Raised Beach deposits and alluvium from published 1-inch map (solid)

Sheet 40. Parts of the Plain of Kinross from manuscript 6-inch maps.

Boulder-clay

Alluvium

Terraces

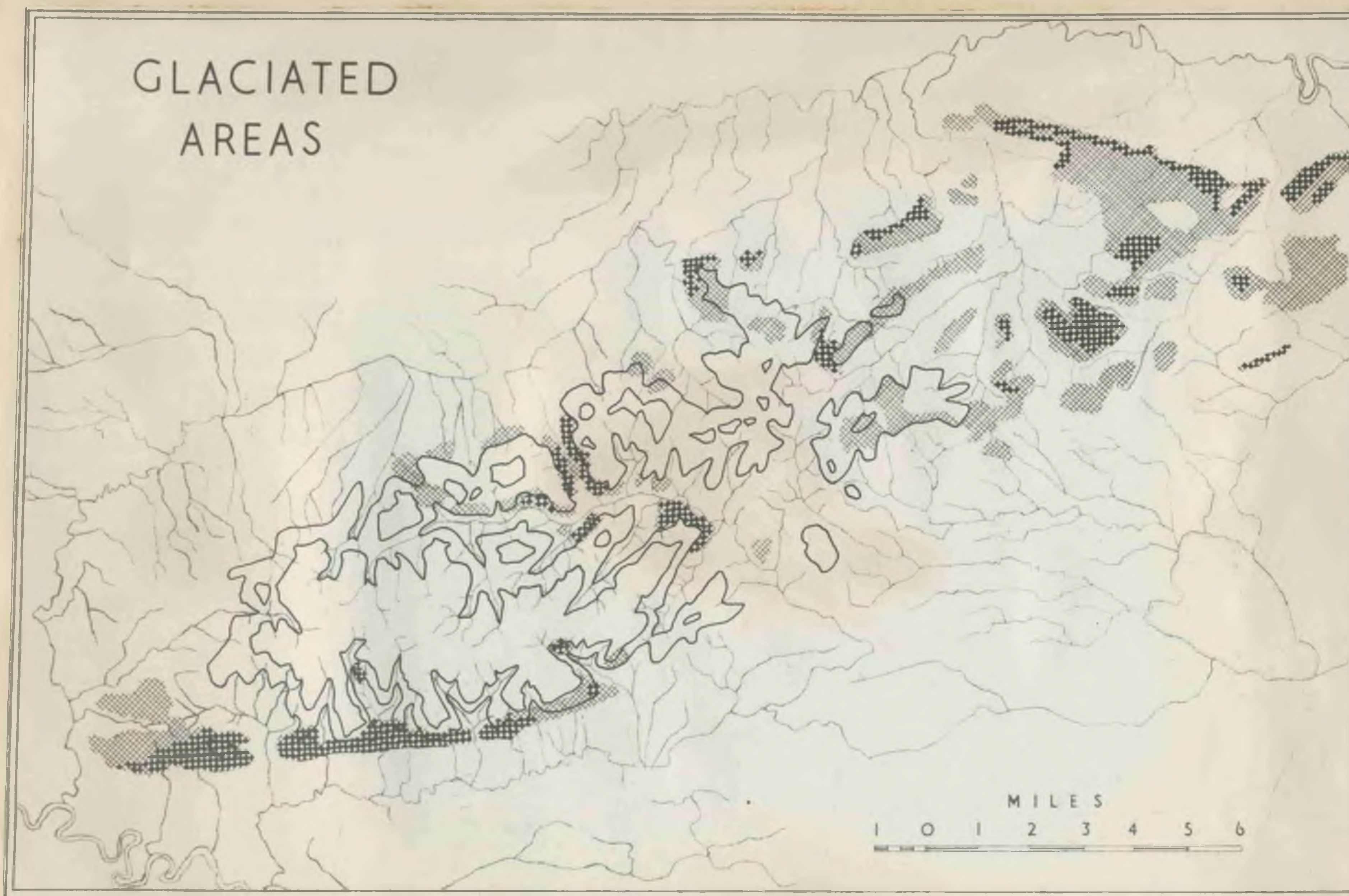
Peat

Fluvio-glacial sands & gravels

Raised Beach deposits

Edge of Raised Beaches

GLACIATED AREAS



Areas where glaciation has produced hummocky, broken ground, or oversteepened slopes.

Heavily glaciated. Bare rock occurs frequently.

Bare rock infrequent.

1200′ and 1500′ contours shown.

THE DEVON BURIED CHANNEL

200 — Contours at intervals of 100' to 500' above sea-level, then at 250' intervals.

−200 — Contours showing probable depth of rock-head below sea-level, at intervals of 100.'

Buried channels as envisaged by H. M. Cadell.

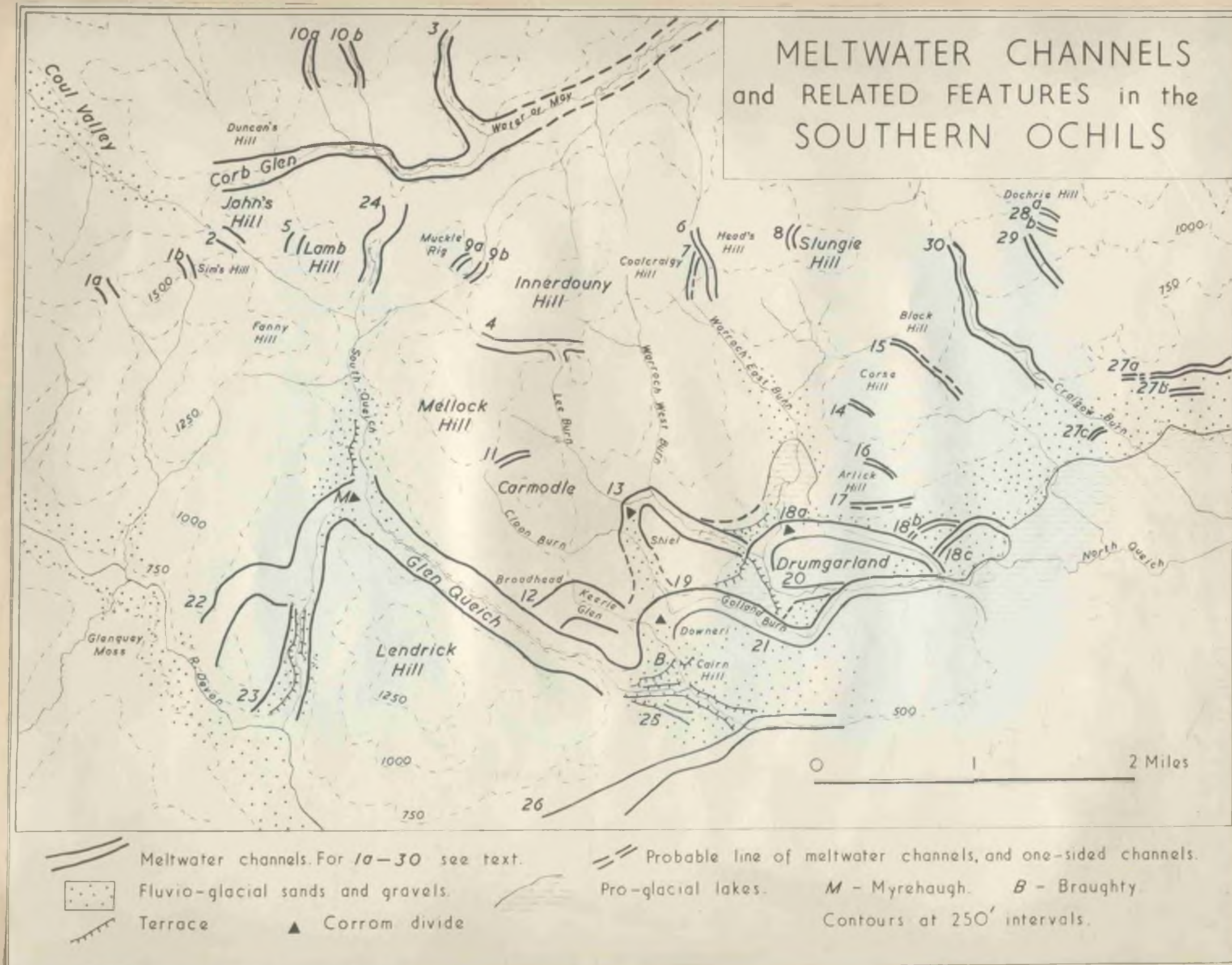
•102 Position of boreholes and depth of rockhead below sea-level.

Figures followed by + indicate that rockhead was not reached

Figures preceded by + indicate height of rockhead above sea-level

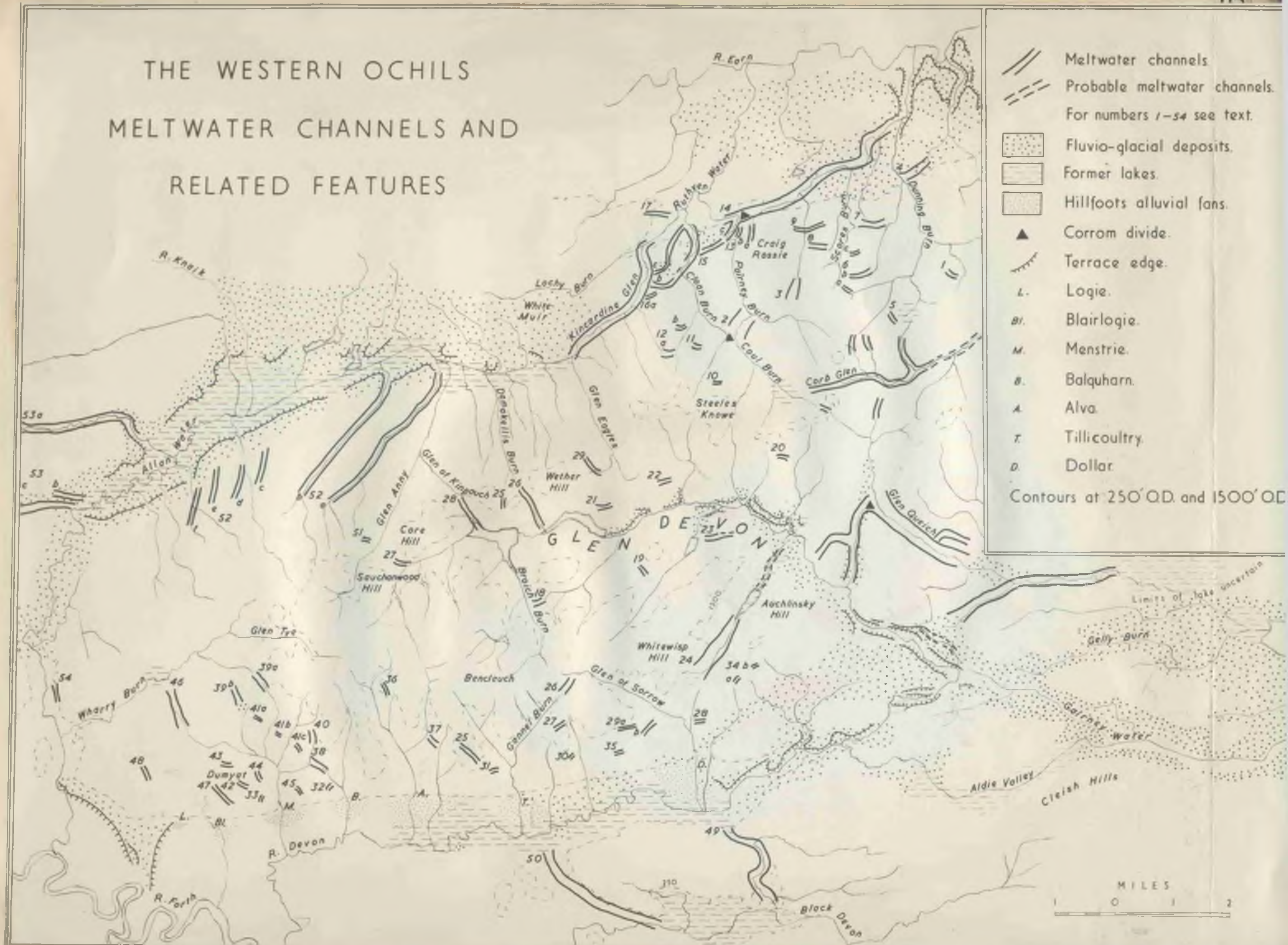
Map and inset compiled from maps and records of the National Coal Board, Edinburgh.

National Grid lines at 1 kilometre intervals indicated.

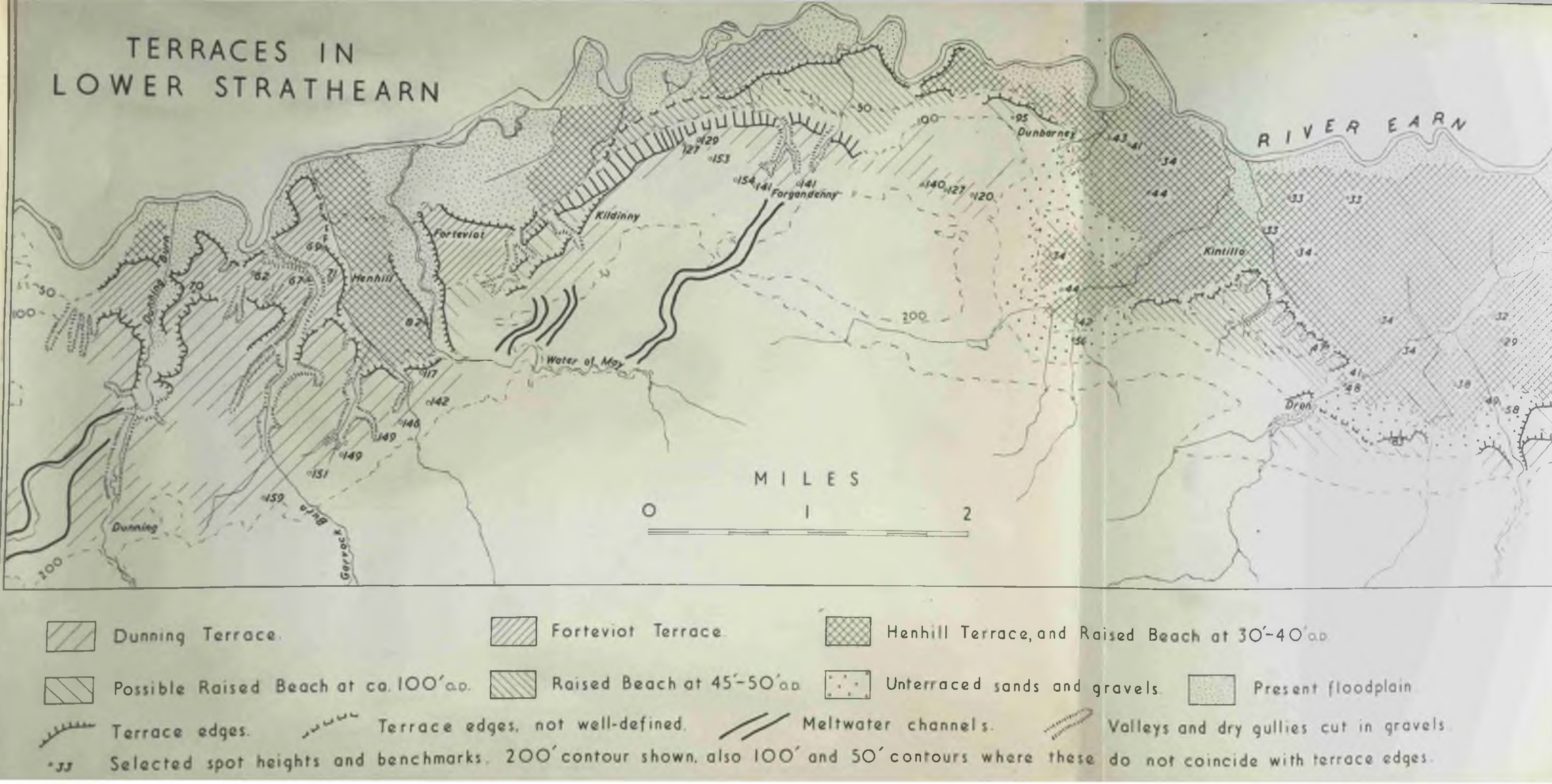


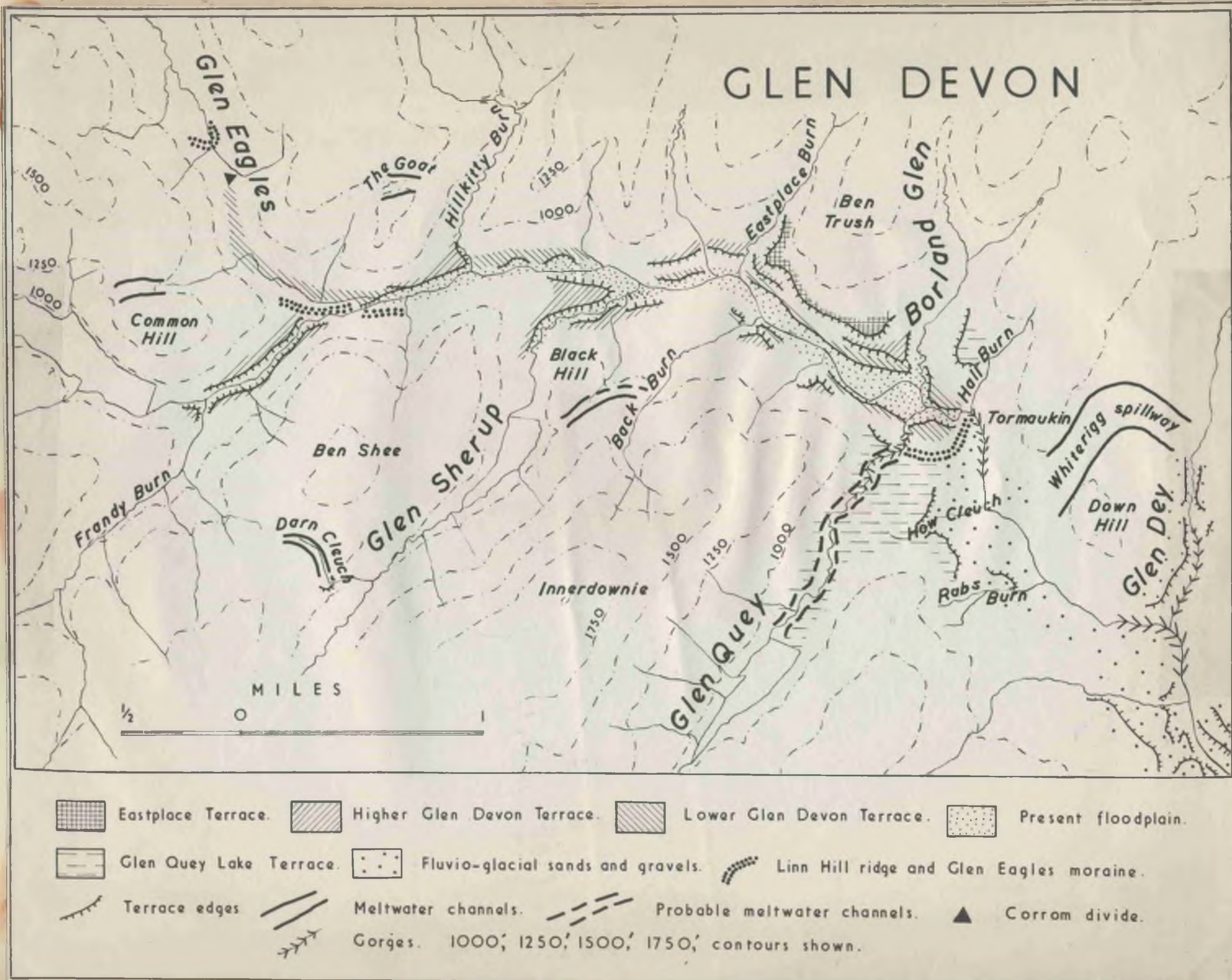
MELTWATER CHANNELS and RELATED FEATURES in the SOUTHERN OCHILS
Coul Valley
Duncan's Hill
Corb Glen
John's Hill
Sim's Hill
Fanny Hill
Lamb Hill
Muckle Rig
Water of May
Innerdouny Hill
Coalcraigy Hill
Head's Hill
Slungie Hill
Dochrie Hill
Black Hill
Corse Hill
Artick Hill
South Queich
Mellock Hill
Lee Burn
Warroch West Burn
Warroch East Burn
Craigow Burn
North Queich
Carmodle
Cloon Burn
Shiel
Drumgarland
Broadhead
Keerie Glen
Glen Queich
Golland Burn
Downeri
Cairn Hill
Lendrick Hill
Glenquey Moss
R. Devon
0 1 2 Miles
Meltwater channels. For 1a—30 see text.
Probable line of meltwater channels, and one-sided channels.
Fluvio-glacial sands and gravels.
Pro-glacial lakes.
M - Myrehaugh.
B - Braughty
Terrace
Corrom divide
Contours at 250′ intervals.


MELTWATER CHANNELS
and RELATED FEATURES in the
NORTHERN OCHILS
Meltwater channels.
For 1 – 46j see text.
Probable line of meltwater channels, and one-sided channels.
Fluvio-glacial sands and gravels.
Terrace.
Corrom divide.
Pro-glacial lakes.
S - Stronachy
P - Path of Condie.
Contours at 250′ intervals.
MILES
0
1
2
Law at Dumbuils
Westhall Hill
Glenearn Hill
Cultoucher Hill
West Dron Hill
Dron Hill
Balmanno Hill
Craigbeny Hill
Kelty Burn
Dron Burn
Clevage Hills
Condie Hill
Water of May
Berry Hill
Fordel Burn
Eastertown Merch Burn
Fritie Burn
R. Farg
Mill Burn
Arlick Hill
Whitehill Head
Chapel Burn
Slateford Burn
Baulk Hill
Carleith Hill
Dochrie Hill
Tillyrie Hill
Glendy Burn
Gatloch Valley
Balcanquhal Valley
Lossley Burn
R. Eden
Slungie Hill



THE WESTERN OCHILS
MELTWATER CHANNELS AND
RELATED FEATURES
Meltwater channels.
Probable meltwater channels.
For numbers 1–54 see text.
Fluvio-glacial deposits.
Former lakes.
Hillfoots alluvial fans.
Corrom divide.
Terrace edge.
L. Logie.
Bl. Blairlogie.
M. Menstrie.
B. Balquharn.
A. Alva.
T. Tillicoultry.
D. Dollar.
Contours at 250' O.D. and 1500' O.D.
MILES
1 0 1 2
R. Earn
R. Knaik
Ruthven Water
Dunning Burn
Lochy Burn
White Muir
Kincardine Glen
Craig Rossie
Pairney Burn
Coul Burn
Cloan Burn
Steeles Knowe
Coul Glen
Scores Burn
Allan Water
Danakellis Burn
Glen Eagles
Wether Hill
Glen of Kinpauch
Glen Anny
Core Hill
Sauchanwood Hill
GLEN DEVON
Glen Quey
Auchlinsky Hill
Whitewisp Hill
Glen of Sorrow
Broich Burn
Bencleuch
Gannel Burn
Glen Tye
Wharry Burn
Dumyat
R. Devon
R. Forth
Black Devon
Aldie Valley
Cleish Hills
Gairney Water
Gelly Burn
Limits of lake uncertain


TERRACES IN
LOWER STRATHEARN
RIVER EARN
Dunbarney
Forgandenny
Kildinny
Forteviot
Henhill
Kintillo
Dron
Dunning
Dunning Burn
Water of May
Garvock Burn
MILES
0
1
2
200
100
50
Dunning Terrace.
Forteviot Terrace.
Henhill Terrace, and Raised Beach at 30'–40' O.D.
Possible Raised Beach at ca. 100' O.D.
Raised Beach at 45'–50' O.D.
Unterraced sands and gravels.
Present floodplain.
Terrace edges.
Terrace edges, not well-defined.
Meltwater channels.
Valleys and dry gullies cut in gravels.
·33 Selected spot heights and benchmarks. 200' contour shown, also 100' and 50' contours where these do not coincide with terrace edges.


GLEN DEVON
Glen Eagles
The Goat
Hillkitty Burn
Eastplace Burn
Ben Trush
Glen Borland
Common Hill
Black Hill
Back Burn
Hall Burn
Tormaukin
Whiterigg spillway
Ben Shee
Glen Sherup
Frandy Burn
Darn Cleuch
How Cleuch
Down Hill
Glen Dey
Innerdownie
Rabs Burn
Glen Quey
1500
1250
1000
1750
MILES
½
O
1
Eastplace Terrace.
Higher Glen Devon Terrace.
Lower Glen Devon Terrace.
Present floodplain.
Glen Quey Lake Terrace.
Fluvio-glacial sands and gravels.
Linn Hill ridge and Glen Eagles moraine.
Terrace edges
Meltwater channels.
Probable meltwater channels.
Corrom divide.
Gorges. 1000,' 1250,' 1500,' 1750,' contours shown.

ORDNANCE SURVEY OF SCOTLAND

PERTH & STRATH EARN

POPULAR EDITION ONE-INCH MAP (WITH NATIONAL GRID)

SHEET 63

Scale: One Inch to One Statute Mile

Scale of Miles

Scale of Yards

Scale of Kilometres

THE NATIONAL GRID

ORDNANCE SURVEY OF SCOTLAND

STIRLING & DUNFERMLINE

POPULAR EDITION ONE-INCH MAP (WITH NATIONAL GRID)

SHEET 67

ORDNANCE SURVEY OF SCOTLAND

DUNDEE & ST ANDREWS

POPULAR EDITION ONE-INCH MAP (WITH NATIONAL GRID) SHEET 64