TO THE SUMMER

OF

1975

THE GLACIATION OF CENTRAL AYRSHIRE

by

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Thesis submitted to the University of Glasgow
for the Degree of Doctor of Philosophy.

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SUMMARY

TITLE. "The Glaciation of central Ayrshire".

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Introduction.

The aim of this study is to examine the glacial geomorphology of central Ayrshire in order to reconstruct the sequence of events during the last glaciation and deglaciation. This has entailed the compilation of as much information as possible on glacially-eroded features, glacial deposits and raised beaches. This study is of particular relevance for 2 major reasons:-

a) Central Ayrshire was last studied on a systematic basis in the years leading upto 1939. No attempt has been made, therefore, to decipher the glacial history of the area by using concepts and techniques of study formulated over the last 40 years.

b) To extend the detailed research in the field of glacial geomorphology undertaken by McLellan (1967), Rose, Gemmell(1971), Ward and May.

Procedure.

All the literature of relevance to the study was examined. It was divided into three major categories:-

a) Regional - accounts of studies completed within central Ayrshire, in the vicinity and elsewhere in Britain.

b) Systematic - accounts of glacial, fluvioglacial and marine processes.

c) Methodological - accounts of the techniques and the methodology used in glacial geomorphological studies.

From a detailed examination of morphology, deposits, air photographs and borehole records a map of the glacial geomorphology and superficial deposits was compiled at the scale of I : I0560. The total amount of fieldwork exceeded 6 months; the bulk of it was completed in the summers of I974 and I975. In both fieldwork seasons till fabric analyses were completed and samples of materials taken back to the laboratory for further analysis.

Conclusions

I) There is no evidence anywhere in central Ayrshire to indicate that it was glaciated before approximately 27500 years B.P. when the last ice-sheets (Late-Devensian) built up to submerge the area.

2) At some time before the onset of the last glaciation sea level in central Ayrshire (and across the Firth of Clyde in Kintyre) was approximately I05m. to I50m. above present sea level.

3) Between 27,500 years B.P. and I8,000 years B.P. the ice masses from the Highlands and the Southern Uplands which occupied central Ayrshire built up to their maximum extent and completely enveloped it.

4) From I8,000 years B.P. to I0,000 years B.P. the deglaciation of the area was completed.

5) The highest raised beach (24-26m. O.D.) was deposited at approximately I3,000 years B.P..

6) Between II,000 years B.P. and I0,000 years B.P. ice with a Southern Upland origin advanced/readvanced and affected a limited part of central Ayrshire in the extreme south-east.

7) Between 8,400 years B.P. and 6,600 years B.P. the two lowest raised beaches (I0-I2m. O.D. and 5-7m. O.D.) were deposited.

William G. Holden, B.Sc.
August, I977.

CHAPTER I

INTRODUCTION

I.I: Introduction

This thesis is concerned with the description and analysis of the glacial geomorphology of a limited part of west-central Scotland (hereafter referred to as central Ayrshire or the thesis area) (Fig. I.I). Glacial geomorphology includes the study of the features produced by the processes of glacial erosion, glacial deposition, fluvioglacial erosion and fluvioglacial deposition. Numerous studies in areas of contemporary glaciation have shown the relationships between the form of glacial and fluvioglacial landforms and the advance, direction of movement and mode of retreat of an ice mass (Russell I892, I893; Reid I896; Tarr and Martin I906; Tarr I909; von Engeln I9I2; Muir I9I5; Mannerfelt I945, I949; Hoppe I950; Goldthwait I963; Clayton I964; Price I964, I965, I966; Boulton I967, I968.). By the accurate mapping of glacial landforms in the thesis area and their subsequent analysis with regard to ice advance and retreat a clear understanding of the effects of the last glaciation on central Ayrshire is possible.

I.2: The Study

Detailed studies concerning the former glaciation of the area around Glasgow have been undertaken in the last decade by Rose, who worked to the east and north of Glasgow, McLellan (I967), who worked in central Lanarkshire, Ward, who researched into the glaciation and associated sea-level changes in northern Ayrshire and Renfrewshire, and Gemmell (I97I), who studied the glaciation of the Island of Arran. May has recently embarked upon a research project in

Fig. 1.1 Location of Thesis Area.

Upper Nithsdale and Annandale. It is highly desirable, therefore, to extend this detailed research work into Central Ayrshire because of its potential value in elucidating the former ice movements which occurred to the south of Glasgow during the last glaciation. It is also desirable to study the effects of the last glaciation in central Ayrshire because, despite its close proximity to Glasgow, little detailed work has been completed on a systematic basis since the original survey by the Officiers of the Geological Survey of Scotland in 1868 which was partially revised in 1927. The results of this revision were only published in 1949 (Eyles et al) (although the Memoir was ready for publication in 1939 but was postponed due to the outbreak of war). From this it is clear that no attempt has been made to systematically analyse the glacial geomorphology of central Ayrshire using any concepts formulated over the last forty years. This study is therefore, long overdue.

The study was undertaken by the detailed mapping of the whole thesis area on a large scale (1:10560 or 1:10,000). All exposed sections in the thesis area were examined and described and, at selected sections, samples (conforming to BS 1377) were collected for analysis in the laboratory by wet sieving. (Appendix I). 50 stones were selected at random from these samples in order to identify their rock-types.

Several sections of till were analysed to indicate the former direction of ice movement from the orientation and dip of stones included within the till (Appendix II). The majority of stones within the till have their long axes aligned parallel to the direction of ice flow (Holmes, 1941). Holmes (1941) also suggested that stones dip into the direction from which the ice which deposited them moved, although Harris (1971) stated that this is not always the case. Harris (1969b) suggested only 50 stones are needed to complete this analysis. Precise statistical tests may be applied to these data in order to ascertain a mean pebble orientation and its degree of reliability (Andrews, 1965) (Appendix III).

Two fieldwork seasons were used to map the glacial geomorphology of the thesis area, and examine each exposure. Unfortunately, due to the large extent of central Ayrshire, only a cursory examination of the well-developed raised beaches could be attempted. No detailed levelling programme has therefore been completed. It is felt that the proper examination of these features constitutes a thesis in itself.

I.3: Central Ayrshire - Location and Extent

Scotland may be divided into three distinct morphological regions. Firstly, the rugged Highlands in the north of Scotland, secondly, the low-lying Midland Valley and thirdly, the subdued Southern Uplands (Fig. I.I). The boundaries of central Ayrshire extend from the low-lying Midland Valley across the Southern Upland Fault and therefore into the Southern Uplands (Fig. I.I).

Central Ayrshire has a total area of approximately I250 sq. km.. Its maximum distance from north to south is 32 km. and from east to west is 45 km. (Fig. I.2). The northern boundary of central Ayrshire is defined along its western half by grid line NS35 and along its eastern half by the old county boundary between Ayrshire and Lanarkshire (Fig. I.2). The area to the north-west was studied by Ward and the area to the north-east was studied by McLellan (I967) (Fig. I.2). The boundary to the east is defined by the old county boundary between Ayrshire and Lanarkshire in the north and Ayrshire, Dumfriesshire and Kirkcudbrightshire in the south (Fig. I.2). Part of this eastern boundary represents the limits of McLellan's area (I967) (Fig. I.2). The southern boundary of central Ayrshire is delimited along its eastern half by the old Ayrshire and Kirkcudbrightshire county boundary and along its western half by grid line NS05 (Fig. I.2). The western boundary is delineated by the coastline of the Firth of Clyde from just south of Turnberry to just north of Troon (Fig. I.2). The main towns within central Ayrshire are Ayr, Prestwick, Troon, Mauchline, Catrine, Muirkirk, Cumnock, New Cumnock, Dalmellington and Maybole (Fig. I.2).

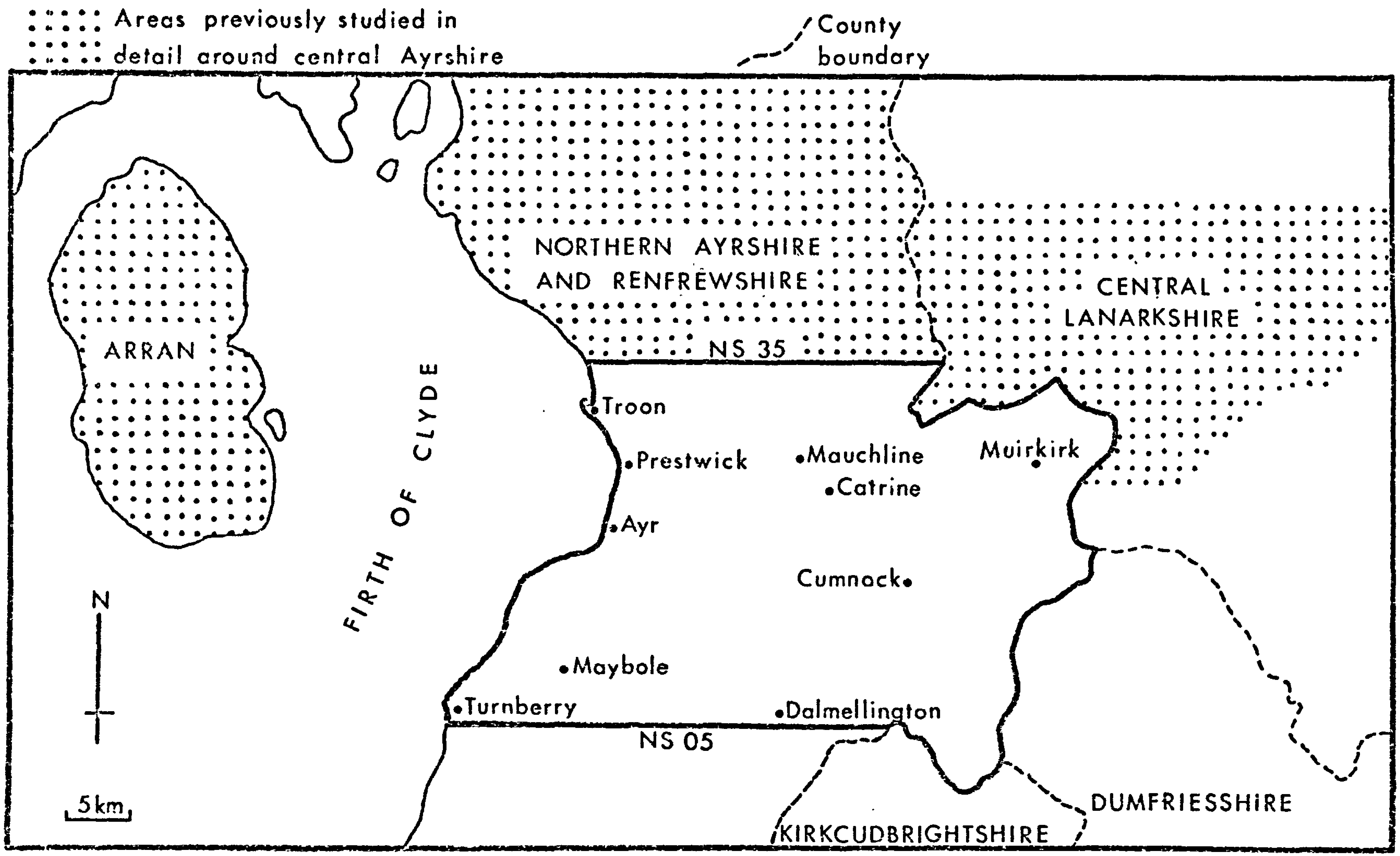


Fig. 1.2 Central Ayrshire - Location and Extent.

I.4: Central Ayrshire - Geology

Geologically, central Ayrshire may be subdivided into two quite distinct parts. I) - a limited area in the south-east which lies to the south-east of the Southern Upland Fault (Fig. I.3). This part of central Ayrshire is the upthrusted side of the Fault which has brought very resistant, highly contorted, Ordovician age rocks to outcrop at the surface. 2) - the remainder of central Ayrshire which lies to the north-west of the Southern Upland Fault. Structurally, this part of the thesis area has a basin configuration (Fig. I.3). The rocks within this structural unit range from Silurian to Tertiary in age. The rock-types are generally much less resistant to erosion and less contorted than the rocks to the south-east of the Southern Upland Fault.

The oldest rocks, therefore, in central Ayrshire outcrop to the south-east of the Southern Upland Fault (Fig. I.3). These resistant Ordovician age strata are gabbros and vesicular - basaltic - spilitic lavas of Arenig age, mudstones and cherts of Arenig-Llaldeilo age, greywackes and grey and black shales of Llandeilo age, grey and black shales of Caradoc age and greywackes, shales and pebbly grits (the famous "Häggis rock") of Ashgillian age (Eyles et al 1949). However, greywacke is by far the most common rock-type.

During the Caledonian earth movements in late-Silurian times, which produced the Southern Upland Fault, these rocks of Ordovician age were intensely folded. The axes of all the folds produced at this time in central Ayrshire were orientated in a north-east to south-west direction.

To the north-west of the Southern Upland Fault lies the Mauchline Basin. This structural unit has a profound influence upon the geology of the remaining part of the thesis area.

The Downtonian, or more precisely the " post-Ludlow pre-Gedinnian" (Cocks et al 1971, p. 105), inlier constitute the oldest strata in this part of central Ayrshire. These strata, which are part of the anticlinal inlier of the Hagshaw, Nutberry and Dungavel Hill areas, outcrop in the north-eastern part of the thesis area to the north of

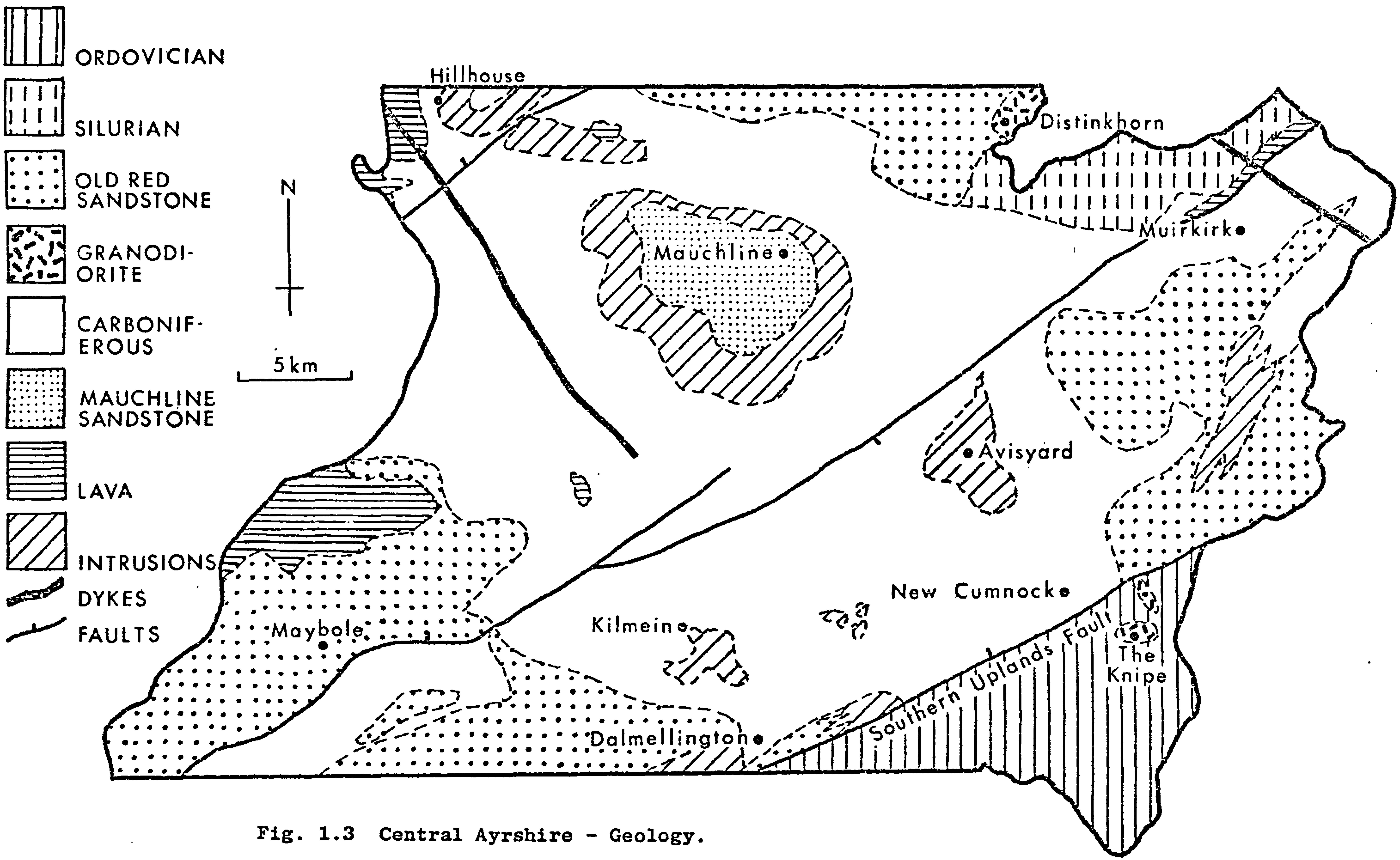


Fig. 1.3 Central Ayrshire - Geology.

Muirkirk (Fig. I.3). They consist of grey sandstones, grey flaggy and sandy shales, blue shale and bands of hard greywacke. (A Geikie et al 1871, p. 9).

Conformable on the Downtonian strata is the Old Red Sandstone age formation. These rocks, which include resistant sediments, lavas and intrusions are discontinuously exposed in the north, east and south of this part of the thesis area (Fig. I.3). The succession is also present across the Firth of Clyde on the Island of Arran. The distribution of these Old Red Sandstone rocks directly relates to the structural configuration of the Mauchline Basin. It causes the oldest rocks to outcrop at the edges and the youngest rocks to outcrop at the centre of the basin.

The Old Red Sandstone rocks in the northern and eastern parts of the thesis area have limited outcrops (Fig. I.3). The largest outcrop is in the south around the town of Maybole (Fig. I.3). The most important rock-type in this group, and in the thesis area as a whole in terms of potential usefulness in this study, is granodiorite. This importance is due to its highly distinctive character and its very limited outcrop; it is the one rock-type that does not outcrop more or less continuously around the basin and therefore identification of granodiorite erratics within the tills of the area may be of invaluable assistance when endeavouring to plot former directions of ice movement. There are only two plutonic granodiorite intrusions within central Ayrshire :-

a) The Distinkhorn complex which occupies part of the old Ayrshire/Lanarkshire county boundary in the northern part of the thesis area (Fig. I.3). "This igneous complex covers over 3(three) square miles (5.5 sq. km.)" (Macgregor, 1948, p. 25), and the dominant rock-type is hornblende - biotite granodiorite. Because it was intruded into less-resistant Silurian and Old Red Sandstone rock-types, this part of the thesis area forms a distinct hill mass.

b) The Knipe granodiorite intrusion outcrops in the south-eastern part of the thesis area near New Cumnock (Fig. I.3). Although this intrusion is smaller than that at Distinkhorn, it still forms a conspicuous elevated part of the landscape. This pluton, which is of biotite - hornblende granodiorite, was intruded into the complexly folded rocks of Ordovician age which lie to the south-east of the Southern Upland Fault.

One other granitic intrusion which may be of considerable importance in relation to central Ayrshire outcrops 5km. to the south of Dalmellington around Loch Doon.

Several smaller intrusions of Old Red Sandstone age are also represented in the thesis area. These are mainly the resistant volcanic necks. Such small and often isolated features may be of importance to this study because they frequently represent the 'crag' of crag and tail features. The identification of such features is an invaluable asset when trying to determine former ice movements in an area. An outcrop of very distinctive "pink felstone" (Geikie, 1873, p. 23) exists in the extreme north-eastern part of the thesis area - stretching from north of Muirkirk north-eastwards across the old county boundary into Lanarkshire (Fig. I.3). Again the identification of this rock-type as erratics in tills may be of invaluable assistance when plotting former ice movements.

The next youngest rocks in the Mauchline Basin are of Carboniferous age. Lithological groups within the Carboniferous are Carboniferous Limestone (now including Calciferous Sandstone), Millstone Grit and Coal Measures. Recently, Mykura (1965, p. 9) suggested that at least part of the "Permian" deposits in central Ayrshire may be of Carboniferous age: ".... the kylitic and teshenitic dolerite sills which cut the Carboniferous sediments of Ayrshire, and the intrusive monchiquites, which are closely associated with the "Permian" volcanic necks of south-west Ayrshire, are now to be taken to be of Upper Coal Measure age" (p. 9). These sills include Hillhouse Sill, Avisyard Sill and the Kilmein Sill (Fig. I.3). Mykura also suggested that the greater part of the "Permian" lavas and sediments may be Carboniferous in age: ".... It seems likely that the base of the New Red Sandstone (Permian) in the Southern Uplands is diachronous, and the basal beds of the Solway Basin and in north-west England may be considerably younger than the New Red Sandstone of Ayrshire" (p. 9). However, in terms of the aims of this study, the lithological characteristics are of greatest importance.

The principal Carboniferous sediments are sandstones and shales. Other, less extensive, rock-types include limestone, coals, ironstones, and oil shales. Due to the basin configuration, of which these rocks form an integral part, they outcrop on all sides of the structure (Fig. I.3). They may therefore be of little use in determining former ice movements if found as erratics. However, the most distinctive rock-type in this basin has a limited, and therefore potentially the most useful, outcrop at its centre, around the town of Mauchline. This is the Mauchline sandstone (Fig. I.3). This rock-type represents the former existence of ".... a vast accumulation of sand-dunes", (Eyles et al, 1949, p. 107). Its characteristics are most distinctive:"The colour varies little, ranging from brick-red to bright orange .... they are composed predominantly of quartz-grains of which the larger are wind-rounded; they are almost free from mica" (p. 107).

Central Ayrshire is traversed by basalt, dolerite and teshenite dykes of Tertiary age. These dykes, which are orientated in a north-west to south-east direction, are the youngest rocks in the thesis area. It is believed (Eyles et al, 1949) that these intrusions were contemporaneous with the formation of the Mauchline Basin because its fold axis has a similar north-west to south-east orientation.

I.5: Central Ayrshire - Relief and Drainage

The effect of the geology upon the relief of central Ayrshire is clearly expressed by Eyles et al (1949):"The broader physiographical features are directly controlled by the solid geology" (p. 10).

As would be expected, the part of the thesis area with the highest altitude lies to the south-east of the Southern Upland Fault (Fig. I.4). This high altitude is directly related to the resistant, steeply dipping Ordovician age rocks which underlie this part of central Ayrshire. The landscape is characterised by steep-sided hills which rise to a maximum altitude of 701m. at Blackcraig Hill (Fig. I.4). The relative relief values in this

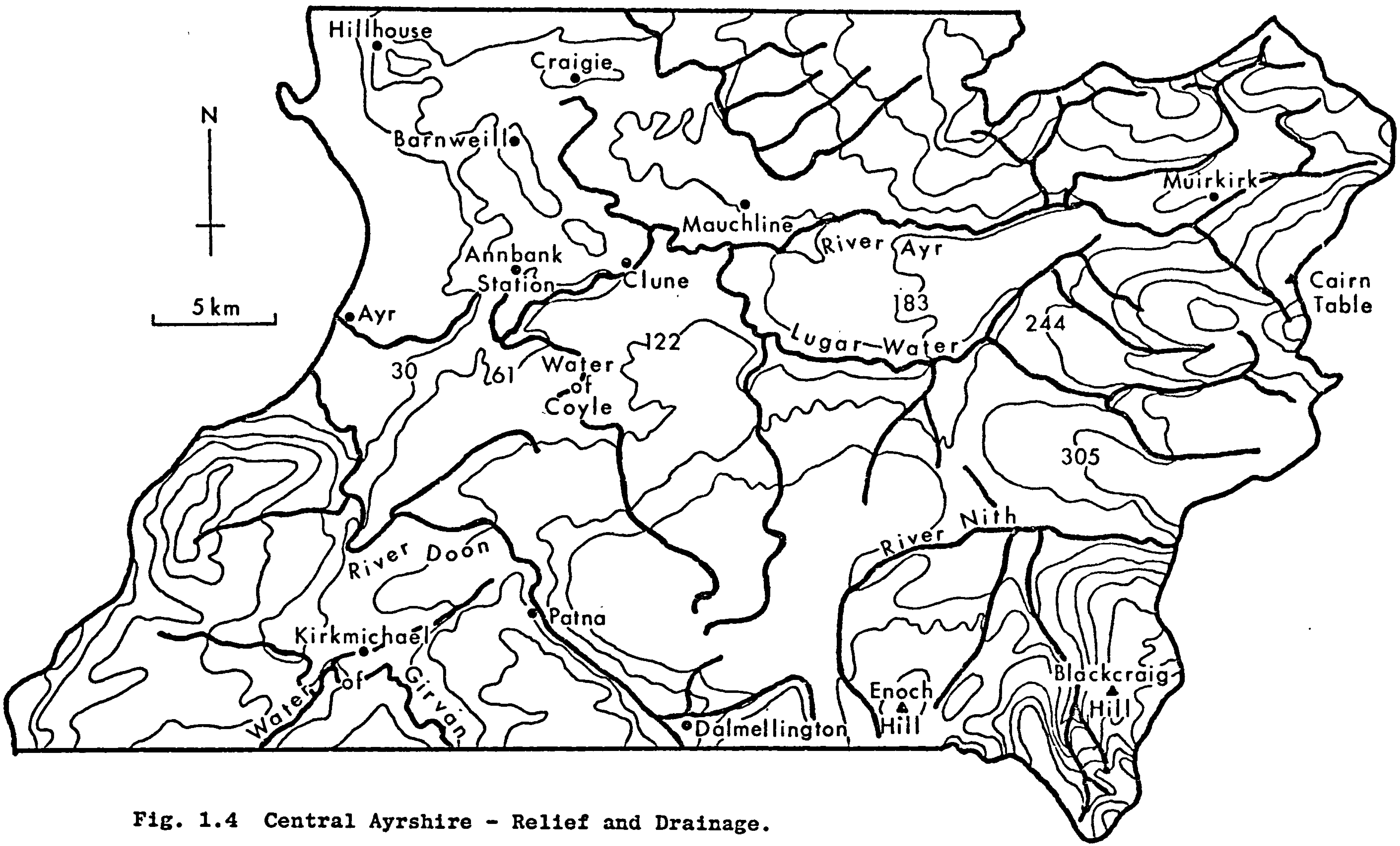


Fig. 1.4 Central Ayrshire - Relief and Drainage.

south-eastern part of the thesis area average approximately 170m.; the maximum value is 385m. These hills have a smoothed, rounded character and are often separated by broad, open valleys. A pattern of north-east to south-west orientated ridges and valleys exist in this part of central Ayrshire which are interpreted as a reflection of the Caledonian 'grain' of the underlying solid rocks.

The Old Red Sandstone age deposits which mainly outcrop in the east and south of the thesis area are also characterised by steep-sided, smoothed, rounded hills. However, they fail to reach the same altitude as the rocks to the south-east of the Southern Upland Fault. Cairn Table, which lies on the eastern boundary of central Ayrshire, is the highest summit with an Old Red Sandstone age foundation, 593m.O.D. (Fig. 1.4).

Carboniferous age rocks in central Ayrshire give rise to two distinct relief types. The first type is common on the eastern and southern edges of the Mauchline Basin. Due to the intrusion of resistant igneous rocks between the beds of less-resistant sediments, the succession as a whole may be regarded as resistant to erosion. This has produced an elevated plateau at approximately 300m. O.D.. The very gently undulating morphology of this region of central Ayrshire(relative relief values rarely exceed 75m.) reflects the almost horizontal character of the beds of rock.

The second relief region based upon Carboniferous age rocks lies to the west and towards the centre of the Mauchline Basin. This region is relatively low-lying altitudinally and is characterised by gently undulating relief; average relative relief values are approximately 75m. The low-lying character of this region is a reflection of the relatively easily eroded rock-types (where resistance to erosion has not been increased by the intrusion of igneous rocks) and due to the structural influence of the downwarped Mauchline Basin. A few ridges of higher ground exist in this part of central Ayrshire such as between Hillhouse and Craigie and between Barnweill and Clune (Fig. 1.4). These ridges correspond to outcrops of resistant volcanic rock.

The gently undulating morphology of the western part of central

Ayrshire is abruptly terminated at approximately 30m. O.D.. This is the upper altitudinal limit of the raised beach features which exist along most of the coastline of the thesis area and which extend to a maximum of 4km. inland (Fig. I.4).

Drainage within the thesis area is dominated by four major systems, the River Ayr, the River Doon, the Water of Girvan and the River Nith (Fig. I.4).

The River Ayr rises to the north-east of Muirkirk and flows for 35km. from east to west before it discharges into the Firth of Clyde at the town of Ayr (Fig. I.4). The Lugar Water, and Water of Coyle are two of the largest tributary streams of the River Ayr. The Lugar Water flows generally from south-east to north-west and joins the River Ayr 2km. south of Mauchline. The Water of Coyle flows generally from south to north and joins the River Ayr 4km. south of Annbank Station. The River Ayr has an extensive catchment area (Fig. I.4).

The River Doon flows out of Loch Doon which is 7km. south of Dalmellington and is therefore outside the thesis area. The River Doon generally flows from south-east to north-west along a valley which is deep, broad and U-shaped from the southern boundary of the thesis area to Patna (Fig. I.4). It then becomes very broad, open and V-shaped. The different valley forms represent a change in the resistance to erosion of the rock-types along the valley. Because of the deep U-shape of the upper part of the valley, the catchment area of the river is small.

Rising on the Loch Doon granite mass to the south of the thesis area at Loch Girvan Eye is the Water of Girvan. However, this river is only represented in central Ayrshire by a relatively small length of its course, approximately 10km. (Fig. I.4). 5km. of its course in central Ayrshire flows from south-east to north-west and 5km. flows from north-east to south-west. The Water of Girvan does therefore turn quite sharply through 90° near Kirkmichael (Fig. I.4).

Represented in central Ayrshire by its upper reaches only, the River Nith rises near Enoch Hill in the southern part of the thesis area (Fig. I.4). The River Nith flows for 7km. from north to south before turning to flow to the east across the remainder of central Ayrshire. This river eventually discharges into the Solway Firth after flowing through the Southern Uplands.

I.6: Central Ayrshire - Previous Work.

This section deals specifically with the glacial history of central Ayrshire as indicated by previous research completed inside and outside the area. It would, however, be capricious to attempt this without reference to the gradual integration of ideas through time which has lead to the development of the glacial theory as it is understood today. It is important, therefore, to examine how developments of the glacial theory have influenced the literature relating to the glacial history of central Ayrshire.

Prior to I840 the origin of most of the landforms and superficial deposits in Scotland was attributed to processes that operated during cataclysms. One such cataclysmic event was described by Buckland; (I823), his name for it was "Reliquiae Diluvanae" - The Great Submergence. At the time such a suggestion seemed the most likely to explain the existence of such features as bedrock covered upto high altitudes with accumulations of clays, sands, gravels and boulders which showed no apparent regularity. The descriptions of these deposits by geologists around this time were perspicacious and some of the associated conclusions (e.g. that these deposits indicate rapid deposition) were accurate. However, the agent of transportation and deposition was considered to be a violent deluge of water - the Noachian Flood. At this time very little was known about the processes and associated features produced by ice.

Buckland's book "Reliquiae Diluvanae" (I823) motivated many geologists to examine the widespread superficial deposits of Britain. Due to these detailed analyses and subsequent comparisons with contemporary marine processes, it soon became clear that the "Great Submergence" origin suggested by Buckland failed to explain certain characteristics peculiar to the unconsolodated superficial deposits. These anomalies included the generally unstratified nature of the deposits, the angularity of clasts and the widespread occurrence among the clasts of rock-types exotic to any particular area.

Lyell (1833) explained the anomalies in the superficial deposits by the introduction of the action of strong currents and floating ice into the submergence hypothesis. These ideas soon gained a considerable amount of support from contemporary geologists.

Four years later (1837) Agassiz first published his theory of glaciation. He explained the polishing of rocks, the transport of exotic rock-types, morainic deposition and other related features by the action of land-ice. The glacial theory was precipitated by the study of contemporary Alpine glaciers and associated regions in Switzerland. When this theory was translated into English one year later it was widely acclaimed. After a visit by Agassiz to Scotland in 1840 his hypothesis was widely accepted by geologists, including Buckland himself, as an explanation for many of the landscape features in Britain. Lyell and Darwin also accepted the idea of land-ice action, though they did have some reservations. Soon after 1840 the glacial theory became "uninfluential" (Hansen, 1970, p. 137). This was mainly the result of adverse reactions from some contemporary geologists, especially the influential Murchison who supported the floating-ice hypothesis. Hansen (1970) described this: "(he) by his (Murchison's) eloquence and influence delimited the general outlook of British geology for at least two decades," (p. 140).

It was approximately two decades later that Archibald Geikie (1863) writing on the "Glacial Drift of Scotland" revived interest in the glacial theory. His paper is a classic and few geomorphologists would argue that the establishment and application of the concepts of glaciation in Scotland owe more to A. Geikie than to any other person. His observations and descriptions were accurate and his subsequent explanations were, for the most part, correct; they even withstand rigourous scrutiny today.

A. Geikie caused great embarrassment to the exponents of the floating ice theory by simple logical deductions, for example, "The striae descend into the little dimples and hollows, and thus plainly indicate that the agent which produced them could not have been a rigid mass of sea borne ice, but must have been able to mould itself upon the rocks along which it moved." (A. Geikie I863, pp. 29-30). He also described striae found on the slate hills to the north of Loch Fad:"(the abrading agent) .... came up the steep northern face of that eminence, went right over the summit and pursued its course down into the next valley beyond." (p. 30). This is impossible to explain by the action of floating ice.

Based upon evidence derived from the study of striations, roche moutonees and erratics A. Geikie suggested the former movements (and origins) of the ice which occupied central Ayrshire. Reference was made to this in his classic paper of I863 but it is more clearly expressed in some of his later works. ".... in Ayrshire lay the meeting place of the masses of ice which moved southwards from the Highlands and northwards from the Silurian uplands of Galloway, Nithsdale and Clydesdale. "(Geikie et al , Explanation of Sheet I5, I87I, p. 38). He also stated:"It appears that the high ground ranging from the sources of the Afton north-eastwards through the Lowther and Leadhills to the Clyde, have served as a central axis of dispersion for the ice of the glacial period. This is shown by the fact that the striae on the rocks diverge from this axial line to the low grounds on the north and south." (p. 38).

By amalgamating all his work he elaborated the hypothesis of ice movements across central Ayrshire in "The Scenery of Scotland" (I90I) "From the direction of striae, it is evident that the Southern Uplands formed another centre of dispersion for the southern part of the Scottish ice-sheet (To speak more accurately there were several centres of movement of the ice that lay on these uplands. But the southern ice-field may be regarded as one vast sheet that moved outwards and downwards into the low grounds on all sides). A vast mass of ice flowed northwards into the plain of Ayrshire, where, joining the stream that was descending from the Highlands, it bent round to the west and went southwards down the Firth of Clyde.... Across the eastern part... the pressure of the deep and wide mer de glace, which descended from the Highlands into the Lowland valley, seems to have driven the southern ice eastwards". (A. Geikie I90I, pp. 34I-342) (Fig. I.5).

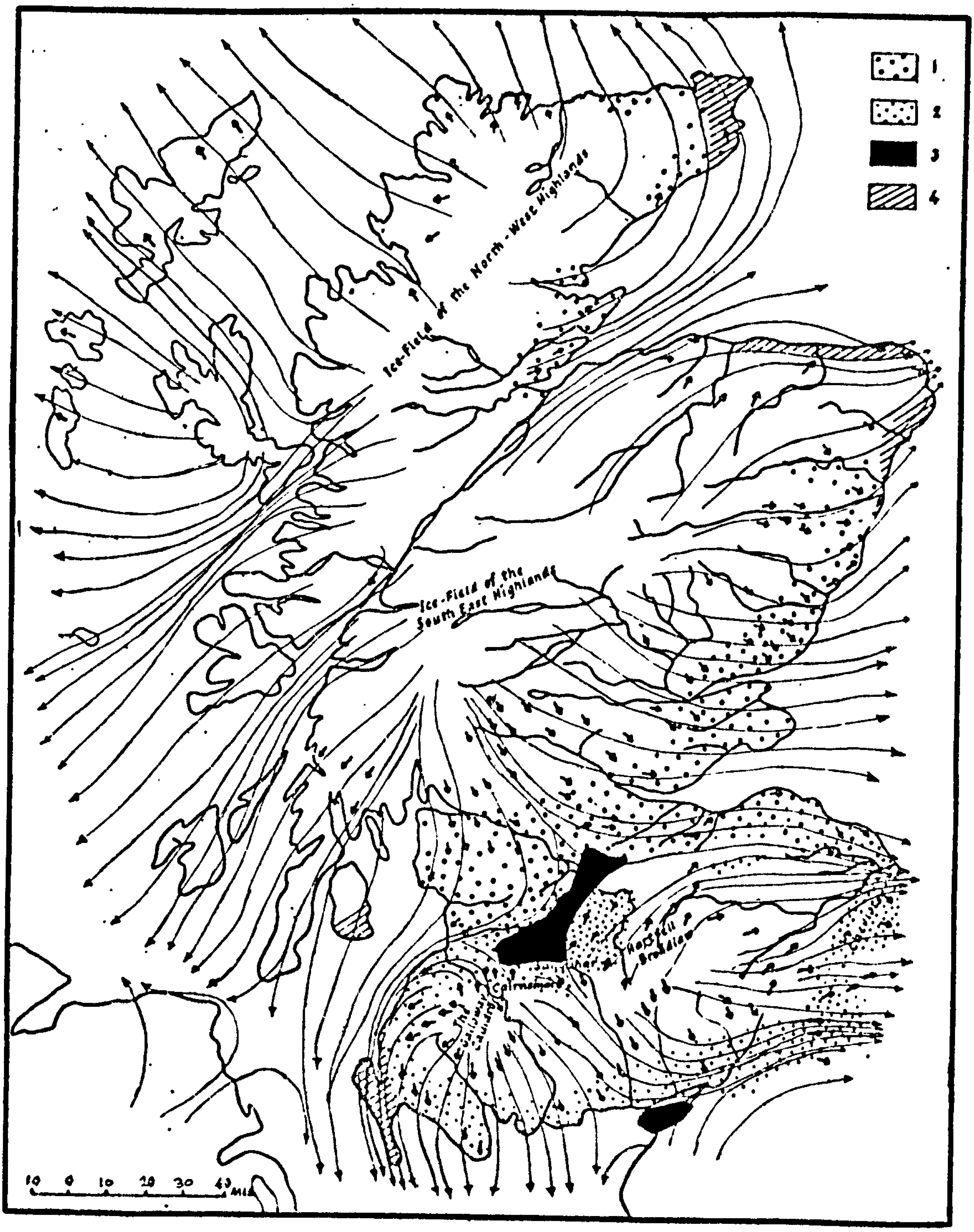


Fig. 1.5 Glaciation in Scotland - Geikie, 1894

1. Highland Erratics
2. Southern Upland Erratics
3. Debateable Ground
4. Shelly Till

→ Striae

James Geikie, the brother of Archibald, was also actively involved at the time in explaining the landscape of Scotland in terms of glaciation. He explained with great accuracy the origin of some features which had caused his brother some difficulty, for instance, the high altitude sands and gravels on interfluves which were widespread in Scotland. "In most cases such unfossiliferous deposits are probably of subglacial origin - they point to the action of water flowing underneath the ice sheet, and are therefore the same age as the till itself." (J. Geikie 1894, p. 90). One of J. Geikie's more important deductions was that the intensity of glacial activity fluctuated during the last glaciation. He hinted at a halt during the retreat of ice or its disappearance and subsequent re-introduction thus :- "The mounds and concentric ridges of the Highlands and Southern Uplands can only be terminal moraines, and points to a time when snow covered the higher districts of the country and sent down streams of ice into the mountain glens. That these glaciers really belong to the closing period of the Great Ice Age, it proved by the fact that in the Southern Uplands they have sometimes scooped out the moraine of earlier times from the bottom of valleys, but have left it untouched at heights on the hill-slopes which the later glaciers were unable to reach. Yet not a few of these latest glaciers were of considerable importance, as one may judge from the size and position of the moraines. Even the most extensive, however, were but pigmies when compared to those of earlier cold periods." (p. 269).

In the same volume J. Geikie pointed out more anomalies in the floating ice theory and subsequently strengthened the land - ice theory. At this time, and over the following 25 years or so, a great deal of "information about landforms and deposits associated with existing glaciers." (Price 1973, p. 6) was accumulated by American earth scientists working in Alaska (Russell 1892, 1893; Reid 1896; Tarr and Martin 1906; Tarr 1909; Tarr and Butler 1909; von Engeln 1912; Tarr and Martin 1914; Muir 1915). These studies, which provided detailed descriptions of wide ice fronts and the terminus of long valley glaciers as well as classic piedmont lobes, seemed to be a timely response to a comment by J. Geikie (1894): "Geologists are now agreed that the observed phenomena (i.e. the Scottish landscape) can only be explained by reference to what is taking place in Arctic and Alpine regions." (p. 56). Despite all the researches in areas of contemporary glacial activity the view that the superficial deposits of central Ayrshire were deposited during the Great Submergence was still held by some workers until as late as 1927 (Smith 1898; Gregory 1927). However, by the mid-1920's most geologists in Britain accepted that Scotland had been sealed in huge oscillating envelopes of ice, eroding, grinding, plucking and finally depositing in a particular fashion, thus producing characteristic landforms and deposits. Examination of the glacial and fluvioglacial landforms in central Ayrshire from the 1920's to the 1950's was dominated by Charlesworth (1926a,1926b) and the Geological Survey of Scotland (1948, 1949). Charlesworth's two papers in 1926 dealt with - 1) the glacial geology of the Southern Uplands west of Annandale and Upper Clydesdale and - 2) the readvance marginal kame-moraine of the south of Scotland and some later stages of retreat. Both these works relate to specific glacial features which exist within central Ayrshire and they served to indicate local and regional patterns of glaciation.

Charlesworth (1926a) maintained that all the evidence of retreat of the Southern Uplands ice in south-west Scotland is furnished by moraines or outwash fans, marginal drainage channels being generally absent. Based upon this evidence he suggested that the ice back-wasted into a series of valley glaciers. The moraines formed by this retreat in the valleys were either due to a temporary halt in ice recession or due to a slight readvance. Charlesworth ascribed the absence of an outer moraine in central Ayrshire (i.e. where the Southern Upland ice attained its maximum northward extent) to the confluence of this ice-sheet with the Highland ice-sheet.

In his second paper of 1926 Charlesworth (1926b) referred to the "great morainic belts" of southern Scotland as being "...without doubt the most conspicuous and easily recognisable and determinable of the drift formations." (1926b, p. 26). Charlesworth noted that the "outermost" morainic belt skirted the northern flanks of the Southern

Uplands. He continued;"... The (Highlands) ice-sheet at this stage was still extremely powerful; it overode the Pentland Hills, abutted against the slopes of the Southern Uplands to an altitude exceeding in places I,000 feet (300m.), filled the shallow seas on the west, and spread out far over the sea floor on the east" (p. 27). This deflection of Highland ice by Southern Upland ice is similar to that suggested by A. Geikie (I90I, p. 34I-342) (Fig. I.5).

The "great morainic belt" is reported by Charlesworth (I926b) to extend without a break from St. Abbs head to the Clyde above Lanark and the vicinity of New Cumnock, occurring again at Stranraer and the Rhinns of Galloway (p. 27). A detailed pattern of the retreat of the Highland ice-sheet from the "Lammermuir - Stranraer moraine" is promoted by Charlesworth in this paper and a considerable amount of the evidence upon which it is based lies within central Ayrshire (Fig. I.6). He continued : ".... a kettle-moraine runs along the south-side of the Douglas valley to Muirkirk, whence "there is a straggling line of kames" (Mem. geol. surv., Sheet 23 (I873, p. 44) on the moors to New Cumnock. At this period the ice apparently covered more or less completely the Hagshaw and Nutberry Hills, which extend northwards from Muirkirk to the Irvine and Avon valleys. As in the case of the Pentland Hills, the thinning of the ice, consequent upon the retreat, caused an early emergence of the higher summits and the formation of two ice-lobes - the one, the "Airds Moss Lobe", thrust from the west into the Ayr valley to Muirkirk, the other extending up the Douglas Water, from the east or north-east. The marginal streams flowing along the north edge of the "Airds Moss Lobe" and the drainage of the ever-increasing ice-free area of the Hagshaw and Nutberry Hills carved a series of channels ... the highest was observed at an altitude of approximately I300 feet (400m.) O.D.". (Charlesworth I926b, p. 32-33) (Fig. I.6).

Charlesworth maintained that along the margin of the "Airds Moss Lobe" a kame terrace was deposited around Meanlour Hill. A similtaneous shrinkage of its southern margin initiated the formation of some marginal channels between the valleys of the Gass and the Ayr; these drained to the north-east into "Lake Muirkirk". The existence

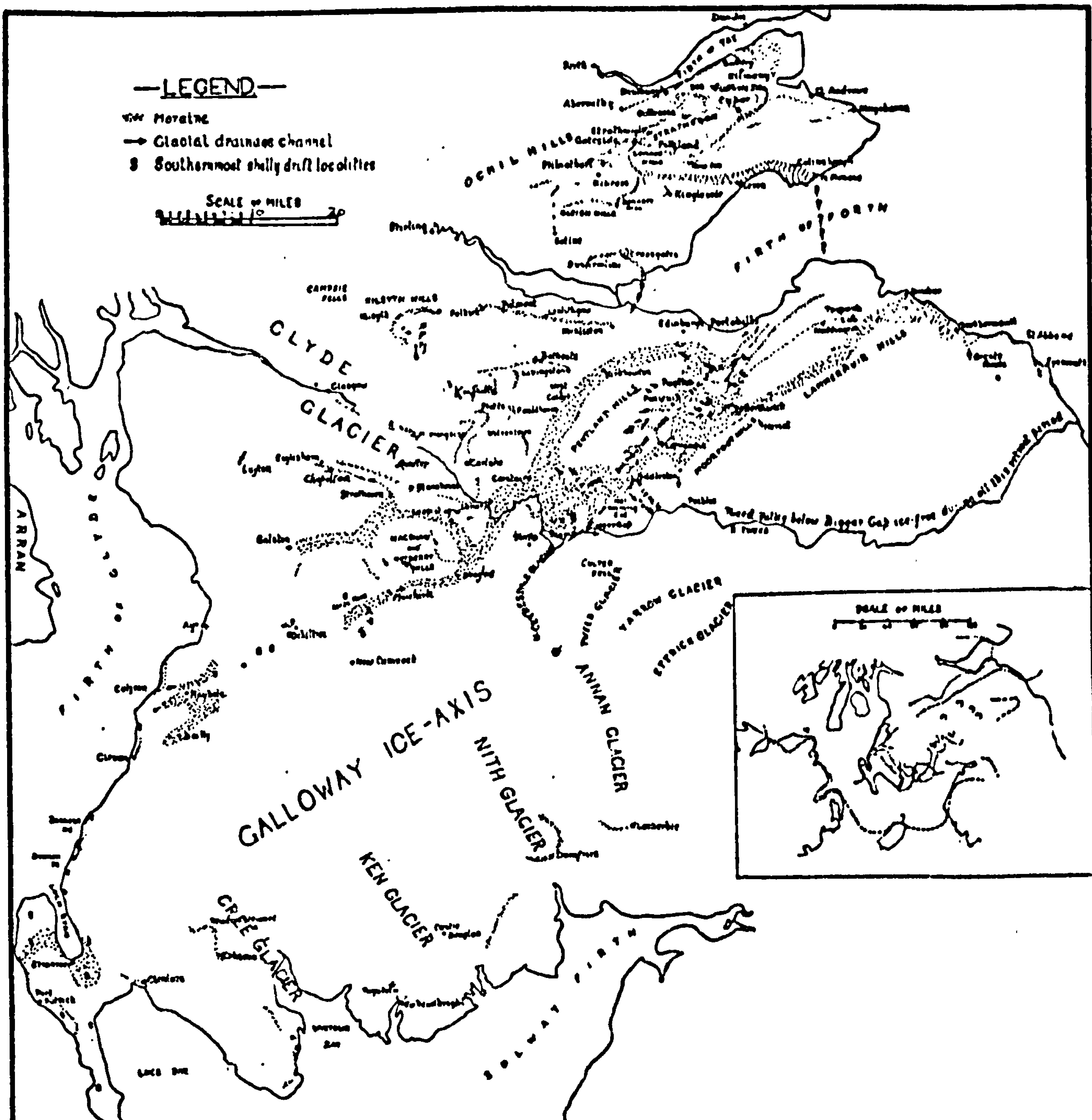


Fig. 1.6 Glaciation in Southern Scotland - Charlesworth,1926b.

of this ice-dammed lake had also been suggested by J. Geikie in 1894 (p. 179) and more general considerations relating to ice-dammed lakes had been propounded by Kendall (1902). The later work was widely accepted by geologists from the early 1900's until the late 1950's. These waters of "Lake Muirkirk" drained eastwards across the Ayr/Douglas watershed into the Douglas valley.

A series of "tumultuous morainic mounds" (Mem. geol. surv., Sheet 14, 1869, p. 25) were recognised by Charlesworth in the neighbourhood of Maybole (Fig. 1.6). Moraines of a slightly later date were said to exist to the east of Maybole. The moraines in this part of central Ayrshire were correlated with the "Pentlands-Carstairs-Galston moraine" (henceforth the "Pentland-Maybole moraine") - the earlier "Lammermuir-Stranraer moraine" being absent from south Ayrshire (Charlesworth 1926b, p. 39). The large gap in the "Pentland-Maybole moraine" between Galston and Maybole is ascribed to the confluent nature of the Highland ice-sheet with the Southern Upland ice-sheet.

Referring to the dissipation of the ice from central Ayrshire Charlesworth continued:"... The manner of the later recession from south and central Ayrshire is difficult to ascertain. The Doon and Lugar Water glaciers doubtless shrank southwards up the valleys while the Highland ice withdrew northerly or north-westerly, its edge swinging off the coast and out to sea in a series of crescentic curves ..." (1926b, p. 39).

The evidence used by Charlesworth which suggested readvances of ice in the form of sheets and lobes was varied:-

1) The presence of schist and gneiss erratics, which are of Highland origin, could only be substantiated north of the moraine ridges.
2) The shelly boulder clays (tills) identified by John Smith (1898) in central Ayrshire were also used because they are only found north of the morainic ridges identified by Charlesworth.
3) Multi-sequence exposures of till-sand and gravel-till were understood to signify a regional readvance of ice.
4) Meltwater channels were interpreted as an indication of an ice-dammed lake or as features eroded in an ice-marginal situation.

5) That ice always back-wasted towards its source area.

The conclusions reached by Charlesworth in 1926 are a good indication of the state of knowledge of the mode of ice advance and retreat in the mid-1920's.

The Officers of the Geological Survey of Scotland were industrious in central Ayrshire from 1920 to 1949. A great deal of new information was presented in the "Summary of Progress" series of publications. The information contained in these articles was integrated and put in a regional context with the publication of the memoir "The Geology of Central Ayrshire" in 1949. The chapter which relates to the glacial period began: "If the complete history of events during the Glacial period in central Ayrshire were known it is possible that, for this area as for other parts of Britain (Wright 1937, chaps. IV, V, and VI), more than one glaciation would have to be chronicled. As far as evidence at present takes us, however, only one glacial episode is apparent" (Eyles et al, 1949, p. 124). In the same chapter the "one glacial episode" is divided into three distinct phases. The first of these was a movement from west to east of a confluent ice stream of Highland and Southern Upland origin and the Highland ice is reported to be the dominant component. (Fig. I.7). An unusual characteristic of a west to east flow of ice across central Ayrshire would have been that it flowed uphill. The west to east transport of boulders of distinctive rock-types such as lugarite was used by Eyles et al as a strong indication of this movement. Other evidence of this west to east movement of ice was the frequent occurrence of marine arctic shell fragments in the boulder clay (till) of the area (which were thought to be derived from the Firth of Clyde) and the west to east elongation of a number of drumlin ridges - especially between Ayr and Coylton. Evidence for the powerful pressure exerted by the Highland ice was indicated by the altitude to which shelly boulder clay (till) was carried (1061 feet (323m.)) and by the short distance the ice-stream from the Southern Uplands was able to move northward, before being diverted to the east and south-west.

The second phase of glaciation recognised by Eyles et al was the relaxation of the pressure of the Highland ice (or conversely an increase in the pressure exerted by the Southern Upland ice, though this was not suggested by Eyles et al). This was concurrent with a northward extension of ice from the Southern Uplands, and a westward thrust of ice occupying the high area (Distinkhorn - Muirkirk - Sanquhar). (Eyles et al 1949, p. 124) (Fig. 1.7).

The evidence for this second phase of ice movement was based upon the existence of boulders from parent outcrops which lie to the south-east of the Southern Upland Fault in till deposits which are a considerable distance north-west of the fault. These rock-types mainly included greywackes and Loch Doon grandiorites. However, Eyles et al also noticed in till deposits the existence of these rock-types together with Highland erratics and shell fragments. This was explained by a zone across central Ayrshire where the "crossing over" of ice-masses had taken place. Eyles et al explained that no apparent break in the deposition of boulder clay (till) was evident; there was merely a tendency for a greater concentration of grandioritic boulders in the upper parts of boulder clay (till) exposures and a lightening in the colour. A change in the texture of the boulder clay (till) from a clay to a loam or a sand was also used as evidence for the former existence of a "crossing over" zone of ice-sheets. The general movements of the Southern Upland ice-sheet as recognised by Eyles et al was based upon evidence derived from the study striae, crag and tails, roche moutonee and glaciated troughs. These features indicated a general movement from the south-east but deflections east and west were still in evidence (Fig. 1.7).

The third and final phase of the glacial episode in central Ayrshire was the general retreat. Eyles et al suggest that during the retreat the Highland and Southern Upland ice-masses gradually parted. The Highland ice retreated from east to west and south-west across the Ayrshire lowlands and the Southern Upland ice assumed a south to south-easterly retreat. Eyles et al commented upon the general absence of deposits which are characteristic of glacial retreat such as moraines, gravel spreads and eskers. The explanation offerred was : ".... while the lowland ice was retreating to lower and lower levels, the meltwaters remained stagnant along the ice front or sceped back under it, instead of flowing freely away" (p. 129). This explanation was also used to account for the sparse distribution of meltwater

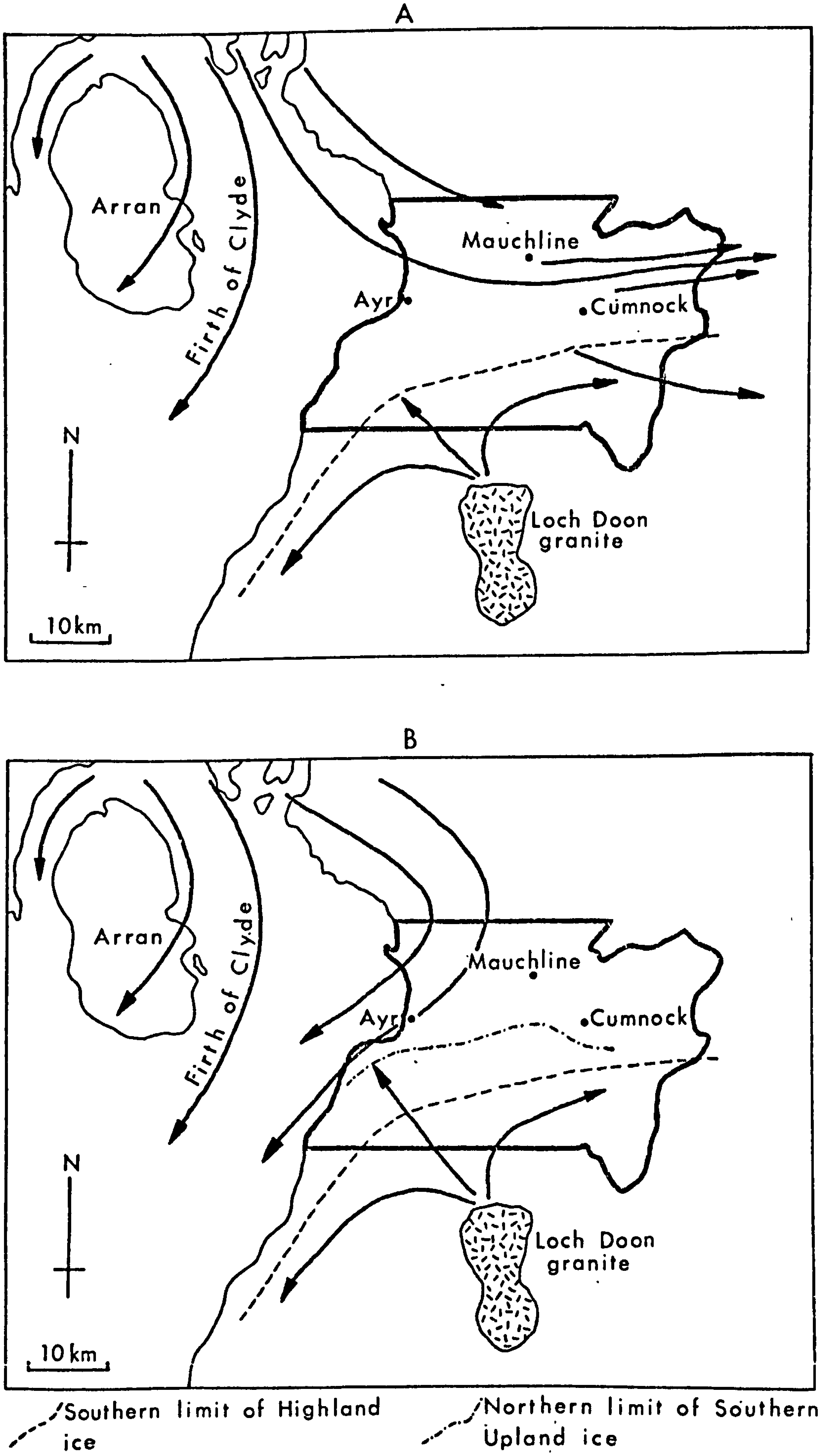


Fig. 1.7 Glaciation in Ayrshire - Eyles et al, 1949.

A. At glacial maximum. B. At a later stage.

channels.

Eyles et al reiterated J. Geikie's original idea (which was supported by Charlesworth 1926b, p. 33) of the existence of "Lake Muirkirk" which was impounded when the ice was established around Cumnock. It was suggested that the waters of this lake eventually escaped into the Nith valley (i.e. to the south) via a series of channels which lie to the south-east of Cumnock. This view of the draining of "Lake Muirkirk" is at variance with Charlesworth's idea that the waters drained eastwards into the Douglas valley. Another suggestion by Eyles et al at variance with Charlesworth's hypothesis was that Southern Upland ice was the last to have extended across the thesis area before ice decay.

Channels which exist in conjunction with the Maybole morainic spread (described by Charlesworth) were also noted by Eyles et al. It was concluded that this was a frontal moraine which was the product of "... a halt or even a slight readvance, of a large ice-lobe in its retiral seaward between Brown Carrick Hill on the north and the rising ground south of the Girvan valley". (p. 132). The evidence for the formation of this moraine included the study of "overflow" channels which lie to the north of the spread. Two distinct boulder clays (tills) were also identified in the vicinity of Maybole, the lower till was reported to be of Southern Upland origin and the upper till was reported to be of local origin. The upper till displays the morainicmorphology. This view of the moraine having been formed in front of ice which lay to the west is opposed to Charlesworth's (1926b, p. 39) view that the ice-mass lay to the east.

Eyles et al also provided a section in this memoir which dealt with the identification of raised beaches within the thesis area. Raised beaches were recognised along the western fringe of central Ayrshire to approximate altitudes of 110 feet (33.5m.), 95 feet (29m.), 80 feet (24.5m.), 75 feet (23m.), 70 feet (21.5m.), 40 feet (12m.) and not more than 20 feet (6m.) (Eyles et al 1949, p. 139-135). No suggestion of the age of these beaches is offerred.

Detailed work in central Ayrshire since the publication of the Sheet 14 Memoir has been absent. The most important works are the result of research completed outside the thesis area which have made great use of observations from areas of contemporary glaciation (Sissons I958a, I958b, I958c, I960, I96Ia, I96Ib, I963, I964, I967b; Price I960; McLellan I967; Clapperton I968, I97I; Gemmell I97I). Some of these works have indicated broad regional patterns of glacial advance and retreat and this has meant a subsequent reappraisal of existing descriptions of glacial and fluvioglacial features and deposits in central Ayrshire.

The early work by Sissons, who has been the most industrious researcher in the field of Scottish glaciation, concentrated on local problems such as subglacial drainage around the Tinto Hills in Lanarkshire or fluvioglacial deposition in the Eddleston valley (I958b, I96Ia). The detail and accuracy of this work is praiseworthy. However, it is the broad regional implications of these works which are of relevance to the study of glaciation in central Ayrshire. For instance, Sissons argues that various eskers are so well preserved that they could not have survived unless the ice around them was stagnant at the time of their formation (Sissons I96Ia, p. I90). Sissons continued: "The concept of stagnation has long been applied to thin ice occupying low ground in Scotland, but it does not appear to have been applied to the thicker ice in upland areas"(p. I9I). The reappraisal of glacial retreat by the process of widespread stagnation and decay of an ice-sheet in situ was largely based upon ideas developed by Flint (I929) who worked in North America and especially Mannerfelt (I945, I949) who worked in Scandinavia. "Hollingworth (I952) was the first British worker to apply the conclusions of Scandinavian workers in Britain, but it was Sissons ... who really followed the Scandinavians methodology and applied their concepts of downwastage and subglacial and englacial drainage with great success" (Price I973, p. I0).

By using the concept of ice stagnation in Britain Sissons showed that Kendall's (I902) hypothesis which related to "overflow channels" from proglacial lakes was untenable (I958a, I958b, I958c). Sissons in these early papers also re-examined parts of the "moraines" identified by Charlesworth (I926a, I926b). His conclusion from this re-examination was:"... The so-called Kame-moraine of the Eddleston valley, Peebleshire, has been shown to have formed by streams washing material into dead ice". (Sissons 1961a, p. 192). Evidence which indicates that the Southern Upland ice-sheet became stagnant is afforded by the ".... almost featureless till mantling hill slopes ... the occurrence of eskers winding downslope and of numerous subglacial channels, some of the latter descending slopes for several hundred feet" (Sissons 1961a, P. 192-193).

Working specifically on the central and eastern parts of Charlesworth's "Lammermuir-Stranraer moraine" Sissons (1961b) concluded that the feature is ".. composed almost everywhere of fluvioglacial deposits formed in association with dead ice" (p. 391). In the same paper he agreed with one of the conclusions of Eyles et al (1949) "over a considerable length of the northern edge of the Southern Uplands the last glacier ice came from the Southern Uplands, not from the Highlands as Charlesworth maintained" (Sissons 1961c, p. 391).

Having rejected the suggestion that the "Lammermuir-Stranraer moraine" was a true moraine which reflected a stage of ice readvance Sissons (1963, 1964) himself suggested a readvance (this was based upon an original idea by Simpson (1933)) - the Perth readvance. Sissons based the existence of the Perth readvance upon both morphological and stratigraphical evidence, especially the latter. According to Sissons ice during the Perth readvance enveloped the whole of the thesis area (Fig. 1.8).

In 1967 Sissons systematised all the previous research relating to the glacial geomorphology of Scotland to produce "The Evolution of Scotland's Scenery". In this Sissons postulated three major readvances of ice since the maximum extent of the last glaciation: the Aberdeen-Lammermuir readvance, the Perth readvance and the Loch Lomond readvance (Fig. 1.8). The oldest of these readvances was the Aberdeen-Lammermuir readvance,the existence of which has now been rejected (Clapperton and Sugden, 1972). Also rejected is the Perth readvance - the objections to this readvance have been expressed by Paterson (1974). It is now generally agreed that sound evidence for only one major readvance, the Loch Lomond readvance, exists.

Detailed studies were carried out in areas in close proximity to central Ayrshire by McLellan (1967) in central Lanarkshire and by

Fig. 1.8 Successive limits of the last ice-sheet and associated directions of ice movement. Sissons, 1967b.

Gemmell (I97I) on the Island of Arran. McLellan's (I967) study in central Lanarkshire is of particular interest with reference to central Ayrshire because they are immediately adjacent areas. The main conclusions included:-

I) Central Lanarkshire was overridden by ice on several occasions.
2) The most recent of these ice invasions occurred during Zone I times and is, as suggested by Sissons, to be correlated with the stage known elsewhere as the Perth readvance.
3) The area was affected by two ice masses, one from the Southern Uplands which moved from a generally west - south - westerly direction across central Ayrshire and over the watershed, the other was of Highland origin and moved from a generally west - north - westerly direction (Fig. I.9).

The work by Gemmell on the glacial geomorphology of the Island of Arran is also of relevance to the study of central Ayrshire. Gemmell (I97I) does not support the hypothesis of a Perth readvance of ice. He suggests that evidence, which in the past was used as an indication of such a readvance, is best explained by a halt during the general retreat of ice. Highland ice moved generally from north to south across the island but in the later stages of glaciation the ice in the south-eastern part of Arran was deflected to flow towards the south-west. Gemmell suggests that this relates to the extension of ice from the Southern Uplands which altered ice flow in the Firth of Clyde (I97I, p. I78). There was no doubt in Gemmell's mind of the existence of a Loch Lomond readvance - the maximum extension of this readvance was "... delimited with a fair degree of accuracy in Arran by a series of well preserved moraines .." (I973, p. 37).

Gemmell (I97I) also produced an explanation and relative chronology for the raised shorelines on the island of Arran. He identified a late-glacial shoreline which varies in altitude from 27-28m. O.D. in the south of the island to 30-33m. O.D. at its northern limit. He was not able to locate any shoreline deposit on Arran at such an altitude in the northern part of the island, the highest shorelines in the northern part are found at I7-24m. O.D.. However, the I7-24m. O.D. shoreline is clearly discernable in the southern part of the

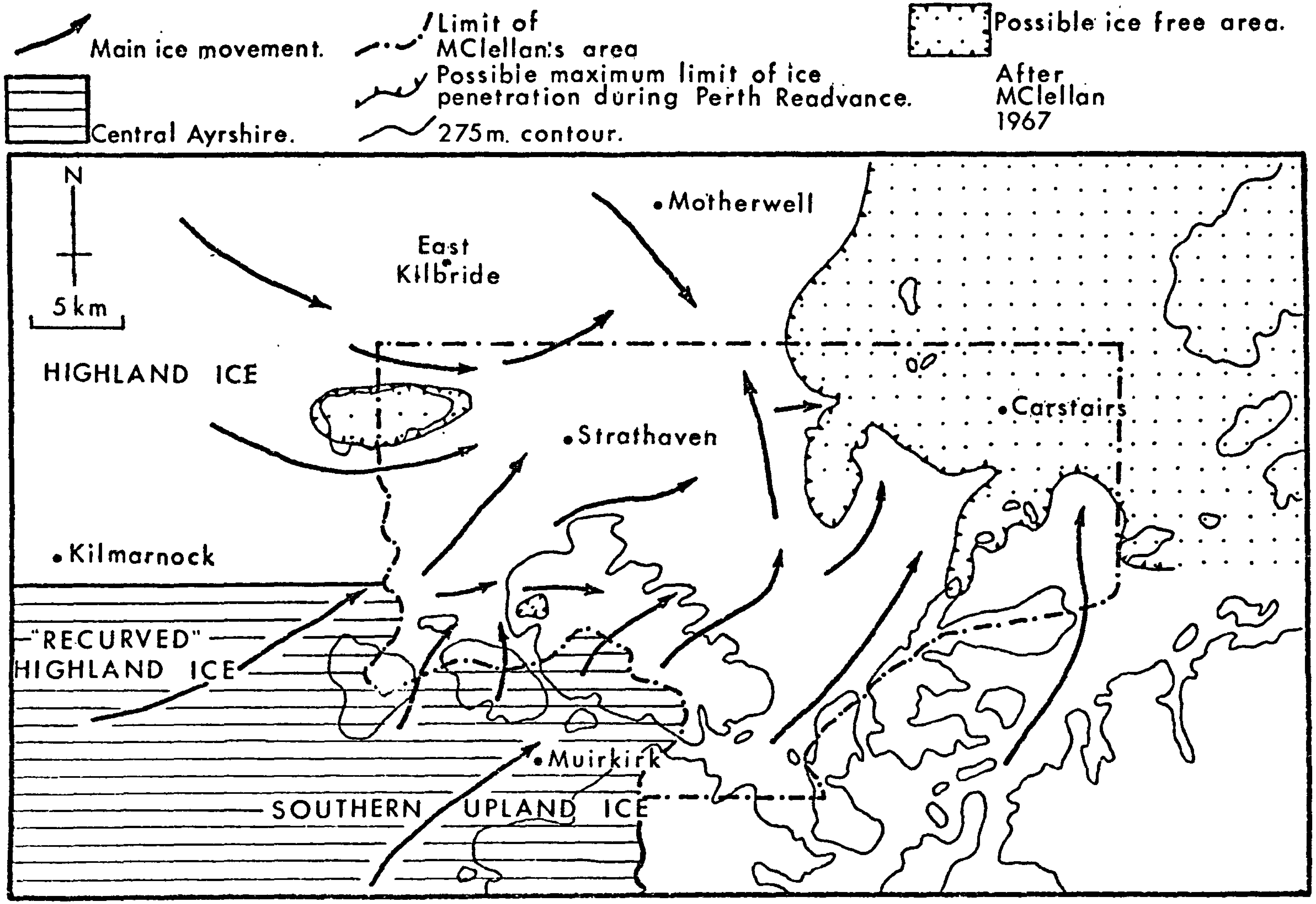


Fig. 1.9 Glaciation in Ayrshire/Lanarkshire - McLellan, 1967.

island and it is distinct from the 27-33m. O.D. shoreline. Because of the fragmentary nature of the Main Post-glacial Shoreline on Arran Gemmell used methods developed by Andrews (I970) to aid the study. From this, the main Post-glacial Shoreline was found to be at an altitude of IOm. O.D. in the north of the island and just under 9m. O.D. in the south. Gemmell's results and methods were seriously criticised by Gray (I975) who concluded "Thus I am lead to believe that Gemmell's lateglacial history of the Firth of Clyde may be considerably in error and I hope that future workers will be cautious in adopting his results". (p. I3I).

Raised beaches have been identified in central Ayrshire by Jardine (I97I) and at other points along the Firth of Clyde and the Solway Firth (Jardine I962a, I962b, I964, I975), (Fig. I.IO). He described the raised beaches thus:"Along the Firth of Clyde seaboard between Ayr and Ardrossan (Fig. I.IO) occur remnants of at least one late Pleistocene shoreline and associated coastal deposits .... Throughout most of its length the shore-line is cut in till and as a result, an ill-defined coastal feature is now preserved. At Heads of Ayr and Hillhouse (Fig. I.IO), the shore-line was located in solid rock; prominent headlands of the late Pleistocene coast occurred at those localities". (p. I03-I04). He referred to the deposits as follows:"....The late Pleistocene coastal deposits of central Ayrshire are mainly stratified sands and gravels, occurring at heights of up to 24m. A.O.D." (Jardine I97I, p. I04). Jardine (I97I) also identified post-glacial beaches in central Ayrshire: "The positions of former Holcene shore-lines in south-west Scotland are fairly accurately known, both along the northern seaboard of the Solway Firth and in the Firth of Clyde area. At some localities two distinct shore-lines are identifiable. The higher is the equivalent of the Main Post-glacial shoreline described in other parts of Scotland. It was formed at the maximum of the Holocene marine transgression. The lower shore-line represents a temporary halt position in regression of the Holocene sea from its maximum to its present position" (cf Donner I963, IO) (p. I06-I07). Referring to central Ayrshire specifically Jardine stated:"In central Ayrshire, at the maximum of the Holocene marine transgression, the sea occupied wide bays to the north and south

Fig. 1.10 Raised Beaches in Ayrshire - Jardine, 1971.

south of Hillhouse (Fig. I.IO). ... the maximum height of the surface of the deposits is I2m. A.O.D.", (p. I09).

Patterns of ice advance and decay and related sea level changes for central Ayrshire has been built up since the pioneering work of the Geikie brothers in the mid-I9th century. However, two potentially useful techniques of study have been developed within the past 20 years; these are pollen analysis and absolute radiometric dating. Pollen analysis deals with the identification of pollen spores from peat deposits or sedimentary deposits. Pollen diagrams are then constructed which indicate the dominant vegetational types at the time of deposition of the peat or sediment. These vegetational types may then be interpreted as representative of particular climatic regimes. It is possible, therefore, to construct a pollen diagram from earliest Late-glacial times (Pollen Zone I) to recent times (Pollen Zone VIII). These studies only provide a relative chronology.

The dating of biogenic material by the carbon I4 technique provides an absolute chronology. The combination of reliable pollen analyses and carbon I4 dates from around central Ayrshire (Donner I957, I970; Bishop I963, I970; Sissons I967a, I974b; Peacock I97I; Jardine I97I, I975; Gemmell I973; Gray I974), indicates an accurate chronology of glaciation and related events:-

I) Central Ayrshire was ice-free 27,000 yrs B.P.

2) It is generally agreed that the Devensian (i.e. the last ice sheet) reached its maximum extent about I8,000 yrs.B.P. The last ice-sheet, therefore, developed to its maximum dimensions in 9,000 years.

3) After it reached its maximum extent the ice-sheet in Scotland waned. It is not certain whether the ice-sheet disappeared completely from Scotland and re-established itself or whether remnants remained, but a readvance of ice occurred between II,000 and I0,000 years B.P.; the Loch Lomond readvance.

4) During ice decay the late-Pleistocene raised beaches were probably deposited approximately I3,000 years B.P..

5) Post glacial beaches were deposited between 8,400 years B.P. and 6,600 years B.P.

I.7: Organisation of the Thesis

The thesis consists of seven chapters. The first chapter introduces the study, the area and the previous literature relating to the glaciation of central Ayrshire. Chapters 2, 3, 4, 5, and 6 describe and analyse the glacial geomorphology of 5 sub-areas which comprise central Ayrshire. The 5 sub-areas were arbitarily defined but where possible the watersheds between major drainage systems within the thesis area were used (Fig. I.II). Area I is discussed in Chapter 2, Area II is discussed in Chapter 3 and so on. Each chapter is introduced with reference to its location and extent, and its relief and drainage and geological characteristics. The features which are related to the glaciation of central Ayrshire are then systematically described and analysed in detail, with particular reference to form and distribution. In each chapter the description and analysis of features and deposits are subdivided under the headings of glacial erosion, glacial deposition, fluvioglacial erosion and fluvioglacial deposition. In Chapters 3 and 4 (Areas III and IV) a fifth subdivision which relates to raised beaches and other evidence which suggests former high stands of sea level is presented (these are the only two areas of central Ayrshire which contain such features). At the end of each of these chapters a brief resumé of the evidence is offered and subsequently considered as a whole in terms of former ice movements and ice limits. A glacial chronology is also propounded in the conclusion of each chapter.

Chapter 7 is the conclusion. The conclusions reached in Chapters 2 to 6 are assessed and considered in relation to central Ayrshire as a whole. A discussion is presented on how these conslusions affect the literature relating to central Ayrshire and this part of Scotland generally.

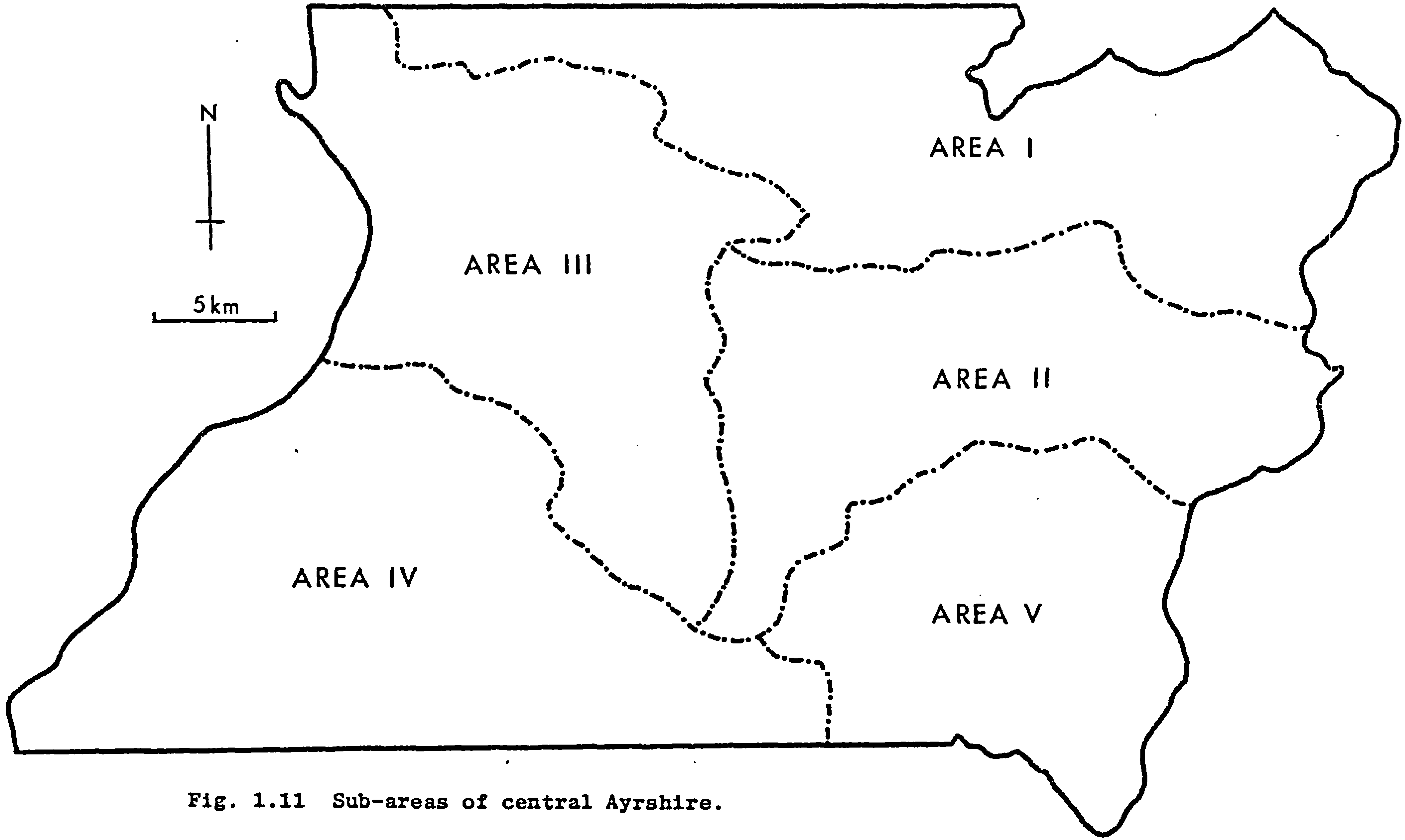


Fig. 1.11 Sub-areas of central Ayrshire.

CHAPTER 2

AREA I

2.I: Introduction: Location and Extent

Area I is the northern part of central Ayrshire and is approximately 285 sq. km. in extent (Fig. 2.I). It is 25 km. from east to west and 8 km. from north to south. The western half of the northern limit of the area is represented by grid line NS35 and the eastern half is represented by the old Ayrshire/Lanarkshire county boundary (Fig. 2.I). The eastern limit of the area is entirely represented by the old Ayrshire/Lanarkshire county boundary. The southern limit of Area I is represented in the eastern half by the watershed between the Lugar drainage system (Area II) and the Upper Ayr drainage system (Area I) and in the western half by the watershed between the Lower Ayr drainage system (Area III) and the Upper Ayr drainage system (Fig. 2.I).

Area I contains evidence of glacial erosion, glacial deposition, fluvioglacial erosion and fluvioglacial deposition. Throughout the area the distribution and intensity of this evidence is diverse and as a result its scale of presentation varies for clarity of description.

2.2: Relief and Drainage

Area I has a variety of relief forms between its highest altitude of 593m. O.D. at Cairn Table in the east and its lowest altitude of I5m. O.D. near Dundonald in the west (Fig. 2.2). These relief forms are of two distinct types which are related to the solid geology (Fig. 2.3). The first type of relief is confined to the eastern part of the area and the second type is confined to the western part.

The first type of relief form is characterised by high altitude, steep-sided hills which are underlain by resistant Silurian greywackes, Old Red Sandstone sandstones and Carboniferous igneous rocks (Cairn Table (593 m.), Little Cairn Table (5I6 m.), Preisthill (493 m.) and Starpet Rig (450 m.)). These rocks are brought to the surface by

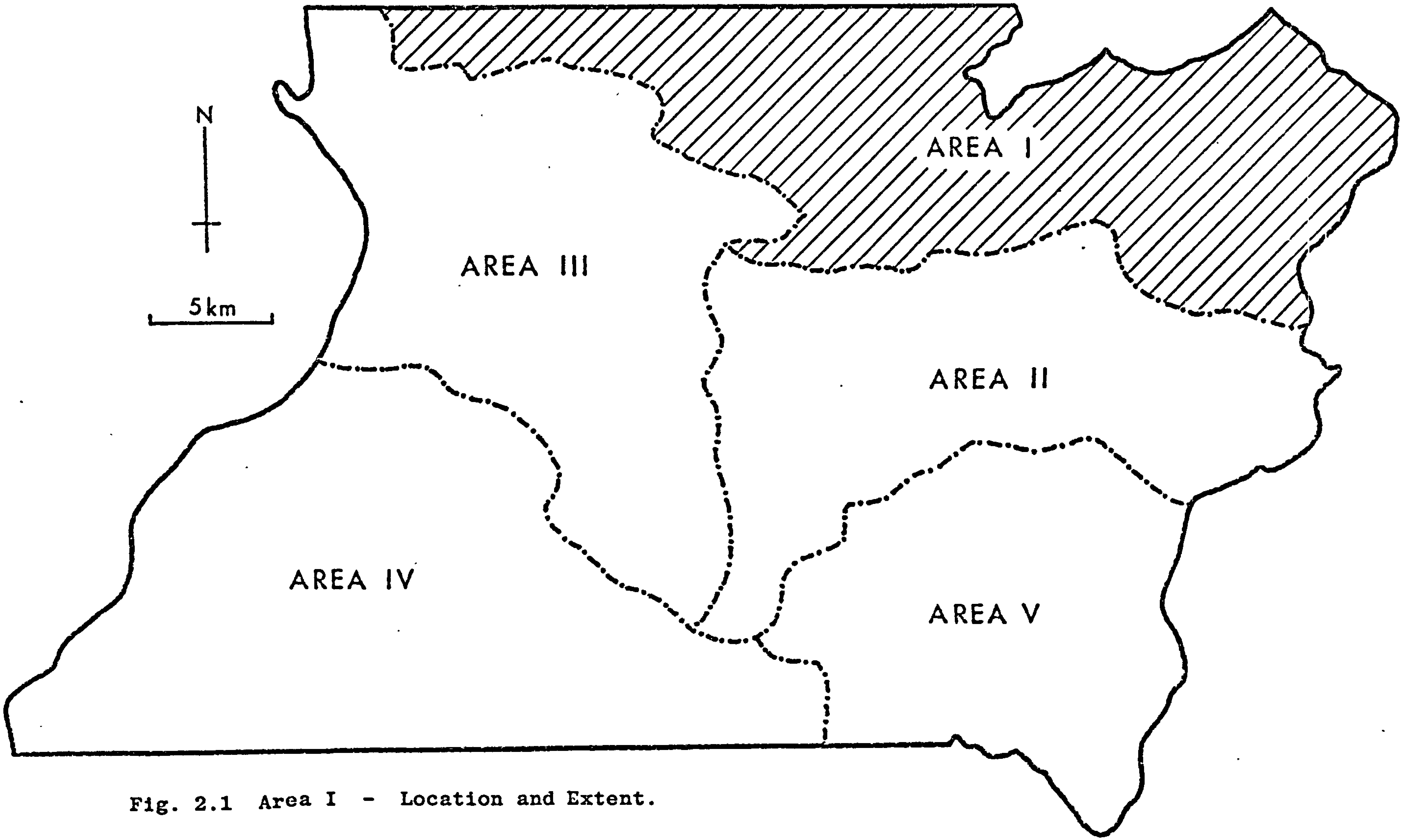


Fig. 2.1 Area I - Location and Extent.

their peripheral position to the Mauchline Basin and proximity to the Southern Upland Fault. A series of north-east to south-west orientated ridges, which reflect the Caledonian 'grain' of the country rock, are also characteristic of the eastern part of the area. These ridges are generally steep-sided except for the lower slopes where the extensive drift cover masks the solid form. The valleys between these ridges are occupied by the major lines of drainage. Relative relief values in this higher, eastern part of Area I are as great as 370 m..

The second type of relief, which is confined to the western part of the area, is characterised by gently undulating morphology. Its altitudinally low-lying nature is a combination of underlying rock-types which are not resistant to erosion and which have been down-warped as part of the Mauchline Basin. The rock-types are predominantly Carboniferous shales and sandstones. The undulating relief of the western part of Area I is only interrupted where resistant teshenitic intrusions outcrop through the drift cover such as at Craigie and Hillhead (Fig. 2.2). Relative relief values, however, rarely exceed IIO m..

The drainage of Area I has a generally dendritic pattern (Fig. 2.2). The main lines of drainage in the higher part of the area are all contained within deep, broad valleys and include the River Ayr, which drains from east to west, the Greenock Water, which drains from north-east to south-west, and the Garpel Water which drains from south-east to north-west (Fig. 2.2). Drift - filled valleys revealed by the examination of borehole records and anomalous patterns in the present-day drainage system show that some alteration of drainage took place during the last glaciation.

In the lower, western part of Area I, where glacial accumulation has been greatest, the streams occupy narrow, shallow valleys. The main stream in this part of the area is the Cessnock Water which flows for IO km. from north-east to south-west from its source on Blackside before turning abruptly to flow from south-east to north-west for the rest of its course (Fig. 2.2). The tributaries of the Cessnock Water, which include the Killock Burn and the Mare Burn, all flow generally from north-east to south-west, that is, parallel to the upper IO km. course of the main stream (Fig. 2.2).

Area I, therefore, has two distinct parts on the basis of relief, which is a reflection of the solid geology. The higher, eastern part

Fig. 2.2 Area I - Relief and Drainage.

Fig. 2.3 Area I - Geology.

is characterised by steep-sided hills and ridges which are separated by deep, broad valleys. The lower, western part is characterised by gently undulating morphology eroded into by rivers which occupy narrow, shallow valleys.

2.3: Glacial Erosion

There are few landforms in Area I which may be explained purely in terms of glacial erosion. The features of glacial erosion found in the area are striations, ice - moulded forms and glacially-breached colls (Fig. 2.4). However, some of these features are of limited use in determining former ice movements without reference to evidence provided by other glacial and fluvioglacial forms.

Only seven striations have been recorded within Area I, all of them by the Officers of the Geological Survey of Scotland (Fig. 2.4). Six of these have been examined and one, the only cross-striation on Fig. 2.4, could not be located. The striations, which are generally confined to the eastern part of the area, have diverse orientations. The diversity of these few striations is so great that it forbids any reliable indication of former ice movements in Area I. This is especially so when it is considered that "... any individual striation will only express ice movement at that point and local movements will be strongly affected by local topographical irregularities." (Embleton and King,1968, p. 138).

The ice - moulded forms are the most conspicuous and easily recognisable glacially-eroded features in Area I. They are located near the western extremity of the area (Fig. 2.4). These glacially-eroded features, which are elongated in a north-east to south-west direction, have steep, smooth slopes which face toward the north-east. The maximum height of these steep slopes above the surrounding land is 60 m.. These steep slopes are semi-circular in plan and have a maximum diameter of 600 m.. From the highest point on these features gentle slopes over 2 km. long descend to the south-west (Plate 2A).

These ice-moulded forms are composed entirely of resistant teshenitic dolerite which outcrops in this part of Area I in the form of the Hillhouse Sill. These features, however, are restricted to

Plate 2A Ice-Moulded Forms near Dundonald

Plate 2B General view of the Meltwater Channels Eroded into the side of Starpet Rig the northernmost part of the outcrop (Fig. 2.5). Although these features have the morphological requirements, the homogenious rock-type forbids the use of the term 'crag and tail' to describe them. The ice which moulded these forms may have moved from the north-east or the south-west, though the smooth character of the steep-sided end of the form suggests that a movement of ice from the north-east is more likely. Evidence from features of glacial erosion to the north of Area I in Northern Ayrshire and Renfrewshire, which has been studied by Ward, indicates a general movement of ice from the north-east (pers. comm. I0/6/76).

When active ice spreads across an area from which there is no free outlet the level of the ice will rise. The outlet may be blocked by other ice or ice may be accumulating more quickly than it is being removed by melting or transportation or ice may be advancing up a reverse gradient (i.e. uphill). If the thickness of ice continues to increase the ice surface will eventually rise above the lowest col. The surplus ice will escape across the col into any neighbouring low ground. The col will be considerably steepened and deepened as a result of this overflow of ice. With increasing glaciation the level of ice may rise to such an extent that all available cols are used by a series of diffluent ice-streams. The term 'transfluence' may be used when this stage is reached (Embleton and King,I968, p. I74).

Within Area I 2I glacially-breached cols have been identified. As would be expected,most of these are restricted to the major watersheds in the north-east and east of the area (Fig. 2.4). The existence of glacially-breached cols upto an altitude of 480m. O.D., in addition to the streamlined nature of many nearby summits, strongly indicates that Area I was completely covered by ice. If this is accepted, it is correct to conclude that the glacially-breached cols were eroded by transfluent ice.

McLellan (I967) examined many of these glacially-breached cols from the other side of the watershed in central Lanarkshire. He suggested that the orientation of glacially-breached cols in the western part of his thesis area fell into 2 distinct groups, one

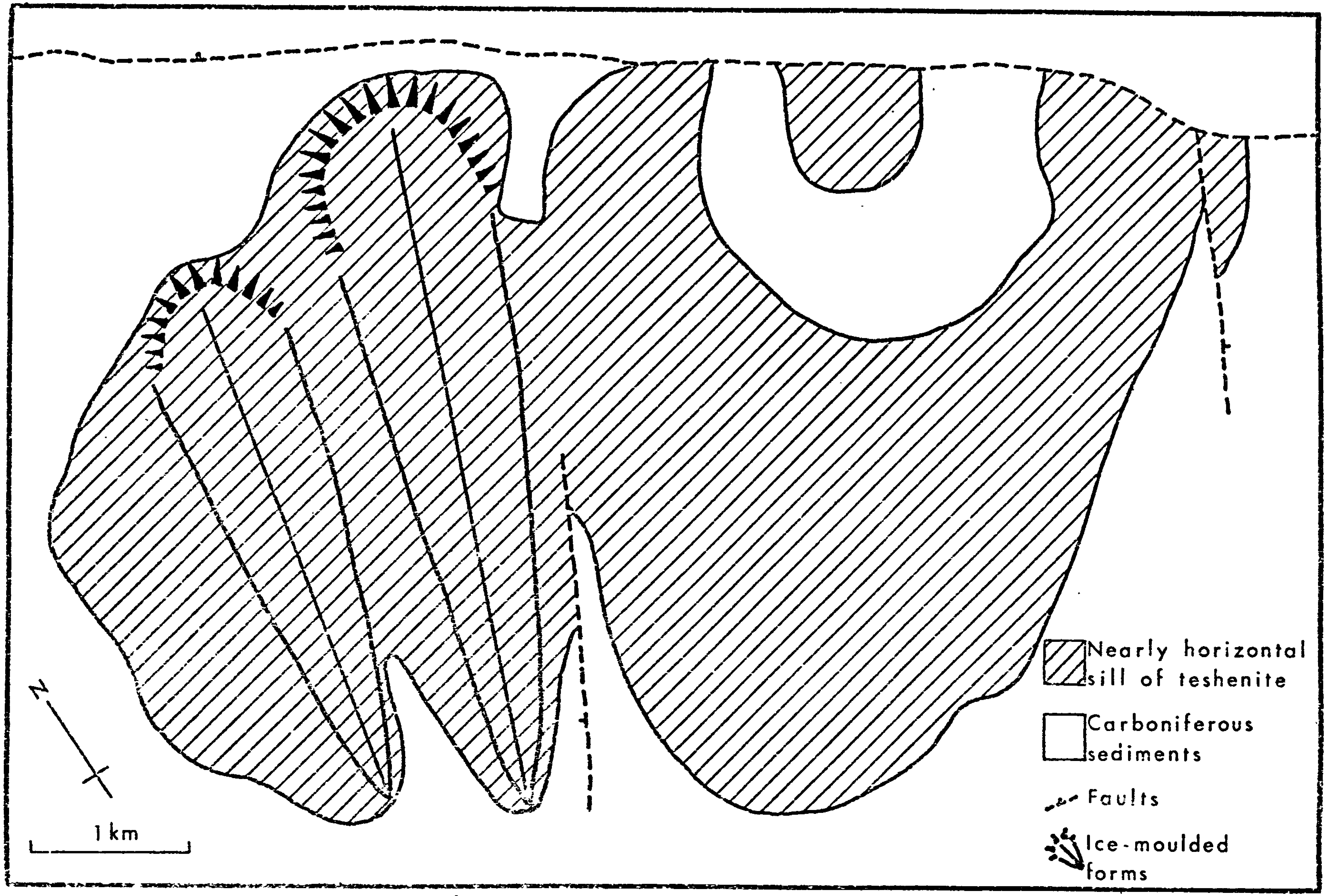


Fig. 2.5 Geology of the Ice-moulded features at Hillhouse.

orientated north-north-east to south-south-west and one orientated north-north-west to south-south-east. Based upon the assumption that the orientation of cols relfects the regional direction of movement of ice which erode them, McLellan (1967) concluded that two phases were indicated, firstly, a movement from the north-north-west and secondly, a movement from the south-south-west. Because of the diverse orientations of the glacially-breached cols in Area I, no such ice movements may be hypothesised. However, there is a fundamental objection to the suggestion by McLellan that glacially-breached cols reflect the regional direction of ice movement. There is no reason why cols with an established pre-glacial orientation should have this orientation altered by the passage of ice. Any surplus diffluent ice which moved into these cols may be expected to alter the dimensions of them, but not their orientation. The orientations of glacially-breached cols, therefore, are not considered to be reliable indicators of former ice movements.

The traditional explanation concerning the former ice movements within Area I was summarised by Eyles et al (1949, p. 125). It was concluded that during the early stage of the last glaciation Highland ice crossed Area I from west to east. At a later stage due to a ".. relaxation of the pressure of the Highland ice." (1949, p. 124) the ice-sheet which was centred on the Southern Uplands advanced and deflected the Highland ice and caused it to flow from the north-east in the western part of the area. It is not possible to evaluate the accuracy of this model from the evidence of former ice movements based upon the study of glacially eroded features. However, some conclusions may be made. Area I was occupied by ice exotic to the area. This exotic ice reached a minimum altitude of 480m. O.D. and probably covered the entire landscape. Evidence relating to former ice movements strongly indicates a movement from the north-east in the western part of Area I. No evidence exists which suggests a movement of ice from west to east across the area.

2.4: Glacial Deposition

John Smith (1904) stated :"In no part of Scotland are the drift deposits better seen, perhaps, than in Ayrshire." (p. 521). With glacial deposits in parts of Area I in excess of 35m. thick, this is a valid statement. Within Area I, as with central Ayrshire as a whole, features which relate to glacial deposition are more prominent than those which relate to glacial erosion. The distribution of glacial deposits generally mirrors the distribution of glacially eroded forms (Fig. 2.4). The deposits are thicker and more extensive in low-lying parts and they are thinner and eventually disappear at higher altitudes.

Till, the most common component of the drift, covers over half the surface of Area I (Fig. 2.4). On the basis of distribution, two distinct zones of till cover are recognised; these relate to the relief subdivision mentioned earlier (p.26). The first of these zones is the eastern part of Area I where the till has a generally irregular distribution. Solid rock, sands and gravels and peat are the other materials present at the surface (Fig. 2.4). The second zone is the western part of the area where till is almost exclusively the surface material. There are very limited solid rock outcrops or alluvium and peat accumulations. Sands and gravels are absent from this part of Area I (Fig. 2.4).

From the study of borehole records and the examination of every drift exposure in Area I the maximum thickness of till is over 35m.. However, till not situated in the lower part of Area I or the valley bottoms of the higher part rarely exceeds a thickness of 3m.. The highest altitude at which till is found is repeatedly around 425m. O.D. This suggests a minimum altitude for the former ice cover in Area I.

Several different colours of till exist at various locations in Area I. The colours include black, blue, brown and red. The colour of these tills is closely related to the colour of the bedrock upon which they lie. This is exemplified in Fig. 2.4 where sites 2k, 2m, 2n and 2p are composed of brown, blue/brown, brown/red and tills respectively. The brown and blue/brown tills at Sites 2k and 2m are underlain by predominantly blue Carboniferous age shales which weather brown. The brown/red and red tills at Sites 2n and 2p have Old Red Sandstone and Downtonian age sandstone foundations which are dominantly red in colour.

The matrices of tills vary from clayey to sandy. Generally, the blue and black tills have clayey matrices and the brown and red tills have sandy matrices. This reflects the grain size of the underlying solid rocks. However, the most important field observation is that, where good exposures are available for examination, no difficulty is experienced in differentiating till from any other drift deposit.

Many exposures within Area I reveal only one till. Where this exists, a minimum of three units are usually identified:-

3) Soil.

2) Weathered till.

I) Till.

In many instances till contains inclusions, usually in the form of lenses, of sands, gravels or both.

The till in Area I, which is commonly a shade of brown, usually contains fragments of marine shells and angular clasts of sandstones, dolerites and shists. The often well-striated clasts average 5-I5 cm. in length, though occasionally they are as large as 50 cm.. The clasts are bound together by a silty matrix which gives the till its compact character. The till is underlain in most parts of Area I by disintegrated bedrock, but in a limited part, between Sorn and Muirkirk, the till is underlain by a unit of sand and gravel and a lower till (Fig. 2.4).

In order to aid description, some of the characteristics of the till exposures have beem examined in detail (Sites 2a, 2b, 2c, 2e and 2f; Fig. 2.4). These detailed studies include preferred-stone orientation analyses, particle-size analyses and erratic counts. The results of these studies are summarised in Table 2A and Figs. 2.6, 2.8, 2.I0).

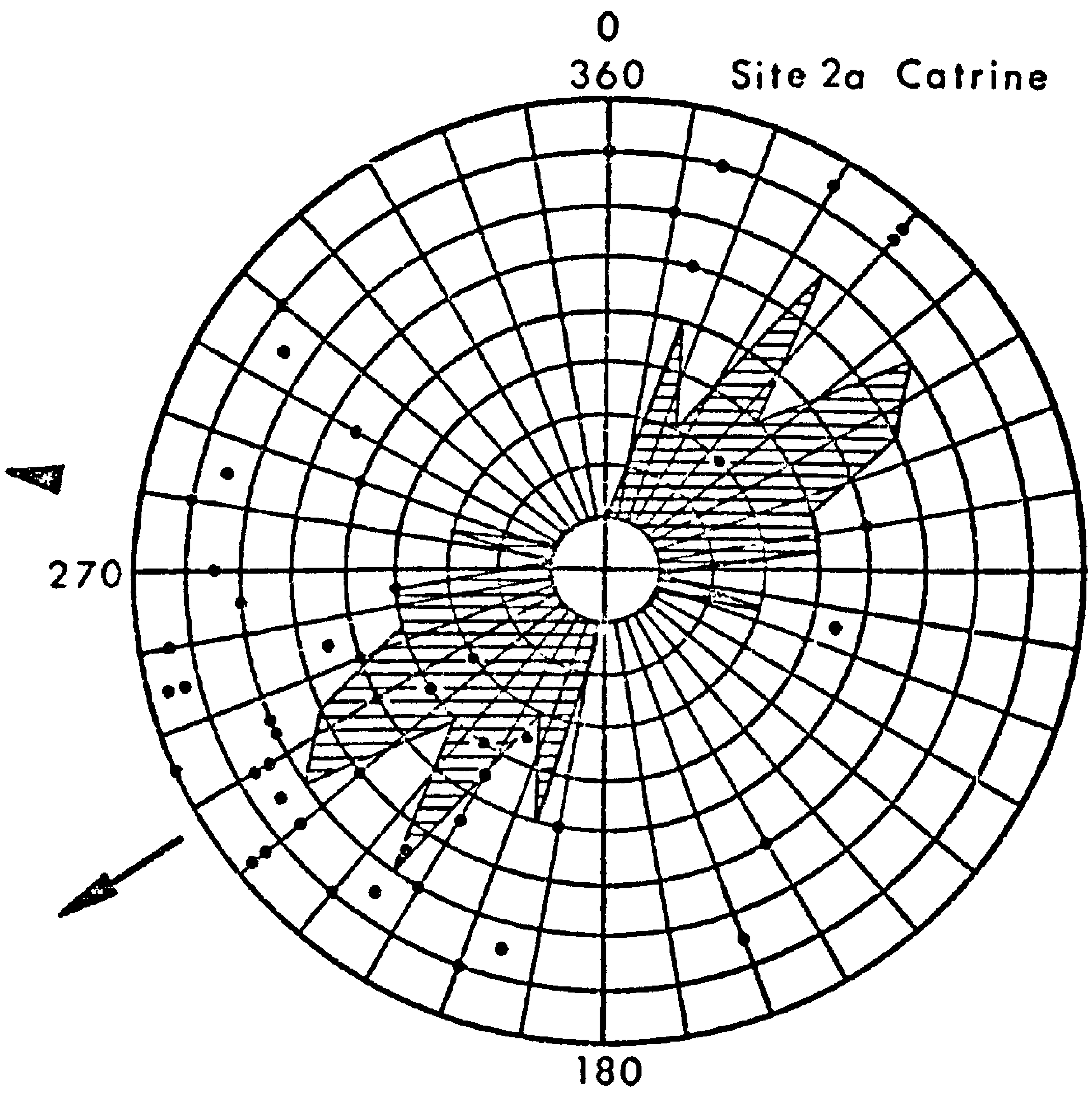
Site 2a, which is in the valley of the Bogend Burn Ikm. south of Catrine, is an exposure 8m. thick composed entirely of red/brown, stiff, sandy, shelly till (Fig. 2.4). From a preferred-stone orientation analysis a mean orientation of stones contained in the till of 238° was calculated.

<u>TABLE 2A</u>

Till characteristics in Area I

	Catrine Site 2a	Sorn Mains Site 2b	Merkland Burn Site 2c	Castle Hill Site 2e	Upper Greenock Site 2f	Lower Greenock Site 2f
Mean stone orientation	238°	23°	281°	307°		80°
Chi square	43.64	18.02	37.89	23.46		40.04
Dip strength	18.00	0.72	9.68	5.12		13.52
% Gravel	8.52				19.97	13.77
% Sand	44.40				57.71	55.16
% Silt/clay	47.08				22.32	31.06
% Local rocks	92	94			98	88
% Highland rocks	8	6			0	12
% Southern Upland rocks	0	0			0	0
% Unidentifiable rocks	0	0			2	0
Shell fragments	Yes	Yes	Yes	No	No	Yes

TILL FABRICS FROM AREA 1



Mean stone orientation

Slope

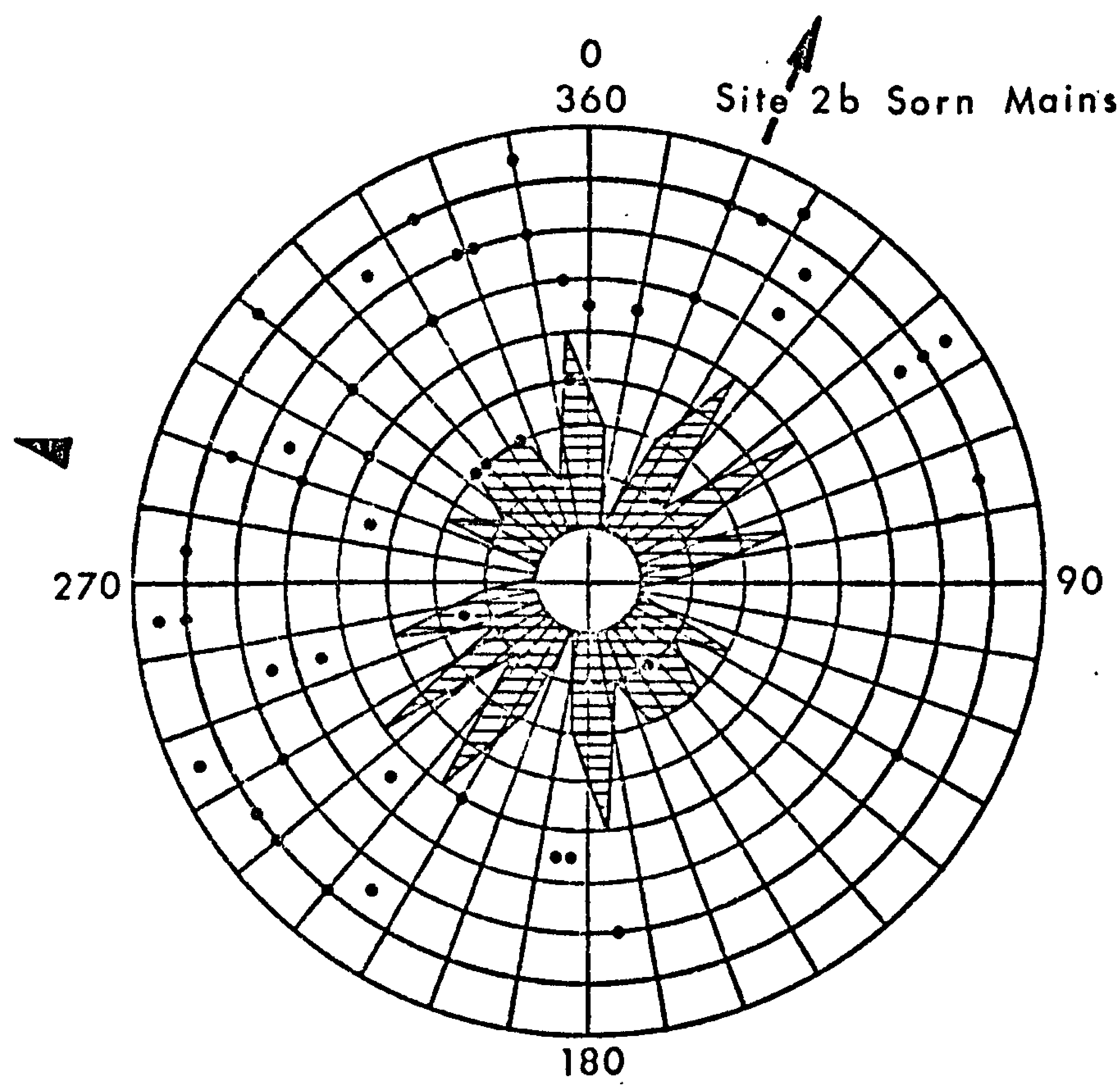


FIG. 2·6

(Appendix I)(Figs. 2.4, 2.6; Table 2A). From these data a chi-square value of 43.64 was also calculated for this mean orientation (Appendix 2). When tabulated with 8 degrees of freedom this value is statistically significant at the 99.9% level of confidence. A dip-strength value of I8.00 was also calculated from these data which, when tabulated with I degree of freedom, is also statistically significant at the 99.9% level of confidence. These results imply that these data would only occur by chance once in every thousand observations.

The traditional interpretation of these results would be that they indicate that the ice which deposited the till at Site 2a moved parallel and towards the mean orientation of stones (i.e. the stones have a tendency to dip towards the direction of movement) (Richter I936; Holmes I94I ; Harrison I957). However, Harris (I969b) rejects this traditional view "There is usually a tendency for pebbles (stones) to plunge towards the direction from which the ice was moving ... but this is not always the case." (p. 49). Harris (I969b) elaborates this argument and concludes that for any particular mean stone orientation any one of two directions of ice movement may be indicated:-

I) parallel and towards the mean stone orientation

2) parallel and away from the mean stone orientation.

If this is accepted, a mean stone orientation of 238° may indicate that the ice which deposited the till at Site 2a moved from either the north-east or the south-west. An examination of other characteristics of this till may indicate the former direction of ice movement more precisely.

A count of the rock-type of 50 stones selected randomly from the till shows that 8% are of Highland origin and that the remaining 92% are of local origin. This is regarded as strong evidence that the ice which deposited the till at this point probably originated in the Highlands, and to be more precise, probably in the west Highlands.

The fragments of marine shells which are contained within this till indicate that the ice which deposited it at some time spread across an area formerly occupied by the sea. If this is correct, ice which moved from the north-east, north, north-west or west could have picked up shell fragments and deposited them at Site 2a (Fig. 2.7). However, due to the results of the preferred stone orientation analysis, a movement of ice from the north-east is the most likely.

Site 2b, which is near Sorn Mains, is a section I0m. thick composed entirely of brown, sandy, shelly till (Fig. 2.4). From a sample of 50 elongated stones contained within the till a mean orientation of 23° was calculated (Figs.2.4, 2.6; Table 2A). A chi-square value of I8.02 was calculated for this mean stone orientation which, when tabulated with 8 degrees of freedom, is statistically significant at the 95% level of confidence. These results strongly suggest that the ice which deposited the till in this part of Area I moved either from the north-north-east or the south-south-west. A study of some of the other characteristics of the till at this site may indicate the actual direction of ice movement.

Erratic counts of stones in the till show 6% are of Highland origin and the remaining 94% are of local origin. This strongly suggests that the ice which deposited the till at this site probably moved from the north. Shell fragments, of which there are more at this exposure of till than any other in central Ayrshire, include well preserved, though sometimes striated, specimens of Arctica islandica and Astarte compressa. The presence of these shell fragments in the till indicates a general movement of the ice by which it was deposited from either the north-east, north, north-west or the west. It seems highly likely, therefore, that the ice moved from the north-north-east in this part of Area I.

Two exposures of till, which are the topmost components of multi-sequence stratigraphical successions, were examined at Site 2e, Castle Hill and Site 2f, Greenockmains (Fig. 2.4). The stratigraphical successions of the two sites are:-

Site 2e Castle Hill Fig. 2.4 200m. O.D.

3. Till. 4m.
2. Sand with limited gravel inclusions. 8m.
I. Till. 3m.

Site 2f Greenockmains Fig. 2.4 2I5m. O.D.

3. Till. 4m.
2. Sand and gravel. 20m.
I. Till. 5m.

Fig. 2.7 Areas Formerly Occupied by the Sea around Central Ayrshire.

The upper till at Castle Hill is dark brown, clayey and contains many sub-rounded and sub-angular clasts of sandstone. A preferred-stone orientation analysis enabled a mean stone orientation of 307° to be calculated (Fig. 2.4, 2.8; Table 2A). A chi-square value of 23.46 was calculated for this mean stone orientation which, when tabulated with 8 degrees of freedom, is statistically significant at the 99% level of confidence. A dip-strength value of 5.12 was also calculated from these data which, when tabulated with 1 degree of freedom, is statistically significant at the 95% level of confidence. These results strongly suggest that the ice which deposited the till in this part of Area I moved from the south-east or the north-west. Without an indication of the actual direction of ice movement from the study of erratics, these results remain imprecise.

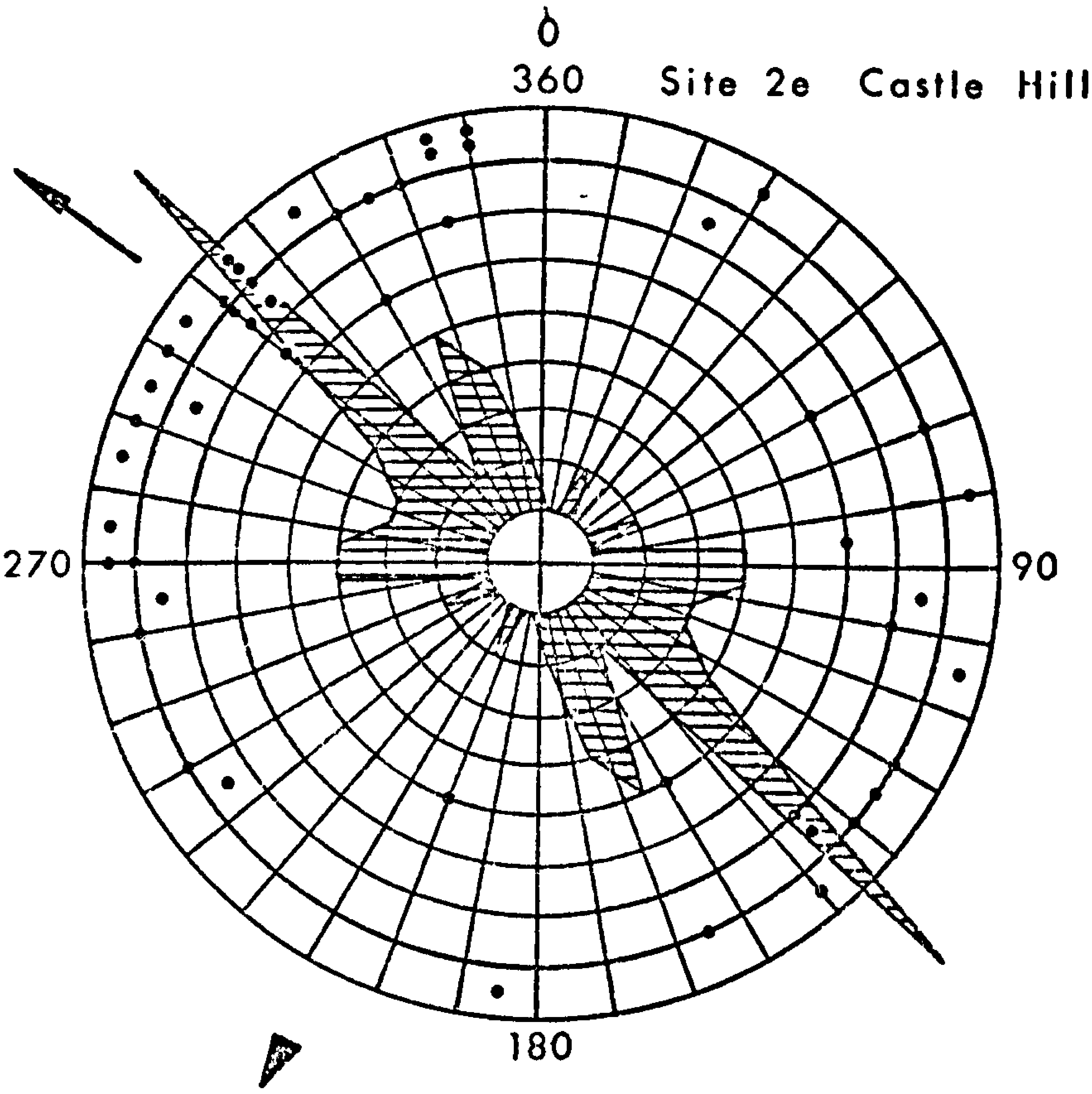
A random sample of 50 stones was selected from the till and their rock-types were recorded. All the erratics were of local origin and, despite extensive examination, no shell fragments could be found in this till. This upper till at Castle Hill, therefore, has quite different characteristics from the till examined at Sites 2a and 2b and it is most unfortunate that the erratic content does not indicate precisely whether the ice by which it was deposited moved from the south-east or north-west.

Site 2f at Greenockmains is half a km. to the north-east of Site 2e at Castle Hill (Fig. 2.4). At Greenockmains the upper till is red/brown and sandy. Despite the difference in colour and texture between the stratigraphically similar tills at Sites 2e and 2f, they share important characteristics (Table 2A). They both lack erratics which are of Highland origin and they both lack shell fragments. As at Castle Hill, no indication of the direction of ice movement is given by the study of erratics.

Some exposures of till in Area I lie below either sand and gravel deposits or sand and gravel deposits overlain by an upper till. The exposures of lower till are concentrated in the eastern part of Area I in the Ayr, Greenock and Whitehaugh valleys.

The finest exposure of lower till is at Site 2f at Greenockmains

TILL FABRICS FROM AREA I



Mean stone orientation

Slope

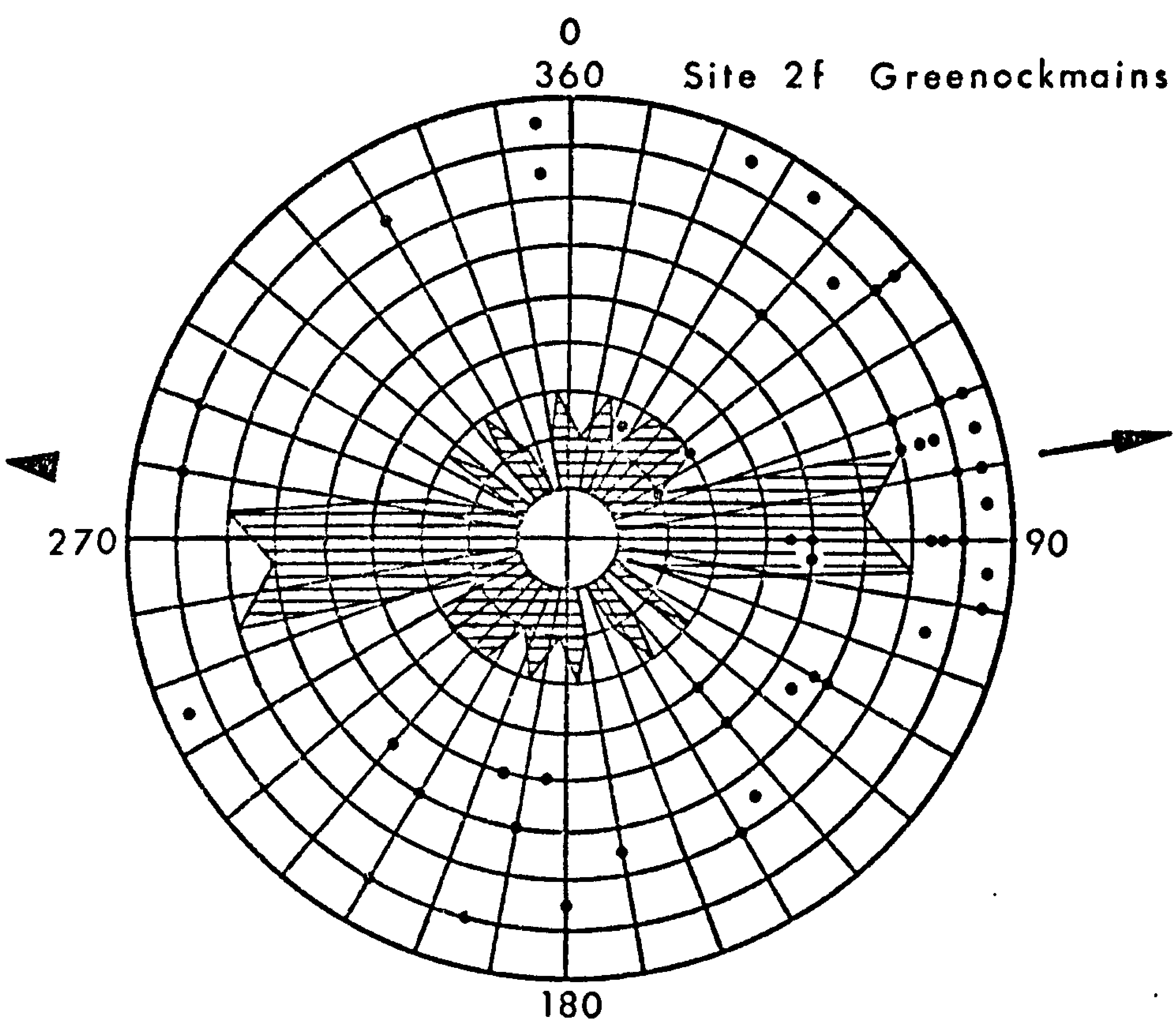


FIG. 2·8

(Fig. 2.4). The stratigraphy of this exposure is shown on p.34. The lower till, which has a minimum thickness of 5m. (base not seen), is chocolate brown and has a silty texture. From a preferred-stone orientation analysis a mean stone orientation of 80° was calculated (Figs. 2.4, 2.8; Table 2A). A chi-square value of 40.04 was calculated for thismean stone orientation which, when tabulated with 8 degrees of freedom, is statistically significant at the 99.9% level of confidence. A dip-strength of I3.52 was also calculated from these data which, when tabulated with I degree of freedom, is also statistically significant at the 99.9% level of confidence. These results strongly indicate that the ice which deposited this lower till generally moved from the east or the west.

A count of a random sample of 50 stones contained within this till, completed in order to identify their rock-types, shows that I2% are of Highland origin and the remaining 88% are of local origin. This is regarded as strong evidence for the suggestion that the ice which deposited this till originated to the north in the Highlands. This is also suggested by the presence of fragments of marine shells (Arctica islandica, T uritella communis) in the till. Consideration of the local topograghy suggests that ice which originated in the Highlands and moved generally from the north-east across the western part of Area I would probably have been deflected around Blackside (Fig. 2.9). This would have caused the ice to flow from the west across the eastern part of the area.

Another exposure of till was examined in the valley of the Merkland Burn at Site 2c (Fig. 2.4). The stratigraphy of this exposure is :-

Site 2c Merkland Burn Fig. 2.4 205m. O.D.

3. Till. 8m.

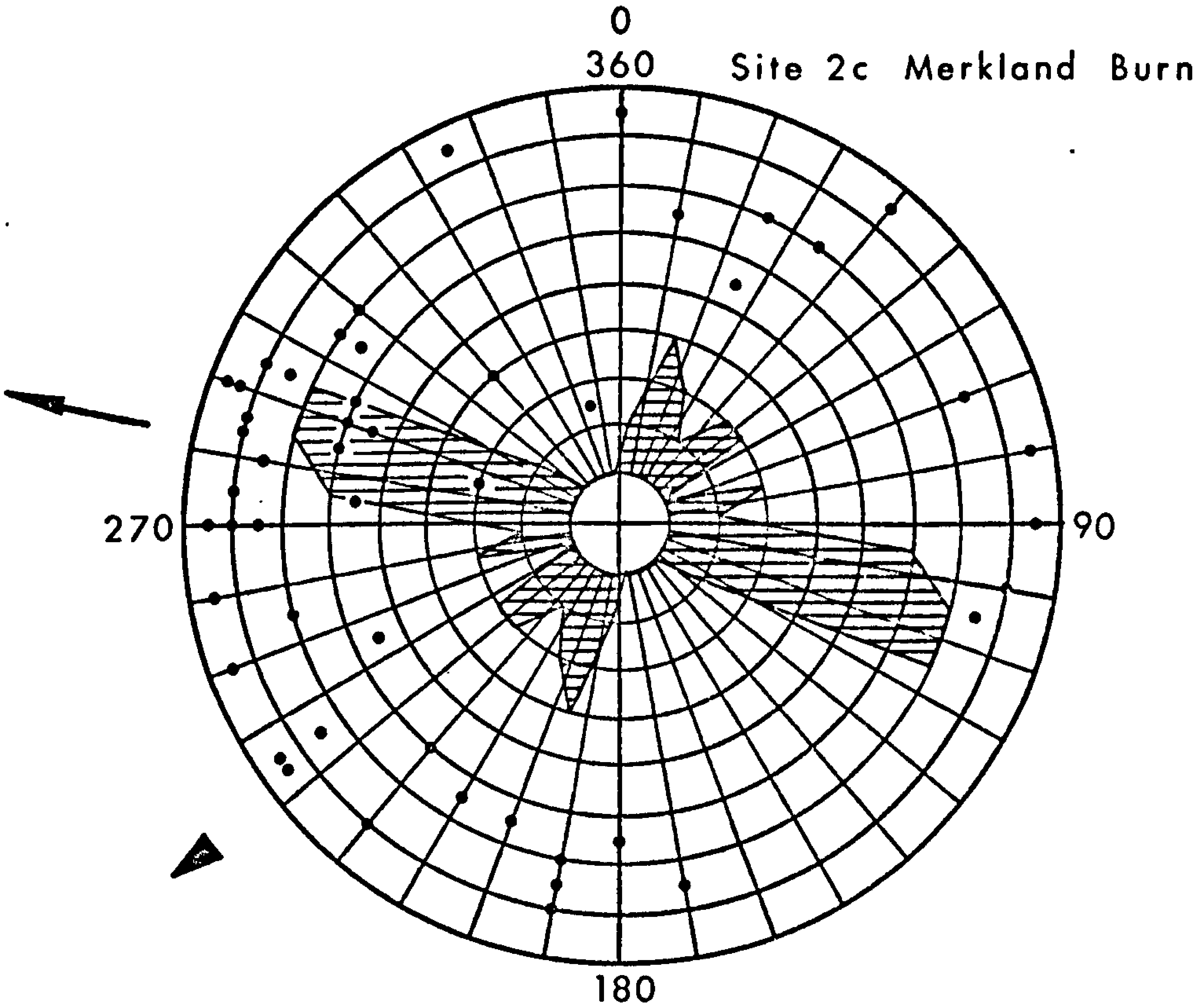
2. Fine - Medium Gravel. I.5m.

I. Till. 3m.

Only the lower till, which is chocolate brown with a silty texture, could be examined. A mean-stone orientation of 28I° was calculated for this till which has a chi-square value of 37.89 (Figs. 2.4, 2.IO; Table 2A). This value, when tabulated with 8 degrees of freedom, is statistically significant at the 99.9% level

Fig. 2.9 Deflection of Ice around Blackside.

TILL FABRICS FROM AREA I



Mean stone orientation

Slope

FIG. 2·10

of confidence. A dip-strength of 9.68 was also calculated from these data which, when tabulated with I degree of freedom, is statistically significant at the 95% level of confidence. This indicates that the ice which deposited the lower till at Site 2c moved either from the north-west or the south-east. However, the presence of erratics of Highland rock-types and fragments of marine shells in the till implies that the ice moved from the north-west. The most likely source of this ice was in the west Highlands.

The presence or absence of erratics of Highland rock-types and shell fragments are the only characteristics of the tills examined in detail to differ to any significant degree (Table 2A). It is most convenient that they are the easiest characteristics to establish; they are established in the field and not back in the laboratory. Further investigations into the till characteristics in Area I, therefore, concentrated on whether any erratics of Highland rock-types and shell fragments were present.

The examination of every till exposure in the area shows shelly till to be youngest till everywhere except for a limited part, only 8 sq. km. in extent, between Sorn and Muirkirk (Fig. 2.4). It is in this part of Area I that till which contains no erratics of Highland rock-types or shell fragments outcrops above considerable thicknesses of sand and gravel and the shelly till containing erratics of Highland origin (Fig. 2.II). This implies that two distinct tills outcrop in Area I:-

I) An extensive shelly till containing erratic of Highland rock-types.
2) A limited outcrop of non-shelly till which contains only locally derived material.

The existence of these two tills in Area I, which are always separated by fluvioglacial deposits, may indicate a minor re-advance of the Highland ice which occupied the area. The non-shelly till is too small an outcrop to indicate a major re-advance of ice.

Glacial deposits not only possess internal characteristics which enable former ice movements at particular points to be plotted, but also external, morphological characteristics which are useful in

Fig. 2.11 Summary of Drift Stratigraphy in Area I.

elucidating former ice movements. Although the range of external features includes moraines, fluted ground moraines and drumlins, only the latter are present in Area I. The distribution of drumlins is confined entirely to the western part of the area (Fig. 2.4). These elongated features are generally orientated in a north-east to south-west direction, though some drumlins near the northern boundary of the area are elongated in a north to south direction (Fig. 2.4). The presence of these north to south orientated drumlins is most conspicuous as they are surrounded on 3 sides by north-east to south-west orientated drumlins. Ward (pers. comm. IO/6/I975) shows that this north-east to south-west orientation of drumlins extends to the north of central Ayrshire into northern Ayrshire and Renfrewshire.

Variety in size and shape is one of the main characteristics of drumlins identified in Area I (Fig. 2.4). The long axes of the drumlins range from IOOm. to IOOOm. and their shape varies from almost circular (length:breadth=I:I) to elongated oval (length:breadth=4:I). The drumlins which are orientated in a north-east to south-west direction are larger and better developed than those orientated in a north to south direction.

One of the drumlins orientated in a north-east to south-west direction has smaller drumlins elongated in a north to south direction superimposed on its crest. This drumlin lies half a km. north of Crossroads (Figs. 2.4, 2.I2). Similar features have been described in northern Ayrshire by Richey et al (I930, p. 324) and subsequently by Ward (pers. comm. IO/6/I976). Richey et al concluded that 'crossing drumlins' imply that two dissimilar movements of ice were involved in their formation, a major movement which formed the 'base' drumlin and a minor movement which formed the 'superimposed' drumlins.

Although the formation of drumlins is a subject of much debate amongst geomorphologists, it is generally agreed that they are streamlined and elongated parallel to the last movement of ice across an area. It is also generally accepted that the highest point along the crest of the drumlin, and hence the stoss end, faces the direction from which the ice moved (Gravenor, I953; Hill, I970; Embleton and King, I975). As Menzies (I977) explains: "As well as

Fig.2.12 Drumlin at Crossroads.

an up - ice migration of the hummock crest, it may be assumed that the hummock will be the nucleus around which further till deposits will accrete. As the ice passes over and around the proto drumlin, streamlining of the drumlin will take place and thus the beginnings of the characteristic drumlin shape will be produced. Once this shape begins to be produced and the moving ice begins to come into equilibrium with the drumlin form further accretion may continue either until the drumlin size approaches the critical safety factor level, or the supply of fresh till is exhausted or glaciological changes occur." (p. 20). However, McGown et al (1974) pointed out that the movement of ice which forms drumlins is not necessarily the movement of ice which deposits the drift out of which the drumlins are moulded.

Based upon an analysis of drumlin shape and the position of the highest point along the crest, it is possible to suggest former directions of ice movements across the western part of Area I. The majority of drumlins are wider at the north-eastern end than the south-western end (the actual numbers are II wider at the north-eastern end and only I wider at the south-western end; the remainder are elliptical). Seventeen drumlins have their highest points along the crest towards the north-eastern (or northern) ends of the drumlins. Only one drumlin has its highest point towards the south-western end. These results are a very strong indication that the ice which moulded the drumlins moved from a generally north-eastern direction. However, because of the presence of smaller north to south orientated drumlins, and in one instance their superimposition on a north-east to south-west orientated drumlin, it is likely that a minor movement of ice from north to south also took place. This north - south movement of ice post-dated the major north-east to south-west 'drumlin forming' movement of ice.

Glacial deposition is widespread throughout Area I upto an altitude of 425m. O.D.. Shelly till which contains erratics of Highland origin normally exists as a single unit but on the valley floors and lower hillsides in the eastern part of the area the shelly till often has a mantle of either fluvioglacial deposits or fluvioglacial deposits and an upper till. Wherever the lower limit of the shelly till is seen, it always lies upon disintegrated bedrock. In one part of the area only 8 sq. km. in extent between Sorn and Muirkirk a till which contains no shell fragments or erratics of Highland origin overlies fluvioglacial sand and gravel and a lower shelly till. The direction of the former movements of ice in Area I which deposited the glacial material is suggested by mean stone orientations, erratic counts and drumlin orientations.

The direction of the ice movement indicated by the mean stone orientations are contradictory. It is considered, therefore, that mean stone orientations indicate one of two possible movements: either a movement parallel and towards the mean stone orientation or a movement parallel and away from the mean stone orientation. The precise direction of ice movement is often suggested by other till characteristics.

The study of the erratic content of the tills in Area I establishes that the brown, shelly till, the lowest unit of the drift, was probably deposited by ice which originated in the Highlands and moved generally from the north. This study also shows the existence of a shell-less till in Area I which contains only local rock-types. This shell-less till is always separated from the shelly till by a considerable thickness of fluvioglacial sands and gravels. Such stratigraphical associations between two different tills strongly suggests a readvance of the Highland ice which affected Area I. However, the limited extent of such stratigraphical associations suggests that the readvance was a minor one.

The concentration of drumlins in Area I provides strong evidence for a former movement of ice from the north-east in the western part of the area. However, a minor movement of ice from a generally northern direction is also indicated. This may correspond to the evidence for a minor readvance of ice in the eastern part of the area.

When all the evidence relating to the former directions of ice movement in Area I is combined, it fits into part of the model ice movement suggested by Eyles et al (1949); the ice moved from the north-east in the western part of the area and from the west in the eastern part of the area. However, Eyles et al suggested a movement of ice from the west across the whole of Area I prior to these movements. No evidence of any such west to east movement exists in the western part of Area I. In fact, Bailey (1925) admits that the suggested west to east movement of ice across Area I is not based upon morphological considerations: "... at one time the parting of the ways (of ice streams) lay on what is now once more the floor of the sea. In most glacial maps, in agreement with evidence derived from striae and crag and tails, the divide is shown as lying well inland. There can be no doubt that such an inland position was maintained for a very long period. For instance, as Mr. Anderson points out, the crags of the Dundonald Hills, north of Ayr, have ... their tails directed south-westwards towards the sea. The sea floor position for the parting is conceived as having operated at a period earlier than the shaping of the Dundonald Hills. It is postulated primarily to account for the wide distribution of shelly boulder clay (till) in central Ayrshire." (p. 101-102). It is shown on p.34 and Fig. 2. 7 that the existence of shell fragments within the till may also be explained by a general movement of ice from the north.

In view of such strong evidence for the former movements of ice in Area I, the primary movement suggested by Eyles et al from the west is considered untenable; it is therefore rejected.

2.5: Fluvioglacial Erosion

Much of the evidence which relates to the erosive capacity of meltwater in central Ayrshire is in Area I. Over 50 meltwater channels have been identified. In some instances the identification of meltwater channels is not difficult. Characteristics such as humped (up-down) long profiles, abrupt beginnings and terminations and anomalous positions in relation to present day drainage patterns aid identification. Difficulties, however, are encountered, especially where channels contain contemporaneous streams and have been considerably refashioned.

The physical characteristics of the meltwater channels in Area I vary widely. Some have been cut in solid rock, some in till and others in sand and gravel. The channel form reflects the type of material in which they were eroded. Channels cut in solid rock are generally the longest, deepest and widest with the most sharply defined form; the channels cut in till do not attain similar dimensions or sharpness of form; and the channels cut in sand and gravel are often indistinct.

Although meltwater channels exist near to the eastern and northern margins, their distribution within Area I is irregular (Fig. 2.4). The majority of meltwater channels are in the eastern part of Area I on steep hillsides such as Starpet Rig, Cairn Hill and Blackside. The meltwater channels which exist near the western margin of Area I are situated near Dundonald (Fig. 2.4). These channels, however, are not as well developed or as extensive as those in the eastern part of the area.

The largest concentration of meltwater channels, which lies to the north-east of Muirkirk, warrants primary examination (Figs. 2.4, 2.I3; Plate 2B). This system of meltwater channels was first described by John Smith (I898). He identified only the most impressive channels and failed to describe many of the smaller channels in the system. John Smith concluded that these meltwater channels were cut during glaciation: "... when the valley of the Greenock Water was choked up with ice, which came down from Middlefield Law and obliged the waters of the district to flow in a south-east direction towards the head of the Ayr Water." (p. 333).

The only other detailed description of these channels, which was far more accurate than that of Smith's, was completed by the Officers of the Geological Survey of Scotland (I9II). The accompanying conclsion was that these channels were "overflow channels" from glacial lakes (after Kendall (I902)).

Charlesworth (1926b) briefly referred to these channels and concluded: "The marginal streams flowing along the north edge of the "Airds Moss Lobe" and the drainage of the ever-increasing ice-free

Fig. 2.13 Channel Systems 1-10 - Area I

area of Hagshaw and Nutberry Hills carved a series of channels..." (p. 32-33). A detailed study of these features in relation to other glacial and fluvioglacial features may help to clarify their mode of origin.

Channel I is the meltwater channel with the highest altitude in Area I with an intake at approximately 400m. O.D. (Fig. 2.I3). This channel has a straight course over 300m. long which cuts through a ridge which separates the Dippal valley and the Ponesk valley. This channel, which slopes from north to south, is IOm. deep with a 25m. wide flat floor. The lack of exposures makes it difficult to determine the material into which this channel is eroded but, its sharpness of form suggests it is cut in solid rock.

A gap in the eastern side-wall of Channel I near its southern end leads into Channel Ia (Fig. 2.I3). This connection between these channels has an up - down character. Channel Ia is IOOOm. long and slopes to the south-east. It has a maximum depth of IOm. and its flat floor has a maximum width of 25m.. The subdued form of this channel suggests it was eroded into till.

Channel 2 has a intake at approximately 385m. O.D.. This intake is the starting point of an extensive series of meltwater features which are situated on the south facing side of Starpet Rig (Fig. 2.I3). Immediately from its intake, Channel 2 has a IOm. wide flat floor which does not alter throughout its IOOOm. slightly curved, sinuous course, except at its lower end where it exceeds 30m.. The amount of incision, however, does vary along its south-east sloping course and reaches a maximum depth of 30m. (Plate 2C). It is evident from exposures in the side-walls that the channel was entirely eroded into solid rock.

Channel 3, which has an intake at approximately 360m. O.D., is sub-parallel to Channel 2 (Fig. 2.I3). The channel has a 25m. wide flat floor immediately from its intake and along most of its 400m. sinuous course. Exposures show the channel to have been eroded in solid rock.

Channel 4 has a broad ill-defined intake in close proximity to the termini of Channels 2 and 3 (Fig. 2.I3). Channel 4 may have been a continuation of these two channels. Because the upper part slopes to the north-west and the lower 400m. of its 500m. course slopes to the

Plate 2C Meltwater Channel 2

Plate 2D Meltwater Channel 4 and the top of the Delta-Kame south-east, the channel has a humped profile. For 200m. of its course from its intake, the channel is 10m. deep and has a flat floor 12m. wide. Exposures show that this part of Channel 4 was eroded into solid rock. The lower 300m. of its course has a V-shaped cross section with a depth of 25m. (Plate 2D). This profile shows that this part of the channel was eroded in sand and gravel.

The next lowest unit in this channel system, though distinctive, does not have a channel form. It is a bench-like feature 600m. long with a flat floor 15m. wide and one side 8m. high. The intake of this south-east sloping feature (number 5 in Fig. 2.13) has an altitude of approximately 350m. O.D.

The lowest channel on the south side of Starpet Rig has an intake at 310m. O.D.. Channel 6 has a complex form with at least three separate intakes and two termini (Fig. 2.13; Plates 2E, 2F, 2G). For ease of description this has been classed as one channel. It is 1000m. long and sinuous. In parts the channel has a 25m. wide flat floor and a depth of 35m.. Channel 6 has a very pronounced humped profile and, like most channels in this system, it slopes to the south-east. Exposures reveal that the channel was eroded in solid rock.

The Ponesk Channel, Channel 7, is the largest meltwater channel in Area I. It is 2000m. long, 50m. deep and has a flat floor 150m. wide (Plate 2H). The sinuous, south-east sloping Channel 7 cuts through a ridge orientated north-east to south-west. This ridge separates the Ponesk valley from the Ayr valley (Plate 2I). The northern side-wall of Channel 7 is joined by smaller, sub-parallel channels at three points (Fig. 2.13). These smaller channels, which slope towards the main channel, do not reach its floor and are, therefore, left "hanging" high above it (Plate 2J). The consistent south-east slope of the main channel is abruptly interrupted at its lower end where it turns through 90° to slope to the south-west (Fig. 2.13). This alteration in slope direction is at an altitude of approximately 255m. O.D..

Another hanging channel is situated near this right-angle bend in Channel 7 (Fig. 2.13). However, this hanging channel (Channel 7a) slopes to the east and is therefore directed away from and not towards the main channel. Field relations suggest that Channel 7b was a continuation of Channel 7a (Fig. 2.13). Channel 7b slopes towards the

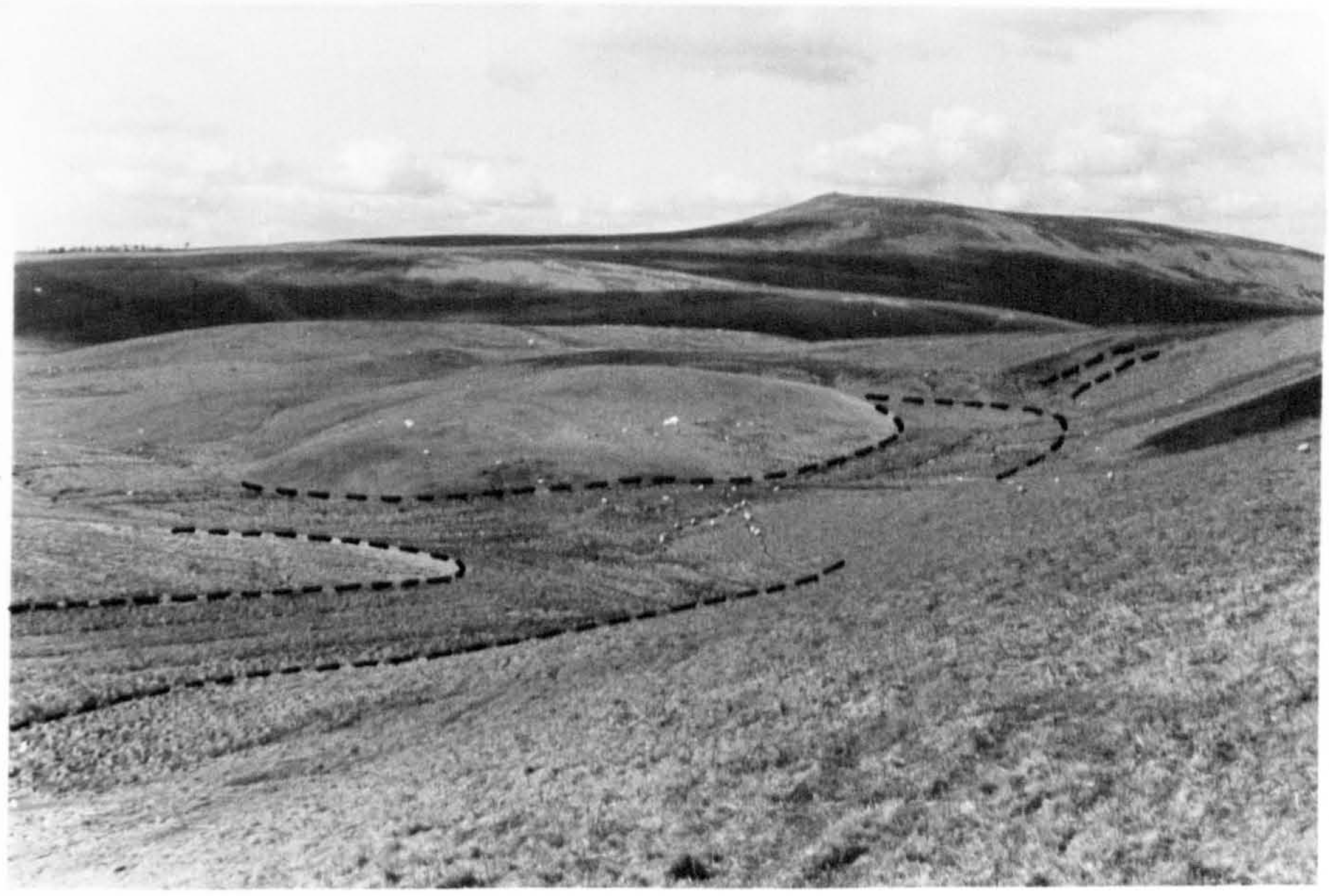


Plate 2E   Meltwater Channel 6 looking towards the north-west and its intakes

Plate 2F   Meltwater Channel 6 looking towards the south-east and its outflow

Plate 2G Meltwater Channel 6 looking towards the north-west and its outflow

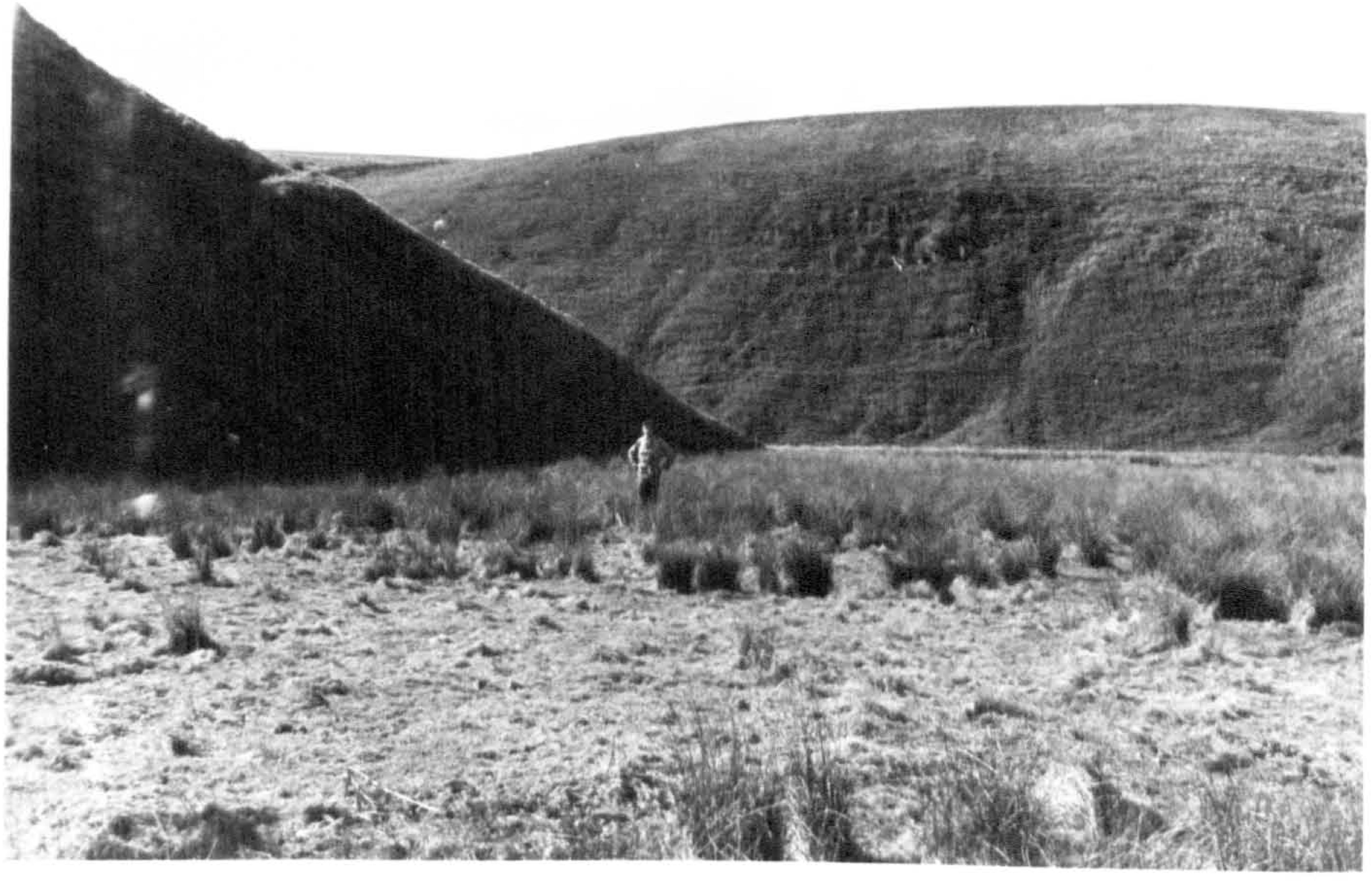


Plate 2H Meltwater Channel 7 with its broad, flat floor and steep sides

Plate 2I Oblique view of Meltwater Channel 7

Plate 2J "Hanging" Meltwater Channel which leads into Meltwater Channel 7 south-east and terminates at an altitude of approximately 255m. O.D..

The area around the lower end of Channel 7 may be of special importance when trying to determine the former direction of meltwater flow which eroded this whole channel system.

The main intake of Channel 8, which is at an altitude of approximately 350m. O.D., is situated on the ridge which separates the Ponesk valley from the Stottencleugh valley (Fig. 2.I3). For the upper half of its I000m. course Channel 8 slopes to the east, while the lower half of its course slopes to the south-east. Throughout its course, a depth of 20m. and a flat floor width of I0m. are common. Two smaller intakes are situated on the northern side of Channel 8 at the heads of short "hanging" channels (Channels 8a and 8b; Fig. 2.I3). The altitudes of these intakes are at 260m. O.D. and 265m. O.D. respectively. Channels 8, 8a and 8b were all eroded in solid rock.

Channel 9 is located at the lower end of the Stottencleugh valley (Fig. 2.I3). From its intake at an altitude of 275m. O.D., the channel slopes to the south-east. A flat floor I5m. wide and a depth of 20m. are characteristic of the main channel. Smaller channels lead into the main channel from the north and the south and two of these are curved with up-down profiles and abrupt beginnings (Fig. 2.I3). Exposures show that these channels were eroded in solid rock.

Channel system I0 has four separate intakes with altitudes around 365m. O.D.. This system is characterised by channels with straight courses which slope to the east or north-east (Fig. 2.I3). These channels are usually 8m. deep with flat floors I2m. wide. Exposures in the channel walls show that they were eroded in both solid rock and till. The overall length of Channel system I0 is approximately 2000m..

The mode of formation of meltwater channels is well documented as a result of much work on contemporary and former areas of meltwater activity by such people as Mannerfelt (I945, I949); Hoppe (I950), Sissons (I958a, b, c, I960a, b, I96Ia, b, I963); Price (I960, I963a), Embleton (I96I, I964), Bowen and Gregory (I965) and Clapperton (I968). It is generally agreed that if channels are large, have abrupt beginnings and endings, an anastomising pattern, humped (up-down) long profiles, associated "hanging" channels and slopes which cut obliquely across the contours, they are of subglacial origin. All these characteristics are represented in this channel system north-east of Muirkirk.

The slope directions of these channels suggest that the meltwater which eroded them generally flowed towards the east across the Ayr / Douglas watershed (Fig. 2.13). This indicates that the ice gradient in this part of Area I probably sloped from west to east (Price, 1973, p. 128). The sub-parallel, stepped nature of this channel system suggests the progressive abandonment of higher channels in favour of lower courses. This sub-parallel succession of channels may represent a lowering of the englacial water-table due to the downwasting of the ice-mass. If this is correct, as the lowering of the englacial water-table continued, the level of meltwater activity along the Ayr / Douglas watershed would have eventually fallen below the lowest altitude of the watershed, which is near Glenbuck, at approximately 255m. O.D.. This would have impeded the free drainage of fluvioglacial meltwater eastwards which in turn would have curtailed channel development. This hypothesis is supported by the lack of channel development in the eastern part of Area I below 255m. O.D.. There is only one small exception, the south-west sloping part of Channel 7. This exception, however, may provide further support for this hypothesis. At its lower end, Channel 7 abruptly changes its slope direction from south-east to south-west at an approximate altitude of 255m. O.D.. The south-east sloping Channel 7a suggests that Channel 7 probably did contain meltwater that flowed towards the lowest point on the Ayr / Douglas watershed. However, some mechanism operated which caused this meltwater to abruptly change direction and flow away from the watershed towards the south-west. The altitude of Channel 7a is approximately 255m. O.D.. It is considered, therefore, that this change in direction of meltwater flow is a result of the englacial water-table being lowered to such an extent that free flow towards the east was impossible and that the meltwater turned to flow to the south-west - probably beneath the ice. This would reduce the speed of the meltwater streams sufficiently to allow extensive fluvioglacial deposition in the eastern part of Area I. It is important, therefore, that the part of Area I west of the terminus of Channel 7 is characterised by extensive sand and gravel deposits. It is highly likely, therefore, that the lowest point of the Ayr / Douglas watershed indirectly controlled the development of the entire meltwater channel system north-east of Muirkirk.

Channel system II, which is comprised of two channels, lies on the north-western side of Cairn Hill (Fig. 2.4). The two channels in this system are almost parallel and they are both 2000m. long, IOm. deep and have a flat floor I2m. wide (Fig. 2.I4). The highest altitude of the intakes of these north-east sloping channels is approximately 320m. O.D.. The channels are sinuous and have humped profiles along their courses which terminate at approximately 260m. O.D.. The lack of streams in these channels and their transgression of the Ayr / Lugar watershed (the boundary between Area I and Area II) emphasises the anomalous position of these channels in relation to the present drainage system.

The form of these channels on the south side of the Ayr valley suggests they were cut subglacially by meltwater which flowed generally eastwards. The ice gradient at this point, therefore, would probably have sloped from west to east. The sub-parallel nature of these two channels suggests the higher channel was abandoned in favour of the lower channel. This would probably have been related to the lowering of the englacial water-table which controlled the level of meltwater activity.

This hypothesis of channel development is reminiscent of that suggested for the channel system north-east of Muirkirk. It is likely, therefore, that the influence of the Ayr / Douglas watershed extended to this part of Area I. It is equally likely, however, that this channel system was produced by local subglacial meltwater activity during the last glaciation.

Another channel system, number I2, is situated south of the River Ayr (Fig. 2.4). This is in the valley of the Garpel Water, on the north-east side of Wardlaw Hill (Fig. 2.4). From the intake with the highest altitude at approximately 350m. O.D., the channels which comprise this system have depths of 7m. and flat floors 9m. wide.

Along the system's 800m. discontinuous, sinuous length a number of reverse gradients exist. The many outcrops on the sides of the channels together with the sharpness of form show that they have been eroded into solid rock.

Fig. 2.14 Channel System 11 - Area I

A subglacial origin is indicated for these channels. The meltwater that eroded them would have flowed towards the north-north-west. No obvious similarity between this channel system and the other channels in Area I exists. Channel system I2, therefore, was probably formed as a result of isolated meltwater activity beneath the ice.

Channel system I3 is situated on the eastern side of Blackside and is comprised of an upper channel system eroded in solid rock and a lower channel system eroded in sand and gravel (Figs. 2.4, 2.I5).

The upper part of this channel system includes channels which begin abruptly and immediately assume flat floors 8m. wide and depths of 8m.. The slope of these upper channels is towards the north-east, which is almost parallel to the contours. Some structural control within the solid rock may have operated to produce the channel forms, but there is little doubt that meltwater fashioned these features to a greater or lesser extent. Some of the channels cut in solid rock are perpendicular to the contours and they slope generally southwards. One such channel, which is IOm. deep and has a flat floor I2m. wide, houses the Wood Burn (Fig. 2.I5). The altitudinal range of the channels cut in solid rock is between 280m. O.D. and 380m. O.D..

With intakes at or below 280m. O.D., the lower group of channels, which were eroded in sand and gravel, do not have sharply defined forms. The depth of these channels is usually 5m. and the flat floor is often 8m. wide. The four channels which make up the lower part of Channel system I3 are parallel to each other and the contours (Fig. 2.I5). A short distance north-west of these channels, the sand and gravel spread in which they were eroded has a kame-like form.

This channel system had a complex origin. The upper part of the system was formed subglacially (as indicated by abrupt channel beginnings and the existence of channels perpendicular to the contours which suggests they may have been subglacial chutes). The lower part of the channel system is probably of a marginal or submarginal origin. This channel system, therefore, owes its origin to two phases of meltwater activity: firstly subglacial, and secondly marginal or submarginal. The meltwater in both cases flowed generally eastwards, which indicates an ice gradient which probably sloped from west to east. The position of

Fig. 2:15 Channel System 13 - Area I

the lower, marginally or submarginally produced channels around Blackside may indicate that this hill emerged as a nunatak during the downwastage of ice in this part of Area I.

The final channel system is situated in the extreme west of Area I, I.5km. south of Dundonald (Fig. 2.4). Channel system I4 is comprised of one single channel and three channels linked by a common intake. Near Wardlaw Hill there is a single channel with a depth of IOm. and a flat floor IOm. wide. The whole of its I50m. straight course, which slopes to the north-east, was eroded in solid rock.

Three hundred metres to the south are three separate channels linked by a common intake. The channels, which were cut in solid rock, have a maximum depth of 8m. and a flat floor width of IOm.. The most westerly channel has an up-down profile with 200m. of its 300m. curved course sloping to the south-west and its upper IOOm. sloping to the north-east. The central branch of this three-channel system has a curved course 250m. in length. The upper IOOm. of its course slope to the south-south-east and the lower I50m. slope to the south-west. The form of this meltwater feature changes from channel-like at its northern end to bench-like at its southern end where the eastern 'channel side' is missing (Fig. 2.I6). The third unit of this channel system is IOOm. long, 8m. deep and has a flat floor IOm. wide. This most easterly channel of channel system I4 slopes to the west.

The three channels, which lie in close proximity to each other and are linked by a common intake, indicate that the meltwater which eroded them flowed from the north-east. The form of the channels indicates that they were cut subglacially in the resistant teshenite of the Hillhouse Sill. The humped profile of the most westerly channel shows that meltwater flowed under hydrostatic pressure in the vicinity and this may explain the seemingly anomalous north-east slope of the single channel near Wardlaw Hill. There is also a possibility that it may have been eroded by isolated meltwater activity. Although the evidence from the study of these channels is not strong enough to allow firm conclusions to be drawn, it is likely that the ice gradient in this part of Area I sloped from north-east to south-west. If this is correct, it agrees with evidence obtained from the study of the features of glacial erosion and deposition.

Fig. 2.16 Channel System 14 - Area I

The overall pattern of meltwater activity, though complex, may be summarised as follows:-

I) The meltwater which subglacially eroded most of the channels in the eastern part of Area I flowed generally eastwards across the Ayr / Douglas watershed. This probably indicates an ice gradient in this part of Area I which sloped from west to east.

2) As this ice decayed, the englacial water-table dropped to such an extent that the flow of meltwater eastwards was halted by the emergence of the Ayr / Douglas watershed. This forced the meltwater in the eastern part of Area I to turn and flow to the south-west (i.e. under the ice).

3) Evidence of meltwater activity in the rest of Area I suggests the emergence of Blackside as a nunatak which attracted subglacial and submarginal meltwater activity. This meltwater flowed in an easterly direction. The existence of an ice gradient which sloped from north-east to south-west in the extreme west of Area I, near Dundonald, may also be indicated.

2.6: Fluvioglacial Deposition

Area I has the greatest amount of surface sand and gravel of any of the five areas of central Ayrshire. This mantle of sand and gravel is wholly confined to the eastern part of Area I (Fig. 2.4). The fluvioglacial sands and gravels within this part of Area I are irregularily distributed and are mostly confined to the valleys of the River Ayr, the Greenock Water and the Whitehaugh Water (Fig. 2.4).

The deposits of fluvioglacial sands and gravels in the Ayr valley are confined to its lower slopes and are elongated parallel to the east-west orientated valley. These deposits are discontinuously exposed over a total length of I2 km.. The altitude of the eastern extremity of this sand and gravel is approximately 250m. O.D. and this altitude is generally maintained along its I2 km. length, though the highest point at approximately 260m. O.D. is near its western end.

The sand and gravel deposits in the Greenock and Whitehaugh valleys are patchily and irregularly distributed upto an altitude of 360m. O.D. (Fig. 2.4).

The thickness of these fluvioglacial sands and gravels may be derived from the borehole records and the examination of exposures. In many cases, only a minimum thickness is obtained because the lower boundary of the surface sands and gravels is not revealed. The thickness of the sands and gravels obtained from these sources in part of the Ayr valley is shown in Fig. 2.17. Borehole records show that the maximum thickness of surface sand and gravel deposits is 17.68m. and that the average thickness of sand and gravel deposits in Area I is approximately 10m.. Some sand and gravel deposits are covered by peat, but often the form of the underlying sand and gravel is still distinctive and therefore aids identification. In one part of Area I, only 8 sq. km. in extent, fluvioglacial sand and gravel upto 20m. thick outcrops between upper and lower till units.

The sand and gravel deposits in Area I have a variety of surface forms which include uneven spreads, mounds and ridges. On the basis of morphology, a two-fold subdivision of the fluvioglacial sands and gravels in the area may be suggested:-

1) the masses of sand and gravel at higher altitudes, such as on the upper slopes of the Greenock and Whitehaugh valleys; these are a series of large, steep-sided mounds and ridges which have a generally hummocky morphology.
2) the fluvioglacial sands and gravels on the lower slopes of the Ayr valley which have a generally uneven and irregular morphology. However, part of these deposits display subdued hummocky morphology.

The fluvioglacial material at higher altitudes is represented both by large accumulations, often over 1 sq. km. in extent, and small, isolated patches. The large accumulations usually display a 'moundy' morphology with individual mounds which rise to over 15m. in height. However, some sand and gravel deposits, both large and small, are represented only by a single hillock. Exposures, though rare, always reveal stratified sands and gravels which are well-rounded and poorly sorted with bedding that is often disrupted by faulting (Plate 2K, Site 2g). These accumulations of sand and gravel at higher altitudes are irregularily distributed between 250m. O.D. and 360m. O.D. (Fig. 2.4).

Fig. 2.17 Thickness of Fluvioglacial Deposits in Area I

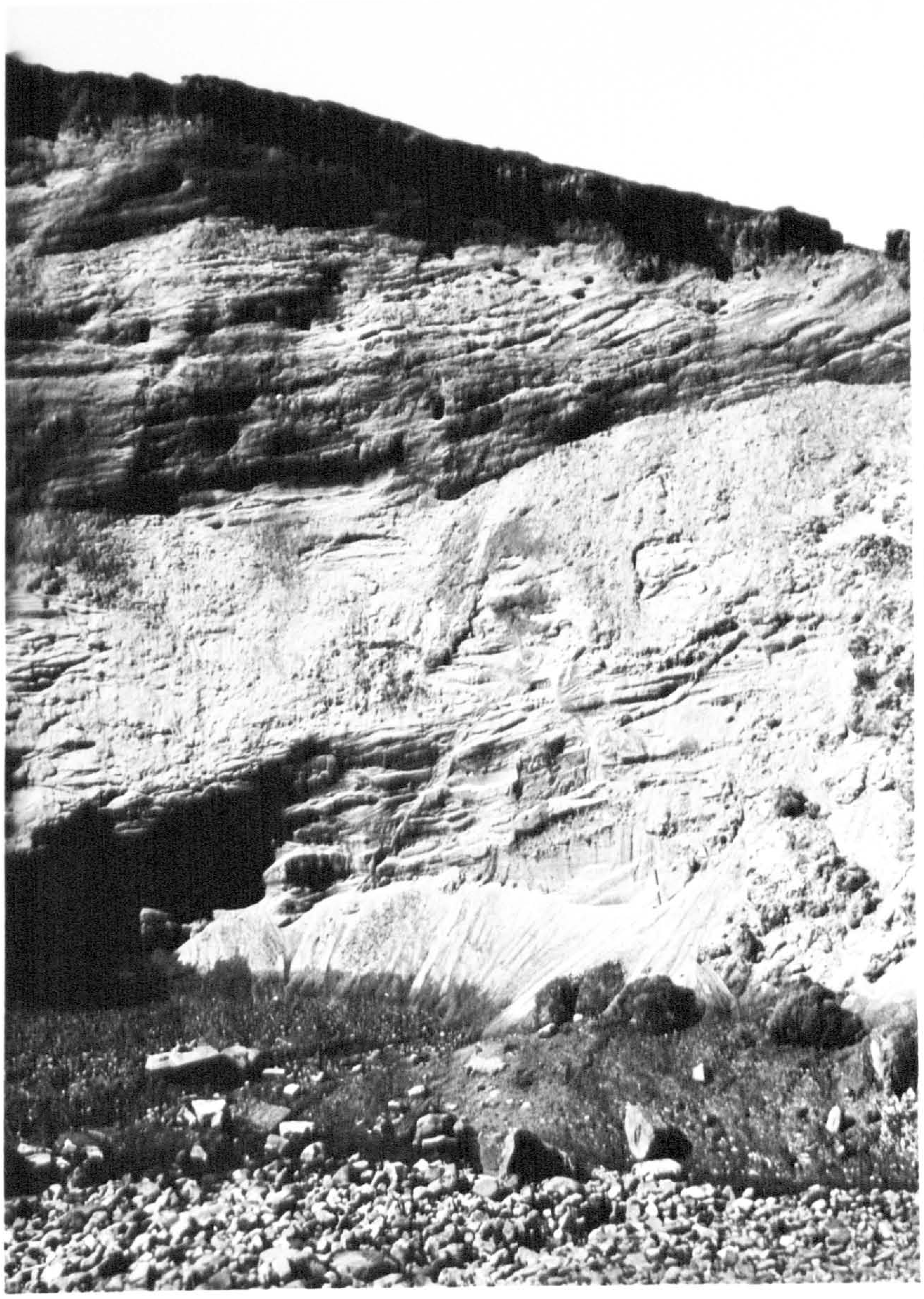


Plate 2K Structure of the Fluvioglacial Deposits which overlie Chocolate Brown, Shelly Till - Site 2g

However, some regularity exists around the 305m. contour on the flanks of Meanlour Hill where all the spreads of sand and gravel consist of a series of large, steep-sided mounds with smooth concavo-convex outlines. These forms are characteristic of kames which would have formed as "…. ice disintegration features, formed in ice marginal, subglacial, englacial or subglacial situations wherever cavities happened to be available for the receipt of water-borne sediment." (Clayton, 1964). The situation of these kami-form spreads of sand and gravel around the 305m. contour on the flanks of Meanlour Hill was explained by Charlesworth (1926b): "… Along the north of the "Airds Moss Lobe" there was laid down the kame terrace which runs from the Whitehaugh Water at 1000 feet (305m.) round Meanlour Hill to Greenock Water" (p. 33). This suggestion by Charlesworth highlights the lack of insight at the time concerning the downwastage of an ice-mass. An "Airds Moss Lobe" of ice is not needed, nor is it indicated from other evidence, to explain the skirting of Meanlour Hill with fluvioglacial sands and gravels. It is more probable that Meanlour Hill emerged as a nunatak during ice decay. The junction between ice and rock would have been an ideal accumulation zone for water-bourne sediment.

An isolated mass of sand and gravel north-east of Muirkirk has a form and situation that warrants special investigation (Fig. 2.4, Site 2 1). The fluvioglacial sand and gravel lies across the lower end of Channel 4 in the Starpet Rig channel system (Fig. 2.4). It is bounded by steep slopes to the south and east which rise 25m. above the hillside before reaching the flat top of the feature which extends northwards for 250m. (Plate 2L). This delta-shaped form is dissected by a stream which runs from west-north-west to east-south-east. This stream has exposed a 15m. section of unstratified, unsorted, medium-coarse, well rounded, dirty gravel. An origin and age relative to the development of Channel 4 may be hypothesised:-

1) Channel 4 was eroded subglacially.
2) The lower end of this channel accumulated fluvioglacial material in a subglacial cavity where deposition took place between the valley side to the north and the ice mass to the south. The meltwater which deposited this fluvioglacial material flowed

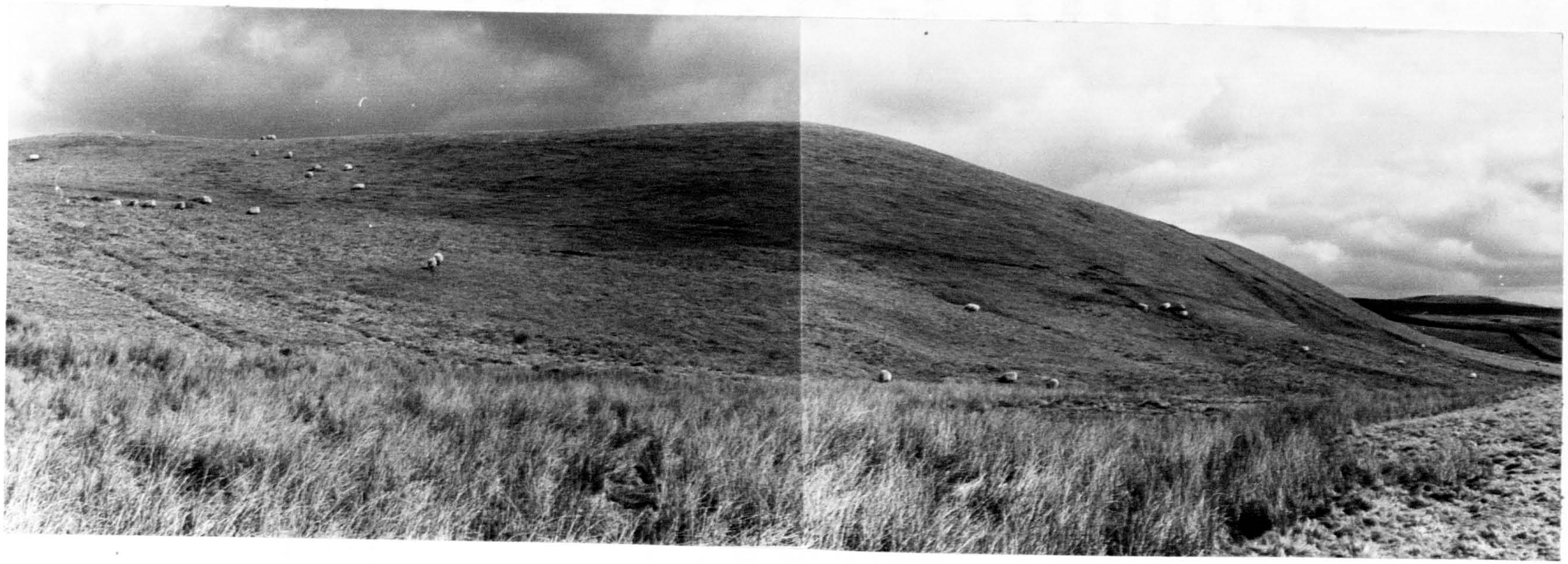


Plate 2L Southern margin of the Delta-Kame at the terminus of Meltwater Channel 4 towards the south-east. The level of deposition would probably have been controlled by the englacial water-table.

3) The ice disappeared and left a delta-kame stranded high on the hillside.

Two elongated ridges composed of stratified sands and gravels are present as part of the fluvioglacial deposits situated high on the hill-sides (Fig. 2.4). Both ridges are sharp-crested and steep-sided but they differ in size, sinuosity and continuity. One ridge is located at Kaims of Avon near the northern limit of Area I (Figs. 2.4, 2.I8). This was first described in I898 by John Smith :"It rises out of the peat in a series of large serpentine hummocks which, on the west side of the Avon, extend to 570 paces (600m.), with a break of I30 paces (I40m.) from its west end ... Further west there are a few small mounds on the moor ... on the east or Lanarkshire side of the Avon it is not so prominent .." (p. 67).

This symmetrical, steep-sided, west to east orientated ridge complex attains a maximum height of 9m., though this may be greater as the peat which surrounds it masks it to an unknown extent. A section, Site 2e, through the ridge is seen where the River Avon has dissected it. The exposure is badly slumped but an indeterminate thickness of coarse gravel which contains occasional rounded cobbles in a yellow silty/sandy matrix is seen. John Smith (I898), however, noted the following section at the same location:-

Site 2e Kaims of Avon (Figs. 2.4, 2.I8) 260m. O.D.

30 feet (9m.)	Very coarse Gravel.
25 feet (7.5m.)	Boulder clay (till) with a thin sand bed.
-	Volcanic Ash.

Smith concluded that the Kaims of Avon were "... part of a very fine moraine ... and evidently a terminal one from the last Avon glacier ..." (I898, p. 67). However, the form of this feature and its close association with some small meltwater channels and isolated mounds of sand and gravel (Figs. 2.4, 2.I8) suggests a subglacial origin or submarginal within decaying ice (Sissons I967b, p. III; Embleton and King, I968, p. 369). This feature, therefore, may be more correctly described as an esker complex. The meltwater which deposited it probably flowed to the

Fig. 2.18 Esker Complex at "Kaims of Avon".

east or west. Based upon evidence of meltwater flow directions from nearby fluvioglacially eroded features, the flow would have probably been to the east. Many workers such as Crosby (1902), Embleton (1964), Sissons (1967b) and Sugden and John (1976) maintain that the orientation of the longest eskers are usually parallel to the last movement of ice in any area. However, in a decaying ice mass, local meltwater directions will be diverse, and therefore, little significance can be given to the orientation of small eskers such as this one as indicators of former ice movements.

Two and a half km. south-east of the Kaims of Avon at Twopenny Knowe is another elongated ridge (Fig. 2.4). This discontinuous ridge, which is over 1000m. long, has a maximum width of 100m. and height of 7m.. The association of this ridge of sand and gravel with meltwater channels and isolated mounds of fluvioglacial material together with its cross-valley situation and east-west orientation are reminiscent of the description of the Kaims of Avon esker. A similar subglacial or submarginal fluvioglacial origin, probably by meltwater which flowed from west to east, is indicated.

The form and situation of these sand and gravel accumulations at higher altitudes suggest they were formed in ice-contact situations under, within, at the margin of, or on top of the decaying ice-mass which occupied Area I. There is strong evidence that Meanlour Hill, and maybe Blackside, emerged as a nunatak as the ice downwasted. At this time the Ayr valley would still be filled with a considerable thickness of ice.

The form of the fluvioglacial sand and gravel deposits on the lower slopes of the Ayr valley is varied. The morphology along the 12km. length of this sand and gravel mantle is generally uneven, but mounds and ridges are present (Fig. 2.4). The highest altitude of the sand and gravel surface is consistently around 250m. O.D., while the base of the sand and gravel slopes from 250m. O.D. on the eastern margin to 185m. O.D. at the western extremity.

The mounds on the lower slopes of the Ayr valley have two distinctive forms which relate to their position within the valley. Firstly, those forms on the hillsides and not confined to the floor of the Ayr valley have subdued and generally rounded forms. These features are similar to the kames described by Sissons (1958b) in the Eddleston Valley. He concluded that: "their more subdued and generally rounded form (was due to) their constituent materials having been let down onto the ground during the melting of a considerable thickness of ice after deposition in their vicinity had ceased." (p. 175). This seems a valid explanation of these sand and gravel mounds.

Secondly, mounds on the floor of the Ayr valley are relatively small with two distinct breaks of slope in the generally concave-convex outline. Hollows with flat floors and relatively steep-sides exist between the mounds. These were probably eroded by water, though definite channels could not be traced over long distances. These mounds, therefore, appear to be residuals of erosive processes rather than the products of ice disintegration; this explains most of the other sand and gravel mounds in Area I. These mounds on the floor of the Ayr valley west of Muirkirk are continuous with sand and gravel spreads to the east of Muirkirk which have a different morphology.

The fluvioglacial deposits on the floor of the Ayr valley east of Muirkirk have an uneven form. Morphologically, the deposits are a series of low hummocks which rarely exceed 2m. in height and are devoid of any consistent arrangement. Only two natural exposures exist in this 5 km. long expanse of sand and gravel. The first exposure, Site 2o, near the eastern extremity of the sand and gravel spread, reveals 2m. of coarse, well-rounded, unsorted, unstratified gravel (Fig. 2.4). The second exposure, Site 2j, on the south side of the River Ayr is south of Muirkirk (Fig. 2.4). This site (Site 2j) shows 2m. of well-stratified sands, gravels, silts and clays of various thicknesses. The materials in these beds are well-rounded and poorly sorted. The bedding dips towards the south-west at an angle of 10°. This evidence strongly suggests that the melt-water which deposited this sand and gravel flowed from the north-east. The origin of these deposits was suggested by Geikie (1894) and Charlesworth (1926b) to have been in the proglacial lake:-" "Lake Muirkirk" .... Sands and gravels swept into the lake, are well displayed about Muirkirk" (Charlesworth, 1926b, p. 33). However, Sissons (1958b), who mapped a similar spread of sands and gravels in the Eddleston valley, concluded that: "The abundance of ice-contact forms shows that the sand and gravel was deposited not in an open lake, but in intimate association with dead-ice" (p. 169). This conclusion also applies to the Ayr valley sand and gravel deposits.

Only one elongated ridge composed of sand and gravel exists on the lower slopes of the Ayr valley (Fig. 2.4). This is situated west-south-west of Muirkirk and is 400m.long, unevenly crested and reaches a maximum height above the surrounding land of 15m. (Plate 2M). The ridge is 100m. wide at the base and has sharply defined steep slopes. The north-facing slope has been trimmed to some extent by the erosive action of the River Ayr which is immediately at its base. The main ridge is orientated west-south-west to east-north-east and some minor ridge-like features on the southern side of the main ridge share this orientation. An exposure examined a short distance beyond the eastern extremity of the ridge at Site 2j is described on p.55 . A second exposure at Site 2i at the western extremity of the ridge (Fig. 2.4) shows 1m. of coarse, unsorted, unbedded and well-rounded gravel. The average size of clast is 6 - 7 cm.. This elongated ridge resembles an esker, both in composition and form. Further support for this suggestion may be obtained from another ridge which lies 1km. to the west. Here, a ridge 100m. long and 4m. high has a similar west-south-west to east-north-east orientation as the main ridge. An exposure at its eastern extremity (Site 2h) shows 3m. of very coarse, unstratified gravel with many of the clasts over 30cm. in diameter. The intervening distance between this shorter ridge and the main ridge coincides with the confluence of the Garpel Water and the River Ayr (Fig. 2.4). This, in addition to the form, composition and orientation of the two ridges suggests they were once one continuous feature which has subsequently been separated by fluvial erosion. This once continuous ridge has therefore been dissected by stream action. However, if this feature is an esker, the direction of meltwater flow by which it was deposited is not clear. The coarsening of material within the ridge strongly indicates that the meltwater flowed from west to east. The bedding, however, at Site 2j strongly suggests that the meltwater flowed from north-east to south-west.

Although the evidence may fit into a pattern of esker development, a number of problems arise:-

Plate 2M "Esker" near Muirkirk

I) The esker-ridge has an altitude of approximately 2I5m. O.D. which is substantially below the level of the adjacent sand and gravel on the lower slopes of the Ayr valley. It will be suggested on p.60 that this sand and gravel was deposited as a continuous spread across the floor of the Ayr valley. If this is correct, it is difficult to envisage how an esker (in sensu stricto) could be formed and preserved below the altitude of this spread. Although Howarth (I97I) described a process of ridge formation on a sandar in Iceland caused by the melting of 2 buried ice masses, it is unlikely that this may be used as a direct analogy.

2) The position of this elongated ridge in relation to the flood plain of the River Ayr makes its preservation, in original form, unlikely. However, no difference was observed between the north and south sides of the ridge, which is surprising because the north side of the ridge has been trimmed by the River Ayr. It is impossible to assess this erosion; it could have effected a total transformation in form of the fluvioglacial deposits on the floor of the Ayr valley. The esker form therefore could have been produced by erosion.

3) The evidence of meltwater movements suggested from the study of the internal characteristics of the material which makes up the ridge are contradictory. Examinations of particle sizes in the ridge indicate that the meltwater which deposited this fluvioglacial material flowed from the west. However, the structure of this material shows that meltwater flowed from the north-east. Fluvio-glacial deposits are characterised by internal variety (Price 1973, p. I3I) and such limited exposures do not allow reliable conclusions to be drawn concerning the direction in which the meltwater flowed when it deposited this material.

4) This part of Area I has suffered greatly from man's exploitation of coal, iron ore and limestone. Tipped waste products from these activities, which are widespread near the ridge, may mask relationships which could be of importance in elucidating the origin of the ridge. From close examination of the drainage pattern around the ridge, a number of streams have been diverted. In particular, a

stream which flows along the base of the south side of the ridge has been altered. This may have been larger before its alteration and could have eroded the south side of the ridge in a similar fashion to the River Ayr on the north side. It is possible that a model of ridge development due to erosion more correctly explains the origin of the Muirkirk 'esker'.

Due to its eroded character and the lack of good exposures, the origin of the sand and gravel on the floor of the Ayr valley is difficult to assess. Despite these difficulties a number of suggestions may be made:-

I) The meltwater which discharged from Channel 7 (Fig. 2.4) would have generally flowed subglacially from east to west. The proximity of the lower end of this huge channel to the eastern extremity of the fluvioglacial deposits on the floor of the Ayr valley suggests that they probably owe their origin, to a large extent, to this flow of meltwater.

2) Channel system II, near Cairn Hill (Fig. 2.4) carried subglacial meltwater which flowed towards the north-east and the lower slopes of the Ayr valley. This may also have been a transport route for some of these fluvioglacial materials.

These suggestions agree with those of Sissons (I958b) who worked in the Eddleston valley: "That this material was not derived (except possibly to a very minor degree) from the ice that occupied the valley, but was instead washed in by the streams that cut the meltwater channels to the west and south-west is suggested by the large volume and proved by the bedding exposed in gravel pits in two of the kames ..." (p. I7I). The evidence is less conclusive in the Ayr valley but it is still highly probable that the sand and gravel accumulated in subglacial cavities near the ice margin. The meltwater which deposited the material would probably have flowed from a variety of directions, but predominantly from the east.

Towards the western extremity of this fluvioglacial spread, the surface sand and gravel disappears below shell-less till. Further west, this fluvioglacial material outcrops in a number of exposures, over a total area of 8 sq. km., above shelly till and below shell-less till. These subsurface deposits of sands and gravels are well exposed at Greenockmains (Site 2f, Fig. 2.4) where they are over 20m. thick (Plate 2N). The

Plate 2N   Exposure at Greenockmains - Site 2f composition and structure of the deposits vary greatly both laterally and vertically. Imbrication studies and the study of the channel forms in these deposits suggests that they were deposited by meltwater which flowed from the north-east. This fits in well with the suggestion that the fluvioglacial deposits on the floor of the Ayr valley were deposited by meltwater which flowed from a generally east to west direction. Due to field relations, this subsurface sand and gravel may be regarded as the same unit of deposition as the surface sand and gravel to the east (Fig. 2.4).

The termination of fluvioglacial deposition is abrupt at an approximate altitude of 185m. O.D. and may indicate "the establishment of a subglacial escape route (which) resulted in the rapid draining of the .." (Sissons, 1958b, p. 174) remainder of the Ayr valley. This was implied by Eyles et al (1949): "while the lowland ice was retreating to lower and lower levels, the meltwaters remained stagnant along the ice front, or seeped back under it, instead of flowing freely away." (p. 129). Because of its large size and deeply incised nature, it is likely that the Ayr valley was the subglacial escape route. An alternative explanation could be that sand and gravel <u>was</u> deposited but has since been removed. However, there is no evidence in support of this.

Fluvioglacial deposition is confined to the eastern part of Area I mainly in the Ayr, Greenock and Whitehaugh valleys. Most of these deposits are between 200m. O.D. and 350m. O.D. and no deposits of fluvioglacial origin are found below 185m. O.D.. Based upon morphology, a two-fold subdivision of the sand and gravel may be suggested:-

1) <u>Sand and gravel at higher altitudes mainly confined to the upper slopes of the Greenock and Whitehaugh valleys.</u> These sand and gravel forms are comprised of a series of large, steep-sided mounds with a few ridges.
2) <u>Sand and gravel confined to the lower slopes of the Ayr valley.</u> These sand and gravel forms are varied and include uneven morphology, subdued mounds and trimmed mounds and ridges.

This distribution and form of fluvioglacial material indicates the mode decay and disappearance of the last ice-sheet from Area I. The retreat of ice in the eastern part of Area I was probably downslope because the movement of ice was upslope from west to east. This is unlike most present-day ice masses which are withdrawing towards higher ground. The result of this fundamental difference, when applied to fluvioglacial deposition, is summarised by Sissons (1958b): "Consequently, thinning of the ice progressed during deglaciation, the ice in the valley became increasingly cut off from its source of supply and probably became more or less inactive at an early stage.... These conditions favoured the extensive development of subglacial and englacial drainage ..." (p. 177). This is certainly true of the eastern part of Area I.

The forms at higher altitudes would have been deposited as kames around the emerging nunataks of Meanlour Hill and Blackside. A kame-delta is also present on the south side of Starpet Hill. The sands and gravels on the lower slopes of the Ayr valley were not deposited in the same manner; they are considered to be the result of debris-laden meltwater, which flowed from the north-east, discharging into cavities near the margin of the ice. Channel 7, which lies to the east of the deposits, would probably have been the main source of debris-laden meltwater. Deposition could take place in this upper part of the Ayr valley because the ice had not decayed sufficiently to allow the rapid, free drainage of meltwater downslope into the Firth of Clyde. After deposition, the original form of the sand and gravel was considerably altered by water action. This produced a variety of eroded forms, including mounds and ridges. It is not clear from the evidence in Area I how the sand and gravel on the upper slopes of the Greenock and Whitehaugh valleys are related chronologically to the sand and gravel deposits on the lower slopes of the Ayr valley.

In an 8 sq. km. part of Area I, between Sorn and Muirkirk, upto 20m. of sand and gravel lies between two tills. Field relations show this subsurface sand and gravel to be the same unit of deposition as the surface sand and gravel in the Ayr valley. The presence of such a thick, extensive accumulation of fluvioglacial material above a shelly till and below a non-shelly till is strong evidence for a minor readvance of ice during general retreat. The lack of sand and gravel on top of this upper 'readvance till, or at any point west of it, suggests that, after the readvance, meltwater was no longer prevented from escaping down-valley into the Firth of Clyde. The result was the rapid drainage of meltwater from the upper and middle Ayr valley. This was not conducive to fluvioglacial deposition.

2.7: Conclusions

From evidence derived from the study of the features of glacial erosion, glacial deposition, fluvioglacial erosion and fluvioglacial deposition, the history of the last glaciation may be summarised as follows:-

I) The presence of shells and Highland erratics in most of the till exposures in Area I suggests that the ice by which it was deposited originated in the west Highlands.

2) The existence of till upto an altitude of 480m. O.D. shows that the Highland ice reached at least this level. However, the stream-line form of many of the hills suggests that ice probably covered the whole of Area I.

3) Ice-moulded forms, erratic counts, mean stone orientations and meltwater channels indicate that the Highland ice moved from the north-east in the western part of Area I. However, the ice movement was deflected around Blackside and associated high ground near the north-central part of the area, which resulted in a generally eastward flow across the eastern part (Fig. 2.I9). This eastward movement of ice in the eastern part of Area I was therefore uphill. This is not normally the case, as ice usually moves down into lower ground and withdraws into higher ground.

4) Extensive meltwater channel development north-east of Muirkirk shows that, during the early stages of ice decay, meltwater in the eastern part of Area I generally flowed from west to east across the Ayr / Douglas watershed.

5) The 90° turn in the lower end of Channel 7, where it changes its slope direction from south-east to south-west at approximately 255m. O.D., and the absence of channels below this altitude suggests that, as ice downwastage continued and the Ayr / Douglas gap emerged,

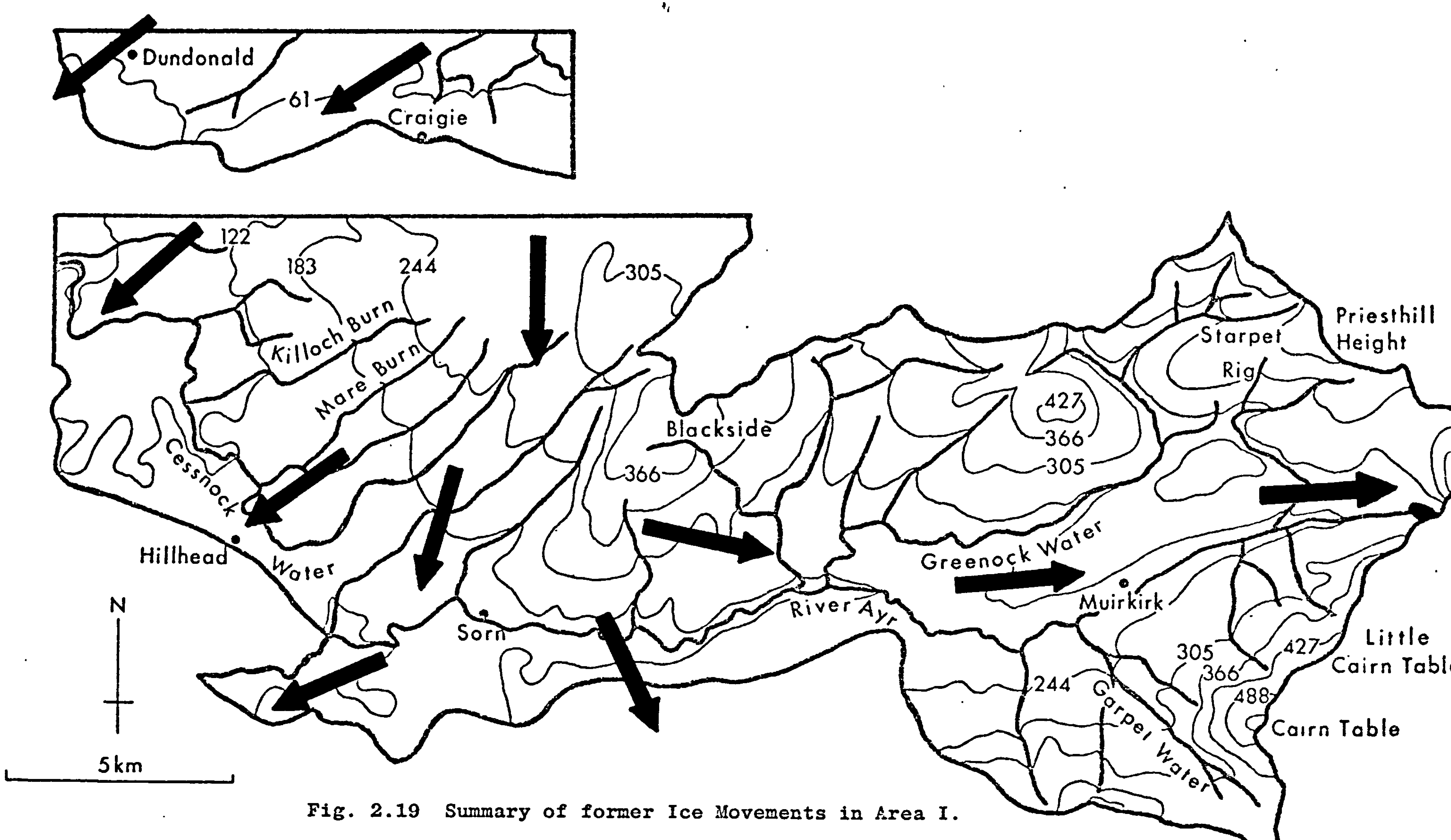


Fig. 2.19 Summary of former Ice Movements in Area I.

the flow of meltwater was disrupted and reversed.

6) During downwastage, Blackside and Meanlour Hill emerged as nunataks and accumulated kami-form fluvioglacial deposits on their flanks. The presence of marginal or submarginal channels on the side of Blackside indicates that the Ayr valley was still filled with ice at this time. The meltwater from Channel 7, which flowed subglacially from east to west, was probably the main transport route of the sand and gravel deposited on the floor of the Ayr valley. This sand and gravel was eroded by water to a considerable degree after deposition.

7) The presence of shell-less till above 20m. of fluvioglacial material as well as a lower shelly till in the Ayr valley strongly suggests the general retreat of ice ceased for a short period. This allowed the ice to readvance over the fluvioglacial sand and gravel and deposit the upper shell-less till.

8) The absence of fluvioglacial sands and gravels in the western part of Area I indicates that the controls on meltwater deposition changed markedly. This was probably due to the advanced state of decay of the ice mass which occupied Area I allowing meltwater to drain freely down the Ayr valley into the Firth of Clyde rapidly after the minor readvance of ice.

CHAPTER 3

AREA II

3.I: Introduction: Location and Extent

Area II extends over approximately 220 sq. km. of the east-central part of central Ayrshire (Fig. 3.I). The area is 25 km. from east to west and I6 km. from north to south. The northern limit of Area II is the watershed between the Upper Ayr drainage system (the eastern part of the southern boundary of Area I) and the Lugar drainage system (Area II) (Fig. 3.I). The eastern boundary of Area II corresponds to the old Ayrshire county boundary with Lanarkshire in the north and Dumfriesshire in the south. Most of the southern boundary of Area II is the watershed between the Nith drainage system (Area V) and the Lugar drainage system. The western extremity of this southern boundary is the exception because it is the boundary between the Doon / Girvan drainage system (Area IV) and the Lugar drainage system. The western boundary is entirely represented by the watershed between the Lower Ayr drainage system (Area III) and the Lugar drainage system (Fig. 3.I).

Area II contains evidence of glacial erosion, glacial deposition and fluvioglacial deposition. Features of fluvioglacial erosion are absent from the area. As with all five areas which make up central Ayrshire, the distribution and intensity of evidence of glacial and fluvioglacial activity is diverse and the scale of presentation is varied for ease of description and presentation.

3.2: Relief and Drainage

Area II may be subdivided into three distinct parts based upon relief: the eastern part, the southern part and the remainder of the area. The relief of Area II strongly reflects the solid geology (Figs. 3 3.3).

The eastern part of the area is heavily dissected and generally

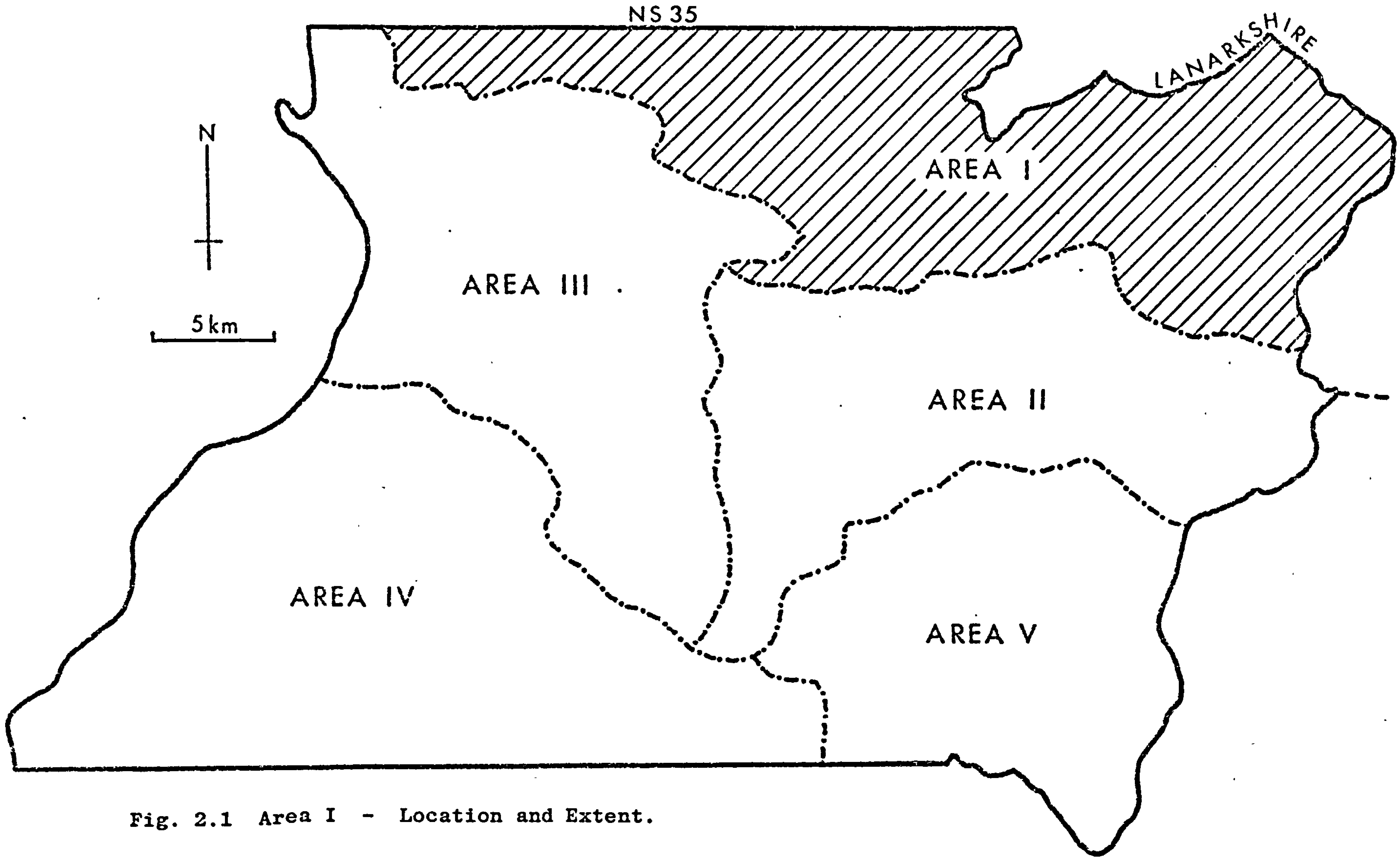


Fig. 2.1 Area I - Location and Extent.

slopes from east to west. This part of Area II contains the highest summits which include Stony Hill (562m), Wardlaw Hill (497m), White Hill (480m), Auchintench Hill (465m) and Niviston Hill (459m) (Fig. 3.2). The high altitude is a result of underlying resistant sandstones. The geological structure of this part of the area is reflected by a series of north-east to south-west orientated ridges. These ridges are to a large extent the reason for the high relative relief values, upto 180m., found in this part of Area II. The ridges are steep-sided except for the lower slopes which are till covered and have generally streamlined forms.

The southern part of Area II which has a generally high altitude has a very gently undulating relief. The highest summits in this part of the area include Benbain (406m), High Mount (365m), Stannery Knowe (363m) and Green Hill (344m) (Fig. 3.2). The relative relief of this peat covered part of Area II rarely exceeds 75m.. Green Hill (344m), which is a volcanic plug, is an example where relative relief exceeds 75m.; but this is the most distinctive landform in the southern part of Area II. This very gently undulating relief is a reflection of the resistant, horizontally bedded, volcanic intrusions of teshenite and theralite between beds of shale. The valleys which contain the main lines of drainage in this part of the area do not fragment the landscape to any significant degree.

On the basis of relief, the remainder of Area II (i.e. the northern and western parts) may be regarded as a single unit. The altitudinal range across this undulating "Ayrshire Plain" - type landscape is from 230m. O.D. in the east to 75m. O.D. in the west. The relative relief values in this part of Area II are 75m. at a maximum. The underlying relatively soft shales and sandstones together with the structural control of the Mauchline Basin gives this part of the area its low-lying character. The very thick drift accumulations explains the subdued nature of the landscape. The major lines of drainage in this part of Area II generally occupy relatively narrow, shallow valleys eroded into the drift material and are not therefore major relief features in themselves.

The Lugar Water is the central branch of the dendritic drainage

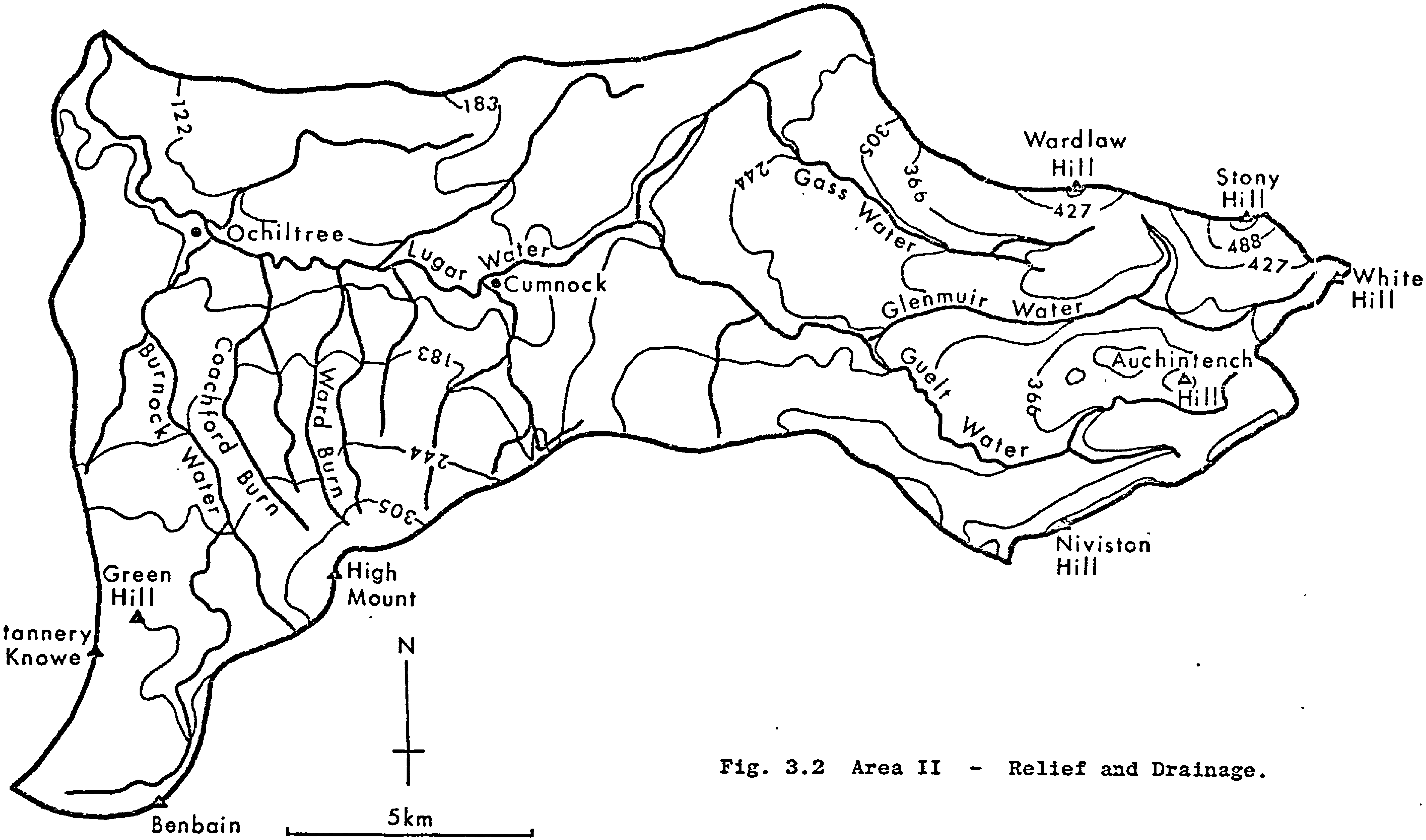


Fig. 3.2 Area II - Relief and Drainage.

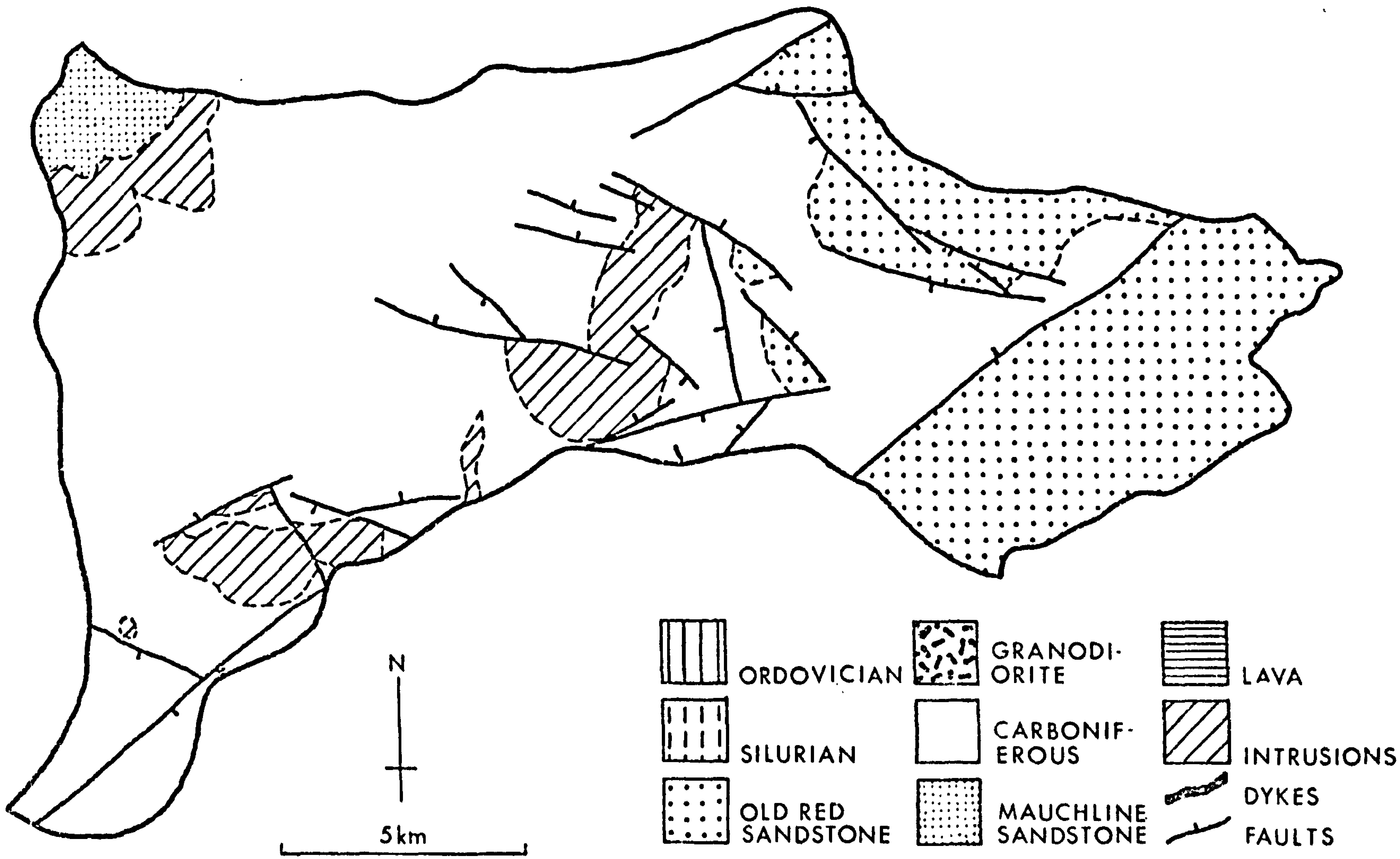


Fig. 3.3 Area II - Geology

pattern of Area II and the main catchment areas are to the east and south of the main stream (Fig. 3.2). The Lugar Water generally flows from east to west. This is also true of the Gass, Glenmuir and Guelt Waters which are its main tributaries in the eastern part. The other main tributaries like the Burnock Water, Coachford Burn and Ward Burn generally flow from south to north into the Lugar Water (Fig. 3.2). Many of the streams, particularly in the eastern part of Area II, are very small in relation to the size of the valley in which they are contained.

Area II, therefore, can be divided into three parts on the basis of relief: the eastern part which is highly dissected and includes the summits with the highest altitudes; the southern part which is slightly lower and very gently undulating: the remainder of Area II with its gently undulating "Ayrshire Plain" - type landscape.

3.3: Glacial Erosion

Area II, like Area I, has few features which may be explained purely in terms of glacial erosion. The features identified in Area II are striations, a single crag and tail, ice-moulded forms and glacially-breached cols (Fig. 3.4). These features are mainly concentrated in the higher parts of the area to the east and south (Fig. 3.4). The scarcity of these features limits their usefulness in determining former directions of ice movement across Area II.

Only five striations have been found within Area II, all of which were originally recorded by the Officers of the Geological Survey of Scotland (Fig. 3.4). Although individual striations are not always reliable indicators of general ice movements (Embleton and King, 1968), the two striations in the eastern part of the area, which are orientated north-west to south-east, may suggest a movement of ice from the north-west or the south-east. If this is correct, it is highly likely that these striations reflect a continuation of the general movement of ice from the west suggested for the eastern part of Area I (Chapter 2).

The two striations in the south-central part of Area II are orientated almost north to south (Fig. 3.4). It is not certain from which direction the ice by which they were eroded moved as this part of Area II is very close to the region in central Ayrshire which Eyles et al (1949) suggested was affected by both Highland ice from the north and Southern Upland ice from the south (Fig. 3.5). One other striation is located in the southern part of Area II and is orientated north-west to south-east. This lies well within the region of central Ayrshire recognised by Eyles et al (1949) to have been affected only by Southern Upland ice. It is more likely, therefore, that the ice which produced this striation moved from the south-east rather than from the north-west.

Without supporting evidence from other glacial and fluvioglacial features in Area II,the former ice movements suggested from the study of these five striations may not be regarded as conclusive.

Green Hill, Benbain and High Mount (Fig. 3.4), which are situated in the southern part of Area II, all have distinctive forms. They have semi-circular, smooth, steep slopes which face towards the south-east and long, gentle slopes which face towards the north-west. The average diameter of the semi-circular parts of the features is 300m. and the average height of the steep slopes is 40m.. The gentle slopes to the north-west are all approximately 800m. in length. All three features have classic 'crag and tail' morphology but only one, Green Hill, has the geological foundation to be categorised as a crag and tail <u>in sensu stricto</u>. Green Hill consists of a resistant volcanic plug which forms the "crag" and part of the less resistant country rock which surrounds it forms the "tail". The features at Benbain and High Mount are made up of a homogenious igneous rock-type (teshenite) and are therefore not definitive crag and tails. These features are regarded as ice-moulded forms. However, it is considered that all three features provide strong evidence that the ice which occupied the southern part of Area II moved from the south-east. The source of this ice would have been in the Southern Uplands.

Fourteen glacially-breached cols have been identified within Area II and they are all located in the high eastern and southern parts

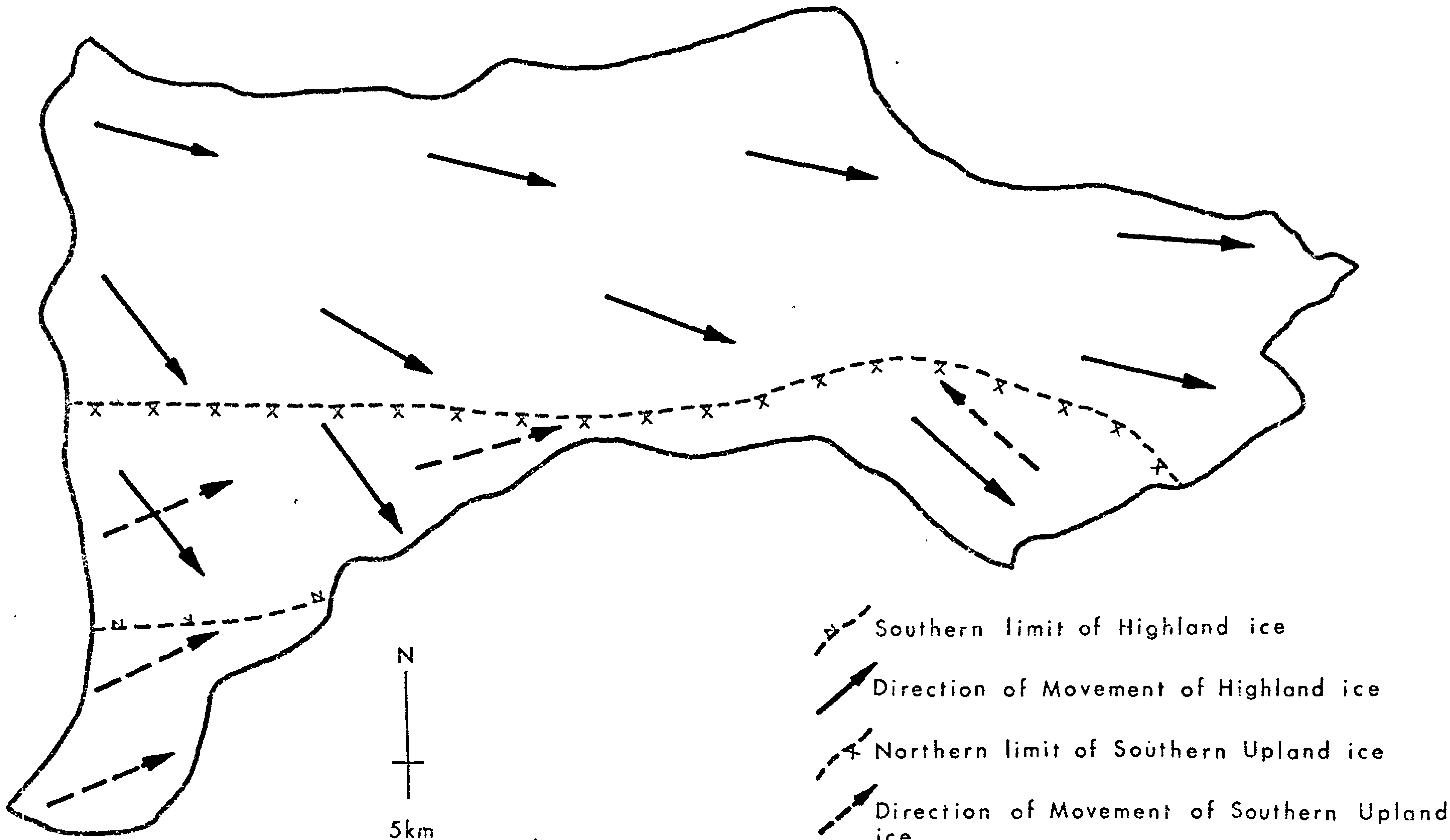


Fig. 3.5 Ice Movements in Area II - Eyles et al, 1949.

(Fig. 3.4). It was concluded in Chapter 2 that glacially-breached cols do not necessarily reflect former ice movements within any area and that their major usefulness is to indicate a minimum altitude for the former ice cover. In this context, the minimum altitude of ice cover in the eastern part of Area II was approximately 420m. O.D. and in the southern part of the area was approximately 340m. O.D.. However, the streamlined nature of many of the summits in Area II suggests a complete ice cover.

The evidence provided by the study of glacially-eroded features indicates that Area II was covered by ice upto an altitude of at least 420m. O.D.. This ice had two diametrically opposed movements which probably reflect diverse origins. The northern and eastern parts of Area II were occupied by ice which moved from the north-west. This is probably an extension of the movement of ice from the west suggested for the eastern part of Area I. Its origin, therefore, was in the west Highlands. The southern part of Area II was affected by ice which moved from the south-east. The origin of this ice would have been in the Southern Uplands. These suggested ice movements support the view of Eyles et al (1949). The movements of ice in Area II, as suggested by the study of features of glacial erosion, are therefore both diverse and complex. The study of other glacial and fluvioglacial features may indicate more precisely the former directions of ice movement in Area II.

3.4: Glacial Deposition

Glacial deposition by the ice which covered Area II was widespread. Despite alterations in the surface distribution due to the deposition of fluvioglacial sands and gravels and the accumulation of peat and alluvium, glacial deposits are still the most common surface material in the area (Fig. 3.4). These glacial deposits are thickest in the low-lying parts of Area II to the north and west and thin out and eventually disappear with increasing altitude. The till deposits consistently thin out and disappear at around 460m. O.D. (Fig. 3.4).

Till covers approximately 70% of the surface area of Area II (Fig. 3.4). Three zones of till cover are recognised in the area and these closely resemble the relief sub-divisions suggested on p. 63. In the eastern part of the area till is present at the surface only on the lower slopes of the Gass, Glenmuir and Guelt valleys. Away from these well-drained lower valley sides, peat accumulations extensively mask the underlying deposits. At higher altitudes superficial deposits are absent and solid rock outcrops (Fig. 3.4). Solid rock is the most common surface material in this part of Area II.

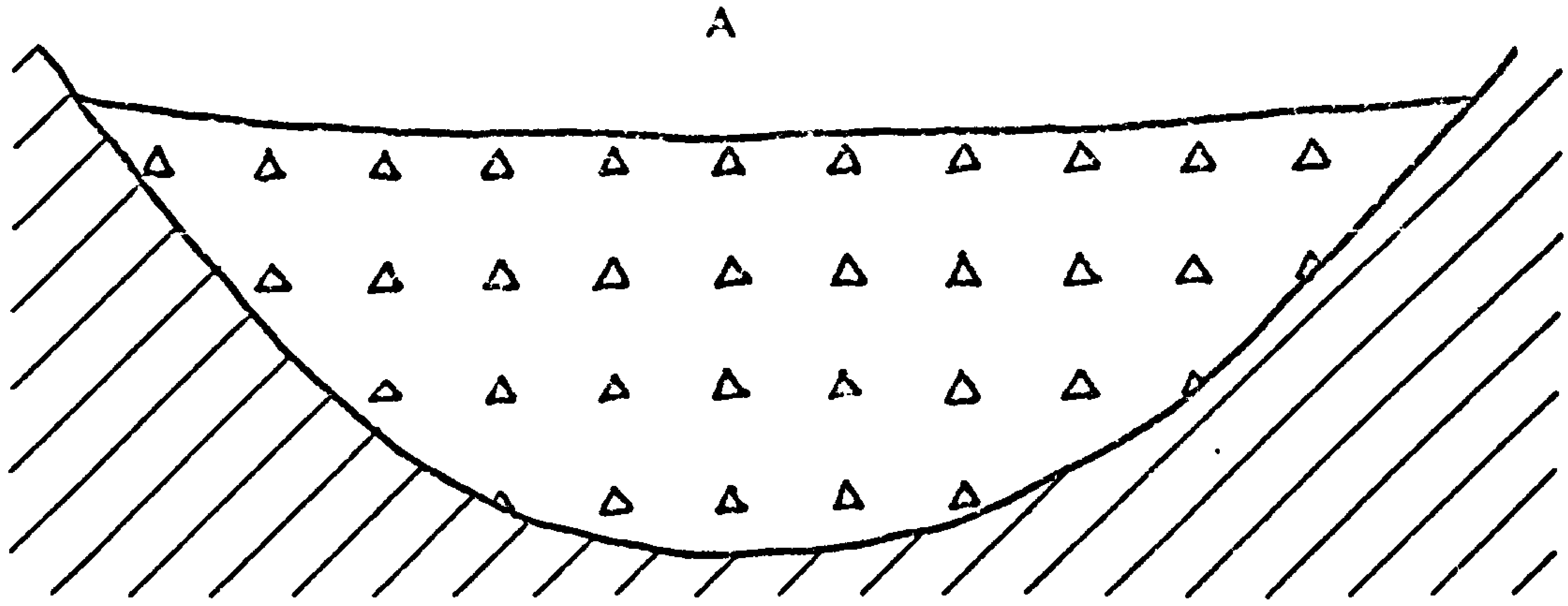
In the southern part of the area, peat is almost the only surface material, with very limited outcrops of till or solid rock (Fig. 3.4).

In the remainder of Area II, till is the most extensive surface material. Very few outcrops of solid rock protrude through the till but relatively large accumulations of peat and fluvioglacial sands and gravels exist in the north-east of this part of Area II (Fig. 3.4). Here, till thicknesses, revealed by borehole records, are commonly 20m..

The colour of the till varies considerably throughout Area II; it generally reflects the colour of the bedrock upon which it lies. The matrices of the till also vary depending upon the type of bedrock. Argillaceous rocks are generally overlain by a clayey till. Arenaceous rocks are generally overlain by a sandy till. Igneous rocks are generally overlain by a very sandy/gritty till which usually contains many large clasts.

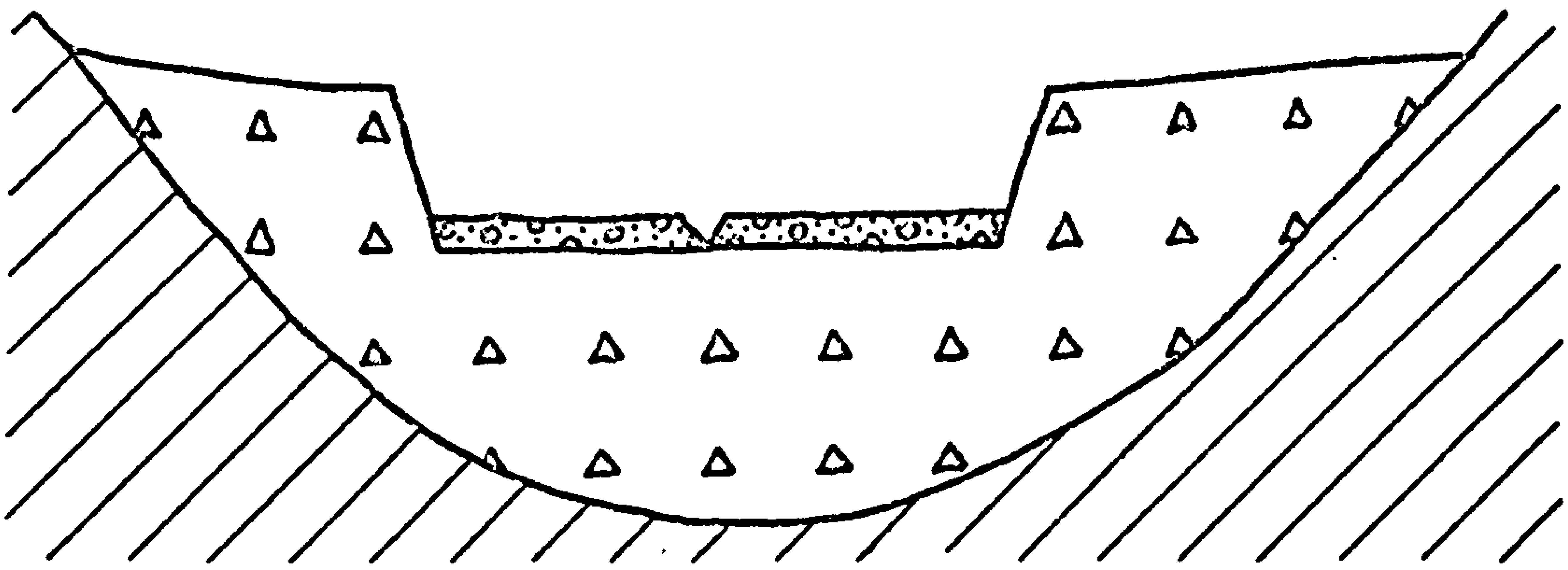
Till in Area II is exposed as a single unit everywhere except in the Guelt valley where "two boulder clays (tills) are clearly visible separated by a deposit of sand and gravel." (Bailey, 1929, p. 72) (Fig. 3.4). However, John Smith and the Officers of the Geological Survey of Scotland noted many "exposures" throughout Area II of a multi-sequence nature. Close examination of some of these supposed 'sequences' of till - sand and gravel - till reveals a till overlain by river gravels (which occupies a bench cut by the river into the till) with an old river cliff exposing till above (Fig. 3.6). The stratigraphy, therefore, is till - sand and gravel - till but the origin of the sand and gravel is fluvial and not fluvioglacial as suggested on many occasions by these other workers.

A



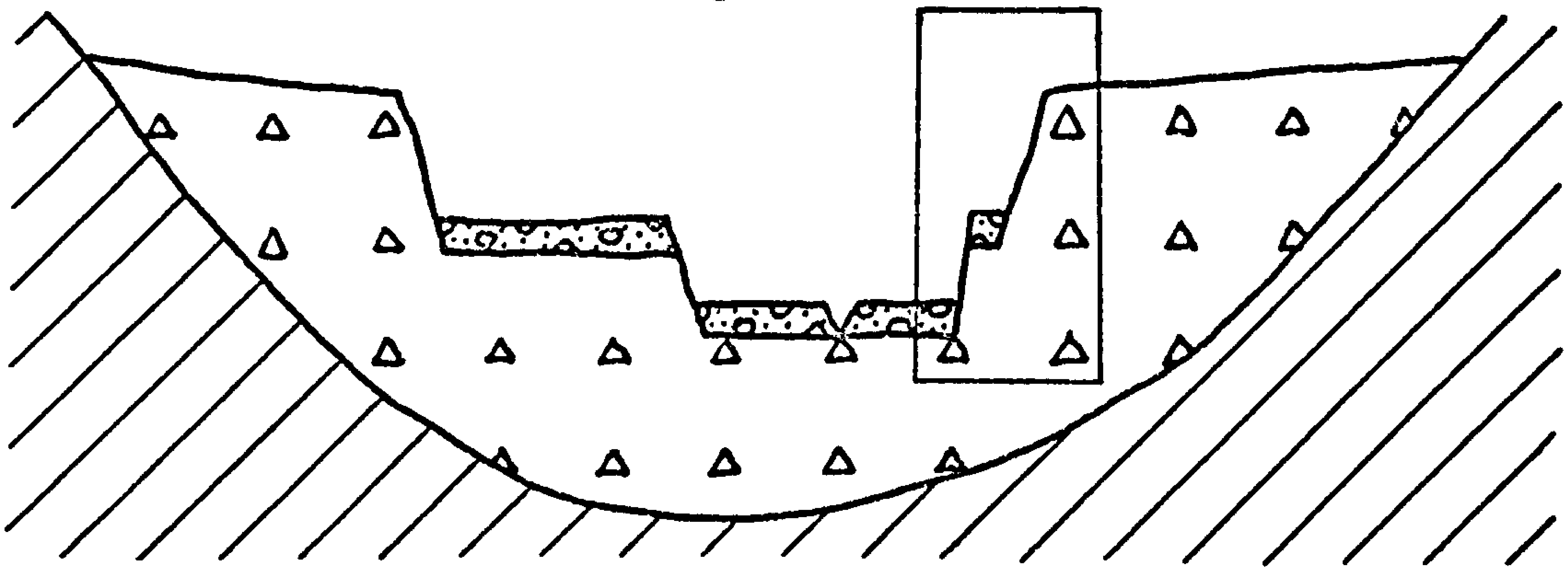
Till infills the valley bottom.

B



First phase of erosion by river into till and the subsequent deposition of river gravels.

C



Second phase of erosion by river into till and river gravels. Results in till - sand and gravel till stratigraphy (in box).

Fig. 3.6 Explanation of the 'Supposed" Multi-sequence Exposures in Area II.

The common characteristics of the tills in Area II are angular and subangular clasts of various sizes and rock-types bound in a silty, sometimes gritty, matrix. The tills are very compact and often form almost vertical exposures upto I5m. high when undercut by streams (Plate 3A). All exposures of till have been examined in an attempt to elucidate former movements of ice across Area II.

Preferred - stone - orientation analyses and erratic counts have been undertaken at three till sites, Sites 3f, 3g and 3b (Fig. 3.4). It is assumed that the results, which are summarised in Table 3A; Figs. 3.7, 3.8 will help to establish both the origin and direction of movement of the ice which deposited the till in which the stones and erratics are contained.

Site 3f is situated in the north-central part of Area II in the valley of the Gass Water (Fig. 3.4). Like many of the exposures in this valley, Site 3f consists of IOm. of brown clayey till which becomes sandier with depth. This exposure contains many inclusions of sand. A preferred - stone - orientation analysis shows the mean orientation of stones in the till to be I04° (Figs. 3.4, 3.7; Table 3A). A chi-square value of 8.68 was calculated for this mean stone orientation, which, when tabulated with 8 degrees of freedom, is not significant at any level of confidence. A dip-strength of 0.72 may also be calculated from these data which, when tabulated with I degree of freedom, is also not significant at any level of confidence. In strict statistical terms, therefore, both the mean orientation of stones and their dip strength are meaningless and no indication of either the origin or the former movements of ice may be suggested based upon these results. However, an examination of erratics within the till may provide useful information concerning the origin and former movement of ice in this part of Area II.

All of the erratics selected randomly from the till at Site 3f are of local origin. However, the presence of the distinctive Mauchline Sandstone, which outcrops to the west-north-west, suggests that the ice which deposited this till moved from a generally west-north-west direction. The abundance of scratched shell fragments indicates that this ice-mass moved across an area formerly occupied by the sea. As with the study of Area I, it is assumed that the

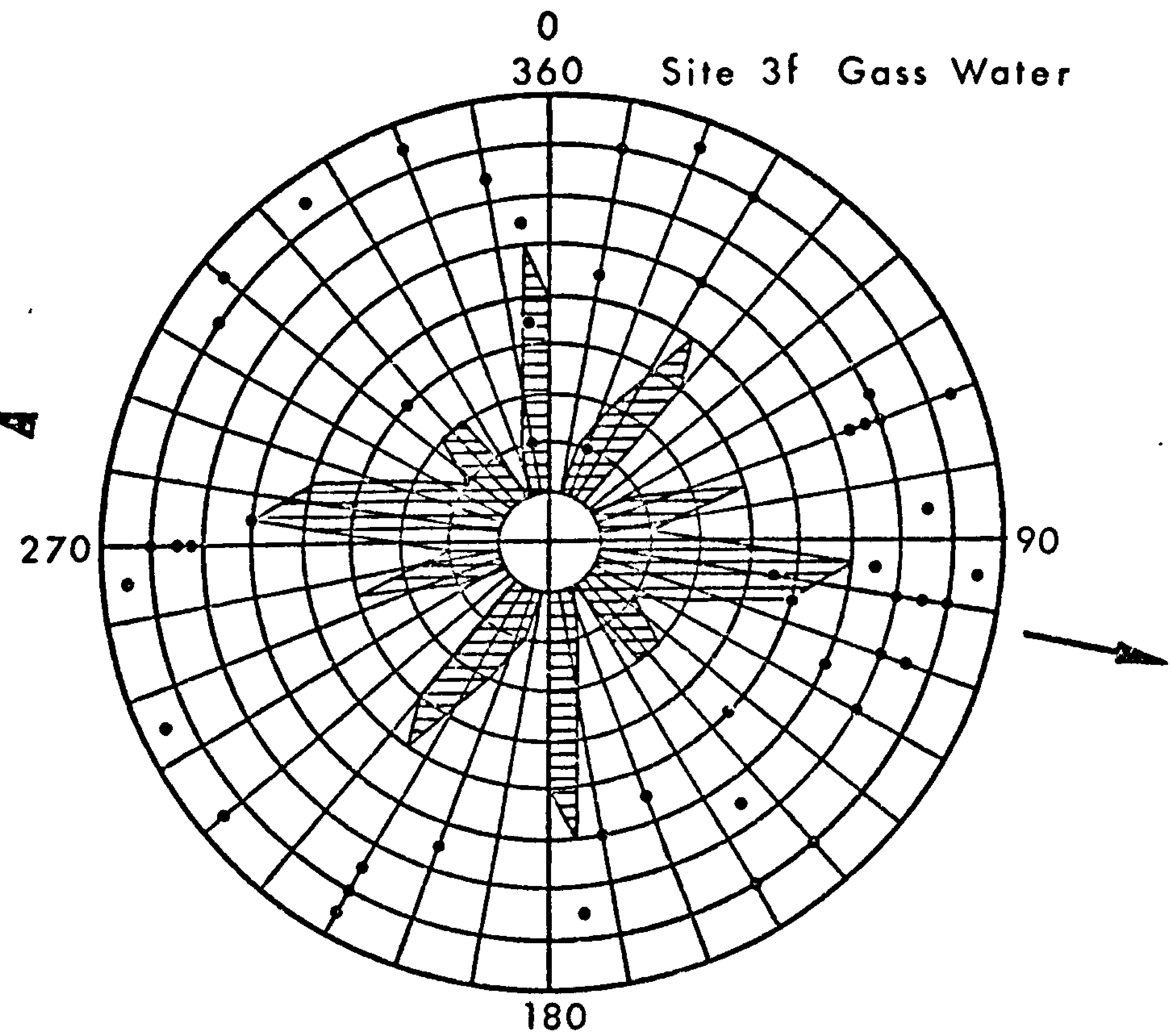
Plate 3A Exposure of Till in the Guelt Valley - Site 3g

TABLE 3A

Till Characteristics in Area II

	Burnock Water Site 3b	Gass Water Site 3f	Guelt Water Site 3g
Mean stone orientation	106^{o}	104^{o}	144^{o}
Chi square	17.33	8.68	28.86
Dip strength	1.28	0.72	3.59
% Gravel	17.62		27.62
% Sand	50.24		40.24
% Silt/Clay	32.14		32.14
% Local rocks	88	100	88
% Highland rocks	0	0	4
% Southern Upland rocks	10	0	0
% Unidentifiable rocks	2	0	8
Shell fragments	No	Yes	Yes

TILL FABRICS FROM AREA II



Mean stone orientation

Slope

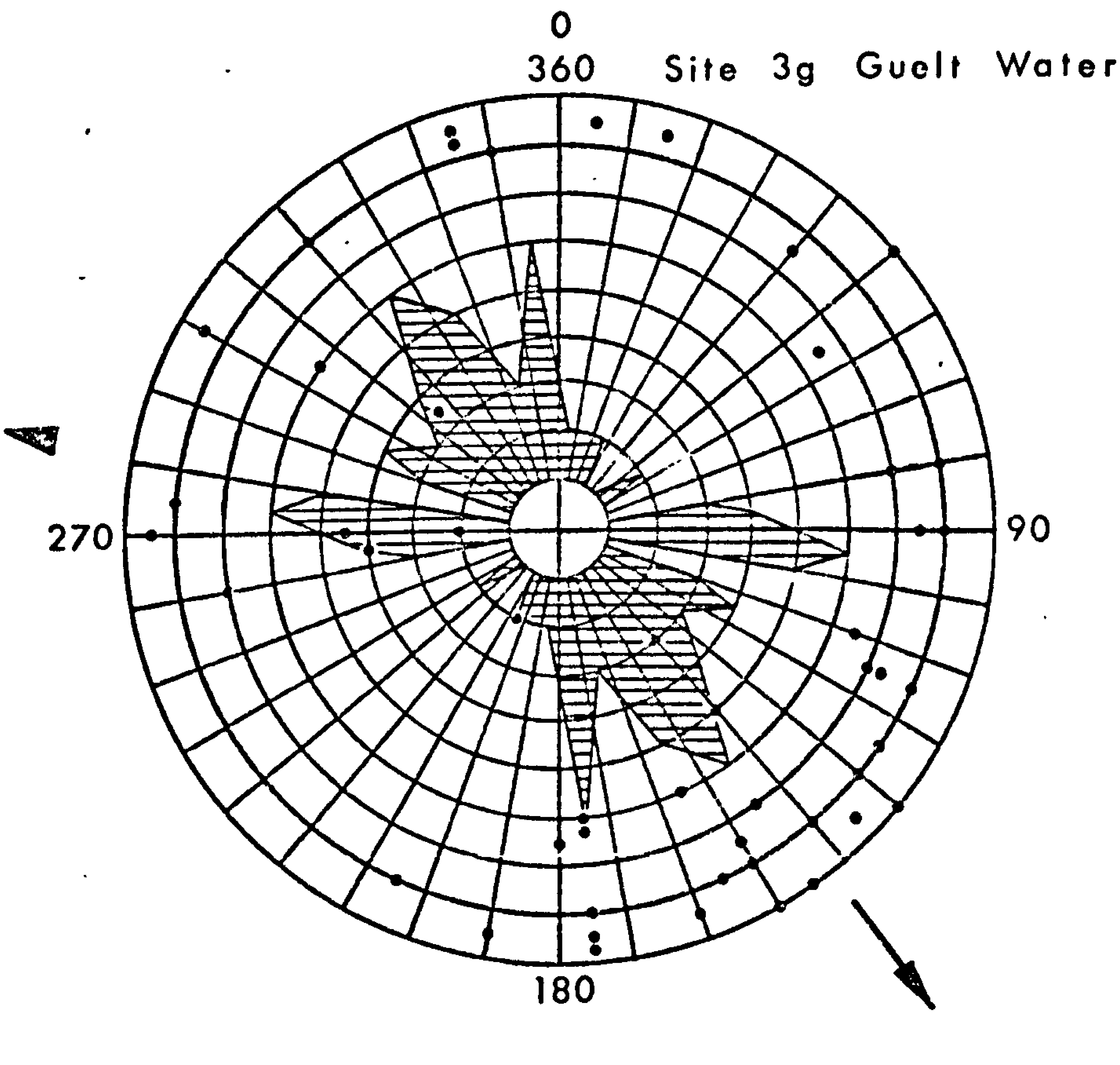


FIG. 3·7

presence of shell fragments or Highland erratics in a till indicates that the ice which deposited it originated in the west Highlands. The lack of these characteristics and the abundance of Southern Upland erratics indicates that the ice which deposited the till originated in the Southern Uplands. The till at Site 2f, therefore, is considered to have been deposited by ice which originated in the west Highlands.

The valley of the Guelt Water is the location of Site 3g (Fig. 3.4; Plate 3A). This is a I5m. almost vertical exposure of very tenacious, sandy, red/brown till which contains clasts of upto 50cm. in diameter. From a sample of 50 stones collected from the till at this site a mean stone orientation of I44° was calculated (Figs. 3.4, 3.7; Table 3A). A chi-square value of 28.86 was calculated for these data which is statistically significant at the 99.9% level of confidence when tabulated with 8 degrees of freedom. The dip-strength, calculated from these data to be 3.59, is not statistically significant at any level of confidence when tabulated with I degree of freedom. The indication from these data is that ice moved from the south-east or the north-west across this part of Area II. The identification of the rock-types of the erratics in this till may help to establish more precisely the direction of ice movement. Local rock-types are dominant, comprising 92% of the total, while 8% are unidentifiable. Among the local rocks is the distinctive Mauchline Sandstone which outcrops to the north west and therefore suggests a former movement of ice from the north-west across this part of Area II. The evidence for a movement of ice from the north-west is supplemented by the abundance of shell fragments in the till at this site. As mentioned previously, tills which contain shell fragments are considered to have been deposited by Highland ice which moved from a generally wetern direction across the north-eastern part of central Ayrshire.

Site 3b is in the valley of the Burnock Water in the southern part of Area II (Fig. 3.4). This exposure has a IOm. thickness of very stiff, silty, often gritty, blue/grey till which contains large sub-angular clasts over Im. in diameter. A mean stone orientation of I06° was calculated for the till at this site (Figs. 3.4, 3.8; Table 3A). A chi-square analysis shows this to be statistically significant

TILL FABRICS FROM AREA II

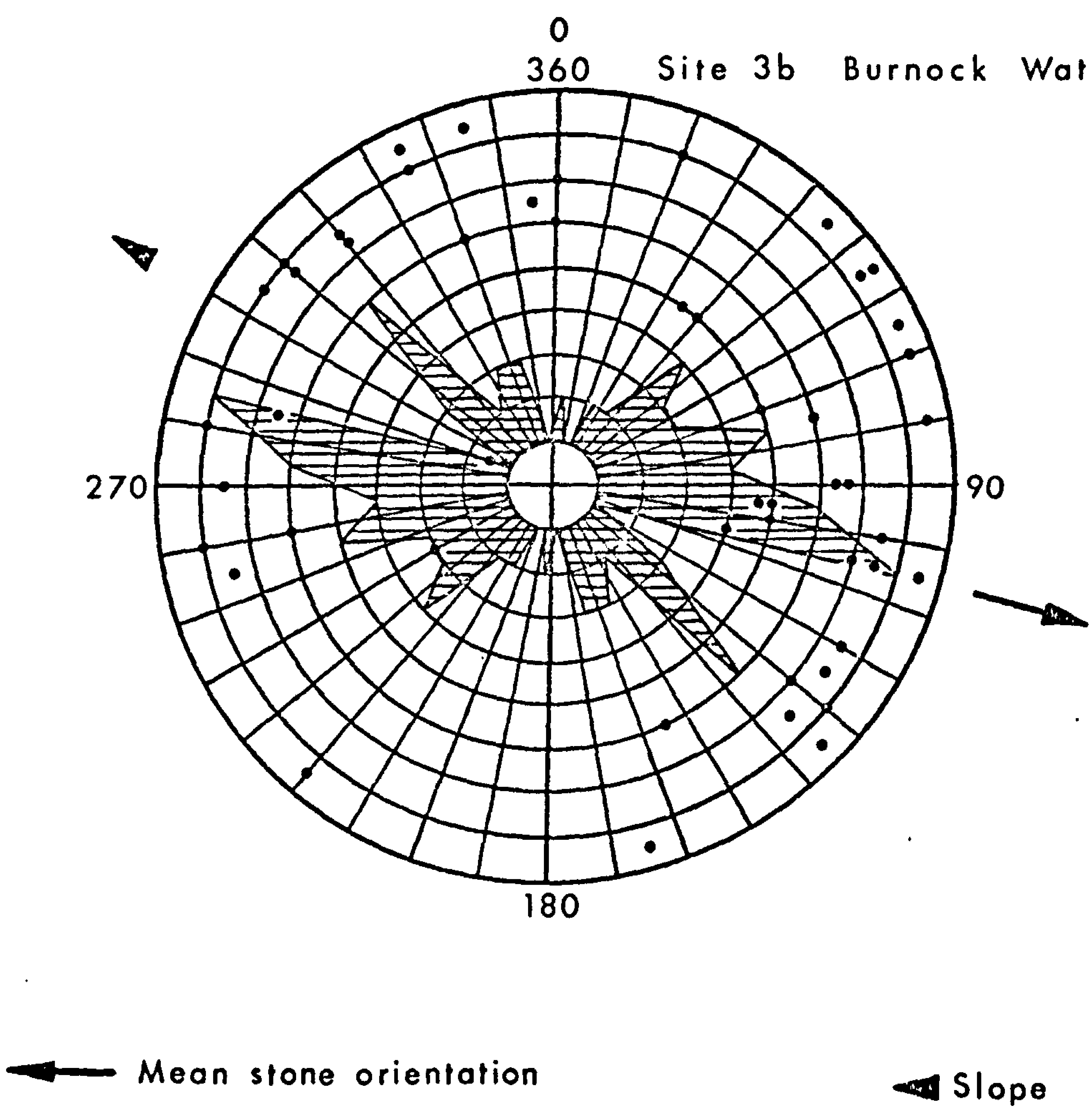


FIG. 3·8

at the 95% level of confidence, with 8 degrees of freedom. A dip-strength of I.24 may also be calculated for these data which, with I degree of freedom, is not statistically significant at any level of confidence. The implication, however, from these results is that the ice which deposited the till at this site moved from a generally west-north-west or east-south-east direction.

Erratic counts from the till at Site 3b show that 88% are of local origin, IO% are of Southern Upland origin and 2% are of Highland origin. Scratched and polished shell fragments are also contained in the till. The presence of shell fragments and Highland erratics suggests that the ice which deposited it probably originated in the west Highlands. However, IO% of the erratics in the till are of Southern Upland rock-types which is strong evidence that the ice by which it was deposited originated in the Southern Uplands. Further support for a Southern Upland origin of ice comes from a nearby exposure where "... stiff greyish boulder clay (till) with boulders of the Laigh Mount dolerite ..." (Geol. Surv. Scot., I9II, map) outcrops. This exposure is 3km. to the north-west of Laigh Mount (Fig. 3.4). This is strong evidence for a former movement of ice from the south-east across this part of Area II which originated in the Southern Uplands. This evidence matches that of ice movements provided by the study of the features of glacial erosion in this part of the area. It seems likely, therefore, that this part of Area II was affected by both Highland ice and Southern Upland ice during the last glaciation. This conclusion verifies the view of Eyles et al (I949) who suggested that ice with a Highland origin once occupied part of central Ayrshire and that, as the pressure exerted by this ice-mass relaxed, ice with a Southern Upland origin advanced to take its place. This would have left a zone across central Ayrshire that had been occupied by the two ice-masses. However, ... "In areas where the crossing over has taken place ... there has been no apparent break in the deposition of the boulder clay (till). There is merely a tendency for a greater concentration of granite boulders in the higher levels of the scars, a lightening of the matrix from shades of brown to grey, and a change in its texture from that of a clay to that of a loam. These changes are such that would normally follow upon a greater admixture of sandy greywacke and granitic material." (Eyles et al, 1949, p. 127). There is no indication, therefore, that this 'crossing over' zone was ice-free between the relaxation of the Highland ice and the advance of the Southern Upland ice.

In an attempt to recognise the maximum extensions of the two ice-masses which occupied Area II, two assumptions are made. Firstly, the presence of shell fragments and/or erratics of Highland origin within the till represents a part of Area II where Highland ice once reached. The southern limit of shell fragments and/or Highland erratics within the till, therefore, represents the southern limit of the Highland ice penetration in Area II (Fig. 3.4). Secondly, the presence of Southern Upland erratics in the till represents a part of Area II where Southern Upland ice once reached. The northern limit of Southern Upland erratics within the till, therefore, represents the northern limit of the Southern Upland ice penetration in Area II (Fig. 3.4).

In only one part of Area II, the Guelt valley (Fig. 3.4), can two distinct layers of till be seen. They are separated by a considerable thickness of sand and gravel. A typical section is :-

Site 3h	Billion Scar	Fig. 3.4	275m. O.D.
4m	Till.		
4m	Sand - with a little gravel.		
7m	Till.		

Detailed examinations of these sections in the Guelt valley are impossible because they are very badly slumped. However, some of the characteristics of the till layers are discernable. The upper till layer is red with a very sandy texture. This till is at least 3m. thick and resembles the typical till of this part of Area II which was described at Site 3g. This till contains a great amount of sandstone erratics - especially Mauchline Sandstone - and fragments of shells. This is interpreted as strong evidence that this till was deposited by Highland ice which moved from the north-west. Bailey (1929), however, noted the presence of "... erratics of greywacke and chert ..." (p. 72) in this till, but no such erratics have been found by the writer. If the observations of Bailey (1929) are correct, the implication is that ice which originated in the Southern Uplands may have extended into at least part of the Guelt valley. This part of Area II, therefore, may be within the "crossing over" zone of the two ice-masses because Bailey's (1929) conclusion concerning the origin of this upper till is very definite: ... "The upper boulder clay (till) was laid down by ice moving westwards off the Southern Uplands after an interval when the sands and gravels were deposited." (p. 72). However, the evidence from the examination of the upper till in the Guelt valley favours its deposition by ice with a Highland origin rather than deposition by ice with a Southern Upland origin.

The till which underlies the sand and gravel and upper till in the Guelt valley is stiff and red/brown with a silty/sandy texture. Contained within the lower till unit are clasts of Mauchline Sandstone and numerous scratched and broken shell fragments. The indication, therefore, is that this till was deposited by Highland ice which generally moved from the north-west. The lower till layer, therefore, has similar distinctive characteristics to the upper till and the till of the surrounding area.

Drumlins are the only surface features associated with the glacial deposits which may give an indication of the former direction of ice movements within Area II. However, only six drumlins have been identified and they are all situated in the north-western extremity of the area below 150m. O.D. (Fig. 3.4). Of the six drumlins identified, only three are complete; the other three drumlins have been eroded to some extent by the action of the Lugar Water. All of these features are orientated in a north-east to south-west direction and two of the three complete drumlins have their highest point towards the north-eastern extremity. The indication from the study of these drumlins is that the ice by which they were formed moved from the north-east. This evidence, together with the similarity of orientations with those drumlins in Area I, and their close proximity to the large spread of drumlins in Area I, suggests an extension of the movement of ice from the north-east, which occurred in the western part of Area I, into the north-western part of Area II.

Till is widely distributed throughout the area upto an altitude of 460m. O.D.. Three distinct zones have been recognised, based upon the amount of till cover. The till zones are closely related to the relief zones recognised on p.63.

Evidence concerning the origin and direction of movement of former ice-masses which occupied Area II is available from the results of drift analyses such as preferred stone orientations and erratic counts. This evidence strongly suggests that Area II has been occupied by two ice-masses: one with a Highland origin, and one with a Southern Upland origin. The northern and eastern parts of the area were occupied by Highland ice and the southern part of the area was occupied by Southern Upland ice. The Highland ice moved from the north-east in the north-western extremity of Area II, while in the eastern part of the area, the ice moved from the north-west. The Southern Upland ice generally moved from the south-east across the southern part of Area II.

Despite the occupations of Area II by ice-masses from different sources, no distinct break in deposition exists between the till deposited by Highland ice and the till deposited by Southern Upland ice. The characteristics of the Highland till gradually merge into the characteristics of the Southern Upland till. There is no evidence, therefore, for more than one glacial episode in Area II, but within this single glacial episode two distinct phases may be recognised :-

a) A movement of confluent ice-masses of Highland and Southern Upland origin, dominated by the Highland component.
b) Relaxation of the pressure exerted by the Highland ice concurrent with an extension of the Southern Upland ice.

Such movements resulted in a zone across Area II which was affected firstly by Highland ice and secondly by Southern Upland ice.

3.5: Fluvioglacial Erosion

Except for a meltwater channel system on the western side of Wardlaw Hill (Fig. 3.4), Area II lacks features which were produced by fluvioglacial erosion. This channel system, which traverses the boundary between Area I and II, was described and discussed in relation to Area I (Chapter 2).

The existence of meltwater channels in any area is dependant upon a number of factors (Sugden and John, 1976):-

I) Characteristics of past ice masses.

2) The glacial history of an area.

3) The shape of the underlying topography.

The ice mass which occupied Area II, from the evidence provided by the existence of the meltwater channel system on the side of Wardlaw Hill (Fig. 3.4), was, in parts at least, at pressure melting point. This is an essential requirement for the development of submarginal and subglacial drainage. It appears, therefore, that the characteristics of the ice mass which occupied Area II were ideal for meltwater channel development. However, none exist in the area, except the Wardlaw Hill channel system, which suggests an alternative explanation to I) is required.

The glacial history of this area may have affected meltwater channel development in a number of ways :-

a) If a glacier margin is stable for a long period, marginal drainage would be expected to operate and leave its mark on the landscape. Because no marginal drainage channels exist in the area, it may be concluded that stable margins were not characteristic of the ice mass which occupied the area.

b) If meltwater channels have been cut subglacially beneath debris-laden ice, during the melt-out sequence the channel development may be covered by drift.

c) The opening of a 'subglacial escape route' for meltwater, from a wide catchment area on top of, within and under the ice, would concentrate its erosive effect to a narrow, deep channel.

The narrow, deep courses of the middle and lower Ayr valley and the Lugar valley may provide evidence in support of this hypothesis.

d) If ice decays as a 'dead-ice mass', it is honeycombed with channels and cavities which constantly change their size, orientation and continuity due to collapse of ice and sediment accumulation. This is not conducive to meltwater channel formation.

e) If, as with central Ayrshire, ice encroaches upon an area up a reverse gradient (i.e. uphill) the meltwater activity during deglaciation may be entirely within englacial conduits (Fig. 3.9). It would not be expected to find evidence of this shown in the landscape.

The manner in which the shape of the underlying topography may affect the existence of meltwater channels is expounded by Sugden and John (1976) as follows: (Note the similarity to c)) "concerning ice directed subglacial channels, the favoured location on the divides carries an interesting implication, namely that the clearest channel systems occur where the direction of ice movement is across the grain of the underlying topography. Where pre-existing valleys run in the direction of ice movement (as in much of Area II), there may be no recognisable channels since the meltwater tends to follow the valley. There are abundant axamples of this phenomenon and it is likely that meltwater flow down suitable orientated valleys has been underestimated." (p. 316).

It is highly likely that the absence of fluvioglacially-eroded features in Area II is due to a combination of the effect of the underlying topography and points b), c), d) and e). It is impossible to assess the relative importance of each of these factors individually but from available evidence it appears that the effect of the underlying topography and the establishment of a 'subglacial escape route' (points c&e) were of greatest significance.

Fig. 3.9 Englacial meltwater flow.

3.6: Fluvioglacial Deposition

Fluvioglacial material is mainly concentrated in the valley of the Bellow Water / Boghead Lane in the north-central part of Area II (Fig. 3.4). These deposits cover an area of approximately 5 sq. km.. Apart from this largest concentration, only three other deposits of fluvioglacial sands and gravels are located within Area II; one is near the north-west corner of the area near Steelpark; one is in a south-central position near Boreland; and one crosses the western boundary of the area near Auchincloig (Fig. 3.4). This last deposit is described and discussed in relation to the fluvioglacial landforms in Area III (Chapter 4).

The fluvioglacial spread in the valley of the Bellow Water / Boghead Lane is continuous with the spread of sand and gravel on the lower slopes of the Ayr Valley in Area I. However, in Area II the fluvioglacial material is much less extensive. It is only 6km. long and 1km. wide at its maximum. The altitude of this north-east to south-west orientated fluvioglacial deposit ranges from 185m. O.D. to 240m. O.D.. The maximum thickness of these deposits, from borehole records, is 10m.. However, the borehole sites are not always conveniently sited. Thus an accurate assessment of the average or maximum thickness of the sands and gravels is impossible. Borehole records show sand and gravel to exist below peat accumulations, especially the peat accumulations in close association with the surface sand and gravel deposits (Fig. 3.10). The suggestion is, therefore, that morphology does not accurately reflect the extent of this sand and gravel and that the discontinuous distribution of sand and gravel forms may represent a continuous spread of sand and gravel that has been buried in parts by peat.

Exposures which reveal the internal constituents of the sand and gravel are generally rare, but pits have been excavated and they always show a variety of fluvioglacial materials. The sand and gravel spread displays a range of surface forms.

Most of the sand and gravel in Area II is in the form of large,

Fig. 3.10 Fluvioglacial Deposits in the Bellow/Boghead Valley.

Plates 3B, 3C   Eskers and Kames in the valley of the Bellow Water relatively low, smooth - outlined, rounded hillocks upto 500m. in diameter (Fig. 3.4). Some of these hillocks reach a height of 30m. but it is not certain that this is an accurate indication of the thickness of the fluvioglacial deposits; some of the height may be accounted for by the subsurface solid form. This is suggested by the examination of borehole records which show the maximum thickness of fluvioglacial material to be only approximately 10m..

Towards the northern part of this sand and gravel accumulation, a number of steep-sided mounds and ridges are evident (Fig. 3.10; Plates 3B, 3C). The steep-sided mounds are upto 150m. in diameter and have a maximum height of 7m.. All these mounds are characterised by smooth concavo-convex profiles. Some of the mounds rise from the extensive sand and gravel accumulations in the valley of the Bellow Water / Boghead Lane, while others protrude through accumulations of peat (Fig. 3.10).

In close proximity to the steep-sided mounds is a steep-sided elongated ridge which is approximately 1 km. in length. This north-east to south-west orientated ridge has 3 distinct parts which have been separated by the erosive action of the Boghead Lane (Fig. 3.10):-

1) Its north-eastern part has a very sinuous course with steep sides and an irregular, well-defined crest. The height of the crest varies from $1\frac{1}{2}$m. to 5m. above the surrounding terrain. It has a relatively constant width of approximately 30m..
2) The middle part of the ridge is 200m. long with a gently curving course. The ridge rises to a height of 4m. and this is relatively constant throughout its length. This feature has an assymetrical cross-section with a bench-like feature cut along the whole of its south-eastern side (Fig. 3.11). This suggests that the ridge has been trimmed to some extent by the action of the Boghead Lane which flows towards the south-west along its south-eastern side.
3) The south-eastern part of the ridge has both an irregular course and height. Its sharply defined crest rises between 2m. and 5m. above the surrounding land. The width of the ridge rarely exceeds 30m.. No alteration by stream action is suggested by the morphology of the ridge.

Fig. 3.11 Cross-section of Part of the Boghead Esker.

These mounds and the elongated ridge have no natural exposures. Pits, however, have been excavated at various points which show them to be composed entirely of fluvioglacial material. The grain-size of the material ranges from fine sand to coarse gravel with no apparent regularity.

Although this fluvioglacial spread in the valley of the Bellow Water / Boghead Lane is continuous with the fluvioglacial spread in the Ayr valley in Area I, important differences in form exist. On the lower slopes of the Ayr valley the fluvioglacial forms are generally subdued with distinct breaks of slope in their profiles. The fluvioglacial forms in the Bellow / Boghead valley, however, are well-developed and steep-sided with smooth concavo-convex profiles. It is reasonable to assume that the difference in form is probably a result of a difference in origin. It was shown in Ch. 2 that many of the forms displayed by the fluvioglacial material in the Ayr valley were produced by water erosion subsequent to deposition. No evidence exists to suggest that the forms of the fluvioglacial deposits in the Bellow / Boghead valley were produced by a similar process. If this is correct, it is highly likely that these fluvioglacial deposits resemble their depositional form. Based upon this assumption, it is probable that the steep-sided mounds and ridges were deposited as ice-contact kames and eskers. This process of deposition would probably have been very similar to that described by Sissons (1958b.) for the Eddleston valley, "... in intimate association with dead ice" (p. 169).

The meltwater that deposited this elongated spread of sand and gravel in the Bellow / Boghead valley flowed from either the north-east or the south-west. It is more likely that it flowed from the north-east down the slope of the valley because the meltwater channels which provided most of the fluvioglacial material deposited on the lower slopes of the Ayr valley (which is continuous with this spread) lie to the north-east. If this is accepted, it is likely that the sand and gravel on the lower slopes of the Ayr valley originally had a similar form to the sand and gravel in the Bellow / Boghead valley and that these ice-contact features have been subsequently removed or altered by water erosion. It is understood, therefore, that the fluvioglacial deposits in the Ayr and Bellow / Boghead valleys have more in common than their forms suggest. Another link between these fluvioglacial spreads is that they both terminate at approximately 185m. O.D.. It was concluded in Ch. 2, that the lack of sand and gravel below this altitude is due to ice decay progressing sufficiently for the ".. establishment of a subglacial escape route which resulted in the rapid draining of the remainder of the Ayr valley" and that this subglacial escape route was probably the deeply incised Ayr valley. However, the deeply incised form of the Lugar valley to the south of these deposits suggests that this may also have been a subglacial escape route. The shallow, broad, open, V-shape of the Bellow / Boghead valley is an indication that it was not a major subglacial escape route for meltwater from Area II. It is possible, therefore, that fluvioglacial deposition in both valleys terminated contemporaneously with the opening up of one subglacial escape route. If this escape route was the middle Ayr valley, the meltwater which flowed into the Bellow / Boghead valley from the upper Ayr valley would have been diverted, and deposition in both valleys would have ceased more or less contemporaneously. This also explains why the forms in the upper Ayr valley have been trimmed, while the forms in the Bellow / Boghead valley have not.

A small, but interesting, fluvioglacial deposit is located in the north-western part of Area II near Steelpark (Figs. 3.4; 3.12). This deposit is contained in a distinctive "amphitheatre" - type depression which abruptly punctuates the gently rolling landscape of the "Ayrshire Plain" which surrounds it. This depression has steep sides 10m. high to the east, south and west; the northern side, however, is missing (Fig. 3.12). This almost circular hollow is 600m. in diameter and upto 30m. deep. A large proportion of the hollow is filled with fluvioglacial material which displays a variety of surface forms. The major constituents of this morphology are ridges and mounds.

Two elongated ridges are present in this depression. Both of them begin near the southern rim of the depression within a distance of 200m. of each other and they are both orientated in a south to north

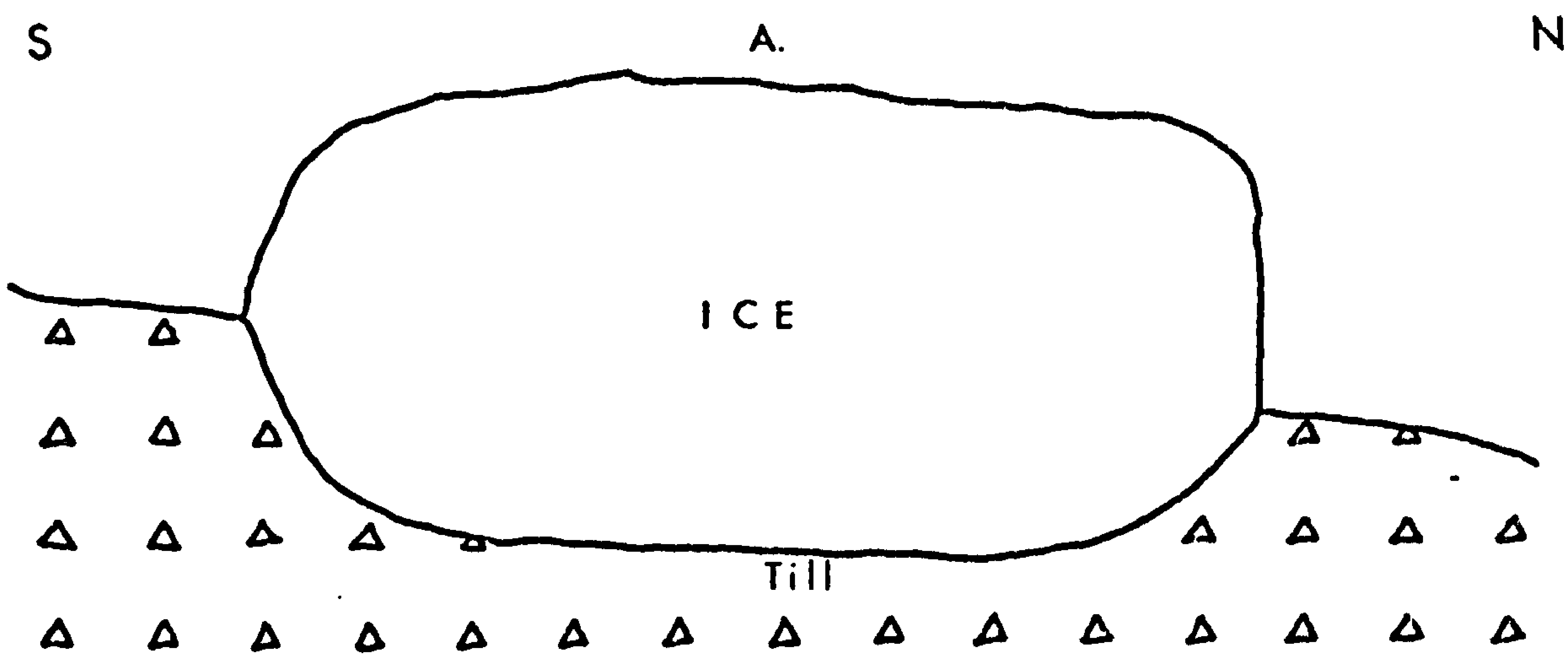
Fig. 3.12 Fluvioglacial Deposits at Steelpark.

direction (Fig. 3.12). The most easterly ridge is steep-sided with an uneven, sharply-defined crest, the height of which varies from 2m. at its southern end to a maximum of 8m. at the northern end. This 300m. long feature terminates in the form of a bulbous lobe approximately 100m. in diameter.

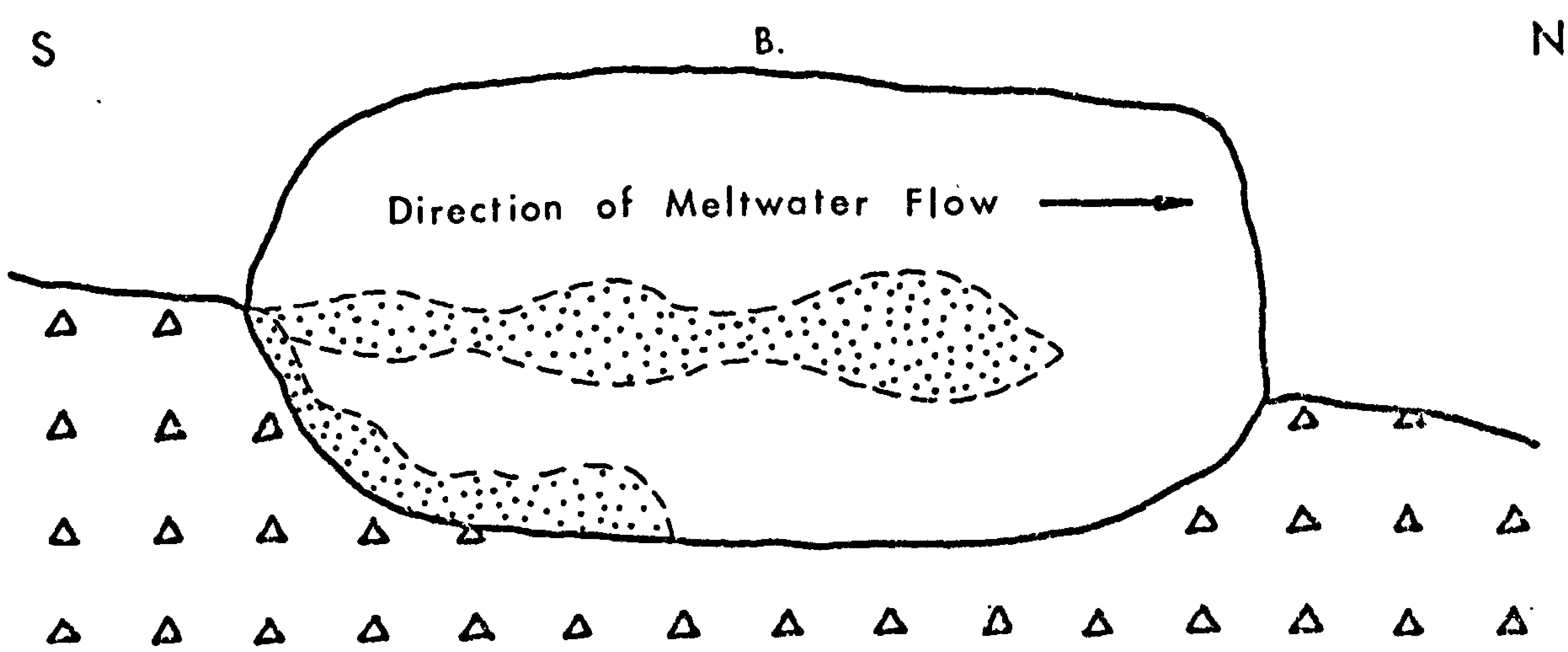
The most westerly ridge-like feature is 500m. long, sinuous and steep-sided. The height of the crest above the floor of the depression ranges from 6m. at its southern extremity to 10m. near its northern extremity. This ridge-like feature is composed of a series of adjoining steep-sided mounds. The size of these mounds increases from south to north (Fig. 3.12). The northern-most mound, and hence the largest, is approximately 150m. in diameter. Part of this lobe-like termination is quarried and this has produced an excellent exposure (Site 3a; Figs. 3.4, 3.12). Site 3a has a 10m. thickness of well bedded, poorly sorted brown sand with lenses of gravel and silt. Lenses heavily charged with coal fragments upto 7cm. thick are also present. Despite faulted and contorted bedding, a general dip of 5° towards the north-north-east may be measured for these strata. This indicates that the meltwater which deposited this material flowed from the south-south-west. Imbrication studies also show that the meltwater which deposited this material probably flowed from the south-south-west. Rock-type examinations show all the material to be of local origin.

From the examination of the location, form and internal characteristics of this fluvioglacial material, an explanation of its origin may be suggested. During the rapid deglaciation of Area II, a large block of ice was left embedded in the till. This large block of ice slowly melted in situ and developed internal drainage characteristics similar to those in large decaying ice-masses such as tunnels and cavities. The tunnels and cavities within the block of ice became filled with sediment and when the ice melted they remained as eskers (Fig. 3.13). The confining wall of till to the north was probably removed due to the erosive action of the Lugar Water sometime after the deposition of the sand and gravel.

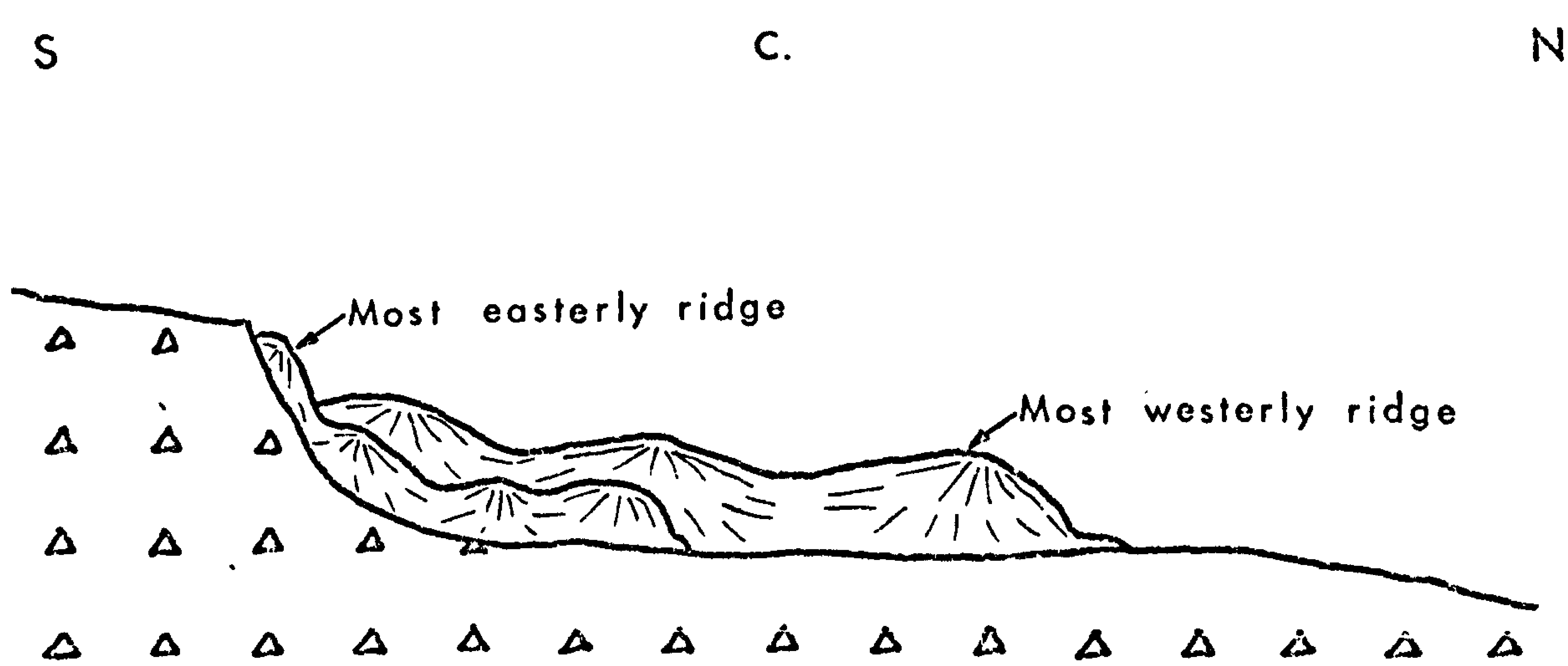
One other small spread of sand and gravel is present in Area II. Between Over Glaisnock and Boreland is an elongated feature 1400m. long



Partially buried block of ice survives after the wastage of the main ice mass.



Englacial or subglacial tunnels and/or cavities develop and are eventually filled with F/G material which was deposited by meltwater which flowed from the south.



Block of ice melts and leaves distinctive fluvioglacial deposits on floor of a hollow. The northern side of the hollow was removed by the erosive action of the Lugor Water.

Fig. 3.13 Origin of Fluvioglacial Deposits at Steelpark.

and upto I50m. wide (Figs. 3.4, 3.I4). It is orientated in an east-south-east to west-north-west direction. The feature is generally steep-sided and has a poorly defined, uneven crest which rises upto I0m. above the surrounding land. This ridge extends from the eastern interfluve of the valley of the Meadow Burn near Boreland to the western interfluve of the Glaisnock valley at Over Glaisnock. The course of the ridge, therefore, traverses two shallow, broad, V-shaped valleys of the Meadow Burn and the valley of the Glaisnock Water (Fig. 3.I4; Plate 3D).

A good exposure is revealed at the eastern end of the ridge where it terminates in the form of a bulbous lobe. This exposure (Site 3c) reveals a 5m. thickness of sands with occasional gravel. The grain size of this sand and gravel varies greatly both laterally and vertically. These deposits are well-rounded, well-bedded, poorly-sorted and faulted. Some of the individual beds are heavily charged with coal fragments; the thickest stratum is approximately I0cm.. Half-way along the course of the ridge at Clockclownie, which is on the interfluve between the Meadow valley and the Glaisncok valley, is a poor exposure, only Im. thick, of medium-coarse, well-rounded, poorly-sorted gravel (Site 3d, Figs. 3.4, 3.I4).

At the western end of the ridge at Over Glaisnock the topsoil of the ridge had been removed in preparation for quarrying (Fig. 3.I4, Site 3c). This shows a lateral exposure over I50m. long and I00m. wide of very coarse gravel. This gravel is well-rounded, poorly-sorted and includes only local rock-types. The gravel is a maximum of 6m. thick at the eastern end of Site 3c and it thins rapidly towards the west. It is only 2m. thick beneath Over Glaisnock farmhouse and it completely disappears a short distance to the west behind the house (pers. comm. farmer, I3/7/I074).

This feature has all the characteristics of an esker ridge. A subglacial origin is suggested by its up - down, cross - valley course. The subglacial meltwater which deposited this material would have flowed either from the west or the east. The coarsening of the grain-size of material within the ridge from east to west indicates that the meltwater flowed from a generally westerly direction. The isolation of this sand and gravel spread and its small size suggests that this

Fig. 3.14 Esker between Boreland and Over Glaisnock.

Plate 3D   Esker between Boreland and Over Glaisnock meltwater activity in this part of Area II was very localised. It is unlikely that the orientation of this ridge, therefore, bears any relationship to the movement of ice in this part of the area (Sugden and John, 1976).

This elongated ridge traverses the lowest point on the watershed between the Lugar drainage system (Area II) and the Nith drainage system (Area V). Because it is preserved, more or less intact, it is unlikely that a great deal of meltwater from Area II drained southwards into the Nith valley since the ridge, which has an altitude of approximately 185m. O.D. (i.e. the lowest altitude on the Lugar / Nith watershed), would have been destroyed. The location of this ridge, therefore, may provide evidence in support of the suggestion that meltwater which affected Area II was abruptly drained along a "subglacial escape route" which lay towards the northern part of the area (or to the north of it). The Ayr valley and the Lugar valley are the most likely routeways.

The only exposures of sands and gravels which lie below a layer of till within Area II are in the Guelt valley. In this valley, sand and gravel is discontinuously exposed over a distance of approximately 3km.. In many exposures, it outcrops as a lens of sand and gravel within the till - this is especially true in the western part of the valley. Fig. 3.4 shows part of the Guelt valley where a continuous spread of sand and gravel outcrops over a distance of 1km.. These deposits are usually fine sands which are structureless and poorly sorted - though some horizontal psuedo-bedding is discernable. Only small amounts of fine gravel are present in these deposits. Good exposures in this sand and gravel are rare due to their very badly slumped nature; (this is because the lower boundary of the permeable sand and gravel layer which lies directly on an impermeable till layer acts as a lubricated zone which makes it ideal for slipping). Any more than a cursory examination is impossible. However, the relatively fine grain-size and lack of bedding in this material suggests that it was deposited in a low-energy fluvioglacial environment. No evidence exists from the study of the situation and the internal characteristics of this sand and gravel layer to suggest that it was an outwash plain produced when the Highland ice which occupied this part of Area II receded before its occupation by the advancing Southern Upland ice as implied by Bailey (1929, p. 72).

This sedimentary sequence in the Guelt valley may be explained in a similar way to that suggested by Kirby (1969, p. 52) for similar sequences in Midlothian. (The two tills were deposited) "... by the same agency moving in the same direction with similar momentum. ... (the two) layers of till are therefore ... regarded as part of a single till; the interstratified sand representing merely breaks within a single process of glacial deposition." This is also expounded by Price (1973):"There can be little doubt that changes in the subglacial environment during melting of a heavily debris-laden ice mass could account for the sedimentary sequences described by ...(Kirby)." (p. 77).

Deposits of fluvioglacial origin are mainly confined to the north-central part of Area II in the Bellow / Boghead valley though small deposits also exist near Steelpark and Boreland (Fig. 3.4). The most extensive deposits are orientated north-east to south-west along the valley of the Bellow Water / Boghead Lane and they display a variety of surface forms. Consideration of the forms and the relation of this sand and gravel to the sand and gravel on the lower slopes of the upper Ayr valley (Area I) suggests that the meltwater which deposited it flowed in a north-easterly direction from the upper Ayr valley. Although the form of the sand and gravel in the Bellow / Boghead valley is different from that in the Ayr valley, it is possible that they once may have been a continuous spread. The relative freshness of form of the sand and gravel in this part of Area II does not suggest any alteration on the scale of that encountered in Area I. This may be explained if the middle Ayr valley was the "subglacial escape route" which drained the eastern parts of the Areas I and II. The meltwater which flowed into Area II, therefore, would have been diverted into the middle Ayr valley. The suggestion that Area I and Area II were affected by similar mechanisms of fluvioglacial deposition is strengthened by the common lowest altitude of deposits - 185m. O.D..

The general lack of sand and gravel deposits below an altitude of

185m. O.D. in Area II suggests that meltwater drained very rapidly from this part of Area II during the later stages of deglaciation in a similar manner to that described by Sissons in the Eddleston valley (1958b, p. 74). The small fluvioglacial deposit at Steelpark, however, does prove that local meltwater activity did occur. The limited extent of sand and gravel below a till layer in the Guelt valley is considered to represent minor subglacial fluvioglacial action within the general phase of glacial deposition.

3.7: Conclusions

From the study of landforms and deposits produced by glacial and fluvioglacial processes, it is possible to suggest the origin, the directions of ice movement and the mode of decay of the ice which affected Area II.

1) The presence of shell fragments and Highland erratics in many of the till exposures in the northern part of Area II indicates that the ice by which it was deposited originated in the west Highlands.
2) The presence of Southern Upland erratics and the lack of shell fragments in many of the till exposures in the southern part of the area indicates that the ice by which it was deposited originated in the Southern Uplands.
3) Ice from these two sources merged to cover the whole of Area II.
4) The Highland ice moved from a north-easterly direction in the north-western part of the area, from a northerly direction in the central part of the area and from a westerly direction in the eastern part of the area (Fig. 3.15). The Southern Upland ice, however, moved from a generally south-eastern direction over the southern part of Area II (Fig. 3.15). The line along which these two ice-masses met fluctuated during the last glaciation. The Highland ice was extensive during the early phase of glaciation but the pressure exerted by this ice-mass

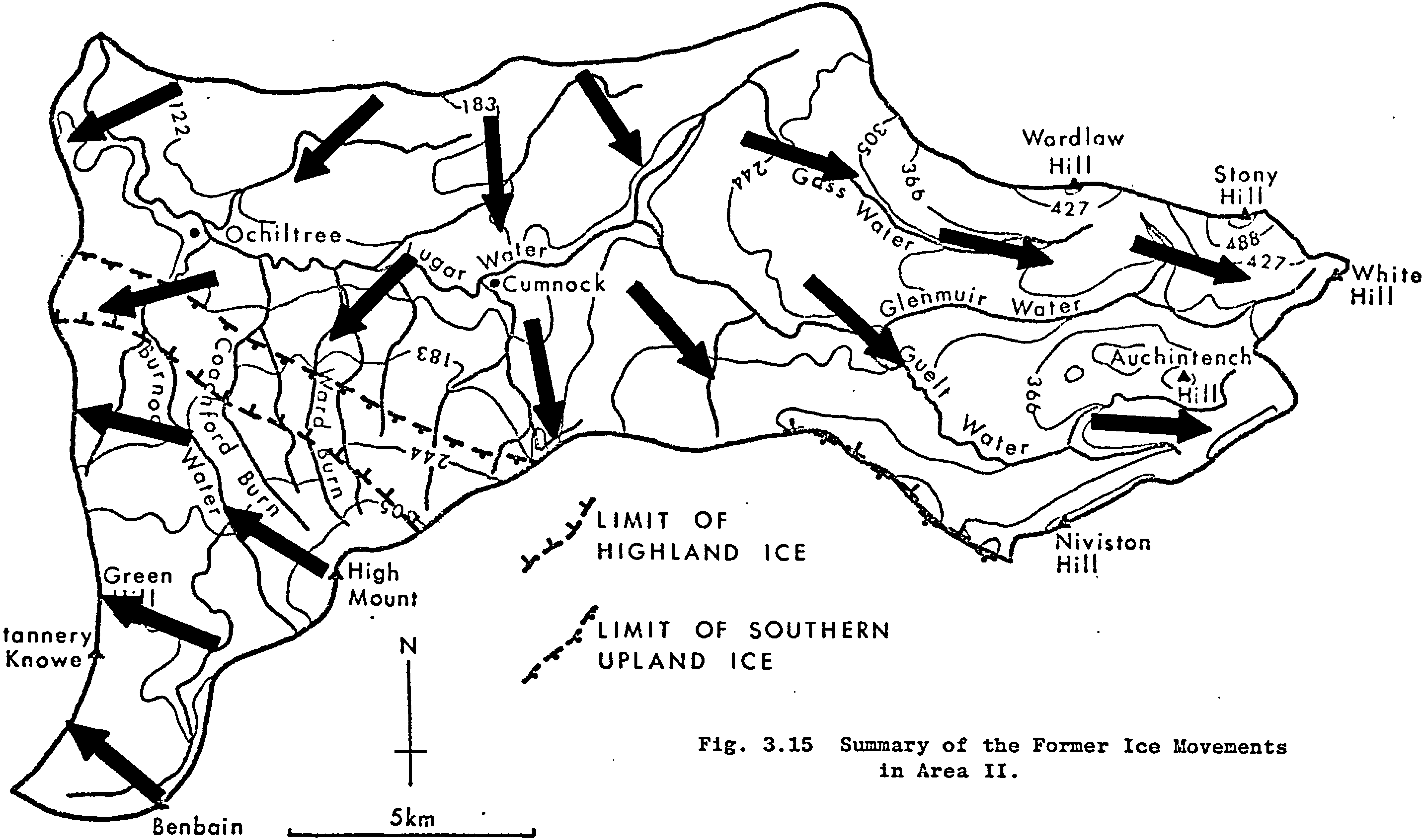


Fig. 3.15 Summary of the Former Ice Movements in Area II.

relaxed and allowed Southern Upland ice to advance over a zone previously occupied by Highland ice.

5) The absence of meltwater channel development in Area II may be due to subsequent masking of features by the thick drift deposits or to the actual lack of meltwater erosion. However, the channel system near Wardlaw Hill described in Ch. 2 shows that at some time during deglaciation meltwater in the north-central part of Area II flowed from a south-westerly direction into the upper Ayr valley.

6) Limited evidence exists to suggest that the meltwater which deposited the sand and gravel in the Bellow / Boghead valley flowed from the north-east; this would have been an extension of the generally east to west flow of meltwater which deposited the sand and gravel on the lower slopes of the upper Ayr valley (Ch. 2). It is likely that the deposition of fluvioglacial material in Areas I and II was subject to similar, if not the same, controls. The most important control may have been the establishment of a "subglacial escape route" along the middle Ayr valley and/or the Lugar valley.

7) The general lack of fluvioglacial features below an altitude of 185m. O.D. suggests the rapid drainage of meltwater, and probably the rapid disappearance of ice, from Area II. However, some isolated fluvioglacial deposition did occur.

CHAPTER 4

AREA III

4.I: Introduction: Location and Extent

Area III, which is approximately 250 sq. km. in extent, is the north-western part of central Ayrshire (Fig. 4.I). It is 2I km. from north to south and I7 km. from east to west. The short, straight northern boundary of the area corresponds to the east - west grid line NS35 (Fig. 4.I). The eastern boundary of Area III corresponds, in the northern part, to the watershed between the Cessnock drainage system (the western part of Area I) and the lower Ayr drainage system (Area III), and in the southern part, to the watershed between the Lugar drainage system (Area II) and the lower Ayr drainage system. The southern boundary of Area III is represented by the watershed between the Doon / Girvan drainage system (Area IV) and the lower Ayr drainage system. The western boundary of the area is delineated by the coastline.

Area III contains evidence of glacial erosion, glacial deposition, fluvioglacial erosion, fluvioglacial deposition and former relatively high stands of sea level. The detailed analysis of these features will enable a relative chronology of events during the last ice to be hypothesised.

4.2: Relief and Drainage

Area III can be subdivided into two parts on the basis of relief:-

I) the extreme south of the area.

2) the remainder of the area (Fig. 4.2).

This subdivision may be explained in terms of the solid geology.

The extreme southern part of Area III, which is 20 sq. km. in extent, is at a much higher altitude than the rest of the area. It has a very gently undulating relief which is similar to, and continuous with, the relief of the southern part of Area II. Summits such as Ewe Hill (379m) and Brown Rig (342m) characterise this small part of Area III (Fig. 4.2).

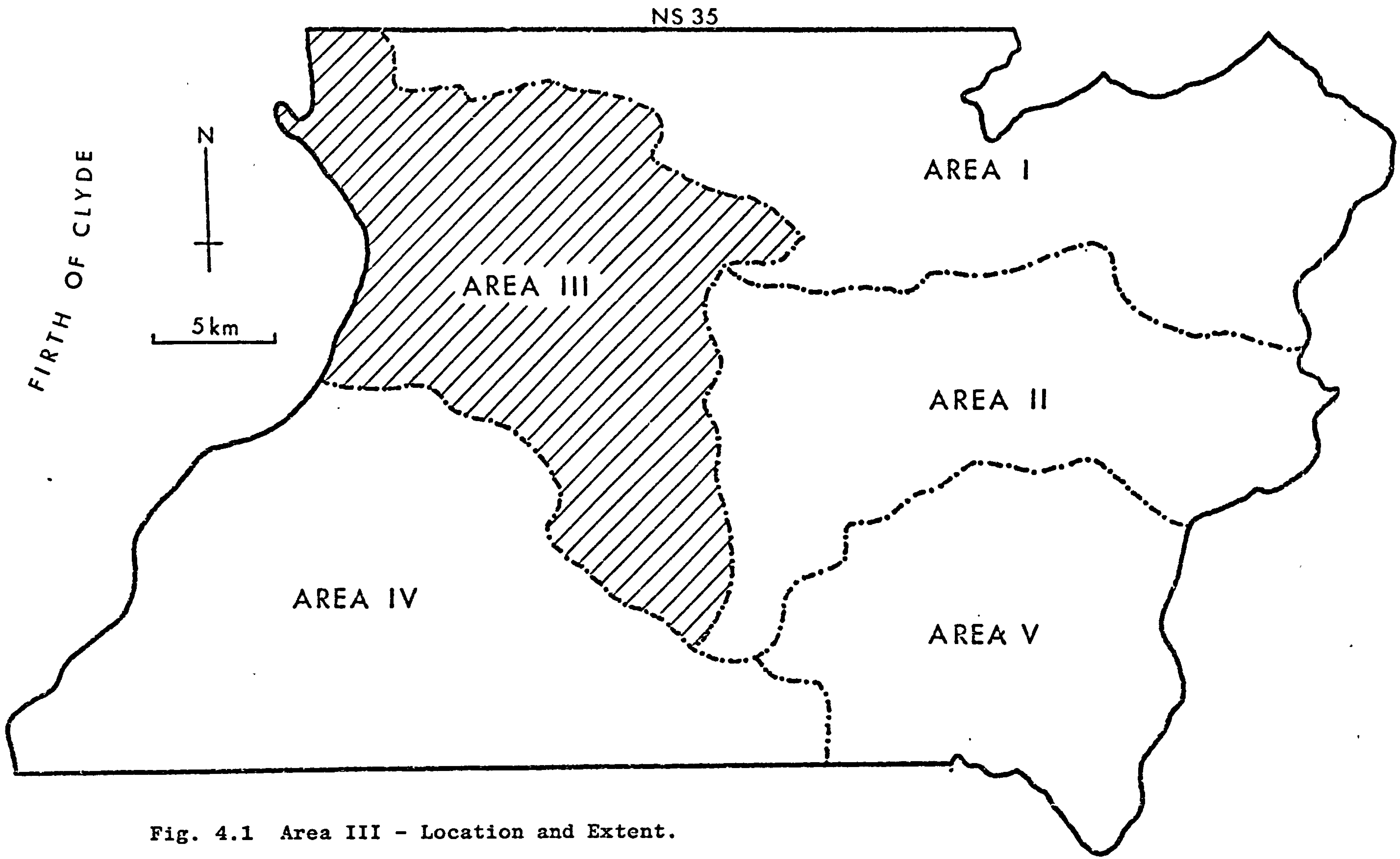


Fig. 4.1 Area III - Location and Extent.

The maximum relative relief value is 105m..

The upland nature of this part of the area is due to the influences of both rock-type and structure. The rock-types are dominantly resistant teshenites and theralites which have been intruded as horizontal sills between beds of shale. The structural control is dominated by the Littlemill fault (Fig. 4.3). This has a vertical displacement of approximately 495m. (Eyles et al, 1949, p. 71) and a north-east to south-west orientation. The downthrown side of the fault lies to the north-west.

The part of Area III to the north-west of the Littlemill fault has a gently undulating relief which is typical of the "Ayrshire Plain". This relatively low-lying east to west sloping landscape is punctuated at only three localitites:-

1) Hillhouse Craigs (145m. O.D.) in the north-western part of the area near Troon.
2) Craigie Hill (155m. O.D.) in the north-central part of the area near Craigie.
3) Craigs of Kyle (230m. O.D.) in the south-western part of the area near Drongan (Fig. 4.2).

Locally these three hills give rise to relative relief values around 140m. but elsewhere in Area III a relative relief value of 60m. is rarely exceeded. These areas of land at higher altitudes all relate to resistant kylitic rock-types which are a part of an extensive series of post - Carboniferous sills which have been severely faulted (Fig. 4.3). The generally low-lying nature of most of Area III reflects a basement of relatively soft shales and sandstones which have been downwarped as the western part of the Mauchline Basin (Fig. 4.3).

The gently undulating relief of most of Area III is abruptly terminated on the western, or seaward, side around the 30m. O.D. contour. To the west of this line (Fig. 4.2) the landscape is characterised by a series of roughly horizontal benches. Two benches are particularly distinctive with altitudes of approximately 12m. and 24m. O.D.. These benches, interpreted as raised beaches, are fringed on their extreme western margins by a series of well-developed sand dunes which are generally 15m. high and 200m. wide.

The drainage in Area III is dominated by the lower course of the east to west flowing River Ayr and the generally south to north course of its main

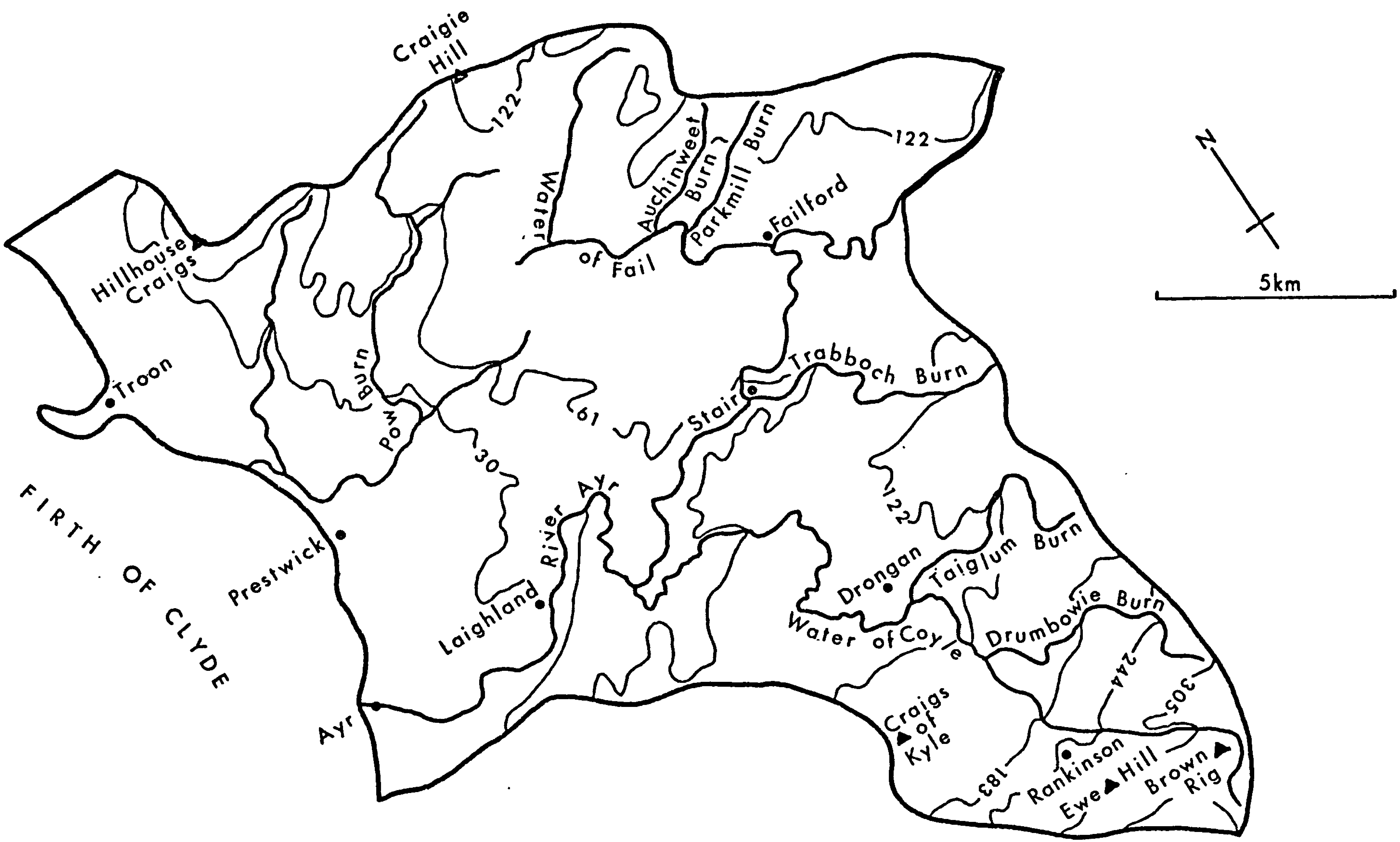


Fig. 4.2 Area III - Relief and Drainage.

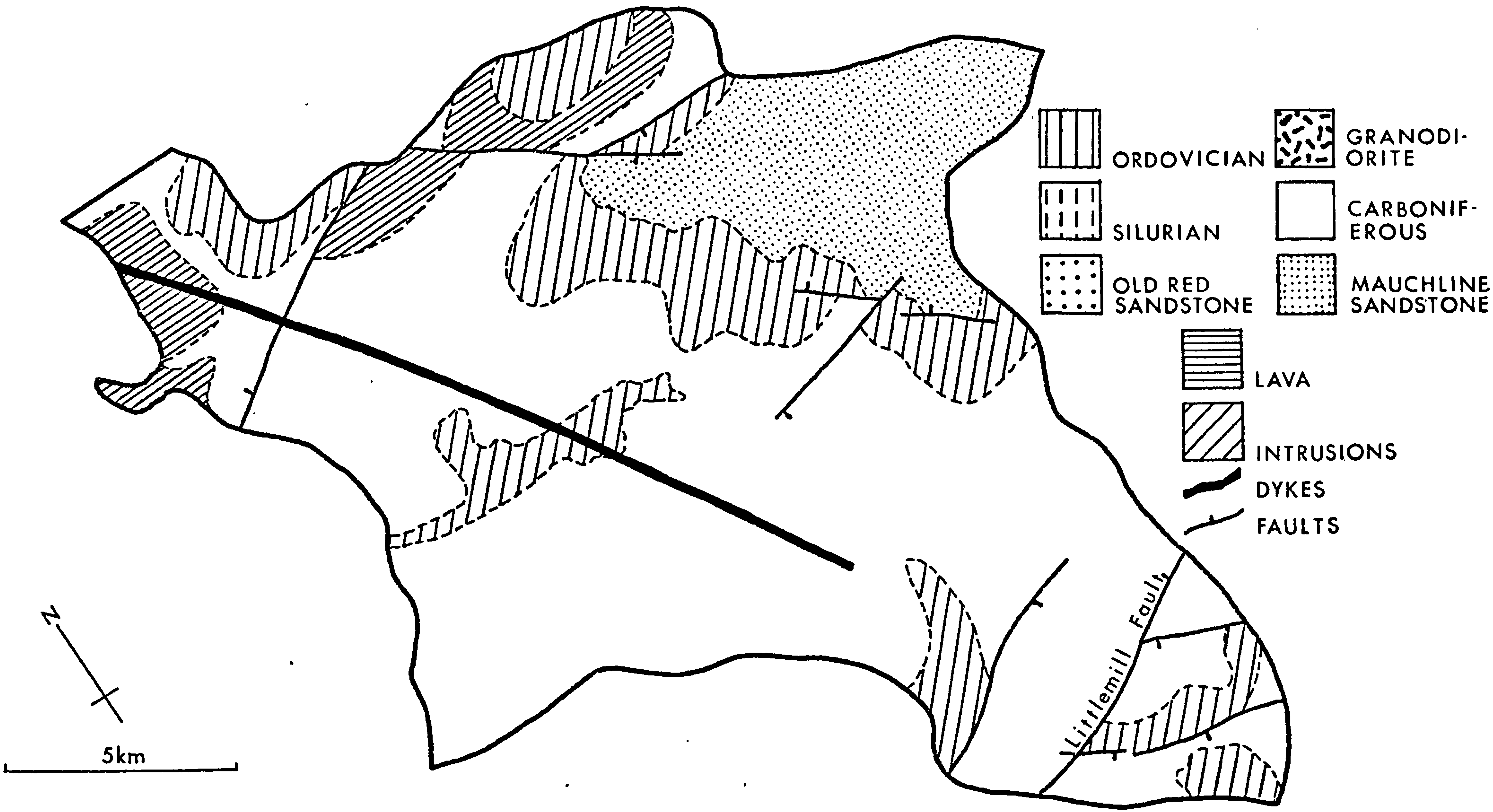


Fig. 4.3 Area III - Geology

tributary, the Water of Coyle. The drainage pattern to the south of the River Ayr is basically dendritic (Fig. 4.2) as most streams flow into the Water of Coyle, which itself generally flows from south to north. To the north-east of the River Ayr the drainage is dominated by the north-west to south-east flowing Water of Fail, which eventually flows into the River Ayr at Failford. The drainage pattern in this part of Area III is trelised with all the tributaries of the Water of Fail flowing from north-east to south-west (Fig. 4.2). Two examples of this are the Parkmill and Auchinweet Burns (Fig. 4.2). These streams share a similar orientation with the tributaries of the Cessnock drainage system in Area I. This may indicate some former connection between the two systems.

The north-western part of Area III has a dendritic drainage pattern the main branch of which, the Pow Burn, discharges into the Firth of Clyde between Troon and Prestwick (Fig. 4.2). This part of the area, therefore, has a separate drainage system to that of the rest of Area III. However, for convenience, it is regarded as part of the lower Ayr drainage system.

Most of the valleys in Area III have very broad, V-shaped cross sections; the Trabboch valley, south-east of Stair, the Taiglum valley, east of Drongan, and the valley of the Drumbowie Burn, north-east of Rankinson, are examples (Fig. 4.2). The lower Ayr valley shows great cross-sectional variety over its 25 km. length. At Laighland, 5 km. east of Ayr, the valley is flat bottomed and bounded by steep sides over $1\frac{1}{2}$ km. apart, while between Stair and Failford, 6 km. to the east-north-east, the valley is a 70m. deep gorge.

Area III, therefore, is, except for 20 sq. km. in the southern extremity, a homogenious area of gently undulating 'Ayrshire Plain' relief which terminates at the highest raised beach level. In only three localities, where resistant volcanic rock outcrops, is the continuity of this landscape broken. The drainage of the area, which is dominated by the lower course of the River Ayr, has a generally dendritic pattern. Generally, the lines of drainage have not dissected the landscape to any considerable extent.

4.3: Glacial Erosion

Erosional features produced by ice are not well represented in Area III. This is hardly surprising in an area that is generally at an altitudinally low-level and has a consistently thick cover of drift. The features of glacial erosion found in the area include striations, two crag and tails, eight ice-moulded forms and one glacially-breached col (Fig. 4.4).

Only one part of Area III, which is situated in the extreme north-west at Hillhouse Quarry, contains striations (Fig. 4.4). These are exposed on top of the Hillhouse Sill, which is being quarried, when the overburden is removed prior to blasting. Large numbers of striations, all of which have a north-east to south-west orientation, can be seen. The indication is that the ice which produced the striations moved from either the north-east or the south-west. However, this location is in close proximity to the 'tail' of an ice-moulded form described in Ch. 2 (Fig. 4.4). It was concluded that the ice-moulded form was more likely produced by ice which moved from the north-east rather than from the south-west. If this is correct, it suggests that these striations were formed by a movement of ice from the north-east in this part of Area III.

Crag and tail features <u>in sensu stricto</u> and ice-moulded forms dominate the glacially-eroded features in Area III (Fig. 4.4). Two crag and tails and eight ice-moulded forms have been identified in the area.

The two crag and tail forms are at Helenton Hill in the north-central part of the area and at Raith Hill which is centrally situated (Fig. 4.4). The feature at Helenton Hill is the larger of the two. It has a crag 300m. in diameter and 30m. high which faces towards the north east (Plates 4A, 4B). Quarrying activity in this part of the feature reveals the agglomeratic material which constitutes the old volcanic vent and the solid morphology of the crag and tail. The highest point of the crag and tail is near the north-eastern extremity of the feature with the steeply sloping end facing the north-east and the gently sloping end facing the south-west. Near to the highest point the solid form is not covered by till, but a thin soil. However, towards the south-western part

Plates 4A, 4B   Crag and Tail near Symington

Fig. 4.5 Cross-section of Helenton Crag and Tail.

of the feature (i.e. the 'tail') till is present and its thickness increases away from the highest point (Fig. 4.5, Plate 4C). The 'tail' of this feature, which is composed of relatively soft shales and sandstones, extends towards the south-west over a distance of approximately one km..

The form and internal constituents of this crag and tail feature strongly indicate that the ice by which it was moulded moved from a north-easterly direction.

The form of Raith Hill (Fig. 4.4) is most distinctive. It stands 20m. above the surrounding land and is elongated in an east to west direction (Plates 4D, 4E). The eastern end of the hill is the highest part and is abruptly terminated by steep sides which form a semi-circle. The western end slopes gently down from the highest point. The hill, therefore, has a steep, high buttress which faces directly towards the east and a gentle slope 500m. long which faces towards the west. No exposures exist in this feature, but its form suggests that it may be a crag and tail. This suggestion proves to be an acceptable description when geological maps are consulted showing the steep, buttress-like end of Raith Hill corresponding with an old volcanic neck. This feature, therefore, is regarded as a crag and tail and the ice which eroded it moved from a generally easterly direction.

Two of the ice-moulded forms shown in Fig. 4.4 (i.e. those in the north-western extremity of the area) straddle the boundary with Area I. They have been described and discussed in relation to the glacial erosion of that area. However, the conclusions from their study are equally useful in relation to the glacial erosion of Area III. These huge forms, eroded out of resistant teshenite, indicate a period of glacial erosion by ice which probably originated in the Highlands and moved from the north-east.

The other ice-moulded forms in Area III are situated in the southern extremity near Rankinson (Fig. 4.4). These features are smaller than those in the northern part of the area. The largest of them is 700m. long and 15m. high. The form of these features is similar to that of a crag and tail - elongated with one steeply sloping and one gently sloping end. The most southerly ice-moulded form has its steep-sided, and higher end facing the east-south-east and the gently sloping end facing the west-north-west.

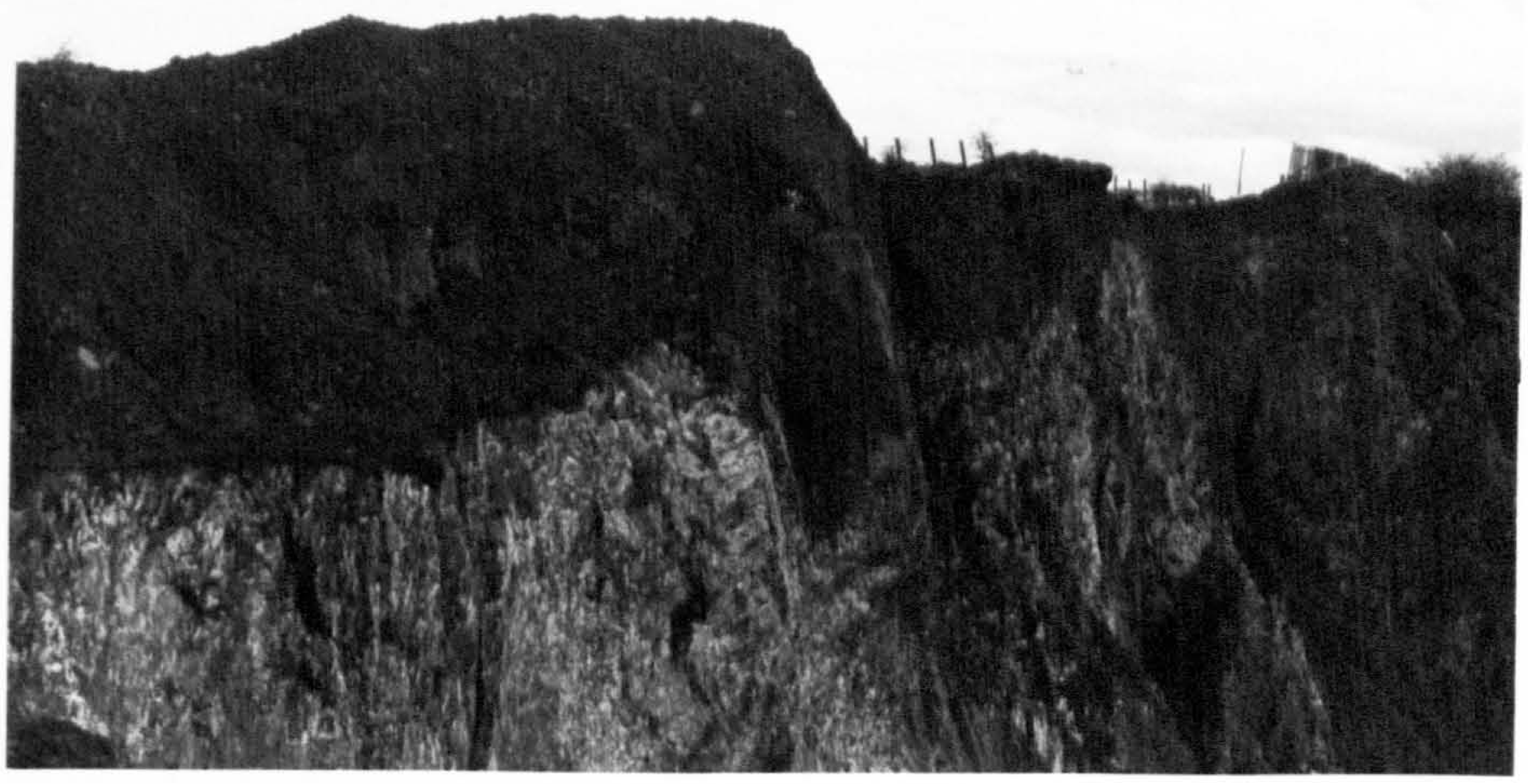


Plate 4C Internal Characteristics of the Crag and Tail near Symington

Plates 4D, 4E   Crag and Tail at Raith Hill

Its shape and smooth steep-sided end is a strong indication that the ice by which it was eroded moved from a generally east-south-east direction. This view corresponds with that expounded by Eyles et al (1949, p. 125, Fig. 19) for ice movement in this part of central Ayrshire.

The remaining ice-moulded forms are situated within the Craigs of Kyle, which is a resistant volcanic intrusion south-west of Drongan (Fig. 4.4). Five ice-moulded forms have been identified within the Craigs. The features are generally elongated east-south-east to west-north-west. All the features have the highest points towards the east-south-east. The east-south-eastern extremities of these hills are characterised by smooth, steep sides, while the west-north-western extremities are characterised by gentle slopes which are sometimes no more than 60m. long and 10m. wide. It seems logical to assume that these features were eroded by ice which moved from a generally east-south-east direction. The most likely source for ice moving in such a direction would have been the Southern Uplands.

The only glacially-breached col in Area III lies across its boundary with Area II (Fig. 4.4). The feature is described and discussed in relation to Area II. The important conclusion derived from this glacially-breached col is that the ice which occupied the southern part of Area III reached a maximum altitude of 360m. O.D..

The study of the glacially eroded landforms in Area III allows some conclusions to be drawn. The pattern of ice movement across the area was complex; in the northern part of the area ice moved from the north-east while in the southern part of the area ice moved from the south-east. It is not unreasonable to assume that these diverse movements of ice reflect diverse origins of ice - the movement of ice from the north-east reflecting a Highland ice source and the movement of ice from the south-east reflecting a Southern Upland ice source. The east to west movement of ice suggested at Raith Hill which is in the central part of Area III (Fig. 4.4) may be explained by the resultant direction of ice movement that would occur when the Highland and Southern Upland ice-masses met.

Other features which relate to glacial deposition, fluvioglacial erosion or fluvioglacial deposition may provide additional information concerning former ice movements and origins in Area III.

4.4: Glacial Deposition

The distribution of glacial deposits in Area III is almost uniform. Till is widespread upto an altitude of 335m. O.D. and is only absent in a few localities (Fig. 4.4). The most striking absence of till as a surface material is along the western flank of the area. This is due to the presence of raised beach and wind-blown sand deposits. However, borehole records show till to be present below these sands and gravels. Till is also absent where solid rock outcrops as the surface material. This is confined to places where resistant igneous intrusions protrude through the till cover (Fig. 4.4). The Hillhouse Sill, in the northern part of the area, is an example. It outcrops in two localities, to the west of Dundonald and around Craigie. Further south an elongated outcrop of solid rock, which has a north-east to south-west orientation, exists between Barnweill and Clune (Fig. 4.4). This is a segment of the western part of the Mauchline Basin where resistant basaltic lavas are the surface material. Solid rock outcrops are also present at the Craigs of Kyle towards the southern part of the area (Fig. 4.4). Such outcrops of solid rock in an extensive area of till deposits are not uncommon, as Price (1973) explains: "A thick cover of till tends to mask the underlying bedrock topography and pre-glacial valley systems may be completely obliterated, the till being thickest in the bedrock depressions and thinnest over bedrock protuberances. In some instances bedrock ridges may stand above the general level of the ground moraine". (p. 75-76).

In the southern extremity of the area, peat is present at the surface. However, this only covers a maximum of 8 sq. km.. An examination of borehole records shows that the maximum thickness of till in Area III is consistently around 30m. and from this it is apparent that the till deposits do have a masking effect on the underlying bedrock topography, similar to that described by Price (1973, pp. 75-76).

The colour of the till to some extent reflects the solid geology of Area III. The colours are shades of brown and reflect the predominance of sandstone as the bedrock of the area. The till matrices are mainly sandy or silty/sandy; this again reflects the arenaceous rock-types which underlie the area. Only towards the southern part of the area do these characteristics change to any degree. Here the colours of the till become shades of grey and the matrices are much more gritty. This is interpreted as an indication of the change in the underlying geology from arenaceous rocks to igneous rocks. The examination of geological maps shows this interpretation to be correct (Geol. Surv. Scot., Sheet I4, Solid, I949, map).

An examination of all the exposures of drift in Area III shows that till is only present as a single unit. Fluvioglacial and marine deposits often lie on top of the till, but no unconsolidated deposits are found to underlie it. Till is often exposed in an almost vertical face upto I5m. thick; this is a result of river erosion.

Fabric analyses have been completed at 5 sites (4a, 4b, 4d, 4e and 4f) within Area III in an attempt to elucidate the direction and source of the ice which deposited the till. The results are summarised in Table 4A and Figs. 4.4, 4.6, 4.7, 4.8.

The first of these sites, Site 4a, is situated in the north-western extremity of the area (Fig. 4.4). This till section was formed when the overburden on top of the Hillhouse Sill was removed prior to quarrying. A total till thickness of 5m. lies directly on top of the polished, striated bedrock surface of the sill. The till is dark blue, stiff and very clayey.

A mean orientation of stones within this till of 287° was calculated (Table 4A; Figs. 4.4, 4.6). However, Fig. 4.6 clearly shows the stone orientation to be bi-modal. This is also indicated by the chi-square value (II.93) for these data which shows that the mean orientation is not statistically significant at any level of confidence (with 8 degrees of freedom). A dip-strength value of 0 (zero) was also calculated for these data. This suggests that they are not a reliable indication of the direction of ice movement in this part of Area III.

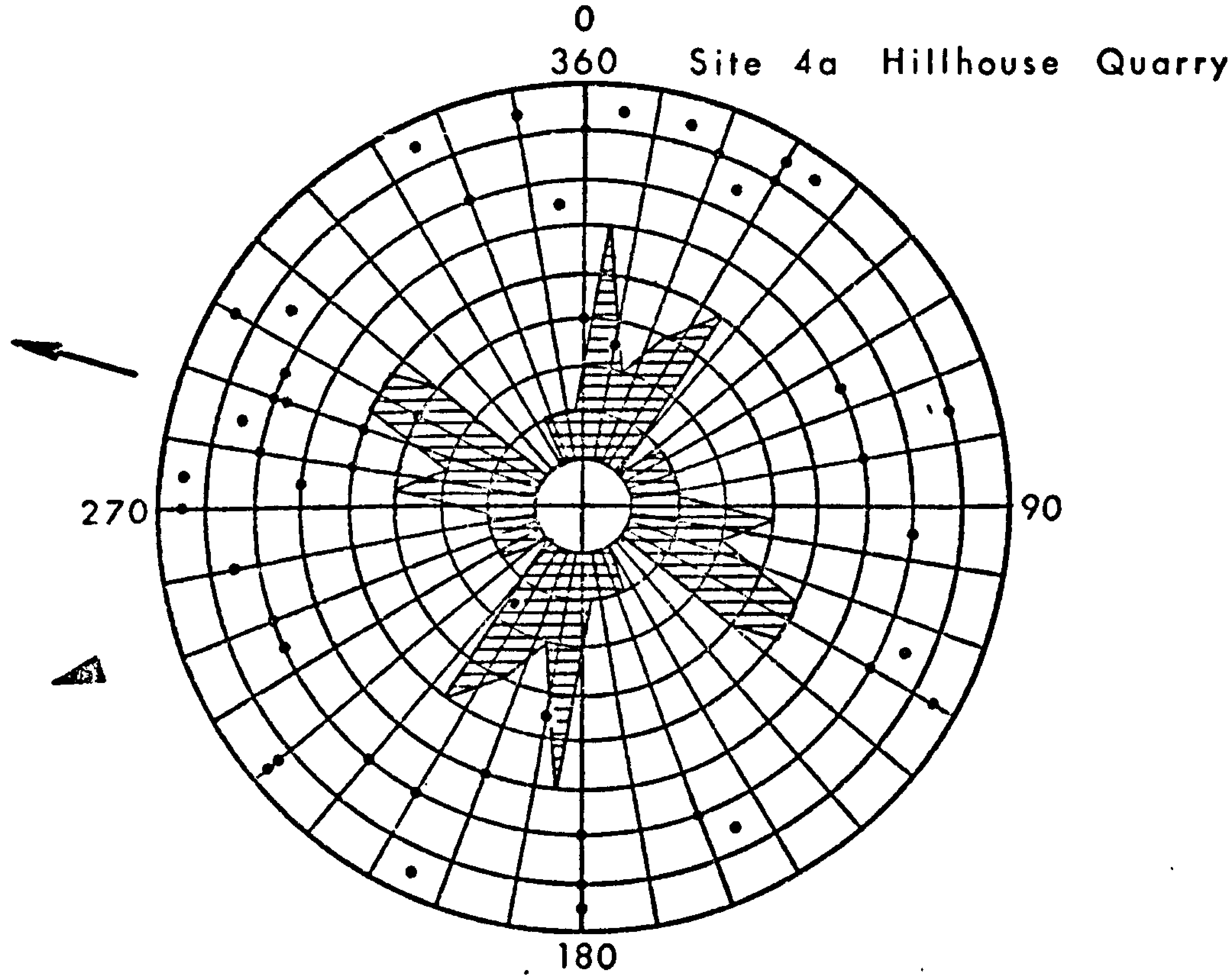
An examination of the rock-type of a sample of 50 erratics from this till shows 94% to be of local derivation while 4% are of Highland derivation. 2% of the erratics are unidentifiable. Shell fragments, though present, are only represented by very small pieces. However, the indication is clear; this till was probably deposited by ice which originated in the

TABLE 4A

Till characteristics in Area III

	Parkthorn Quarry Site 4a	Helenton Hill Site 4c	Annbank Station Site 4d	Drongan Mains Site 4e	Rankinson Site 4f
Mean stone orientation	287^{o}	254^{o}	277^{o}	142^{o}	126^{o}
Chi square	11.93	39.30	47.60	14.12	12.65
Dip strength	0	8.00	0	6.48	1.28
% Gravel					
% Sand					
% Silt/Clay					
% Local rocks	94	100	94	92	86
% Highland rocks	4	0	2	0	0
% Southern Upland rocks	0	0	0	8	14
% Unidentifiable rocks	2	0	4	0	0
Shell Fragments	Yes	No	Yes	Yes	No

TILL FABRICS FROM AREA III



Mean stone orientation

Slope

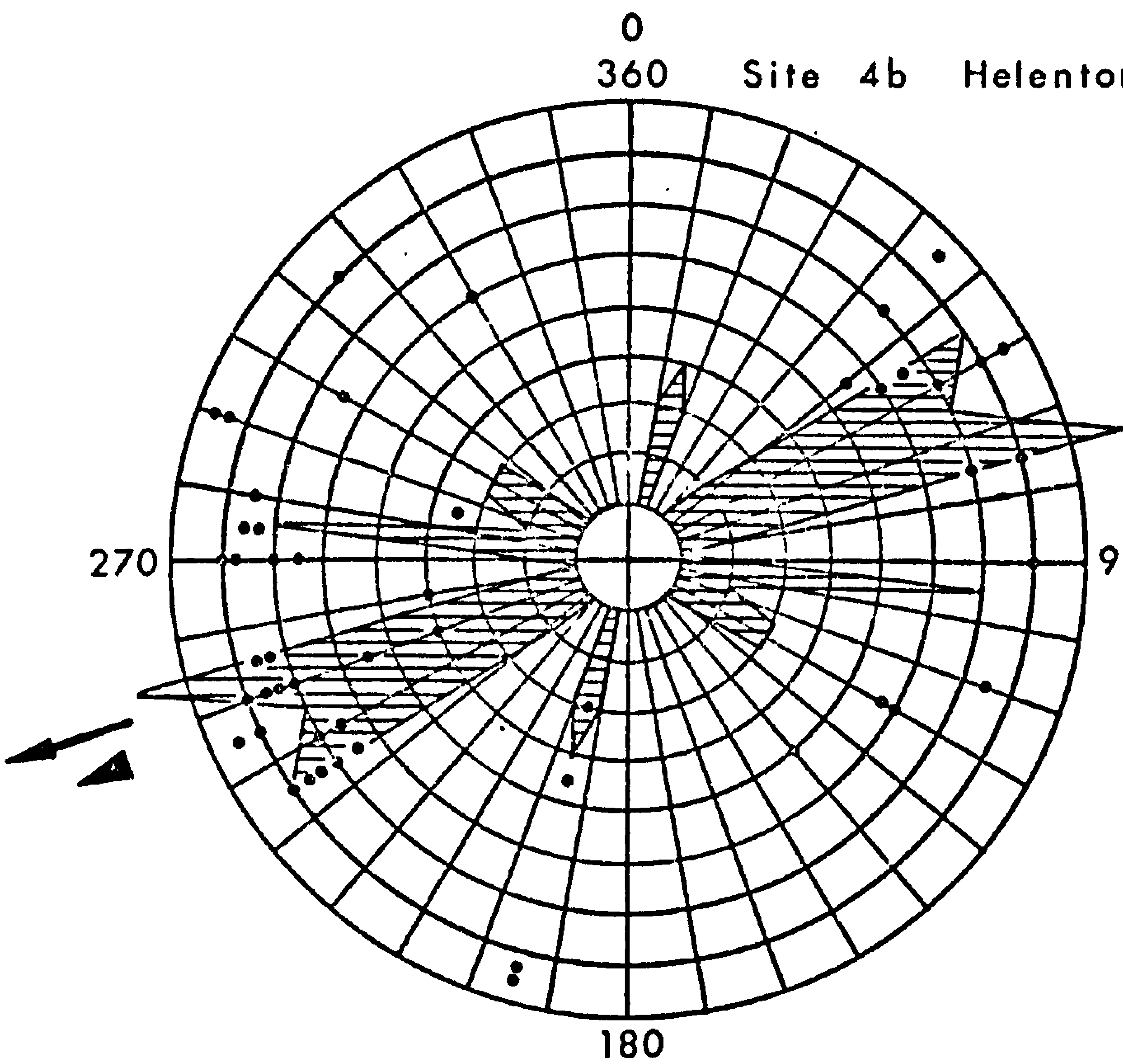


FIG. 4·6

West Highlands. Its situation in relation to the ice-moulded form upon which it lies suggests that the ice by which it was deposited moved from the north-east.

Fabric analyses have also been carried out on the till exposed on top of the finest example of a crag and tail feature in Area III at Helenton Hill (Site 4b, Fig. 4.4). As explained on p.90 , quarrying activity has exposed a till which thickens towards the south-west (i.e. away from the crag). The section is 7m. thick and has the following stratigraphy:-

Site 4b	Helenton Hill	O.D. 98m.	Fig. 4.4
3	Weathered red/brown till		2m.
2	Fresh red/brown till		4m.
I	Laminated clay		½m.
0	Bedrock		

From a preferred-stone orientation analysis based upon a sample of 50 stones a mean orientation of 254° was calculated (Table 4A; Figs. 4.4, 4.6). A chi-square value of 39.30 shows that this orientation is statistically significant, when tabulated with 8 degrees of freedom, at the 99.9% level of confidence. A dip-strength value of 8.00 was also calculated from these data and, when tabulated with I degree of freedom, it proves to be statistically significant at the 99% level of confidence. These results strongly indicate that the ice which deposited this till on top of the Helenton crag and tail moved from a generally north-eastern or south-western direction. An examination of the rock-types of the erratics in the till was undertaken in order to ascertain the precise direction of ice movement.

Of the 50 stones selected at random from the till, 98% are of local origin and 2% are of Highland origin. The presence of Highland erratics, however, is regarded as sufficient evidence to corroberate the suggestion that the ice moved from a generally north-eastern direction. Further evidence for a north-easterly movement of ice is provided by closer examination of the erratics of local origin, as all of them (IOO%) are vent agglomerates, and the only exposure of such a rock-type is a short distance to the north-east - the 'crag' itself.

After a preferred-stone orientation analysis at Site 4d in the valley of the River Ayr near Annbank (Fig. 4.4) a mean stone orientation of 277°

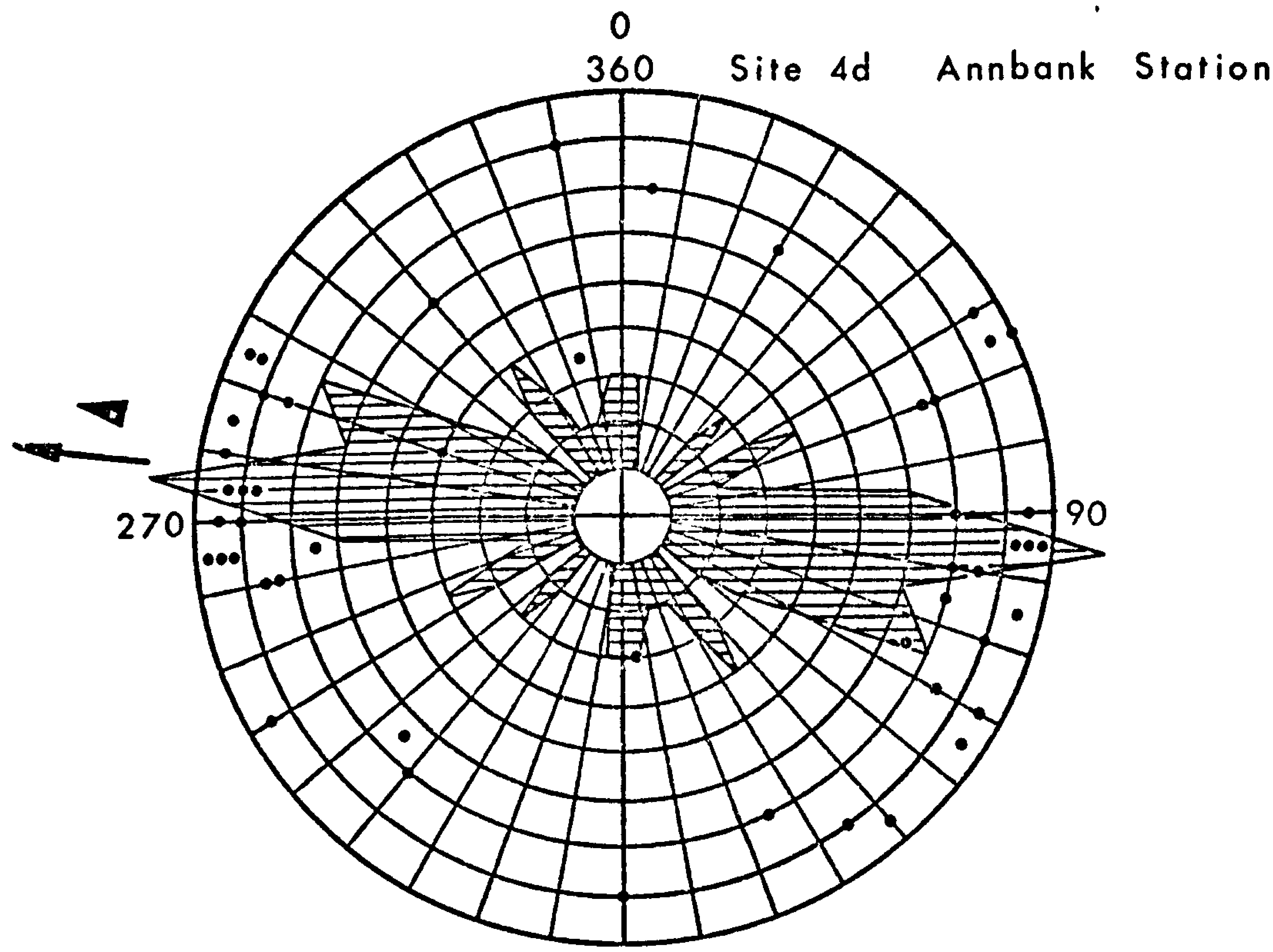
was calculated (Table 4A; Figs. 4.4, 4.7). This exposure is 8m. thick and composed entirely of brown, sandy till. This section has been cut by the erosive action of the River Ayr. A chi-square value of 47.6 was calculated for this mean orientation, which, when tabulated with 8 degrees of freedom, is statistically significant at the 99.9% level of confidence. However, the dip-strength for these data is 0 (zero). The inference from these statistics is that the ice which deposited this till moved from either a generally eastern or western direction. Examination of the rock-type of the erratics in this till may help to indicate more precisely the former direction of ice movement.

A random sample of 50 stones contains 94% local rocks, 2% Highland rocks and 4% unidentifiable rocks. The strong indication is that the ice which deposited this till originated in the West Highlands. This is also indicated by the presence of small broken shell fragments. However, it is still not clear whether the ice moved from a generally eastern or western direction.

Near Drongan Mains (Fig. 4.4) there is a 10m. thick exposure of brown till overlain by 2m. of sand and gravel. (Site 4e). A preferred-stone orientation analysis was completed on the till and it yielded a mean stone orientation of 142° (Table 4A; Figs. 4.4, 4.7). A chi-square value of 14.12 was calculated for this mean orientation which, when tabulated with 8 degrees of freedom, is not statistically significant. A dip-strength value of 6.48, however, is statistically significant at the 95% level of confidence when tabulated with one degree of freedom. The mean orientation of stones which indicates a movement of ice in this part of Area III from the north-west or the south-east is therefore unreliable.

An examination of the rock-type of the erratics contained within this till shows that 92% are of local origin and that the remaining 8% are of Southern Upland origin. Fragments of marine molluscs are also common components of the till. The presence of Southern Upland erratics are interpreted as an indication that this till was deposited by ice of Southern Upland origin. However, shell fragments indicate a Highland origin for the ice. It is clear from this seemingly contradictory evidence that this part of Area III lies within the "crossing over zone" suggested by Eyles et al (1949, p. 127). This zone was originally occupied by

TILL FABRICS FROM AREA III



Mean stone orientation

Slope

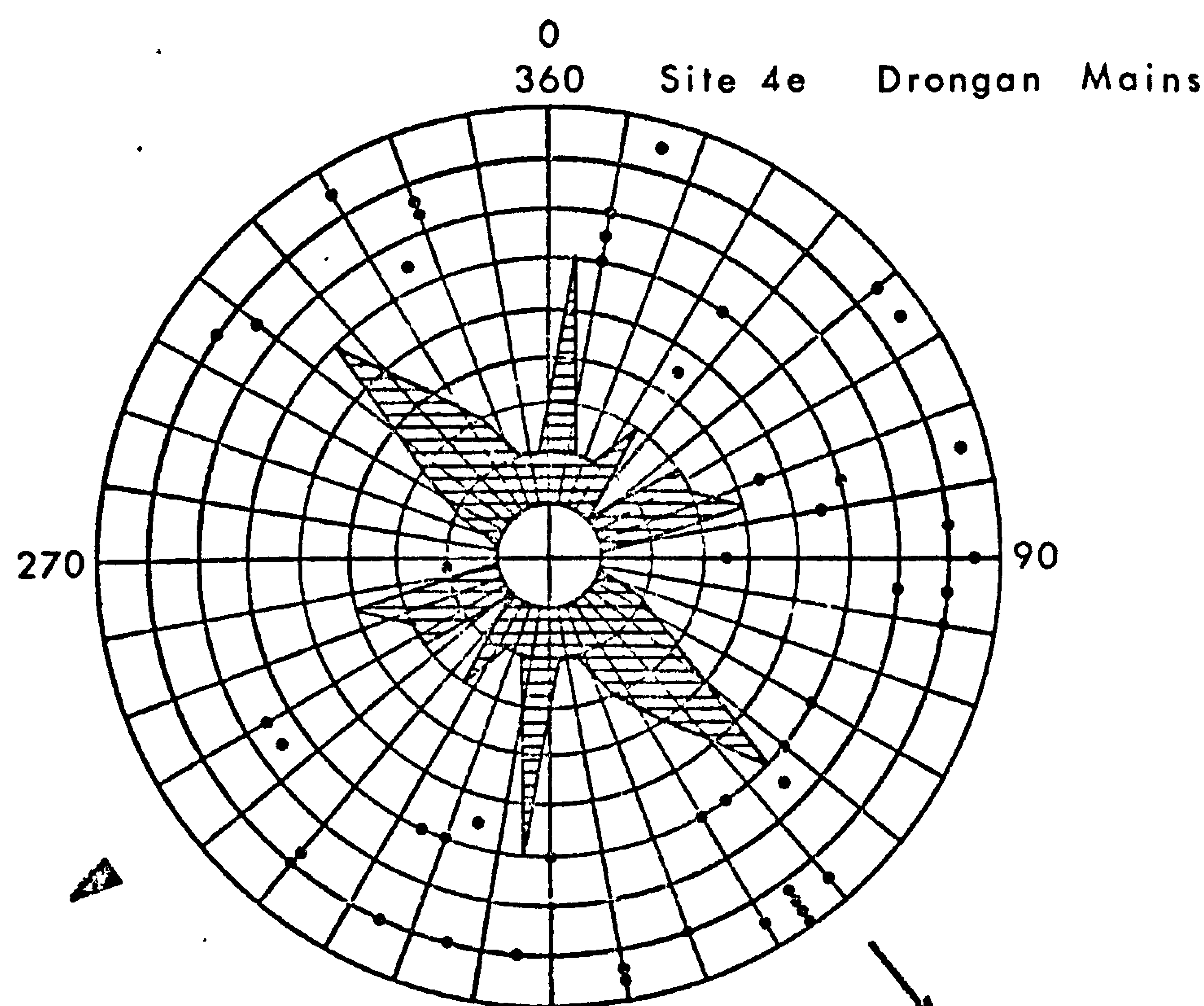


FIG. 4·7

Highland ice, but when the pressure exerted by this ice relaxed, it allowed the Southern Upland ice to move across an area previously occupied by Highland ice. If this is correct, it would seem that the last ice to occupy this part of Area III originated in the Southern Uplands. It is highly likely, therefore, that this ice would have moved from a generally south-eastern direction.

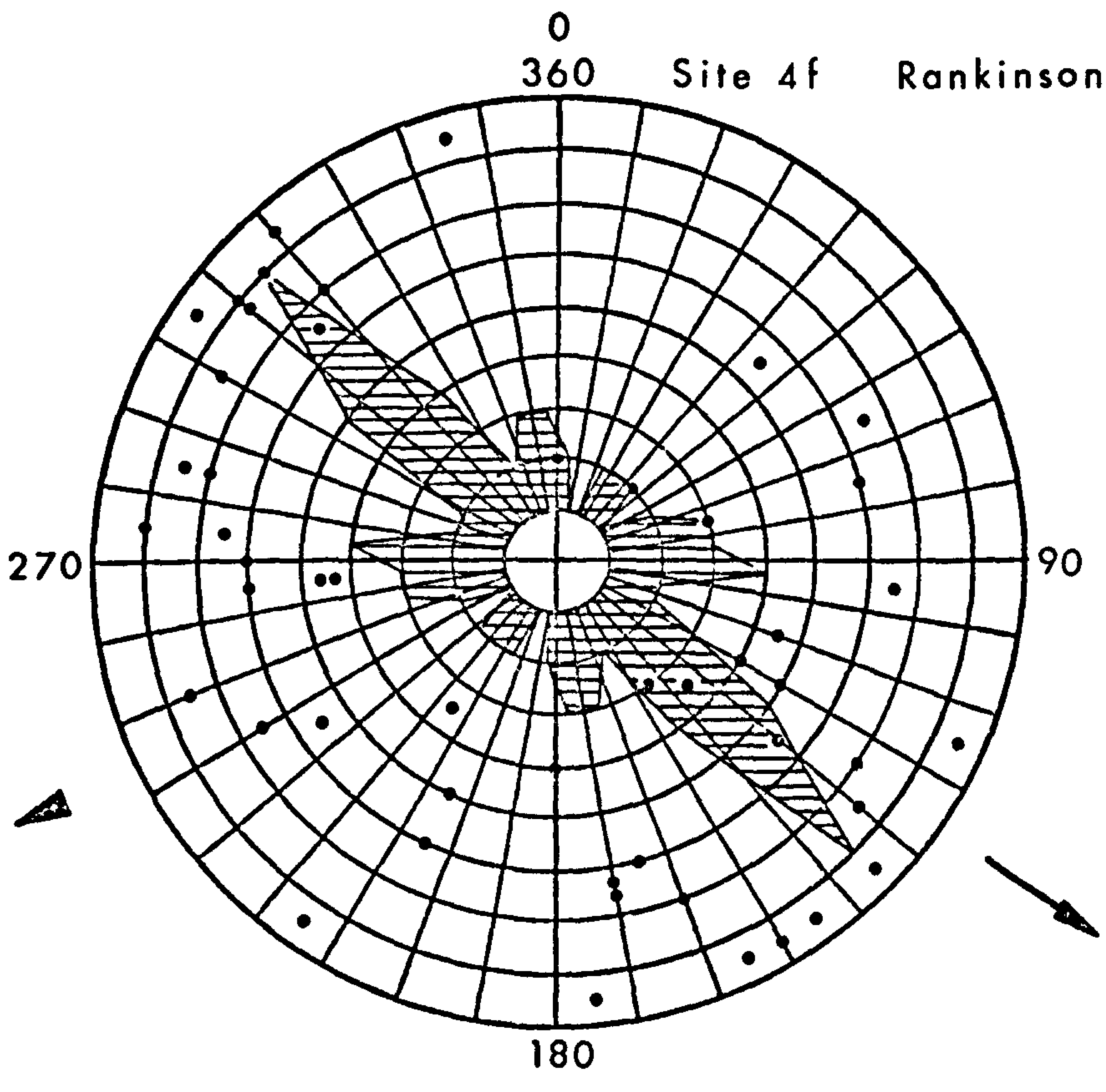
The last till exposure to be examined in detail in Area III is Site 4f which is 2 km. south-east of Rankinson (Fig. 4.4). This exposure, in the valley of the Water of Coyle, is I5m. thick and is composed entirely of grey/blue sandy till which contains erratics of Loch Doon granite upto 2m. in diameter. A mean orientation of stones within this till of I26° was calculated (Table 4A; Figs. 4.4, 4.8). This allows a chi-square value of I2.65 to be calculated for the mean stone orientation. However, when this chi-square value is tabulated with 8 degrees of freedom it shows the mean orientation of stones not to be statistically significant at any level of confidence.

The origin and former ice movements in this part of Area III may be indicated by an examination of the rock-types of the erratics within the till. A random sample of 50 erratics demonstrates that 86% are of local origin and that the remaining I4% are of Southern Upland origin. No Highland rock-types or shell fragments are found in the till at this site. The strong indication from these results is that the ice which deposited this till originated in the Southern Uplands and probably moved from a generally south-eastern direction. It appears that Highland ice did not extend this far south into Area III.

The examination of every till exposure in Area III confirms the important dichotomy between till characteristics noted during the fabric analyses. In the northern part of Area III, till everywhere contains Highland erratics and shell fragments. In the southern part of Area III, no Highland erratics or shell fragments are included, but Southern Upland erratics are common. Between these two extremes is a zone where the till contains both sets of characteristics, Highland erratics and shell fragments as well as Southern Upland erratics. No distinct break between tills which contain these characteristics exists in Area III.

Evidence relating to the former direction of ice movements may also

TILL FABRICS FROM AREA III



Mean stone orientation

Slope

FIG. 4·8

be obtained from the drumlins which exist in Area III. Many of these are composed of till. A few, however, are composed of solid rock, but, because there is no difference between the characteristics of these drumlins, they will all be described and discussed together.

Drumlins are widely distributed throughout the whole of Area III (Fig. 4.4). Two parts of the area are conspicuous by their lack of drumlins, the southern extremity and the western margin (i.e. the highest part and the raised beaches). It is hardly surprising that the highest part of the area does not contain drumlins as "They occur for the most part in lowland situations ..." (Sugden and John 1976, p. 266). However, the low-lying western margin, with its close proximity to extensive drumlin fields, would be expected to display a 'drumlin landscape'. This may be explained as follows:- Drumlins at one time were extensive in this part of Area III, but due to relatively high stands of sea-level during the Lateglacial, they were removed by marine erosion and replaced by raised beach features. Evidence exists near St. Quivox to support this suggestion (Fig. 4.4) (See section 4.7).

The drumlins are generally elongated from north-east to south-west (Fig. 4.4). However, close examination shows a slight change in orientation from north to south across the area. In the northern part a strong north-east to south-west trend exists which, towards the central part, becomes an east-north-east to west-south-west trend, while in the southern part, the trend is distinctly east to west. These orientations may reflect the major drumlin forming movement of ice across Area III. However, it is not clear whether this movement was from a generally north-easterly or a south-westerly direction. A study of drumlin parameters may help in the interpretation of these features.

The size and shape of the drumlins in Area III vary considerably, as does the position of the highest point along the crest. The lengths vary from 100m. to over 1000m. and the widths range from 50m. to 250m.. Six times as many drumlins have their steeper end facing towards the north-east than the south-west; (the actual figures are 12:2). This strongly suggests that the ice which formed them moved from a north-easterly direction. Eight times as many drumlins have their highest point nearer the north-eastern end of the feature than the south-western end; (the actual figures are 24:3). Again this is interpreted as strong evidence for a generally north-east to south-west movement of ice across the area. The movement of ice was more east-west towards the southern part of Area III. This corresponds with the movements of ice already indicated by other features in Area III and also in Area I and Area II.

The evidence provided by the study of glacial deposits aids the understanding of the former movements and origin of the ice which affected Area III. It was affected by two ice-masses from different sources: one from the Highlands which moved from the north-east and affected the northern part of the area, and one from the Southern Uplands which moved from the south-east and affected the southern part of the area. These former movements of ice across the area indicated by the features of glacial deposition resemble those indicated by the features of glacial erosion.

These movements of ice are similar to those suggested by Eyles et al (1949) for the latter phase of ice movement. However, as with Areas I and II, no evidence is available to suggest that there was an initial movement of ice from west to east across the northern part of Area III, as indicated by Eyles et al (1949, p. 125).

4.5: Fluvioglacial Erosion

Area III is not well endowed with landforms that have been formed by the action of meltwater (Fig. 4.4). Only one small meltwater channel system exists in the area (with the exception of the system carved into the Dundonald Hills (channel system 14) which straddles the boundary between Area I and Area II and which is described and discussed in relation to Area I). The small meltwater channel system is situated near Craigie in the north-central part of the area (Fig. 4.4). Fragments of meltwater channels exist in four other localities, all of which are confined to the southern part of the area (Fig. 4.4).

In some instances, a degree of difficulty is experienced when deciding whether or not large, broad valleys, which contain relatively small streams are the product of the processes of fluvioglacial erosion. However, these valleys do not display many of the characteristics typical of meltwater channels, such as steep, confining walls on either side of a broad flat floor. Although such characteristics may have been masked by subsequent depositional activity, it is considered that these valleys are the product of 'normal' fluvial processes.

The channel system near Craigie was first mapped by the Officers of the Geological Survey for Scotland for inclusion on the I" Sheet I4, published in I870. The Officers recognised only one channel approximately 500m. in length. This slightly curved channel was described as having a generally north-east to south-west orientation, and a floor sloping to the north-east. When this channel was mapped by the writer in May I975 it was found to be more complex and extensive (Figs. 4.4, 4.9). The whole system is over I500m. in length and is comprised of one main channel and three smaller subsidiary channels.

The main channel, though discontinuous, is over I500m. long with a flat floor upto I5m. wide. The steep sides of the channel are I2m. high in places and well-defined. Numerous exposures in the channel sides show that this feature is eroded entirely into the solid rock of the district, which is resistant teshenite. The long-profile of the north-east to south-west orientated channel is humped. From its north-eastern extremity for a distance of 400m. the main channel slopes towards the north-east; the remaining II00m. of its course slopes gently towards the south-west. This may indicate a flow of meltwater from either the south-west or the north-east. In the steep south-eastern side of the main channel, two breaks exist which lead into short channels which generally slope towards the south (Fig. 4.9). These small features are upto 5m. deep, 200m. long and have flat floors upto I2m. wide. A short, well-defined channel is connected to the main channel at its north-eastern extremity. This 300m. long curved channel, which is eroded into solid rock, has assymmetrical sides. The northern side is 9m. high and the southern side is I3m. high. The floor of this meltwater channel, which slopes consistently towards the north-east, is I0m. broad in parts.

The evidence relating to meltwater flow obtained from the analysis of the Craigie channel system is poor. However, the humped long-profile of the main channel strongly suggests that the meltwater by which it was produced flowed subglacially under hydrostatic pressure. It is not clear

Fig. 4.9 Channel System 1 - Area III.

whether the meltwater flowed from the north-east or the south-west (i.e. whether the junction between the main channel and the smaller channel to the north was a common intake or a common outflow point for meltwater). There is not enough field evidence to enable a reliable conclusion to be drawn indicating the former direction of meltwater flow in this part of Area III. However, it is well-established that meltwater usually flows sub-parallel to the ice gradient (and hence the direction of ice movement) in an area (Embleton and King, 1968, p. 263). If this is correct, it is considered more likely that the meltwater in this part of Area III flowed from the north-east because here the ice gradient sloped from north-east to south-west. This conclusion implies that a correlation may exist between the Craigie channels and the Harpercroft channels 6 km. to the west, which are described and discussed in relation to Area I (Channel system I4). The conclusion drawn about these channels is that they were also formed by meltwater which flowed from the north-east.

The fragments of meltwater channels in the southern part of the area are small and widely spaced (Fig. 4.4). The three most southerly fragments are eroded into solid rock. They are 10m. deep and have flat floors 10m. wide. The meltwater channel form, which usually consists of steep confining side walls and broad, flat floors, is maintained for very short distances (300m. maximum) and is gradually replaced by a broad, open V-shaped cross-section. However, it is unlikely that parts of these valleys carried meltwater while other parts did not. It is considered that the meltwater channel form was at one time more extensive and it has been subsequently masked or modified by various processes. Due to the lack of good evidence, any conclusions concerning the former direction of meltwater flow in this part of Area III would be largely speculative. Therefore, the south to north flow of meltwater in this part of the area, which is suggested by the consistent south to north channel gradients, is regarded as no more than speculative.

The most northerly of these channel fragments near Clydenock (Fig. 4.4) is approximately 1000m. long and eroded entirely into till. This unconsolidated surface material has resulted in a poorly defined channel. However, this channel is very distinctive within the landscape because it is quite dry. Its gradient slopes from north-east to south-west, which in the southern part of Area III is regarded as anomalous to the, albeit poorly, established pattern. The characteristics of this channel may indicate that it was formed by isolated meltwater activity. This may have been Late -glacial.

Features produced by the action of meltwater erosion are not well represented in Area III. This is probably for similar reasons to those discussed in Chapter 3 which explain the lack of fluvioglacially eroded features in Area II. Few firm conclusions may be made concerning meltwater flow within Area III based upon such limited evidence. However, a number of tentative implications present themselves:-

I) It is considered most probable that in the northern part of the area (and almost certainly in the vicinity of the Harpercroft and Craigie channels) meltwater flowed subglacially generally from the north-east.

2) In the southern part of the area the direction of meltwater flow was probably from the south.

3) Late - glacial meltwater activity also existed but on a limited scale.

4.6: Fluvioglacial Deposition

Area III has the least amount of sands and gravels of any of the 5 areas recognised in central Ayrshire. The sand and gravel deposits present, which are identified on the basis of morphology rather than exposures, are confined to a narrow belt which is only 3 km. wide across the southern part of the area (Fig. 4.4). Though the sand and gravel accumulations within this belt are patchily distributed,they may be subdivided into 3 distinct zones (Fig. 4.4):-

I) The eastern zone - around Piperhill and Laurshill.

2) The central zone - between Craigbrae and Carston.

3) The western zone - between Coylton and Bogside.

The eastern zone of sand and gravel traverses the boundary between Area III and Area II but,to maintain continuity,it is dealt with as a single unit in relation to Area III. These sand and gravel accumulations are in the form of subdued, isolated hillocks upto I50m. in diameter and 5m. in height and isolated elongated hillocks, the largest of which is 200m. long and 4m. high. Borehole records for this part of Area III reveal that the average thickness of sand and gravel is 7m.. This sand and gravel always lies directly on top of till.

The greatest concentration of the hillocks is in close proximity to the terminus of a meltwater channel fragment (Figs. 4.4, 4.IO). These hillocks are aligned in a north-north-east to south-south-west direction from the terminus of this fragment of meltwater channel. However, mounds and ridges also exist to the west and north-north-west of the channel fragment. The irregular orientation of these ridges and mounds make it impossible to predict with any confidence the former direction of meltwater movement in this part of Area III. However, from evidence already considered relating to this part of the area (which includes features of glacial erosion, glacial deposition and fluvioglacial erosion), a southerly source would be expected.

The central zone of sand and gravel deposits, which lie in close proximity to the valley of the Water of Coyle (Fig. 4.4, 4.II), is also a series of mounds and elongated ridges. The most southerly feature, which is 300m. west of Craigbrae, is in the form of a rounded hillock 400m. in diameter and 5m. high (Fig. 4.II). A circular depression I5m. across and 2m. deep occupies an east-central position in this hillock. This depression resembles a kettle hole. No natural exposures exist which reveal the internal characteristics of this mound and therefore pits were excavated. These revealed that the mound is composed of brown, well-rounded, coarse, dirty gravel. This is typical of fluvioglacial material deposited in a high-energy environment.

One km. to the north of this feature, near Drongan Mains, is another mound which is I50m. in diameter and has a maximum height of 3m. (Fig. 4.II). An exposure in the eastern side of the feature has been produced by the erosive action of the Water of Coyle near Drongan Mains (Fig. 4.II). This exposure (Site 4e) is described briefly on p.96 ; it contains two units, the lower unit is IOm. of till, and the upper unit is 2m. of sand and gravel. The upper 2m. mainly consists of fine to medium sand with a limited amount of gravel. It is well-bedded (though the bedding is highly

Fig. 4.10 Eastern Zone of Fluvioglacial Deposits -

Fig. 4.11 Central Zone of Fluvioglacial Deposits - Area III.

contorted and contains layers of coal fragments) and poorly sorted. These characteristics are common to kame-like landforms (Embleton and King, 1968, p. 383).

Two hundred metres to the north-east of the kame near Drongan Mains, on the opposite side of the Water of Coyle, is a small part of Area III which displays irregular relief (Fig. 4.II). This part of the area is approximately 350m. by 200m. and has local relative relief values of approximately 4m.. The irregular form suggests that sand and gravel outcrops at the surface and this is verified by borehole records which show a minimum thickness of 2.5m.. A hundred metres to the north-east of this spread of sand and gravel is a distinctive elongated ridge which lies to the south of Carston (Fig. 4.II). It is 500m. long, 70m. wide and 4m. high. The general orientation of the ridge is from west-north-west to east-south-east with the highest point towards the west-north-western end. This elongated feature has a depression 8m. wide and 2m. deep approximately I50m. from its east-south-eastern extremity. The form and situation of this depression indicates that it may be a kettle hole. A short distance to the south of the east-south-eastern extremity of the ridge is an isolated mound 50m. in diameter and 3m. high. There are no exposures in either the ridge or the mound but borehole records show that in parts they consist of over 5m. of coarse sand and gravel. The ridge has all the characteristics of an esker which would probably have been deposited subglacially or englacially (Embleton and King, 1975, p. 493) by meltwater which flowed from either the west-north-west or the east-south-east. Insufficient evidence exists for a firm conclusion to be drawn which would indicate the precise direction of meltwater flow.

The western zone of sand and gravel deposits lie between Coylton and Bogside (Fig. 4.I2). These deposits are most conspicuous within the landscape as they rise out of an expanse of almost flat peat bog which extends from Martnaham Loch in the west to the valley of the Water of Coyle in the east (Fig. 4.I2). This peat, according to borehole records, is over 3m. thick in parts. The morphology of the sand and gravel includes both mounds and ridges. The mounds are generally subdued and rise to a maximum height of 4m. above the surrounding peat. The largest of the mounds is over 300m. in diameter.

Fig. 4.12 Western Zone of Fluvioglacial Deposits - Area III.

Many of the ridges in this part of Area III emerge from mounds (Fig. 4.I2). Some of the sharp-crested, steep-sided ridges reach a height of 5m., a width of 70m. and a length of 350m.. Occasionally mounds and ridges exist as isolated features, with no apparent connection with other sand and gravel deposits. Of the seven ridges identified in this western zone of sand and gravel five are elongated in a generally east to west direction and two are elongated in a north-west to south-east direction.

There are no natural exposures to show the internal constituents of these mounds and ridges, but borehole records provide valuable data. They show the maximum thickness of sand and gravel in this vicinity to be over I7m., though the average thickness is I2m.. Borehole records also show that the sand and gravel lies directly on both solid rock and till, and that the fluvioglacial deposits are much more widespread than their surface form suggests. It would not be unreasonable to assume that this indicates a continuous spread of sand and gravel which, due to subsequent peat accumulation, only occasionally protrudes at the surface. No clear evidence exists to indicate the probable direction of meltwater movement which deposited this material.

The lack of good evidence from the features of fluvioglacial deposition makes it unwise to draw firm conclusions concerning former directions of meltwater flow in Area III. However, the complexity of the movements of meltwater is suggested by the irregular pattern of kames and eskers within the belt of fluvioglacial deposition across the southern part of the area. This complicated sand and gravel morphology is not surprising when it is considered that this part of Area III has been affected by two ice masses: one with a west Highland origin and one with a Southern Upland origin.

The lack of sand and gravel deposits of fluvioglacial origin in many parts of Area III, especially the northern part, may be explained in two ways:-

I) The material was deposited and subsequently removed.

2) The material was never deposited.

No evidence exists which suggests that extensive erosion has taken place in any part of Area 111. From this, it appears that environmental conditions in the area during deglaciation were unfavourable for fluvioglacial deposition. This might have been due to the opening of a subglacial escape route along the Lower Ayr valley; (this would be an extension of the subglacial escape route along the middle Ayr valley that was suggested in Chapter 2 as an explanation for the lack of fluvioglacial deposits in the western part of Area I). This subglacial escape route would have allowed the rapid drainage of meltwater from Area III, leaving little time for the accumulation of fluvioglacial sediments (Sissons, 1958b, p. 174). The size of the Lower Ayr valley (upto 1½ km. across and 45m. deep) supports this suggestion.

4.7: Raised Beaches and Elevated Marine Deposits

Raised beaches are well-developed along the whole of the seaward side of Area III (Fig. 4.4). For most of their length the raised shore platforms covered with beach material have been cut into till. This has resulted in the preservation of ill-defined features which are over 4 km. wide in places (Fig. 4.4). It was decided not to include detailed levelling in the study of the raised beaches owing to the time that would be required to devise and complete a meaningful programme. (It would be especially difficult in the case of central Ayrshire due to the thickness of wind-blown deposits which overlie parts of the raised beaches and the extent of urban development). The examination of these raised coastal features, therefore, involved accurate field mapping which utilised an analysis of borehole records from public and private sources, and altitudes published by the Ordnance Survey.

Near the northern margin of the area, a raised beach at an approximate altitude of 10-12m. O.D. extends inland for a distance of 1½ km. (Fig. 4.4). A well-defined fossil cliff, which is 20m. high and cut in teshenite, represents its landward margin. Further south, east of Barassie, there is a series of three raised beaches (Fig. 4.4). The highest of these is 800m. wide and has an approximate altitude of 24 - 26m. O.D.. Its inland margin is a well-defined fossil cliff which is continuous with the one to the north. However, this fossil cliff only continues southwards for another half a km. before it disappears and is replaced by an ill-defined break of slope which is cut in till. The next highest raised beach east of Barassie is nearly 500m. wide and is at an approximate altitude of 10-12m.. It is therefore continuous with the raised beach to the north. The lowest raised beach is 600m. wide and has an approximate altitude of 4-6m. O.D.. None of these features are very extensive in this part of Area III (Fig. 4.4).

From Barassie to the southern margin of the area, these three raised beaches are preserved in varying degrees, though they are always ill-defined. The higher features at IO-I2m. O.D. and 24-26m. O.D. are much more extensive than the lower feature at 4-6m. O.D.. Fig. 4.I3 shows two cross-sections across this raised beach relief.

An interesting feature exists in conjunction with the maximum inland extent of the 24-26m. O.D. raised beach at St. Quivox (Figs. 4.4, 4.I4). Here, two almost coalescing drumlins have had their characteristic smooth sides trimmed on the seaward margin at an approximate altitude of 24-26m. O.D.. This is strong evidence that the two drumlins were eroded to some extent by marine action when sea level was at its highest subsequent to their formation.

Gray and Lowe (1977) explain that the formation of raised beaches since deglaciation was "mainly due to the interplay between the isostatically rebounding crust and the eustatically rising sea. It is probable that neither of these movements was simple and in addition they were probably complicated by, for example, hydroisostatic movements offshore. The result was a complex history of sea level change that has yet to be fully deciphered" (p. I68). Although many questions remain unanswered, a well-established framework of terminology (and to a lesser extent chronology) has been developed based upon a great amount of evidence produced by many workers (Jardine 1962a, 1962b, 1964, 1967, 1971, 1975; Bishop 1963; Sissons 1966, 1967b, 1969, 1972, 1974b, c; Sissons and Smith 1965; Bishop and Dickson 1970; Gemmell 1971; Gray 1974a, b, 1975b., Bishop and Coupe 1977; Gray and Lowe 1977). The raised beaches in central Ayrshire may be accommodated within this basic framework.

The altitude of the highest raised beach (24-26m. O.D.) in Area III correlates with the altitude of the Lateglacial raised beaches identified in the Firth of Clyde by Jardine (1971) at an altitude of 24m. O.D. and by Gemmell (1971) at an altitude of 27-28m. O.D..

The IO-I2m. O.D. altitudinal range of the next highest beach in central Ayrshire includes the altitude (I2m. O.D.) of a raised beach identified by Jardine (1971). A tentative correlation may also be made between this raised beach and the one identified by Gemmell (1971) around

Fig. 4.13 Cross-sections of Raised Beach Relief - Area III. For location of A-B and C-D see Fig.4.4.

Fig. 4.14 Marine-trimmed Drumlins at St.Quivox.

Arran which has an altitude of approximately IOm. O.D.. Both Jardine and Gemmell concluded that the raised beaches at this altitude are related to the Main Post-glacial shoreline recognised in other parts of Scotland. There is no reason to disagree with these conclusions.

The lowest raised beach, which is at an altitude of 5-7m. O.D. was also identified by Jardine (I97I). A raised beach at a similar altitude (4-6m. O.D.) was recognised by Gemmell (I97I) around Arran. The coastal feature at this altitude was considered by Jardine and Gemmell to represent a temporary halt position in the regression of the Post-glacial sea from its maximum position to its present position.

Geomorphologists generally agree that the Lateglacial raised beaches were deposited at approximately I3,000 yrs. B.P., and that the Post-glacial raised beaches were deposited between 8,400 yrs. B.P. and 6,600 yrs. B.P.. Recently, however, Gray and Lowe (I977) argued against the formal acceptance of dates for the deposition of beaches based upon particular stratigraphical boundaries (as are these) because of "errors in the radiocarbon dating methods, the relatively few dates available and the standard deviation associated with them" (p. 80). The accuracy of the dates suggested for the deposition of this series of raised beaches is therefore debatable.

A marine deposit exists near Afton Lodge (Site 4c, Fig. 4.4) at an altitude of approximately 85m. O.D.. A similar deposit of much more limited extent also exists in Area I near Site 2a, I km. south of Catrine. For ease of description and discussion these two deposits will be considered together. Other similar deposits have been recorded by various workers (Eyles et al I949, Geikie I869) in central Ayrshire but exposures are not available and therefore description is impossible.

The deposit at Afton Lodge is exposed over a 300m. length of the Ladykirk Burn which flows from north-east to south-west in this part of Area III (Fig. 4.4). The general geographical situation of this deposit is that it lies near the base of a north-east to south-west orientated ridge which represents volcanic lavas at the western edge of the Mauchline Basin mentioned on p.93. Examination along this exposure shows the generalised section to be:-

Site 4c	Afton Lodge O.D. = 85m. Fig. 4.4	
3	Angular clasts upto 30 cm. in diameter contained in a red/ brown coarse, sandy, open-textured, weathered matrix.	3.00m.

2 Coarse gravel dipping to the east-south-east (i.e. downstream) at an angle of 5°. 0.3m..

I Stiff, black, shelly, silty clay of marine origin. I.5m. (exposed) a minimum of 5.00m. (by augoring).

Stream cut exposures around this site show that the silty clay is at least 300m. long and I00m. wide. Near the head of the stream the red, sandy, very tough till which is typical of this part of Area III is present. When traced downstream it has an abrupt vertical contact with the marine silty clay. The characteristic till of the vicinity is nowhere found to overlie the silty clay although Eyles et al (I949) described the open-textured, red/brown material which overlies the silty clay as a till. However, this does not necessarily exclude the possibility that till may overlie the silty clay in the other localities in which it has been found (Eyles et al I949, Geikie I869). It is considered that the open-textured, red/brown material is typical of that attributed to slope-wash processes. Attempts to establish the lateral extent of the marine deposit beyond the stream courses by hand augering failed due to the inability of the equipment to penetrate the material lying at the surface. However, hand augering did allow the penetration of the silty clay to a depth of 5.00m..

The area around Afton Lodge is curious in terms of morphology. The landscape is characterised by high density, rounded mounds which are smooth and steep-sided and rise upto a height of I2m.. These hills show no regularity of pattern. Only one other part of central Ayrshire has a similarily distinctive morphology and that is near Tarshaw 2 km. to the north-north-west (Fig. 4.4). It may be significant that it is near Tarshaw that Eyles et al (I949, p. I26) located a similar marine silty clay; unfortunately the writer has not been able to find this exposure.

A characteristic of the marine silty clay is that it weathers pale grey or brown to a depth of one metre. Below this depth the tenacious, black character of the silty clay is prominent. The upper I½ metres of this deposit shows a distinct horizontal stratification (which is best seen when the exposure has been left to weather for a few days). This stratification, (Plates 4F, 4G, 4H), is in the form of alternating layers of coarse sand and silty clay; generally the material becomes finer with depth until it becomes homogeneous silty clay. This marine deposit very

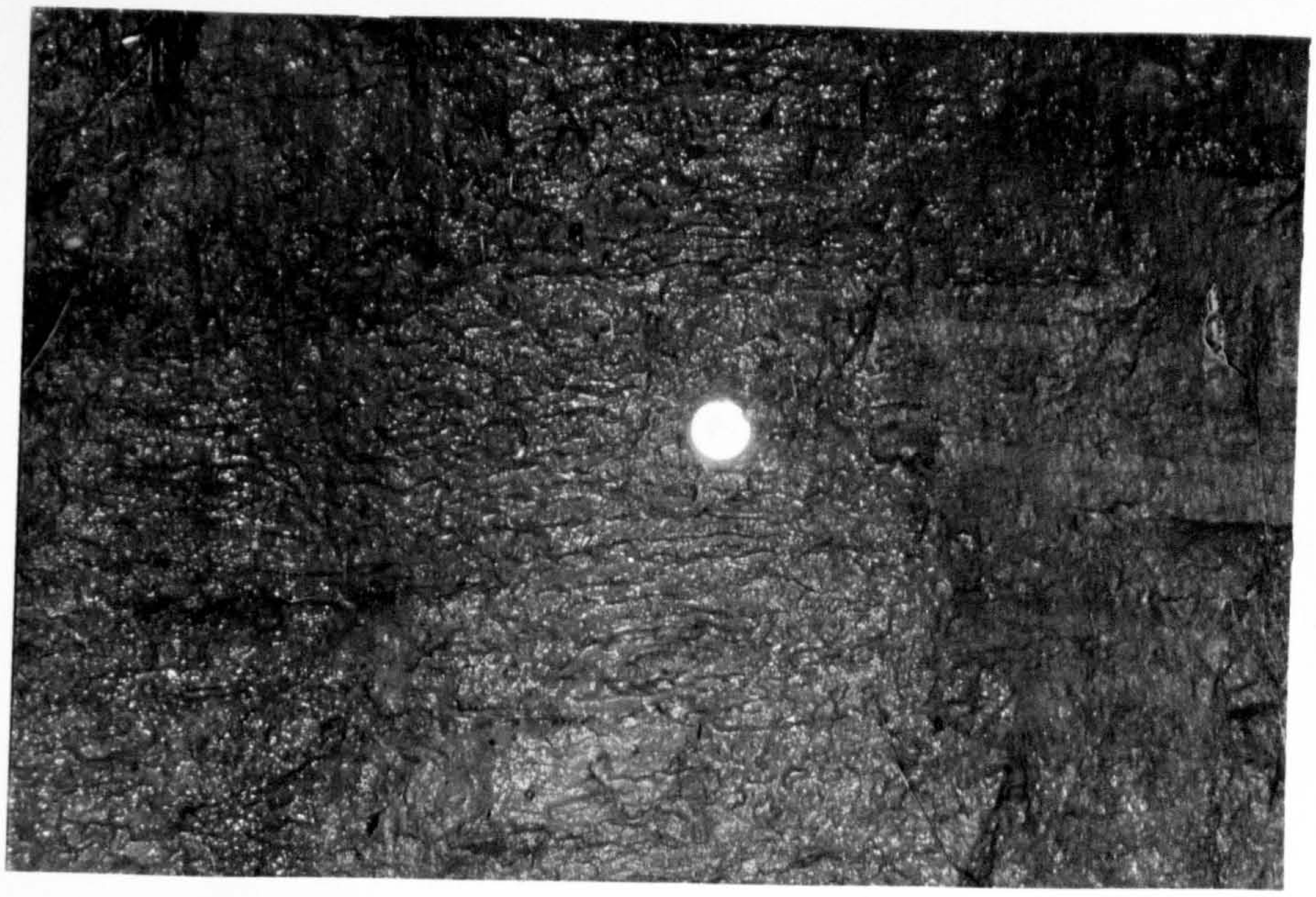


Plate 4F Horizontal Stratification in the Shelly Clay at Afton Lodge

Plate 4G Layers of Sand and Clay in the Upper Parts of the Shelly Clay at Afton Lodge

Plate 4H Close-up of the Layers of Sand and Clay in the Upper Parts of the Shelly Clay at Afton Lodge occasionally contains rounded quartz pebbles upto one cm. in diameter. However, the most conspicuous inclusions within this deposit are shell fragments which all belongto Phyllum Bivalvia and include such species as Arctica islandica and Astarte elliptica; the latter is the more common species. Both are common around the shores of Britain today and have similar natural habitats. In the case of Astarte elliptica it is usually found today ....."living generally in sandy mud ... offshore below 3(three) fathoms (5.5m.), (Tebble, 1966, p. 7I) and Arctica islandica found living ..."on firm bottoms of sand and muddy sand in the intertidal zone to considerable depth." (Tebble, 1966, p. 93). It is highly likely, therefore, that the silty clay is the material in which the bivalves lived - and died. A fragment of Arctica islandica from this deposit has been sent to the Institue of Arctic and Alpine Research in Boulder, Colorado for dating by the Amino-acid technique.

The larger bivalves are always present as fragments upto 2mm. thick. Occasionally, broken pieces of a single valve are found in contact with each other and small shells are frequently found whole. On one occasion a small, whole bivalve (i.e. the two valves were still connected) was located which, when removed from the surrounding silty clay, disintegrated into innumerable fragments. The most striking feature of the shells and shell fragments is their near perfect state of preservation, with the chitinous outer layer still in place as an unbroken cover (Plate 4I, 4J).

Foraminifers are also included in this silty clay. They were extracted by the writer from a sample of 2 kg. of silty clay and subsequently identified by Dr. M. Keen of the Geology Department at the University of Glasgow (Appendix IV). The most common species (34%) is Ammonia beccarii which is closely followed by Quinqueloculina seminulum (30%). However, his conclusion relating to their natural habitat is of importance: "My general conclusion is that its the sort of assemble ge you could find in the Firth of Clyde today between about I5m. and 50m. depth - i.e. its not littoral, but not too deep either." (pers. comm. I2/I2/1976).

The traditional explanation for the origin of the mass of shelly, silty clay (and the deposit near Catrine in Area I) was expounded by Eyles et al (1949): "These masses of shelly clays, clearly distinct from ordinary boulder clay (till), are regarded as portions of the sea floor transported in a frozen condition and deposited as erratics. Their

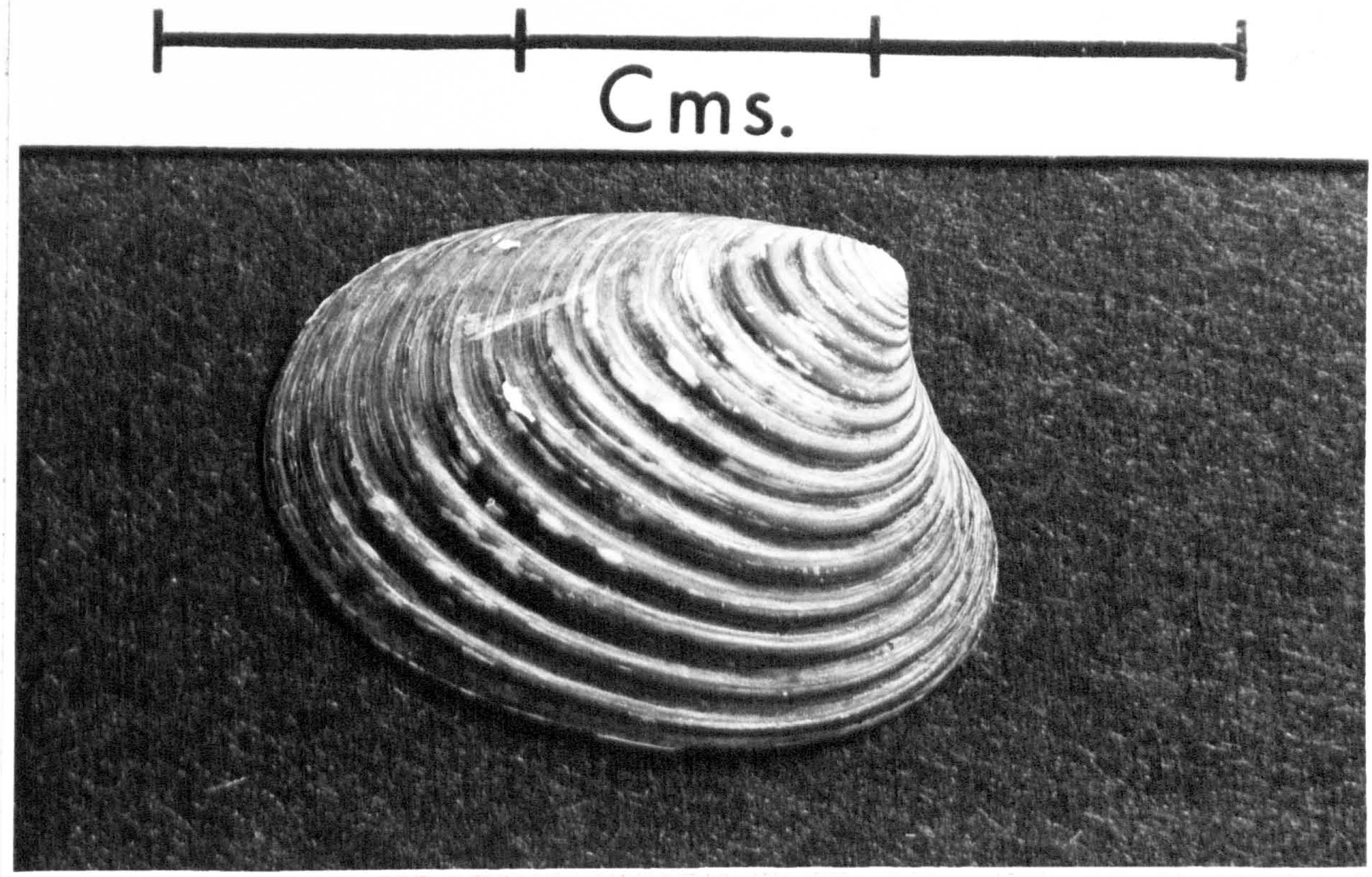


Plate 4I   Excellent State of Preservation which is typical of the Shells contained within the Shelly Clay at Afton Lodge
" - Astarte elliptica"

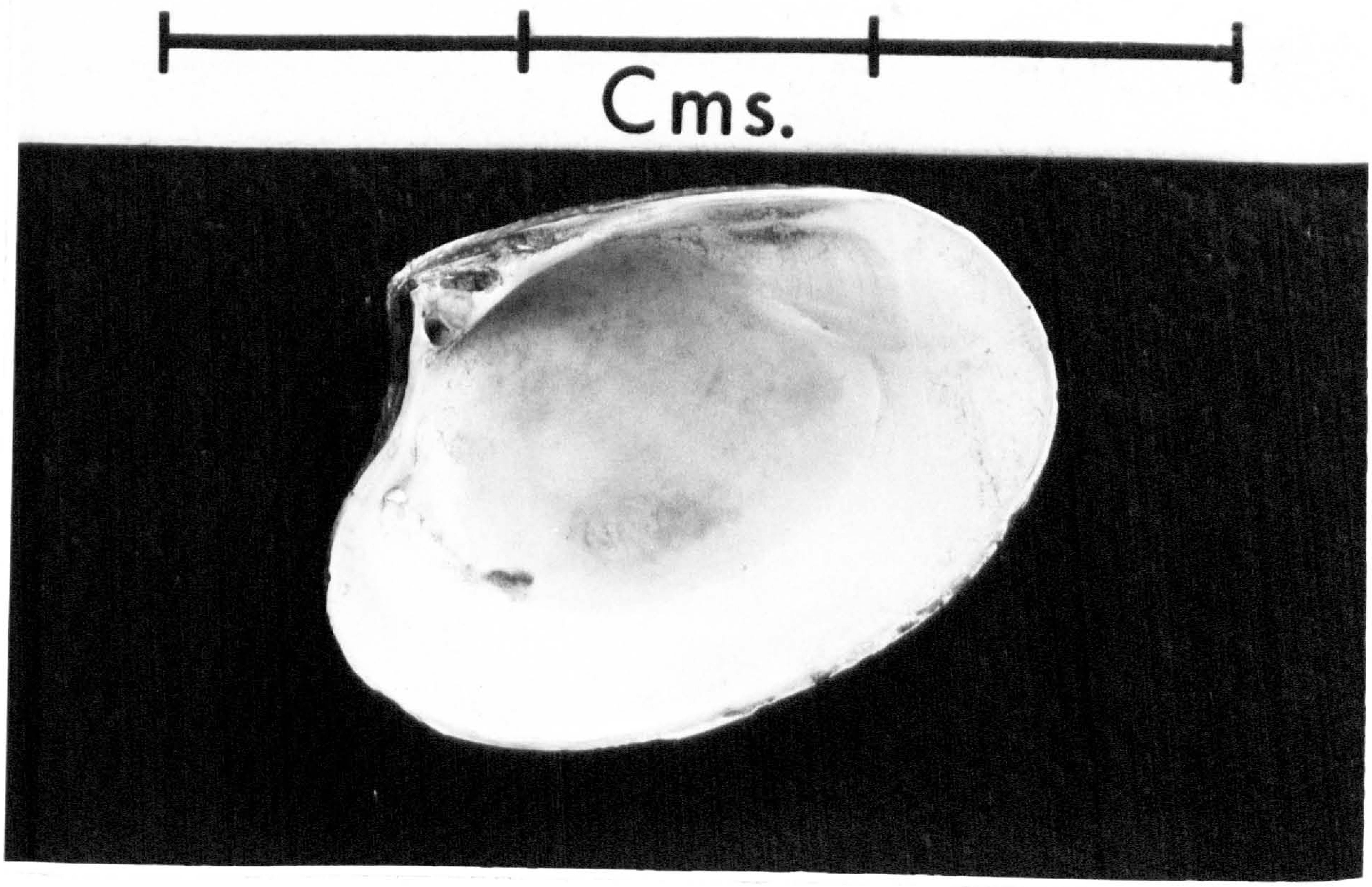


Plate 4J   Excellent State of Preservation which is typical of the Shells contained within the Shelly Clay at Afton Lodge
" - Astarte elliptica"

occurrences are too isolated for them to be considered as representing a marine deposit _in situ_ of preglacial or inter-glacial age" (p. 127). Such an explanation raises a number of questions:-

1) Eyles et al (1949) assumed that a frozen block of sea-bed was transported from the floor of the Firth of Clyde by ice which moved from west to east. It has already been shown, quite conclusively, that no evidence exists in the western part of central Ayrshire for any such movement of ice. The ice moved from north-east to south-west and, therefore, could not have picked up this material from the Firth of Clyde.
2) It is doubtful that a block of material of such dimensions could be picked up, transported and deposited by ice. Meneley (1964) calculated that the physical properties of ice allows boulders upto 25m. in diameter to be supported and tabular slabs upto 8m. thick with a maximum length of 330m.. The actual dimensions of the block of silty clay to be picked up would have been much larger - as Sugden and John (1976) state: "... for all we know at present is the simple fact that breakage and crushing of clasts are essential processes which operate during glacial transport (Holmes, 1960; Drake, 1968)" (Sugden and John, 1976, p. 229).
3) It is considered unlikely that the horizontal stratification would be preserved if this material has been carried (a _minimum_ distance of 14 km.) by ice as an erratic block. The horizontal bedding and the coarsening of the material from bottom to top is considered as representing that the material was deposited _in situ_.
4) If, as suggested by Geikie (1863) and Eyles et al (1949), this marine silty clay is overlaid by till, it would mean that it was deposited before the last advance of ice across the area. If this is correct, it would not be unexpected to find only isolated occurrences of the deposit preserved.

If it is accepted that ice moved generally from the north-east across this part of Area III, Afton Lodge is an ideal situation for the preservation of a marine deposit _in situ_ due to the protective influence of the lava ridge to the north-east which stretches from Barnweill to Clune (Fig. 4.4).

Similar deposits of silty clay have been found at two other localities in Scotland, one is near Clava, Invernesshire and the other is around Bellochantay, in Kintyre. Both these deposits were examined in great detail in the 1890's by a Committee of the British Association for the Advancement of Science which included such eminent geologists as Horne, Robertson, Jamieson, Fraser, Kendall and Bell (Rept. Brit. Adv. Sci., 1893, 1896).

The shelly clay at Clava, which was reported by the committee to be discontinuously exposed over a distance of 700 feet (213m.), and is 16 feet (4.9m.) thick in parts, bears close similarities to the shelly clay in central Ayrshire: "It is a tenacious clay or silt of blue dark grey colour, save the lowest 2 feet (0.6m.) where the tint is brownish grey ... There are slight traces of stratification in the blue clay. At a depth of 3½ feet (1.1m.) a horizontal line was observed in the deposit after exposure for several days to heavy rain, but scarcely any part of this line could be traced when a fresh surface was revealed ... The upper 12 feet (3.6m.) of blue clay is almost free from stones; those which do occur ... vary from the size of peas to 1½ inches (3.8cm.) in diameter as a rule ... Shells are found throughout the whole of the blue clay...They are most abundant at a depth of 2-3 feet (0.61-0.91)m. from the top. Many of the shells are quite whole at all depths, others are partially crushed...In the case of many of the shells the epidermis is in perfect preservation, and no indication of ice markings or abrasion could be detected on any of them...It is important to observe however, that some of the bivalves, such as Astarte, with both valves attached, showing no signs of abrasion and otherwise complete, were found with valves crushed together." (p. 486 -487).

Although the characteristics of the shelly clays in Invernesshire and central Ayrshire are similar, due to poor exposures it is not possible to suggest a stratigraphy for the central Ayrshire shelly clay which may be compared with that from Invernesshire. However, the Invernesshire shelly clay stratigraphy is well-documented (Fig. 4.15). The highest part of the shelly clay has an altitude of 503½ feet (153.4m.) and appears to be continuous for at least 190 yards (173m.) in a "well-nigh horizontal position" (p. 511). The general conclusions of the study included:-

1) "The shells (in the silty clay) are chiefly shallow water species;

Fig. 4.15 Section Showing Shelly Clay at Clava - Horne et al, 1896.

some might have lived at depths varying from I5-20 fathoms or in shallower water near the shore ... Though the fauna is not intensely Arctic, it implies colder conditions than the present" (p. 5II). However, the latter part of this conclusion seems strange because an examination of the Foraminiferas showed that ".. some of the genera found at Clava .. are .. not only 'essentially shallow-water species,' but (as seems more remarkable) to be found chiefly in 'temperate and sub-tropical seas'." (p. 509).

2) "From the assemblage of organic remains and their mode of occurrence it would appear that the deposit is a true marine silt, or, in other words, a portion of the sea-bottom. If the deposit is not in situ, then we can only suppose it must be transported in mass to its present position" (p. 5II).

3) "The direction of ice-flow in the surrounding district, .. seems to point to the conclusion that the land ice which passed over Clava did not previously cross any part of the existing sea-floor." (p. 5II-5I2).

4) "The pressure of the ice that formed the overlying 45 feet (I3.7m.) of boulder clay (till) would be sufficient to account for the crushing of certain shells .." (p. 5I2).

5) "... the Committee are strongly inclined to infer from the assemblage of organic remains and their mode of occurrence, the proved extension of the bed and its apparently undisturbed character, that the shelly clay is in situ, indicating a submergence of the land to the extent of 500 feet." (p. 5II-5I2). However, two of the Committee (Kendall and Bell) were not convinced that the shelly clay was in situ as they said: "... it is with all deference that we have not yet reached a solution of the difficulties connected with the Clava deposit" (p. 5I4).

Considering the potential importance of this deposit in terms of glacial chronology, it is somewhat surprising to discover that only one investigation has been completed at Clava since I893. This investigation was by Peacock (I975). However, what is even more surprising is that the marine shelly clay was not examined by Peacock, especially when it is considered that the aim of the study was to "throw light on the mechanism of deposition of the clay and associated deposits" (Peacock 1975, p. 31). However, on the basis of some highly debatable correlations between beds personally examined by Peacock and those described by Horne et al (1893) Peacock concluded: "New exposures near Drumore of Clava show a succession of glaciogfluvial deposits and material interpreted as flow-till. These strata overlie shelly till which apparently lies at the same horizon as the Clava marine clay. The latter is thought to be a raft enclosed in shelly till, which is interpreted as melt-out till rather than lodgement or flow-till" (p. 37). Some of Peacock's main evidence must be regarded as suspect. Peacock (1975, p. 36) stated: "Rafts of marine clay in a more or less deformed condition and of similar size to the Clava deposit occur farther east enclosed in shelly Boulder Clay of Banffshire (Read 1923; Peacock 1966, 1971)". However, Peacock himself contradicts this to a certain extent on the next page: "The Clava succession, with the exception of the presence of marine shells, is similar to others found in the area" (p. 37). Surely the shell fragments are the distinctive characteristic of the Clava deposit. The suggestion by Peacock that the Clava deposit (i.e. the shelly marine clay) is deformed shows no consideration of the observations of the British Association Committee (1893) who nowhere suggested that the clay was deformed and constantly referred to the horizontal bedding of the clay or the horizontality of sand lenses contained within the clay.

Peacock (1975, p. 36) also suggested that if the British Association Committee had known of "The occurrence of .. rafts, together with information concerning the sometimes excellent preservation of delicate fossils and structures in till" (e.g. Lampugh, 1911)" (p. 36) a different conclusion might have been reached. Two points emerge from this :-

a) The members of the British Association did know of such occurrences. Kendall in his "Additional notes and remarks" in the same paper stated: "Apart, however, from the character of the matrix and contents, the general facts connected with the locality, the uniqueness of the deposit and its limited extent are, in my judgement, strongly against the supposition of its being in place; and masses of sea-bottom, with perfectly preserved shells and microzoa, are known to have been carried by land ice considerable distances." (p. 511).

b) The paper by Lampugh (1911), and all subsequent papers on the subject, do not show that fossils and structures are delicately preserved - except when carried extremely short distances (i.e. less than one mile). Lampugh stated: "... if the operation (of rafting) had began earlier, the shells may have been carried for three or four miles (at a maximum). ... even with so short a journey, the marine material showed hardly any trace of its original order, except in some patches." (p. 234).

However, the overriding objection to Peacock's (1975) view that the marine clay at Clava is ice-rafted is "... that the land-ice ... did not previously traverse the Beauly or Moray Firths. It would appear that the ice which glaciated that portion of the Nairn valley came from the Great Glen, and from the mountains of the south-east..." (Horne et al 1893, p. 501). Recent work by Clapperton and Sugden (1977) prove that this is correct. The ice therefore was moving in the wrong direction to pick up portions of the sea bed and deposit them inland. This is another similarity with the deposit in central Ayrshire. Both deposits are situated behind ridges which are well protected from any ice movements which may have occurred subsequent to their emplacement. When it is considered that a very similar deposit to that at Clava exists at two localities (at least) in central Ayrshire, it seems that the uniqueness of the deposit is questionable. This is especially true when another high-altitude marine clay has been described on the west coast of Kintyre (Horne et al, 1896). It is considered, therefore, unwise to accept the conclusions of Peacock (1975).

The shelly clay in Kintyre is discontinuously exposed over a total length of approximately 4 miles (6.4 km.) and has a maximum thickness of 27.5 feet (8.4m.) (Fig. 4.16). As with the deposit at Clava, remarkable similarities exist between the shelly clay in Kintyre and the shelly clay in central Ayrshire: "The shelly clay (in Kintyre) is stiff, fine, bluish clay, upwards of 5 feet (1.52m.) of the deposit being laid bare. The upper portion seemed to be affected by exposure to the weather, and the darkish-blue colour was chiefly apparent in the lower part ... (it is) ... comparatively free from stones in the upper part, though here and there throughout the section well-rounded stones are met with ... the average size varies from 1 to 3 inches (2.54-7.62cm.) across ... No striations

Fig. 4.16 Section Showing Shelly Clay at Kintyre - Horne et al, 1893.

were observed on any of the stones ... shells were found in abundance ... some of the species were particularly abundant - as, for example, Turritella, Cyprina, Astarte, Leda etc... Many were in excellent preservation but others were broken and fragmentary. Some of the smallest shells ... were entire..." (p. 380-381). Although an examination of the macro-fauna showed that the species are similar to those found in offshore Kintyre today, the micro-fauna analysis showed that "Their wide southern distribution seems to suggest that their true home had not been in a glacial sea". (p. 399). Similar evidence was obtained at Clava regarding the occurrence of certain species of Foraminifera, characteristic of warm-temperate and sub-tropical seas (Rept. Brit. Adv. Sci., 1893).

Conclusions on whether or not the marine clay was in situ were deferred. However, if, as Peacock may suggest, this deposit was ice-rafted, it is difficult to explain how this could happen to a block of unconsolidated material 4 miles (6.4 km.) long. Further evidence against ice-rafting is that ice movements in this part of Kintyre are offshore (i.e. towards the south-west). The deposit is again situated behind a ridge which would be ideal for the preservation of a high-altitude pre-last glaciation/ Devensian marine clay in situ.

It is evident that striking similarities exist between the shelly clay deposits in central Ayrshire, at Clava and in Kintyre. From the detailed study of the central Ayrshire deposit and a consideration of other detailed studies at Clava and Kintyre, a number of conclusions may be made:-

1) The silty clay at Afton Lodge was deposited in a warm temperate sea which was 15-50m. deep.
2) It is evident that the traditional explnation of ice-rafting suggested by Eyles et al (1949) is untenable.
3) It is considered that the silty clay is in situ. This implies that sea-level in central Ayrshire was once approximately 115-150m. above the present level. A marine submergence of this magnitude does not correlate with any Lateglacial or Post-glacial high stand of sea-level recognised in Scotland. The probability that the silty clay is not Lateglacial or Post-glacial is also suggested by the warm temperate fossil fauna it contains. It is considered,

therefore, that the silty clay was deposited before the last (Late - Devensian) glaciation.

4) From an analysis of a curve derived from the Hypsographic Survey of Scotland for central Ayrshire, Halstead (pers. comm.) noted two distinct segments "with a clear break just above 500' (152m.) and this might provisionally be taken as a 'shoreline' to which this deposit might be related as an offshore one" (pers. comm. 8/6/1977). Based upon a similar analysis for the silty clay at Kintyre he stated: "Thus both Ayrshire and Kintyre shelly clays seem related to the same 'sea-level' ... at 470 feet (143m.)" (pers. comm. 8/6/1977).

4.8: Conclusions

Evidence from crag and tail features, "ice-moulded features", erratics and drumlins reveal a definite pattern of ice movement in Area III. However, the evidence which indicates the pattern of ice decay is poor and only allows tentative conclusions.

1) Former ice movements suggested from the study of features of glacial erosion clearly indicate a movement of ice from the north-east in the northern part of Area III. In the southern part of Area III the indication is that ice moved from the south-east, while in the central part strong evidence exists which implies a movement of ice from the east (Fig. 4.17). This is interpreted as an indication that the area was occupied by two ice-masses which had diverse origins.
2) The presence of erratics of Highland rock-types and fragments of shells in the till of the northern part of the area indicates deposition by an ice mass which probably originated in the west Highlands.
3) The presence of erratics of Southern Upland rock-types and the lack of shell fragments in the till of the southern part of the area indicates deposition by an ice-mass which probably originated in the Southern Uplands.

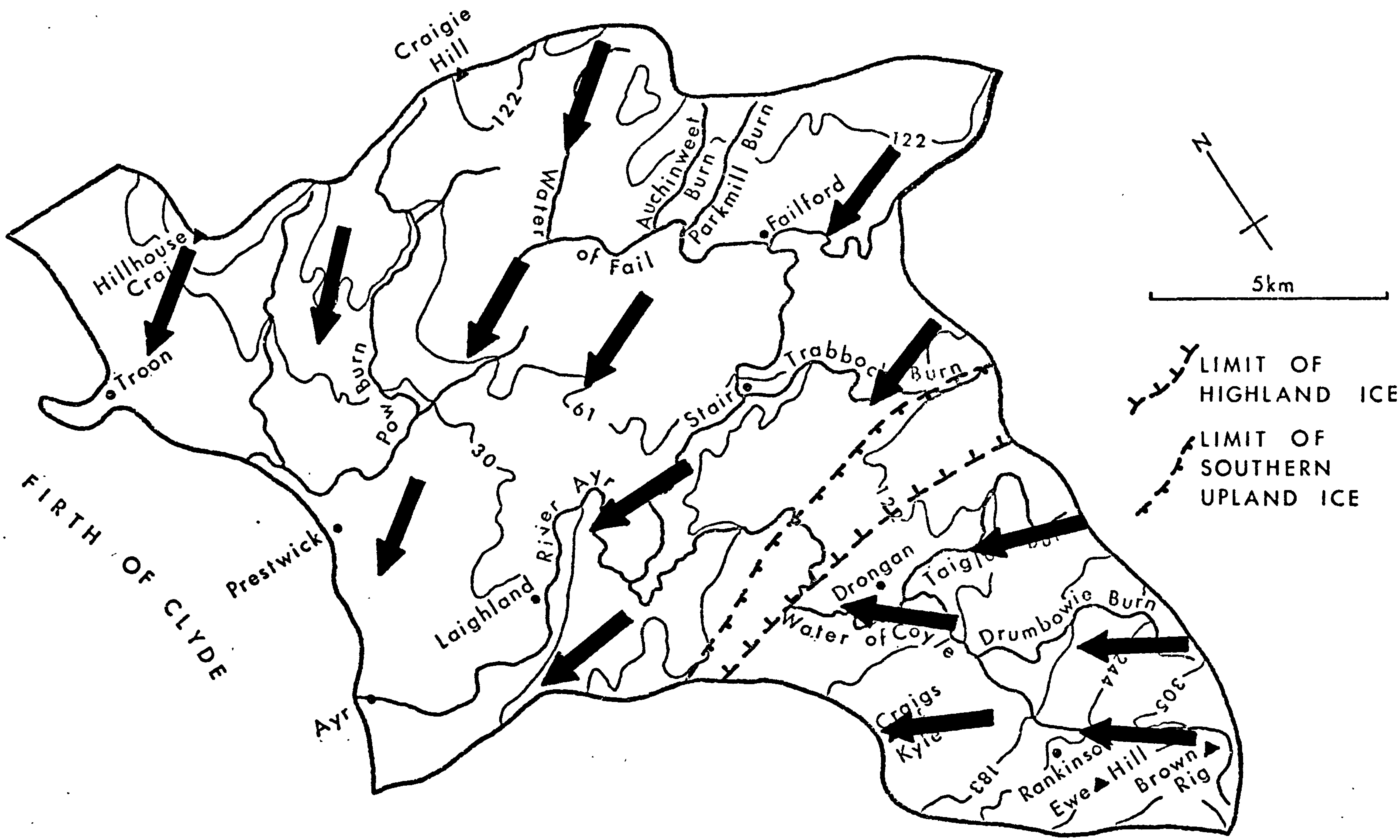


Fig. 4.17 Summary of Former Ice Movements in Area III.

4) Ice from these two sources met across a central part of Area III and flowed towards the Firth of Clyde from an easterly or east-north-easterly direction. The presence of shell fragments, Highland erratics and Southern Upland erratics in the same till shows that the boundary between the ice-masses fluctuated. This resulted in a "zone of crossing" similar to that suggested by Eyles et al (1949) across Area III that was affected by both Highland and Southern Upland ice (Fig. 4.4).

5) The small number of features produced by meltwater erosion may be explained either by their formation and subsequent obliteration or by unfavourable environmental conditions for their formation.

6) The limited extent of fluvioglacial deposits in the area indicates the existence of a 'subglacial escape route' which effected the rapid draining of meltwater from the area. This draining was so rapid that it did not allow the cutting of meltwater channels or extensive deposition of fluvioglacial material. The lower Ayr valley is the route most favoured to have performed this function. This is, therefore, a westward extension of the middle Ayr valley 'subglacial escape route' suggested in Chapters 2 and 3 to account for the lack of fluvioglacial deposits in the western parts of Area I and Area II.

7) Slowly disappearing, stagnant ice is unlikely to have been a characteristic of much of Area III during the latter stages of deglaciation.

8) A series of three raised beaches fringe the western margin of the area at altitudes of 24-26m. O.D., 10-12m. O.D. and 5-7m. O.D.. The highest raised beach is Lateglacial in age and the two lower raised beaches are of Post-glacial age.

9) Evidence exists for a pre-Devensian high stand of sea-level between 115 and 150m. O.D..

CHAPTER 5

AREA IV

5.I: Introduction: Location and Extent

Area IV which is the south-western part of central Ayrshire, has an area of approximately 320 sq. km.. Its maximum dimensions are 2I km. from east to west and IO km. from north to south (Fig. 5.I). The area is roughly triangular in shape; the southern boundary represents the straight line base and the most northerly point represents the apex of the triangle. The southern boundary is an arbitary east-west line along grid line N305. It was chosen as the southern boundary to give central Ayrshire a realistic size for study. The western limit of the area is the Firth of Clyde coast from just south of Turnberry northwards to Ayr, (this is the boundary between Area IV and Area III). The eastern boundary of the area is the watershed between Doon/Girvan drainage system (Area IV)and the other drainage systems which are juxtaposed - the Lugar Drainage system (Area II), the lower Ayr Drainage system (Area III) and the Nith Drainage system (Area V) (Fig. 5.I).

Area IV contains evidence of glacial erosion, glacial deposition, fluvioglacial erosion, fluvioglacial deposition and higher stands of sea-level. The scale and mode of presentation of these features vary according to their size and distribution.

5.2: Relief and Drainage

From its highest altitude at Benbrack (494m.) in the extreme south-eastern part down to sea-level along the western margin, Area IV displays a variety of relief forms. These differences in form are closely associated with the differences in geological characteristics, which in turn, are a reflection of rock-type and/or structure.

The south-eastern part of the area contains the summits with the highest altitudes (Fig. 5.2). This part, which is dissected by the steep-sided, flat floored valley of the River Doon, has a generally subdued,

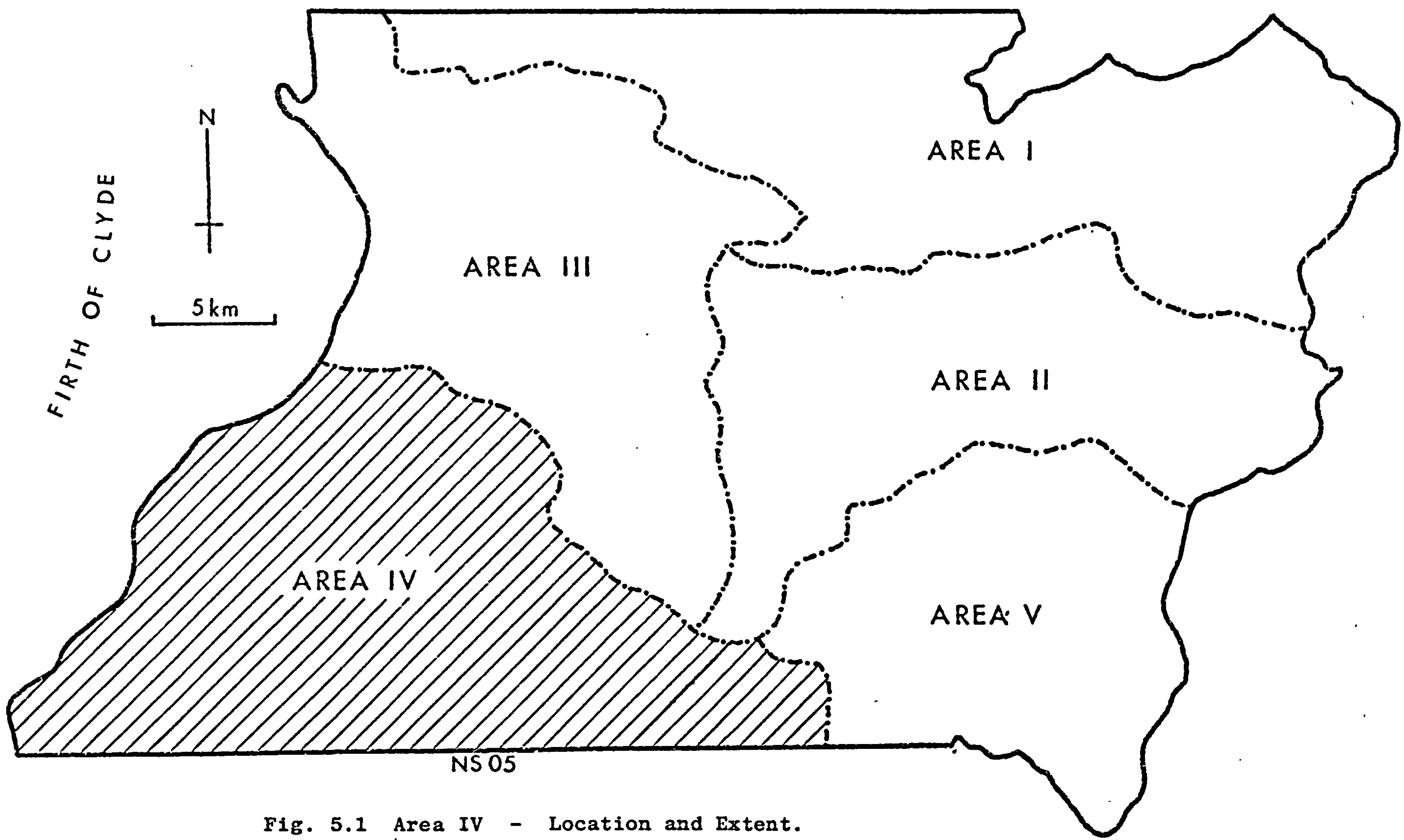


Fig. 5.1 Area IV - Location and Extent.

very gently undulating morphology which is a relection of the nearly horizontal bedding of the underlying Carboniferous shales and sandstones. The high altitude is a reflection of the intrusions of resistant kylite and teshenite sills into the country rock. This is a continuation of similar relief areas described in the southern parts of Areas II and III. Volcanic vents are also an important element in the relief of Area IV as they support some of the highest points in the area, such as Green Hill (307m.) (Fig. 5.2). However, most of the highest points relate to the horizontal igneous intrusions - Benbeoch (464m.), Benquhat Hill (435m.), Kilmein Hill (429m.) and Turgeny (355m.) (Fig. 5.2). The highest peak in Area IV, Benbrack (494m.), which lies 4 km. east of Dalmellington, is in a geological sense, peculiar because it has an Ordovician greywacke foundation which is found nowhere else in Area IV except in the extreme south-eastern corner (Fig. 5.3). This rock-type is brought to the surface because it lies on the upthrust side of the Southern Upland fault.

Upland masses also exist in the western part of Area IV; Brown Carrick Hill (287m.) is the most striking example (Fig. 5.2). This expanse of high ground has a solid foundation of resistant, almost horizontally bedded, basaltic lavas. This structural control has produced a distinctive "stepped" relief in the landscape. Parts of the area which exceed an altitude of I50m. also exist south of Brown Carrick Hill in the vicinity of Mochrum Hill (27Im.) and Craigdow Hill (252m.) (Fig. 5.2). Mochrum Hill owes its origin to a volcanic neck and associated resistant rock-types; (it is, in fact, a crag and tail feature). The high ground around Craigdow Hill is due to the presence of resistant Old Red Sandstone age rocks which have been made more resistant by the intrusion of igneous rocks. The general orientation of these two areas of higher ground is north-east to south-west (Fig. 5.2). This is a reflection of the 'Caledonian' structural control exerted by the proximity of the north-east to south-west orientated Southern Uplands fault.

Much of Area IV lies below an altitude of I50m. O.D. and the display of relief forms is typical of the "Ayrshire Plain", gently undulating with relative relief values rarely esceeding 75m.. There is a corridor of low ground (i.e. below 75m. O.D.) which is centrally situated within the area and runs north-south (Fig. 5.2). This low-lying corridor of

Fig. 5.2 Area IV - Relief and Drainage.

Fig. 5.3 Area IV - Geology.

land contains part of the River Doon, part of the Water of Girvan and the town of Maybole. This, in effect, separates the high ground in the east from the high ground in the west.

In the extreme northern and southern seaward margins around Turnberry and Ayr, there are large, relatively flat expanses of raised beaches (Fig. 5.2). These features extend inland for a maximum distance of 2 km. and terminate at approximately 30m. above O.D..

The drainage pattern in this area has three basic components:-

I) River Doon.

2) Water of Girvan.

3) Isolated drainage by small streams which discharge directly into the Firth of Clyde (Fig. 5.2).

The River Doon dominates the drainage in Area IV (Fig. 5.2). It has a very restricted catchment on either side of the main stream, especially in its upper course, compared to other rivers in central Ayrshire. This may be explained by its occupation of an over-deepened, steep-sided glacial trough because beyond the lower limit of the trough, near Patna, the river system displays a more normal dendritic pattern (Fig. 5.2).

Only a short distance of the total length of the Water of Girvan flows through Area IV, but its tributaries are well represented (Fig. 5.2). Although it is of limited extent, the general pattern of drainage is dendritic. One characteristic of the Water of Girvan is that it quite abruptly turns through 90° just south of Kirkmichael (Fig. 5.2). The Water of Girvan, therefore, enters the area flowing from the south-east and leaves the area flowing from the north-east.

The isolated drainage on the western side of Brown Carrick Hill, which flows directly into the Firth of Clyde, is not of major significance in relation to the area as a whole.

Area IV has therefore three distinct parts on the basis of relief:-

I) the eastern high ground

2) the western high ground

3) the north to south orientated corridor of low ground which separates I) and 2).

The summits, which are higher in the south-eastern part of the area, generally decrease in altitude towards the north-west. The major differences in relief forms reflect differences in rock-type and/or geological structure across the area.

5.3: Glacial Erosion

Area IV contains 2I striations, one roche moutonée, 5 crag and tail features, 8 "ice-moulded features" and a glaciated valley all of which have been produced by glacial erosion. The detailed study of these features is often most helpful when any attempt is made to determine former ice movements in an area.

Twenty-one striations have been found in Area IV and these are mainly confined to the bare rock surfaces which exist at higher altitudes (Fig. 5.4). The striations have a variety of orientations. In the south-western part of the area there are 5 striations all of which have a generally east to west orientation. Brown Carrick Hill in the north-western part of the area has a concentration of I3 striations eroded into it; 6 are orientated in a north-east to south-west direction and 7 are orientated in a north-west to south-east direction. The three remaining striations are situated in the south-eastern part of the area and are orientated in a north-west to south-easterly direction. Although the striations are clustered in 3 separate parts of Area IV, the regularity of orientation within the clusters indicates the general movement of ice in that particular part of the area. If this is correct, the ice in the south-western part of Area IV moved from either the east or west; the ice in the south-eastern part moved from either the south-east or north-west and the ice in the north-western part of the area moved from either the north-west, north-east, south-east or south-west. Consideration of other features of glacial erosion may clarify the situation regarding the actual direction of former ice movements in the area.

Reliable evidence relating to the former movements of ice may be obtained from the study of the 5 crag and tail features in the area (Fig. 5.4). All of them have the distinctive form of a short, steep, smooth side and a long, gently sloping, smooth side. They are all crag and tail features in sensu stricto with the steep-sided parts (the 'crags') representing old volcanic vents and the gently sloping parts (the 'tails') representing the surrounding country rock.

Four of the five crag and tail features are situated in the south-eastern part of the area on the interfluve between the River Door and the Water of Girvan (Fig. 5.4). These four are Patna Hill, Carclout Hill, Chapel Hill and Green Hill; they all have semi-circular 'crags' which are 35m. high at a maximum and face towards the south-east (Plates 5A, 5B). The smooth 'tails', which have a maximum length of I km., slope gently towards the north-west. This evidence strongly suggests that the ice which eroded these features moved from a south-easterly direction. If this hypothesis is accepted, it suggests that the north-west to south-east orientated striations that are found in this part of Area IV were probably formed by ice which moved from a south-easterly direction.

Mochrum Hill, which is situated in the south-western part of the area, is the remaining crag and tail feature. It is the finest example of a crag and tail anywhere in central Ayrshire (Fig. 5.4, Plates 5C, 5D). The 'crag' part of the feature is 600m. in diameter and rises 80m. above the surrounding land. It faces towards the east-north-east. The 'tail' of the feature gently slopes for over I½ km. towards the west-south-west. The direction of ice movement indicated from this study is from the east-north-east. The generally east to west orientated striations in this part of Area IV may also be explained by this movement of ice from the east-north-east.

Other evidence of former movements of ice in Area IV may be derived from the examination of ice-moulded forms which have a similar morphology to crag and tail features but dissimilar geological characteristics; they are usually eroded into homogenious rock-types. These features in Area IV are eroded into resistant intrusive igneous rocks and they are generally confined to the highest altitudes.

Eight ice-moulded forms are situated in the south-eastern part of the area (Fig. 5.4). The largest of these is Benbeoch which is 250m. in diameter and 65m. high (Plates 5E, 5F). From its short, steep-sided end to the extremity of its long, gently sloping end, it has a total length of 700m.. The steep-sided end of this feature faces towards the south-east. This characteristic is common to the other four ice-moulded forms in this part of Area IV - Benbraniachan, Knockannot, White Hill and Dalnean Hill (Fig. 5.4; Plate 5F). The indication of former ice movements in this part of the area from the study of these features is that ice moved from

Plate 5A   Crag and Tail at Patna Hill

Plate 5B   Crag and Tail at Green Hill

Mounted incorrectly!

Plates 5C, 5D   Crag and Tail at Mochrum Hill

Plate 5E Ice-Moulded Form at Benbeoch

Plate 5F Ice-Moulded Forms at Benbeoch and Benbraniachan the south-east. This corresponds with ice movements suggested for this part of Area IV from the study of crag and tail forms.

In the south-western part of the area there are two other ice-moulded forms (Fig. 5.4). These have an almost east to west orientation and they both have the steep-sided end facing towards the east (Fig. 5.4). The former ice movement indicated from the study of these forms is from east to west. Again this corresponds with evidence of ice movements obtained from the study of other glacially eroded features in this part of Area IV.

Dunduff Hill is the remaining ice-moulded form to be examined in Area IV (Fig. 5.4). It is situated on the western side of Brown Carrick Hill and is elongated in a north-east to south-west direction (Fig. 5.4). The steep-sided end faces towards the north-east, which suggests a movement of ice from the north-east. This direction of ice movement also explains the orientation of approximately half the striations found in this part of the area.

The form of the valley of the River Doon between Patna and the southern edge of the area displays all the characteristics of a glaciated trough (Fig. 5.4). This section of the valley, which is IO km. long, has very steep sides which rise upto 200m. above the broad, flat valley bottom which is over I km. wide in places. Borehole records show that the flat nature of the valley floor is due to infilling with alluvial sediments. The maximum thickness of these alluvial sediments is consistently around 4Im. and when a cross-section to rock-head is plotted, based upon evidence from borehole records, the valley is seen to be U-shaped (Fig. 5.5). Borehole records show that the long-profile (rock-head) is irregular (Fig. 5.6). This is a common characteristic of glaciated valleys (Price I973, p. 53). The implication of this evidence is clear; the Doon valley was a major routeway for ice which moved from south-east to north-west. The lack of corries in Area IV suggests that the main ice accumulation areas lay to the south-east in the Southern Uplands, and in this case the Loch Doon Basin.

A single roche moutonée exists approximately 3 km. east of Kirkmichael (Fig. 5.4). This feature is elongated in an east-north-east to west-south-west direction. It consists of a 20m. long, smooth side which gently slopes towards the east-north-east. The jagged, plucked, steep side of the feature faces towards the west-south-west. Although this is an

Fig. 5.5 Rockhead Cross-section of the Doon Valley near Patna.

Fig. 5.6 Rockhead Long-profile of the Doon Valley between Dalmellington and Patna.

isolated feature, it is regarded as strong evidence for a movement of ice from the east-north-east. This ice would have smoothed the rock outcrop which lay in its path on one side (the one facing it) and plucked it on the lee side. This again corresponds with the general pattern of former ice movements deduced from the study of glacially eroded forms.

Two glacially-breached cols have been identified in the extreme south-eastern part of the area. Although they are of little use in determining former ice movements in an area, they do indicate a minimum altitude to which ice reached. In this case it was 475m. O.D.. However, the streamlined nature of the summits in Area IV suggests that ice once covered the whole landscape.

The pattern of ice movement in Area IV was complicated. Strong evidence exists in the south-eastern part of the area to suggest that ice moved from a generally south-easterly direction. However, towards the south-western part, the evidence for a movement from the east, or even the north-east, is equally strong. In the north-western part of Area IV two diverse movements of ice are indicated, one from the north-east and one from the south-east. Features of glacial erosion are absent from the north-eastern part of the area and therefore no suggestion of former ice movements may be made.

It is highly likely that the ice which affected the southern part of Area IV originated in the Southern Uplands. This ice was deflected by Highland ice from its original direction of movement from the south-east and was forced to move from the east in the south-central part, and from the north-east in the south-western part of the area. This Highland ice was a continuation of the flow from the north-east which affected much of Area III. However, the striations orientated from south-east to north-west on Brown Carrick Hill may indicate that this part of Area IV was affected by Southern Upland ice as well as Highland ice. This would have produced a "zone of crossing" similar to that established in Area II and Area III. The scrutiny of other glacial and fluvioglacial features may help to clarify the complex pattern of ice movements in Area IV.

5.4: Glacial Deposition

Approximately 70% of the surface of Area IV is till (Fig. 5.4). Although these deposits are widespread throughout the area, they are noticably absent from certain parts. For instance, till gives way to solid rock as the surface material at higher altitudes on the flanks of the Doon valley (Fig. 5.4). Brown Carrick Hill is another area where solid rock outcrops as the surface material (Fig. 5.4). Solic rock also outcrops near the southern margin of the area around Craigdow Hill and in numerous localities where volcanic plugs stand erect over the gently undulating landscape.

The distribution of till as a surface material is also affected by fluvioglacial sands and gravels, raised beach sands and gravels, wind blown sands and alluvium (Fig. 5.4). Peat is not widespread in Area IV. An extensive spread of morainicmaterial exists in the vicinity of Maybole, which is closely associated with spreads of fluvioglacial sands and gravels and alluvium. Large areas of raised beach materials and wind-blown deposits are present on the western margin of Area IV between Ayr and Brown Carrick Hill and between Glasson Rock and Turnberry (Fig. 5.4).

Examination of borehole records shows that the maximum thickness of till is around 30m. and, as would be expected, corresponds with low-lying land and valley bottoms.

Till colours vary considerably in Area IV; it can be red, brown, blue or grey. It is common in areas of glacial deposition for the colour of the till to relect the colour of the bedrock on which it lies. The matrix of the till also varies according to the texture of the underlying bedrock. Although till characteristics vary throughout the area, exposures and borehole records show that only one unit exists in Area IV. Till (which is a sedimentological term (Price 1973, p. 64, Sugden and John, 1976, p. 214)) is replaced, however, at the surface by a large morainic spread around Maybole (Fig. 5.4). This distinction, therefore, between till and moraine is based entirely on morphological characteristics; this is not a difficult exercise in practice.

Due to the lack of good exposures, the examination of the characteristics of the till in Area IV is often cursory. The colour and texture of the till is examined and the presence or absence of Highland erratics, Southern Upland erratics and shell fragments established. In only one instance could more detailed analyses be completed.

Only the exposures of till in the extreme south-eastern part of the area, east of Dalmellington, are extensive enough to allow a detailed analysis. Of these exposures, the one selected for examination is in the valley of the Linn Burn (Fig. 5.4; Site 5h). The exposure is a 7m. thickness of grey, stiff, coarse-textured till. From a preferred-stone orientation a mean stone orientation of I9I° was calculated (Table 5A; Figs 5.4, 5.7). A chi-square value of II.93 was calculated for this which, when tabulated with 8 degrees of freedom, is not statistically significant at any level of confidence. A dip-strength value of I.28 was calculated from these data which, when tabulated with one degree of freedom, is also not statistically significant at any level of confidence. No reliable indication of the movement of the ice which deposited this till can be made based upon this fabric analysis.

A scrutiny of the rock-type of the erratics in the till was completed on the basis that the results would indicate the origin, and therefore former movement, of the ice by which it was deposited. This shows that 34% of the erratics are of the local Old Red Sandstone and Carboniferous age rock-types. The lithologies are the same as those which form the geological foundation at this point. The remaining 66% of the erratics are all of Southern Upland rock-types (I2% of these are Loch Doon granites). The indication from this evidence is that the ice which deposited this till originated in the Southern Uplands, and, from the abundance of Loch Doon granite erratics, the ice probably moved from a generally southern direction.

Samples of till have been obtained from two sites in Area IV (Sites 5e and 5g, Fig. 5.4) and these were wet sieved in the laboratory (see Appendix 1) in order to reveal the relative grain-size of the material and the relative percentages of the different rock-types of the erratics. The exposures from which the samples have been obtained are small and unsuitable for preferred-stone orientation analyses. However, the results of the mechanical analysis of the tills are of considerable value in interpreting their origin, and hence the probable direction of movement, of the ice which deposited them (Embleton and King, I975, p. 377).

Site 5f lies 3 km. to the east of Waterside and is situated in the

TABLE 5A

Till characteristics in Area IV

	Straiton Site 5e	Dunaskin Burn Site 5g	Linn Burn Site 5h
Mean stone orientation			191°
Chi square			11.93
Dip strength			1.28
% Gravel	34	30	
% Sand	34	52	
% Silt/Clay	32	18	
% Local rocks	54	62	34
% Highland rocks	0	0	66
% Southern Upland rocks	46	38	0
% Unidentifiable rocks	0	0	0
Shell fragments	No	No	No

TILL FABRICS FROM AREA IV

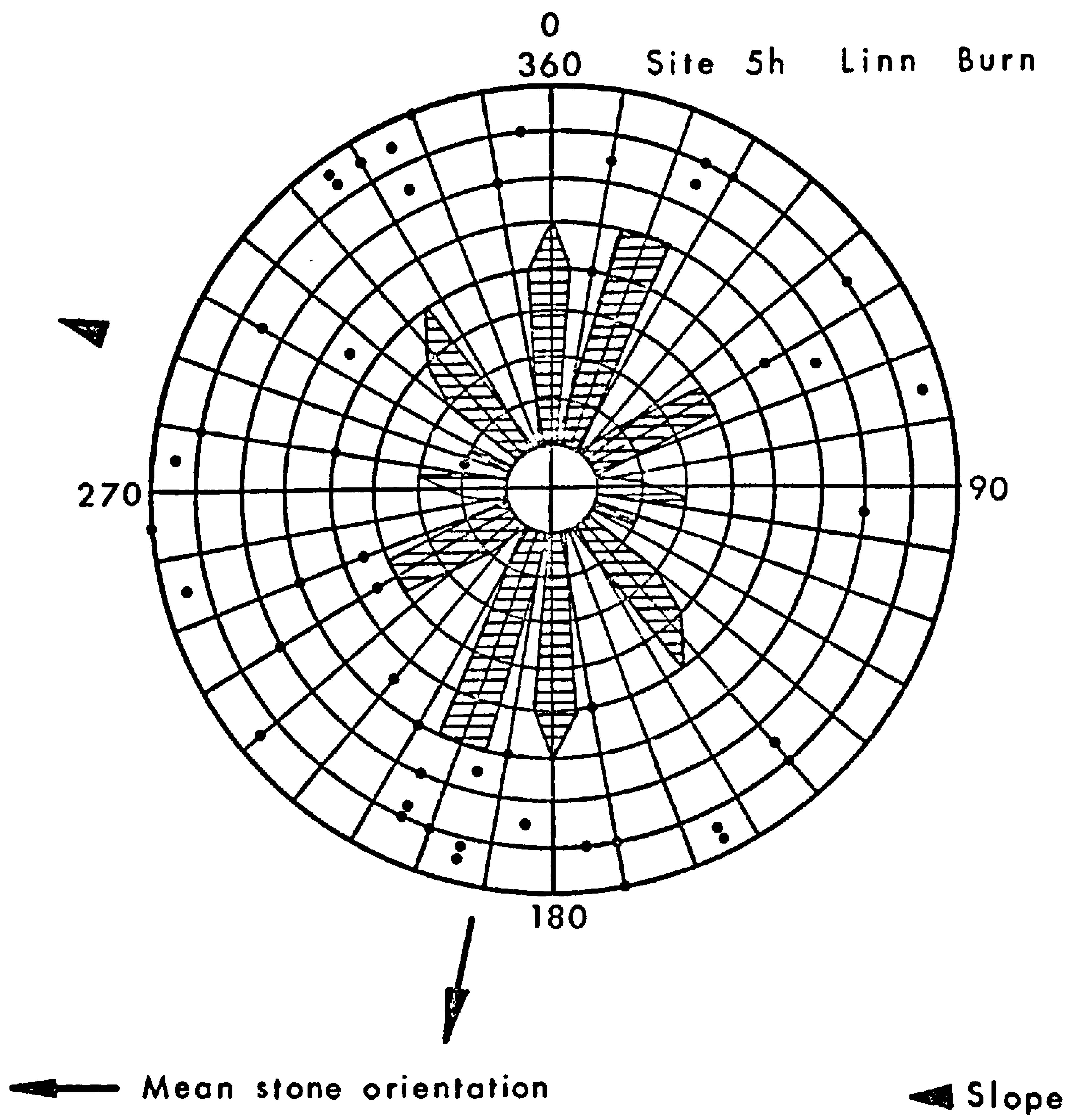


FIG. 5·7

valley of the Dunaskin Burn (Fig. 5.4). The exposure is only 3m. high and is composed entirely of dark grey sandy/gritty till. A particle-size analysis shows that the relative proportions of gravel, sand and silt/clay are 30%, 52% and 18% respectively (Table 5A). The proportion of gravel is approximately 10% higher than in the typical "central Ayrshire" tills which have already been examined (Ch. 2, 3, 4). A count of the rock-type of 50 erratics taken at random shows that the till contains 62% of local derivation and 38% of Southern Upland derivation (Table 5A). This is strong evidence that the ice which deposited this till originated in the Southern Uplands and therefore moved from a generally southern direction.

The second site from which a sample of till has been obtained for mechanical analysis is at the southern extremity of the area near Straiton, which is 6 km. south-east of Kirkmichael (Fig. 5.4, Site 5e). The exposure here is badly slumped but it is clear that it is entirely composed of brown, gritty till. Laboratory analysis shows that the relative proportions of gravel, sand and silt/clay are 34%, 34% and 32% respectively (Table 5A). An examination of the rock-type of the erratics contained within this till shows that 54% are of local sandstones and shales and 46% are of Southern Upland rock-types. The evidence, therefore, strongly suggests that it was deposited by ice which originated in the Southern Uplands. Its direction of movement, therefore, was probably from the south or the south-east.

The large difference in the relative proportions of gravel, sand and silt/clay (especially the gravel content) between these two Southern Upland till sites and the Highland till sites examined in Areas I, II and III is striking. This may be an indication that the origin of the ice mass which deposited any till in central Ayrshire can be determined from an examination of its relative grain-size; (for instance, a high gravel content may be characteristic of a till which was deposited by ice which had a Southern Upland origin).

A cursory examination of all other exposures of till in Area IV concentrates on establishing the presence or absence of either Highland erratics and shell fragments or Southern Upland erratics. The till exposures which contain Highland erratics and shell fragments are restricted to the northern part of the area (Fig. 5.4). The lack of these characteristics and the abundance of Southern Upland erratics in till exposures is confined to the southern part of the area. However, between these two extremes, till exposures contain both sets of characteristics - Highland erratics and shell fragments and Southern Upland erratics. This indicates that the northern part of the area was occupied by Highland ice only and that the southern part was occupied by Southern Upland ice only. The zone between these extremes was occupied by both Highland and Southern Upland ice. Because many exposures of till in this "zone of crossing" become lighter in colour and coarser towards the top, it is considered most likely that Southern Upland ice advanced over an area which had previously been occupied by Highland ice. There is no evidence for a break in deposition in Area IV. The maximum limits of the two ice masses are shown in Fig. 5.4.

The till deposits in Area IV display streamlined rounded hills which are interpreted as drumlins (Plates 5G, 5H, 5I). Approximately 75 drumlins have been mapped and they show a wide variety of shapes and sizes (Fig. 5.4). The shapes vary from almost round (i.e. a length : breadth ratio of I:I) to very elongated (i.e. a length : breadth ratio of 4:I). The lengths of these features vary from 200m. to over I500m. (Fig. 5.4).

The orientations of the long axes of the drumlins vary from one part of the area to another. This is assumed to represent the former movements of ice in the area under which these features were produced (Gravenor, I953). In the north-eastern part of the area the drumlins are generally orientated in a north-east to south-west direction. In the southern part of Area IV, the long axes of the drumlins have a generally east-north-east to west-south-west orientation. In the extreme south-eastern part, the orientation is in a generally east-south-east to west-north-west direction, and in the south-central part, the orientation is generally east to west (Fig. 5.4). A study of the shape of drumlins in Area IV shows eight times as many have their widest parts towards the east rather than towards the west; (the actual ratio is I6:2). The study of the position of the highest point along the crest shows almost ten times as many are in the eastern sector rather than the western sector (the actual ratio is 29:3). This is interpreted as clear evidence that the ice which moulded the north-east

Plates 5G, 5H, 5I   Typical Drumlin landscape of Area IV to south-west orientated drumlins moved from the north-east; the ice which moulded the east to west orientated drumlins moved from the east and the ice which moulded the east-south-east to west-north-west orientated drumlins moved from the east-south-east. This pattern of ice movements reflected by the drumlin evidence mirrors that indicated by other evidence of ice movements in Area IV.

The gently undulating morphology of the till deposits in Area IV is abruptly punctuated around the town of Maybole by a series of irregular, steep-sided, sharp-crested mounds which are, in places, separated by broad flat alluvial spreads (Figs. 5.4, 5.8, 5.9; Plates 5J, 5K, 5L). This moundy/hummocky relief covers approximately I3 sq. km. of the total area of Area IV.

The outline of this expanse is irregular but it has a slight elongation from north-east to south-west. This elongation probably relates to the north-east to south-west orientation of the low ground between the Southern Uplands and Brown Carrick Hill in which it is situated. The outer edges, in many places, merge almost imperceptibly into the undulating relief which is characteristic of the surrounding area.

These mounds, some of which are elongated, vary in size upto a maximum diameter/length of 500m. and height of I5m. (Figs. 5.4, 5.8, 5.9; Plates 5J, 5K, 5L). Detailed mapping, both on the ground and from the study of air photographs, (the results of which are shown in Fig. 5.4) shows that no alignment exists with regard to altitude or orientation. The pattern of mounds is, in effect, nondescript. The altitudinal range of this spread is from 60m. O.D. at its eastern extremity to a maximum of I50m. near its western extremity. Borehole records show that the average thickness of the coarse, dirty sub-angular material which makes up these mounds is consistently around I2m.. The west to east slope of these deposits, therefore, is a reflection of the underlying relief. The general situation of this expanse of uneven morphology is interesting as it is sandwiched between the high ground to the east (the foothills of the Southern Uplands) and the high ground to the west (Brown Carrick Hill) (Fig. 5.4).

Though exposures are rare in these irregular steep-sided mounds, occasional 'sheep lies' or excavated pits always reveal a brown, angular,

Fig. 5.8 Moraine around Maybole.

Fig. 5.9 Moraine around Maybole.

Plate 5J   Moraine and associated Alluvial Spreads near Maybole

Plate 5K Morainic Landscape typical of the Maybole area

Plate 5L Morainic Landscape typical of the Maybole area poorly sorted, unstratified, sub-angular gravel which is weathered to a considerable degree. Examination of the rock-types contained within this shows them to be entirely of local derivation.

An exposure in this material was described by Eyles et al (1949, p. 132-133) from Ballochneill Quarry (Fig. 5.4, Site 5a). It is now completely grassed over and is therefore not available for scrutiny.

Site 5a	Ballochneill Quarry	Fig. 5.4	83m. O.D.
2	Sandy matrix charged with angular boulders of local sandstone. Wisps of sand and gravel dispersed throughout its mass. 2m. thick.		
1	Tenacious dark brown boulder clay (till) with well-striated boulders of sandstone, greywackes and granites of the Loch Doon mass. 4m. thick.		

This description is interpreted as representing a Southern Upland till which is overlain by an angular deposit of local derivation. Boreholes are rare because the geological foundation around Maybole is older than Carboniferous age. However, those that have been recorded do not show this dichotomy in the drift recognised by Eyles et al.

A few exposures exist in areas which are closely associated with this irregular spread. In these adjacent areas, the relief is more subdued and includes distinctive fluvioglacial forms. The exposures always reveal well-bedded, poorly-sorted sands and gravels which are contorted and greatly faulted. This results in a great diversity in the characteristics of the sands and gravels both laterally and vertically (Fig. 5.4; Plates 5M, 5N). This material is typical of that which is deposited in a high-energy fluvioglacial environment.

The description of this hummocky relief, with its associated fluvioglacial forms, bears a close similarity to moraine spreads described by Hoppe (1952), Gravenor and Kupsch (1959), Sissons (1967b) and Sugden and John (1976). The most enlightening and detailed of these works is the classic paper by Gravenor and Kupsch (1959) who worked in western Canada. Note the striking similarity between the terrain around Maybole and the terrain they describe: "Broad tracts of rough morainal topography are common features over much of the western plains (of Canada). Many of these areas are irregular in outline and show no pronounced elongation.

Plate 5M Exposure in the Esker near Chapelton

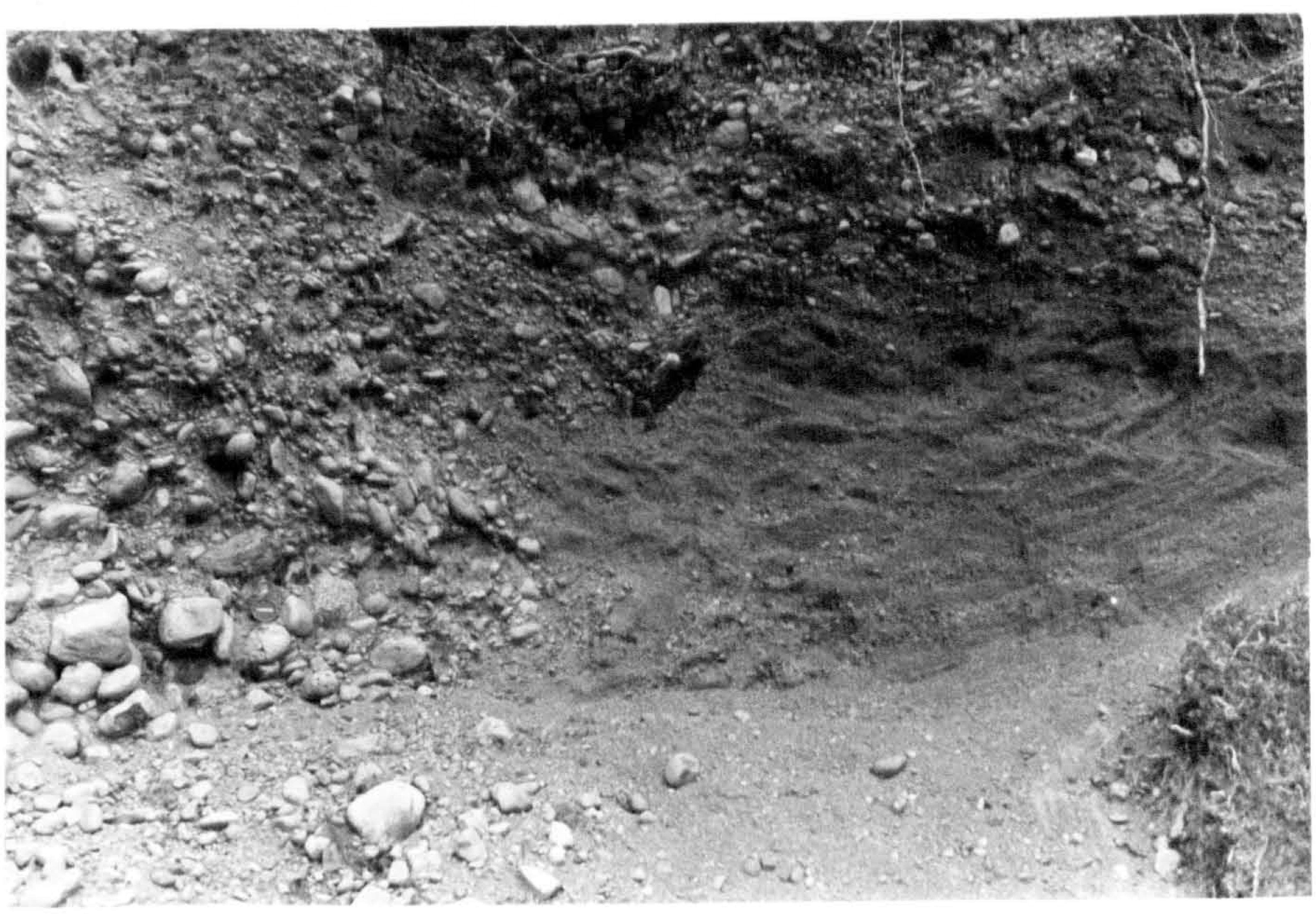


Plate 5N Fluvioglacial Deposits of the Esker near Chapelton

They consist of a nondescript jumble of knolls and mounds of glacial debris... (which) do not allign into ridges and no dominant trends are discernable." (p. 50). Sugden and John (1976) complete the description: "In the midst of the morainic mass there may be recognisable fluvioglacial features such as eskers or kames" (p. 255). Referring to such an expanse of mounds as a hummocky disintegration moraine, Gravenor and Kupsch continue their description: "The hummocky disintegration moraine has a generally rounded outline, its borders are generally indistinct, and they may grade almost imperceptibly into the surrounding low-relief ground moraine" (p. 51). On the same page, a general reference to the likely origin of such a landscape is made: "If no trends, such as aligned knobs or hollows are apparent.. and if the moraine itself is not long and narrow but round and broad the moraine is regarded as deposited by stagnant ice." The precise mode of origin of these hummocks is described in detail by Gravenor and Kupsch (1959); briefly, "... (these mounds are) formed late in the existence of the (ice sheet). The features resulted from the letting down of till due to ablation, from the squeezing up of till into openings at the base of the ice, or from a combination of both causes." (p. 56) (Fig. 5.10). Other workers have agreed with these fundamental concepts (Boulton 1967, Price 1973).

The formation of these "uncontrolled disintegration features" (Gravenor and Kupsch, 1959, p. 50) in association with stagnant ice is a particularly attractive explanation for the forms around Maybole, due to its low-lying situation. This part of Area IV, which is sandwiched between the Southern Uplands to the south-east and Brown Carrick Hill to the north-west, would have been ideal for ice to become stranded in a climatological 'dead' state. The processes described by Gravenor and Kupsch (1959); Hoppe (1952, 1957, 1959); Boulton (1967) and Price (1973) would then have produced the hummocky landscape which characterises this part of Area IV. The fluvioglacial deposits and alluvial spreads in close proximity to the morainic spread probably represent associated meltwater activity within the dead-ice mass similar to that described by Gravenor and Kupsch (1959).

Glacial deposition is widespread in Area IV. Two distinct till units are present in the area but their stratigraphical relationship is not clearly seen. One of the till units is brown, sandy and contains erratics

Fig. 5.10 Formation of Moraine - Gravenor and Kupsch, 1959.

of Highland rocks and shell fragments. This till, which is confined to the northern part of the area, is of Highland origin as is also suggested by the orientation of drumlins which are composed of it. The other till unit is grey, gritty and highly charged with greywackes and Loch Doon granites. This till, which is confined to the southern part of the area, is of Southern Upland origin. These two ice masses moved from different directions to occupy Area IV; the Highland ice moved from the north-east and the Southern Upland ice moved from the south-east. They merged and the contact between them fluctuated which resulted in a 'zone of crossing' which has been affected by both Highland and Southern Upland ice. The meeting of these two ice-masses caused a deflection in ice movements in the western and southern parts of the area. The maximum extensions of the respective ice masses, and therefore the extent of the 'zone of crossing' are shown in Fig. 5.4.

A large morainic spread in the vicinity of Maybole, which lies well within the part of Area IV affected by Southern Upland ice, formed when ice was cut off from its source and the resultant stagnant ice-mass decayed in situ to produce 'uncontrolled disintegration features'(Gravenor and Kupsch, 1959).

5.5: Fluvioglacial Erosion

Few landforms in Area IV may be explained solely by the effects of the erosive capacity of meltwater. Only twelve meltwater channels have been identified and most of these are short and/or poorly developed. All but two of them are contained within a narrow zone of Area IV which is orientated in a south-west to north-east direction and stretches from Turnberry to Bargenock (Fig. 5.4). The identification of these features is based upon relationships to the present drainage pattern (i.e. a small stream in comparison to the size of valley, or its total dryness), rather than upon an abundance of the characteristic features usually associated with meltwater channels, such as humped profiles, steep sides and broad, flat floors.

The poorly developed nature of many of these channels is a reflection of the material into which they were eroded; most were cut into till. However, four of the channels are large, well-developed and eroded into solid rock.

Channel I, which is the most northerly in the area, has one of the most characteristic meltwater channel forms. This 700m. long feature has steep sides upto I5m. high and a broad, flat floor which in places is IOm. wide. The channel slopes from south to north and is at present occupied by a stream which is tiny in relation to the size of the channel. Within I50m. of the lowest point of the channel is an elongated ridge of sand and gravel which is orientated in a generally south to north direction. This meltwater channel, therefore, has a depositional equivalent in very close proximity to its terminus. From this evidence, it is highly likely that channel I was eroded subglacially and that the meltwater that eroded it flowed from south to north. This may indicate a south - to north gradient of the ice which occupied this part of Area IV.

Large channels eroded into solid rock are also located to the south of Dalrymple (Fig. 5.4; Channel system 4). Although these features do not possess classic meltwater channel characteristics, they are interpreted as such because of their size, their relationship to present day drainage patterns and their relationship to nearby fluvioglacial deposits. The three individual channels, which collectively comprise channel system 4, all have gradients which slope towards the north east. Distinctive steep-sides and flat floors may be masked to some extent by the thick cover of till which is a characteristic of this part of Area IV. The most easterly and westerly channels are over I km. long and the central unit of this system is only 500m. long. The westernmost channel leads onto the extensively developed flood plain of the River Doon. The central and eastern channels terminate at the uppermost points of elongated ridges of sand and gravel which share the same south-west to north-east orientation. They also share the same direction of slope. These channels strongly indicate that the meltwater by which they were eroded flowed from the south-west. This may suggest a generally south to north gradient of ice which occupied this part of Area IV.

A similar, though smaller, channel is located 3 km. to the north-east of channel system 4. Channel 2 is 600m. long with a relatively smooth cross-section that is characteristic of channel system 4 which was eroded into solid rock and was probably covered by till (Fig. 5.4). The channel, which contains a very small stream in relation to its size, slopes from north-east to south-west. At the lower end of this feature, there is the uppermost point of a ridge of sand and gravel which winds down the hill-side towards the River Doon. It is considered that this ridge represents the depositional equivalent of the meltwater channel. The meltwater probably flowed from a north-easterly direction which is against the general pattern in this part of Area IV.

The form of the channels which make up channel system 3, 3 km. north-north-east of Maybole, suggests that they were eroded into solid rock. However, a lack of exposures forbids a firm conclusion to be drawn. Each of the four channels which make up this system is steep-sided with a broad, flat floor, the maximum dimensions of which are I2m. and 8m. respectively. All the channels have gradients which slope from south-west to north-east, although the northernmost feature curves around to discharge towards the south-east from a south-westerly intake (Fig. 5.4). The two most easterly channels in this system are closely related to sand and gravel deposits near their lowest points. Again this is assumed to represent the depositional phase of meltwater activity which is related to the erosional phase which produced the channels. If this is correct, it is likely that the channels were eroded subglacially. It is of little doubt that the meltwater which eroded all four channels in channel system 3 flowed from a generally south-western direction.

All other channels in Area IV are short, poorly developed and often isolated (Fig. 5.4). They are therefore of little use in elucidating former directions of meltwater (and hence ice) movements on anything but a very localised scale. However, most of these channels, which are eroded into till, slope from a generally south to north direction. This may be an indication of either the Southern Upland origin of the ice which affected much of Area IV or a series of individual localised meltwater movements.

Features of meltwater erosion in Area IV are not sufficiently well-developed or extensive to allow anything but tenuous conclusions to be made. However, most channels slope from a generally south to north direction (the actual numbers are south to north 7, north to south3) and this probably indicates an ice gradient from south to north - and therefore a Southern Upland origin. It is also possible, based upon the fluvio-glacial evidence, to suggest that the part of Area IV that was occupied by Southern Upland ice was similar to that suggested by the study of glacial features (Fig. 5.4). Although the evidence of meltwater erosion is sparse, the large number of fragments of channels does suggest that a great deal of meltwater activity took place, though this is not well preserved. The reasons for this were explained in Chapter 3 (Section 3.5).

5.6: Fluvioglacial Deposition

Deposits of fluvioglacial origin, though patchily distributed, are quite extensive in Area IV. The main zone of fluvioglacial accumulation is between Minishant, Maybole and Straiton (Fig. 5.4). A smaller zone of sand and gravel deposition is in the valley of the River Doon between Tunnosh Park and Boreland. Isolated masses of sand and gravel are also present near Maidens and Balchriston in the south-west and Bargenoch in the north-eastern part of the area (Fig. 5.4). The northern and western parts lack fluvioglacial deposits.

The fluvioglacial deposits between Straiton and Maybole are discontinuously present over a distance of 9 km. and are confined to a narrow zone which has a north-west to south-east orientation (Fig. 5.4). For approximately half of the distance between Straiton and Maybole (i.e. from Straiton to Aitkenhead) these deposits are confined to the lower slopes of the valley of the Water of Girvan where they are particularly discontinuous. To the north-west of Aitkenhead, the fluvioglacial material is almost a continuous belt over a distance of 3 km. to Broom Knowe (Fig. 5.4). North of Broom Knowe, the deposit sweeps to the south of Chapelton Hill and to the east of Maybole. The altitudinal range of this fluvioglacial material is from a maximum of 122m. O.D. near Straiton to a minimum of approximately 55m. O.D. near Maybole.

The extensive fluvioglacial deposits around Maybole are interspersed with flat alluvial expanses similarly to those between Maybole and Minishant. These fluvioglacial deposits have an altitude of approximately

122m. O.D. west of Maybole and 53m. O.D. at Minishant. Because exposures in these deposits are rare, the close examination of their morphology is a key factor when trying to elucidate the former direction of movement of the meltwater by which they were deposited.

The expanse of sand and gravel from Straiton to Broom Knowe is characterised by smoothed, rounded mounds and elongated ridges (Fig. 5.4). The mounds, which attain a maximum height of 10m. and maximum diameter of 200m., have no distinctive alignment. They are therefore of little use in determining former directions of meltwater movement in this part of Area IV. However, the narrowly confined nature of this spread, which has a north-west to south-east orientation, may be interpreted as representing a flow of meltwater from the north-west or the south-east. This hypothesis is supported by the existence of four north-west to south-east orientated, elongated ridges which are the most distinctive forms between Straiton and Broom Knowe (Fig. 5.4).

At the southern extremity of this fluvioglacial spread, near Straiton, there is an elongated ridge which is over 300m. long and orientated in a north-west to south-east direction (Fig. 5.4). Even allowing for trimming of the north-eastern side of the ridge by the erosive action of the Water of Girvan, it is at least 6m. high with its highest point towards its south-eastern extremity. This feature is considered to be an esker which was deposited by meltwater which flowed from either the south-east or the north-west. Examination of the internal characteristics of the sands and gravels of this ridge may enable the precise direction of meltwater flow to be established. However, it lacks any natural exposures which reveal the internal constituents.

An elongated ridge, which is also orientated in a north-west to south-east direction, is situated 3 km. north-west of Straiton near Clondcard Castle (Fig. 5.4). It is at an approximate altitude of 90m. O.D. and is 250m. long and 6m. high. It has no natural exposures which reveal its internal characteristics. However, pits were excavated and they reveal that it is composed entirely of sands and gravels. The meltwater by which it was deposited flowed from either the north-west or south-east.

One of the finest elongated ridges of sand and gravel in the whole of the thesis area is situated near Kirkmichael House (Fig. 5.4). Unlike the two ridges already described in relation to Area IV, it is not confined to the Girvan valley. Its one km. long, sinuous course is generally orientated from north-west to south-east. It is located on the interfluve between the Water of Girvan and its tributary stream, the Dyrock Burn. The highest altitude of this ridge is approximately 60m. O.D., which is near its south-eastern extremity. The altitude of the ridge reaches a minimum of approximately 50m. O.D. at its north-western extremity. The height of the ridge is 8m. at a maximum along its sharply defined, uneven crest. There are no natural exposures in this feature, but the Officers of the Geological Survey for Scotland recorded I2' (4m.) of coarse structureless gravel at the north-western end of the ridge (Site 5d, Fig. 5.4) (Geol. Surv. Scot., Sheet 14, I9II). There can be little doubt that this feature is an esker deposited by meltwater which flowed either from the south-east or the north-west.

A fourth elongated ridge of fluvioglacial material is located near Chapelton, which is at the north-western extremity of this sand and gravel spread (Fig. 5.4). This ridge is, in fact, made up of two separate ridges which merge into each other. The longer ridge, which is approximately 400m. in length, is curved. Its southern part is orientated east to west but its northern part curves towards the north and combines to give a general orientation from south-south-east to north-north-west. The height of this uneven, sharp-crested ridge rarely exceeds 4m., and this, together with its 40m. width, gives it a subdued character.

Approximately half-way along the course of the ridge, an exposure (Site 5c) reveals 3m. of coarse gravel (Plate 5M). This material is well-rounded, poorly-sorted and well-bedded (Plate 5N). The beds dip towards the north-east at an angle of 30° but closer examinations show that they also dip towards the north-west at an angle of I0°. This material is derived entirely from local rock-types and it is clear that it was deposited in a high-energy fluvioglacial environment. Imbrication studies indicate that the meltwater which deposited this gravel flowed from a generally south-easterly direction.

The shorter ridge is I50m. long and has a maximum height of 4m.. This ridge is orientated in a south-east to north-west direction. Although it has no natural exposures, pits excavated at various points along its course show that it consists of coarse, poorly-sorted material typical of high energy fluvioglacial environments. The orientation of the ridge suggests that the meltwater by which it was deposited flowed from either the north-west or the south-east. Only 20m. to the north-east of the south-eastern extremity of the ridge is a small meltwater channel (Channel 6) which slopes towards the north-west (Fig. 5.4). This suggests that meltwater in the vicinity of this ridge flowed from the south-east to erode this channel. It is most likely, therefore, that a similar flow of melt-water from the south-east resulted in the deposition of this elongated ridge.

The expanse of fluvioglacial deposits between Straiton and Broom Knowe has probably been altered in both form and distribution by subsequent stream erosion. However, the conformity of orientation of the ridges from north-west to south-east suggests that they were all produced by the same, or at least a closely associated movement of meltwater. Strong evidence exists, especially in the northern part of this spread (near Broom Knowe), that meltwater flowed from the south-east. There is a high probability, therefore, that the ice which occupied this part of Area IV originated in the Southern Uplands and that during ice decay the south-east to north-west orientated part of the Water of Girvan valley was a major escape route for debris-laden meltwater. This escape route continued to the north-west beyond this valley and over the interfluve towards Maybole.

Beyond Broom Knowe, a sand and gravel spread exists around Chapelton Hill (Figs. 5.4, 5.II). The maximum altitude of this spread is approximately 60m. O.D.. These sands and gravels display a variety of forms including irregular mounds upto 10m. high (Plate 50). Many of these mounds are elongated and the majority are parallel to the sides of Chapelton Hill (Figs. 5.4, 5.II). Well-developed, elongated ridges also exist which are parallel to the sides of Chapelton Hill. The most noticeable examples of these ridges are near Harkieston Bridge and Lochland (Fig. 5.II).

At Harkieston Bridge there are three elongated ridges, two of which merge together, orientated in an approximately east-west direction (Fig. 5.II). These ridges cover an overall distance of 400m. and are 5m. high at a maximum. They are abruptly terminated at their eastern end by the Chapelton Burn which has produced a distinctive scar. There are no natural

Fig. 5.11 Fluvioglacial Deposits around Chapelton Hill, Maybole.

Plate 50 Typical Morphology of the Fluvioglacial Deposits around Maybole.

exposures in these ridges but pits that have been excavated reveal that they are composed entirely of sands and gravels. Towards the western end, they become ill-defined and eventually disappear. However, 100m. to the north-west, there is a large sinuous ridge which is orientated in a north-west to south-east direction. This ridge is over 600m. long and has a maximum height above the surrounding land of 7m. (Fig. 5.II). Again, this ridge contains no natural exposures but an excavation showed that it consists of sands and gravels. It is highly likely that these ridges are esker ridges which were deposited by meltwater which flowed from a generally south-easterly or easterly direction. This would, in effect, represent a continuation in the flow of meltwater from the south-east which affected the area between Straiton and Broom Knowe.

The three elongated ridges which exist near Lochland are generally orientated in a east-north-east to west-south-west direction (Fig. 5.II). However, towards their western extremity, their curved nature has resulted in a north-west to south-east orientation. They are, in fact, exactly parallel to the sides of Chapelton Hill (Figs. 5.4, 5.II). The maximum length of the ridges is 350m. and their maximum height is 4m.. The features are approximately 35m. broad and they have ill-defined, rounded crests on top of generally subdued forms. A closely associated sand and gravel spread exists to the west across the Barlewan Burn, where it extends for approximately I km. to terminate at Deansmill (Fig. 5.II). This sand and gravel spread, which flanks Chapelton Hill, contains two other elongated ridges near St. John's Cottage (Fig.5.II). These ridges are 450m. long and 6m. high and are orientated in an east-north-east to west-south-west direction and in a south to north direction; again these are parallel to the nearest sides of Chapelton Hill.

The indication of former movements of meltwater from the study of the fluvioglacial spreads around Chapelton Hill is clear. Meltwater, which flowed from a generally south-easterly direction via Broom Knowe, was deflected around Chapelton Hill. Some of the meltwater flowed around the north-eastern side of the hill (Plates 5P, 5Q) and deposited the eskers near Harkieston Bridge, while some meltwater was deflected around the south-eastern part of the hill and deposited the eskers near Lochland and St. John's Cottage. The higher ground to the east and west of Chapelton Hill prohibited free drainage of this meltwater in either of these

Plates 5P, 5Q   Chapelton Hill near Maybole directions. However, the low ground to the north would have been an ideal escape route for meltwater. The broad, flat alluvial spreads of the Chapelton and Stoneyfield Burns suggest that this may have been the route used (Figs. 5.4, 5.II). This hypothesis (Fig. 5.I2) is also supported by the two northernmost eskers in this fluvioglacial spread which lead into the valley of the Stoneyfield Burn (Figs. 5.4, 5.II). It is also indicated that meltwater once flowed towards the north in this part of Area IV by a meltwater channel (Channel 5) which terminates on the floor of the Stoneyfield Burn (Figs. 5.4, 5.II).

To the north of the fluvioglacial deposits around Chapelton Hill there are a number of isolated mounds which, by excavation rather than by examination of natural exposures, have been shown to consist of fluvioglacial sands and gravels (Fig. 5.4). Most of these deposits are closely associated with 60m. contour, but a general fall in the altitude of these deposits from south to north is evident. The general orientation of the mounds and ridges, which are characteristic features of these sand and gravel deposits, is north to south.

An expanse of subdued, irregular relief which contains two north-south orientated elongated ridges exists around High Smithson (Fig. 5.4). The two ridges are 200m. and 300m. long and have a maximum height of 3m.. An exposure at Site 5b shows that the surface material consists of at least 2½m. thickness of fluvioglacial deposits. The upper Im. of this section consists of coarse gravels and below this there is I½m. of fine to coarse sands with occasional gravel and coal layers. The material is well-rounded, poorly-sorted and has distinct current bedding. Studies of this bedding and of the imbrication of the material show that the meltwater by which this sand and gravel was deposited flowed from the south. This direction of meltwater flow may also explain the generally south to north orientation of the ridges which are interpreted as eskers.

Another elongated ridge which is understood to represent an esker is located near Stewart's Craig (Fig. 5.4). This subdued feature which is 350m. long and 5m. high has an east-south-east to west-north-west orientation. Nowhere in this ridge, which slopes from south to north, are the internal constituents exposed, but excavations show that it is composed of sands and gravels. There is no direct evidence concerning the former

Fig. 5.12 Directions of Meltwater Flow in the vicinity of Maybole

direction of the meltwater flow but it is considered highly probable that it was either from the south or the north. However, with a general flow of meltwater from the south clearly indicated for this part of Area IV this is considered to be the most likely direction of flow.

Other deposits of fluvioglacial material are located around Minishant (Fig. 5.4). However, their close association with channel system 3 and extensive alluvial spreads leaves little doubt that they were deposited by meltwater which flowed from a generally south-westerly direction. From this, it is likely that the meltwater which deposited this fluvioglacial material between Maybole and Minishant eventually flowed into the River Doon at two points, Crorieshill and Auchendrane (Fig. 5.4).

The valley of the River Doon from Tunnosh Park and Boreland also contains a series of sand and gravel deposits. The altitude of these deposits ranges from a minimum of 60m. O.D. at Tunnosh Park to a maximum of I25m. O.D. at Boreland (Fig. 5.4). The form of these deposits varies from uneven mounds to elongated ridges; there are IO masses of sand and gravel in this part of Area IV; five are made up of mounds and five are made up of elongated ridges.

At the upstream extremity of this suite of sand and gravel deposits there are two expanses which have a moundy morphology - one on either side of the River Doon. The mounds which make up these masses of fluvioglacial material have no regularity in height, shape or form. Only one exposure exists to show that this morphology is related to an expanse of sand and gravel. This exposure is Site 5f (Fig. 5.4). The section is badly slumped and the only observation that may be made is that I2m. of sands, which contain little gravel, overlies a grey, gritty till charged with Southern Upland erratics. There is no direct evidence to suggest the direction of meltwater flow. However, the existence of a typical Southern Upland till beneath this sand and gravel suggests that the last ice to occupy this part of Area IV was of Southern Upland origin. The likely slope of the ice gradient, and therefore probable direction of flow of meltwater, was from the south-east. It is likely, therefore, that the valley of the River Doon received a large amount of the meltwater from the south-eastern part of Area IV.

To the north-west of Boreland, at Hollybush, a sand and gravel deposit zig-zags down the side of the Doon valley from Malcolmston to a short distance north-west of Hollybush Hotel (Fig. 5.4). This sand and gravel deposit begins at an altitude of I25m. O.D. and eventually winds down to I05m. O.D. along its I½ km. long course. This deposit, which is in the form of a ridge, has a maximum height of 5m. and a maximum width of approximately 40m.. Poor exposures in this ridge show its internal constituents to be entirely poorly-sorted, well-rounded gravels which have an average clast size 30 cm. in diameter. No bedding is discernable from these exposures. This description strongly suggests that the material was deposited in a high-energy fluvioglacial environment. This is also indicated because the lower end of channel 2 marks the starting point of the ridge (Fig. 5.4). It is therefore probably an esker which was deposited by meltwater which flowed from the north-east. This may only represent a local movement into a main meltwater escape route, the valley of the River Doon.

Similar, though more prominent and well-developed ridges exist downstream from the deposits at Hollybush (Fig. 5.4). The ridges ... "... follow closely upon one another in a single line and at the same level (300 feet) (9Im. O.D.) from Macilveenston cottage south of Netherton Torr, a distance of one and a half miles (2½ km.). An isolated mound east of Skeldon Mills is probably part of the same series as it occurs exactly at the same height (altitude)" (Eyles et al 1949, p. I30). These ridges vary in size, the most easterly, near Torr, is the smallest and has a height of 5m. and a width of 35m.. This subdued feature is 360m. long and is more or less continuous with the ridge at Kilmore (Fig 5.4, 5.I3) which is approximately the same length. The Kilmore ridge is well-developed in comparison with the ridge at Torr and has a maximum height of I0m.. The exposures in these two ridges are very poor and show that they are made up of well-rounded, poorly-sorted gravels which are the typical deposits of high-energy fluvioglacial environments. The general orientation of these two ridges is from north-east to south-west - (i.e. they are parallel to the valley of the River Doon). Both of them slope down-valley (i.e. from the north-east towards the south-west) and this may indicate that the meltwater flowed from the north-east i.e. down the Doon valley, although this is not always the case (Howarth, I97I).

Fig. 5.13 Eskers in the Doon Valley.

Approximately 600m. downstream from the ridge at Kilmore, there are two more ridges, one near Netherton Torr and one near Macilveenston (Figs. 5.4, 5.I3). The ridge near Netherton Torr is orientated in a north-west to south-east direction, which is parallel to the valley of the River Doon. This feature is 250m. long and has a sharply-defined, uneven crest upto I2m. above the surrounding landscape. It is at an altitude of approximately 90m. O.D.. At its north-western extremity, it is joined by another ridge which has a north-east to south-west orientation and is dissected by the road (Fig. 5.I3). This ridge, which begins near Macilveenston has steeply-sloping sides (30°) and a well-defined crest. The height of the crest above the surrounding area reaches a maximum of I5m.. There are no natural exposures along either of these two ridges, but excavations show that the internal constituents are coarse, unsorted, well-rounded gravels. The ridges are probably of fluvioglacial origin; it is likely that they are eskers. The esker in the Veenston Glen probably represents the depositional equivalent of the meltwater activity which eroded the channel which terminates at the head of the esker-ridge (Fig. 5.4). The meltwater activity, therefore, was probably subglacial. The direction of meltwater movement was from south-west into the valley of the River Doon. This flow of meltwater may also have filled a north-west to south-east orientated cavity beneath the ice which is represented by the esker near Netherton Torr. An alternative explanation may be that meltwater which flowed down the valley of the Doon from the south-east deposited all the sand and gravel ridges which are parallel to the main orientation of the valley. The esker in Veenston Glen may have been deposited by meltwater which flowed from the south-west along the most easterly channel in channel system 4. The meltwater in this channel flowed to join the main subglacial escape route for meltwater which was the Doon valley.

Three small mounds of sand and gravel exist in the valley of the River Doon between Netherton and Tunnosh Park but they are of little use in indicating former meltwater movements in this part of Area IV. However, they do indicate that fluvioglacial deposition occurred in the Doon valley as far downstream as Tunnosh Park. The trimmed nature of these deposits and their position in relation to the flood plain of the Doon valley indicate subsequent erosion has removed a great deal of evidence relating to fluvioglacial deposition in this part of Area IV.

Throughout Area IV, small isolated spreads of fluvioglacial sands and gravels litter the landscape (Fig. 5.4). One such spread exists towards the north-east near Bargenoch (Fig. 5.4); it is in the form of an elongated ridge which is 750m. long and is orientated in a generally north to south direction. This expanse, however, is comprised of three separate ridges, the heights of which range between 5m. and 7m.. Their steep-sides are assymmetrical in places. This feature has a 3m. thick exposure of sand and gravel which contains coal lenses at its northern extremity. The material is well-rounded, poorly-sorted and well-bedded; the beds dip towards the north-east at an angle of 10^{o}. The indication from this evidence is that the meltwater which deposited this ridge flowed from the south-west. This hypothesis is also substantiated by the proximity of the northward sloping channel I to the uppermost part of this ridge. This ridge system, therefore, probably represents an esker. It is suggested that this part of Area IV (and the adjacent part of Area III) was a major accumulation zone for debris-laden meltwater by the relatively large expanse of fluvioglacial forms in the vicinity. The meltwater is likely to have flowed from a variety of directions into this part of the area.

Small isolated pockets of fluvioglacial material are particularly common near the coastal zone of Area IV, such as at Balchriston and around Maidens (Fig. 5.4). However, these deposits are of little use in elucidating former directions of meltwater movements.

The fluvioglacial deposits in Area IV are widespread between Straiton and Minishant and in the Doon valley. The study of both concentrations provides evidence for complex meltwater flow generally from the south-east - eventually into the Doon valley. This may indicate that the gradient of the ice which occupied the southern part of Area IV sloped from south-east to north-west.

5.7: Raised Beaches

Raised beaches are very well-developed in the north and in the south of the seaward margin of Area IV. Between these extremes they are poorly-developed and very fragmented (Fig. 5.4). In the area the raised shore platforms (upon which the beach material was deposited) have been cut out of solid rock and till. Those cut in till are wider (upto 2 km.) and poorly defined. Those cut in solid rock are narrow and well defined. As with the study of the raised beaches in Area III, no detailed levelling was completed but the same techniques of study were used.

In the northern part of Area IV, the raised coastal features are indistinct. This is not only because they have been eroded into till but also due to the degradation of the features by the River Doon which discharges into the Firth of Clyde at this point. Urban development has also masked the form of these features. However, from east of Doonfoot to Heads of Ayr, a raised beach at an altitude of IO-I2m. O.D. extends inland for a distance of 600m. (Fig. 5.4). The inland margin of this raised coastal feature is poorly defined except around Greenan and Heads of Ayr where the margin is a cliff upto 30m. high (Fig. 5.4). The poorly defined nature is a reflection of the till into which these features were eroded. The high cliff is a reflection of the resistant volcanic rocks (vent agglomerate and ash) into which these features were eroded.

From Heads of Ayr to Glasson Rock a series of discontinuous raised coastal features exists. They occur at three altitudes:- a) 24-26m. O.D. b) IO-I2m. O.D. and c) 5-7m. O.D.. Although the features are of limited extent, they are sharply defined. This is because they have been eroded into solid rock. In one instance, just north of Dunure, two fossil sea-stacks emerge from the IO-I2m. O.D. raised coastal feature.

South of Glasson Rock the raised beaches are extensive and ill-defined. This is because the shore platforms upon which the beach material lies was eroded into till. However, near the southern boundary of the area, where solid rock outcrops, the inland margin of the raised coastal features is a well defined cliff (Plate 5R). Preserved in varying degrees are three raised beaches at altitudes of 24-26m. O.D., IO-I2m. O.D. and 5-7m. O.D. (Figs. 5.4, 5.I4).

The altitudinal ranges of the beaches in Area IV are the same as those identified in Area III to the north. The age relationships between the raised beaches in IV, therefore, are considered to be the same as those in Area III:-

I) The 24-26m. O.D. raised beach is Lateglacial in age.

Plate 5R Raised Beaches near Turnberry

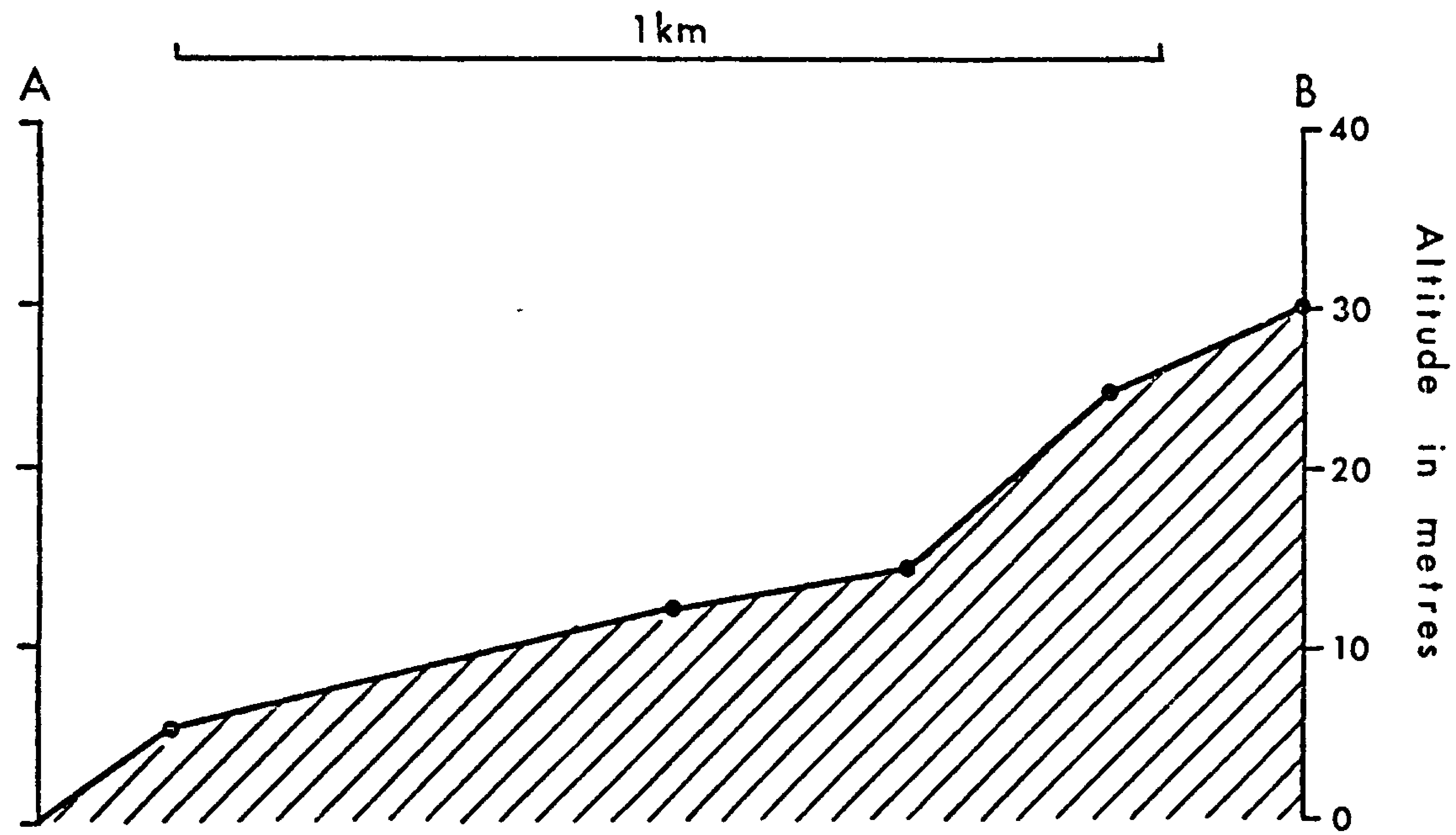


Fig. 5.14 Cross-section of Raised Beach Relief - Area IV.
For location of A-B see Fig. 5.4.

2) The IO-I2m. O.D. raised beach corresponds to the Main Post-glacial raised beach recognised in many parts of Scotland.
3) The 5-7m. raised beach is also of Post-glacial age but relates to a temporary halt position in the regression of the Post-glacial sea from its maximum position.

5.8: Conclusions

The study of the glacial geomorphology in Area IV indicates a complicated glacial history:-

I) The ice movements in the area were varied. In the south-eastern part the ice moved from the south-east, in the south-western part the ice moved from the east and north-east, in the north-western part two movements of ice occurred - one from the north-east and the other from the south-east (Fig. 5.I5). This evidence is interpreted as an indication that the area was occupied by ice with diverse origins.
2) The existence of two distinct tills in Area IV (one containing Highland erratics and shells and one containing Southern Upland erratics) shows that the northern part was occupied by ice with a Highland origin and that the southern part was occupied by ice with a Southern Upland origin. Between these two extremes in a zone where Highland erratics, shell fragments and Southern Upland erratics are found in the same till. This is considered to be the "zone of crossing" suggested by Eyles et al (I949) which has also been indicated in Area II and Area III.
3) A large morainic spread exists in the vicinity of Maybole. This lies well within the part of Area IV occupied by Southern Upland ice and was produced when the ice was cut off from its source. It decayed in situ to form "ice disintegration features".
4) Meltwater flow in the area was complex. The lack of continuous and/or well developed channel systems limits the reliability of any conclusions that may be drawn. However, most channels slope from south to north which is an indication that meltwater generally flowed in that direction.

Fig. 5.15 Summary of Former Ice Movements in Area IV.

5) The amount of fluvioglacial deposits indicates that the ice did not disappear as rapidly from Area IV as some of the other areas. The form of the deposits gives a strong indication that meltwater generally flowed from south-east to north-west and a great deal drained into the Doon valley at a number of points.

6) Isostatic and eustatic changes in sea-level produced three raised beaches which have been preserved along the seaward margin of the area. The altitudes of these features are 24-26m. O.D., IO-I2m. O.D. and 5-7m. O.D.. The highest beach is considered to be Lateglacial in age, and the lower beaches Post-glacial in age.

CHAPTER 6

AREA V.

6.I: Introduction: Location and Extent

Area V, which is the smallest and most compact of the 5 areas recognised in the thesis area, is the south-eastern part of central Ayrshire (Fig. 6.I). It is I75 sq. km. in extent and has a maximum distance from north to south and from east to west of I6 km..

Area V is defined along its northern margin by the watershed between the Nith drainage system (Area V) and the Lugar drainage system (Area II) (Fig. 6.I). Its western extremity is the watershed between the Nith drainage system and the Doon/Girvan drainage system (Area IV). The western part of the southern boundary of the area is an arbitary straight line along the east to west orientated grid-line NS05. The eastern part of the southern boundary is the old county boundary between Ayrshire and Kirkcubrightshire (Fig. 6.I). Thw whole of the eastern boundary of Area V is represented by the old county boundary between Ayrshire and Dumfries-shire (Fig. 6.I).

6.2: Relief and Drainage

The whole of Area V lies above an altitude of I80m. O.D. but it is still possible to sub-divide it into 3 distinct parts on the basis of relief:- I) The extreme north-east 2) the north-west 3) the south-east (Fig. 6.2). These relief sub-divisions strongly reflect the solid geology of the area (Fig. 6.3).

The extreme north-eastern part of the area is of limited extent; it covers only 7 sq. km.. Essentially this part of Area V is one hill - Corsencon (474m.) (Fig. 6.2). However, this steep-sided hill is such a conspicuous feature on the northern side of the Nith valley that it deserves special consideration. An examination of the solid geology shows

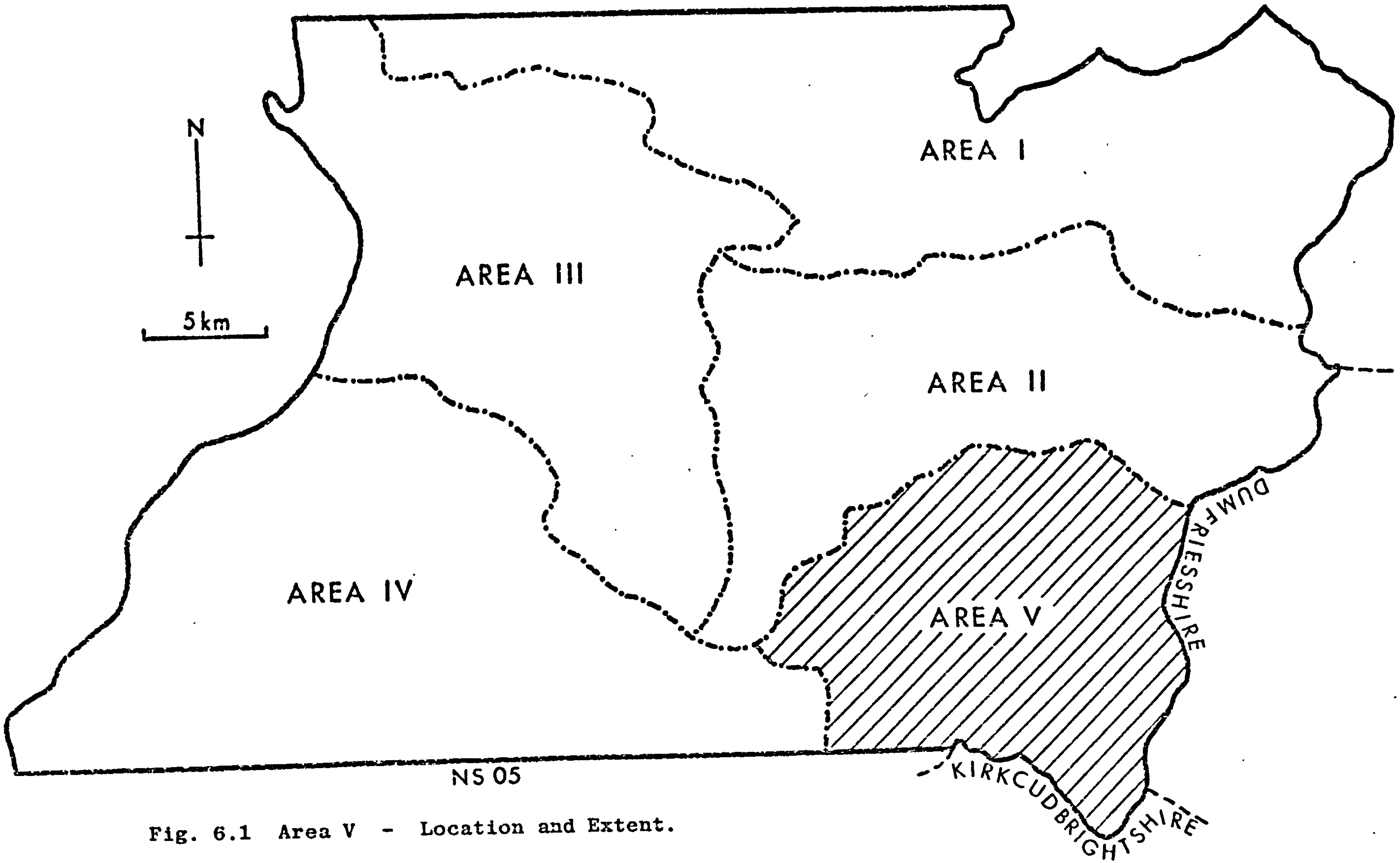


Fig. 6.1 Area V - Location and Extent.

this special consideration to be fully justified because it relates to resistant Old Red Sandstone age sandstones and conglomerates. These are the only outcrops of such rocks in the whole of Area V. This does show, however, that this part of Area V is an extension of the heavily-dissected eastern part of Area II which was identified by its conspicuous relief forms (Ch. 3).

The north-western part of Area V extends over approximately 60 sq. km. (Fig. 6.2). The highest summits in this part include Maneight Hill (42Im.), Meikle Hill (4I3m.), Peat Hill (384m.), Rig Hill (346m.) and Cairnscadden Hill (3I4m.) (Fig. 6.2). The relative relief values rarely exceed 90m.. The very gently undulating morphology characteristic of this part is a reflection of the structural control of the horizontally bedded Carboniferous sediments which, in relative terms, are much less resistant to erosion than the Old Red Sandstone age sediments in the north-east. However, the consistently high altitude is due to the intrusion of teshenite and theralite sills between these sedimentary beds and this has given these strata a greater degree of resistance to erosion. This part of Area V, therefore, is an extension of the very gently undulating relief which typifies the southern part of Area II (Ch. 3).

The relief of the north-western part of Area V has another important component, the extensive flood plains of the River Nith and its tributaries (Fig. 6.2) (Plate 6A) which all have an altitude of around I85m. O.D. and occupy over IO sq. km. of the area. The largest of these flat expanses is in the vicinity of New Cumnock, but sizeable extensions also exist to the east, north and west (Figs.6.2, 6.4).

The south-eastern part of Area V is characterised by very high, steep-sided hills. The relative relief values are as great as 385m. but I70m. is the approximate average. These hills have a higher altitude than any others in the whole of central Ayrshire; Blackcraig Hill (70Im.) is the highest (Fig. 6.2). Other summits include Blacklorg Hill (680m.), Alwhat (629m.), Wedder Hill (598m.), The Knipe (53Im.), Struthers Brae (542m.) and Strandlud Hill (53Im.) (Fig. 6.2).

Many of the summits in Area V rise from prominent north-east to south-west orientated ridges Strandlud Hill (53Im.), Ewe Hill (436m.) and Ashmark Hill (372m.) are three summits which rise above a 5 km. long north-east to south-west orientated ridge (Fig. 6.2). The high altitude and orientation of the ridges is a reflection of the solid geology (Fig. 6.3).

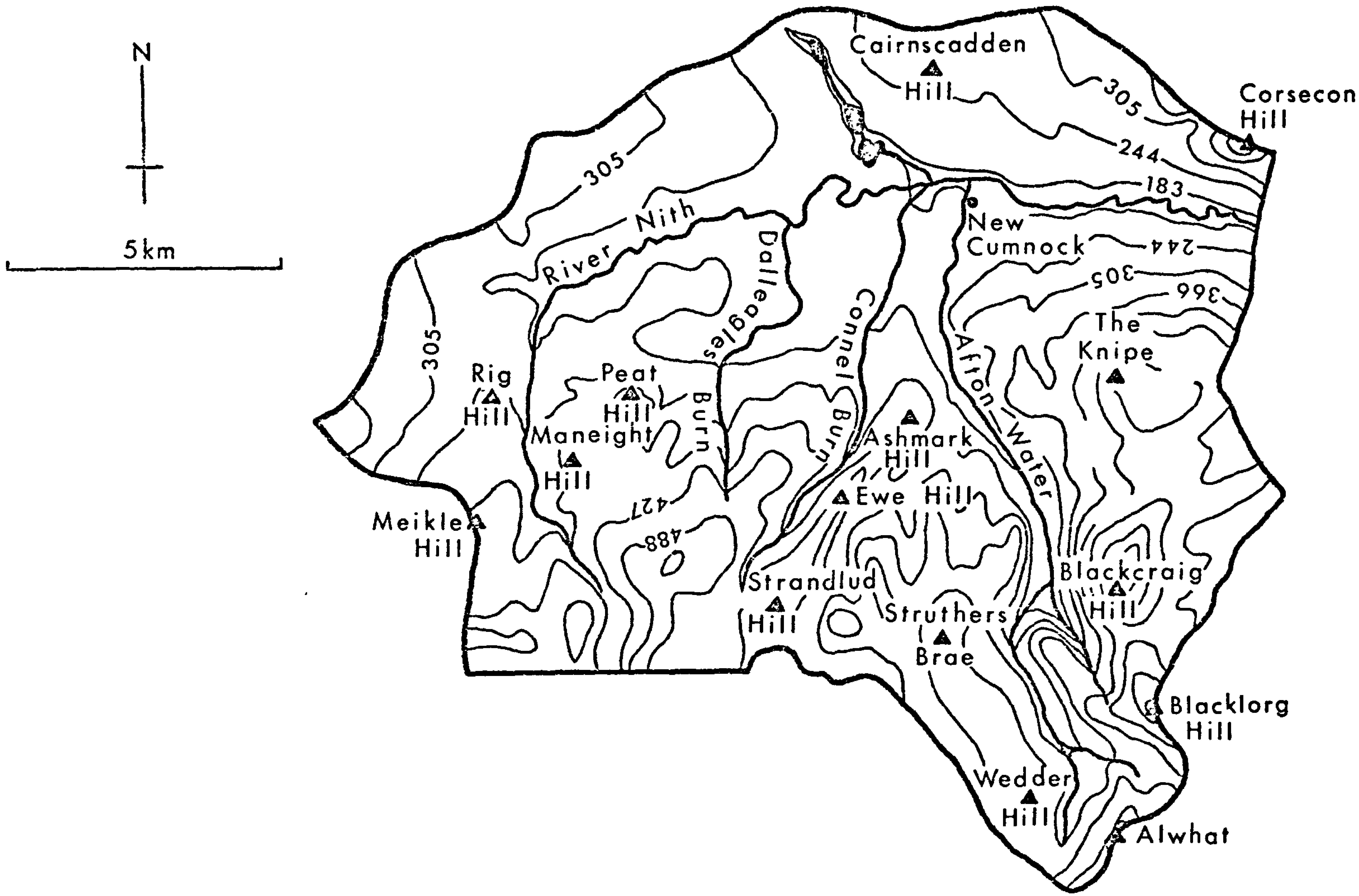


Fig. 6.2 Area V - Relief and Drainage.

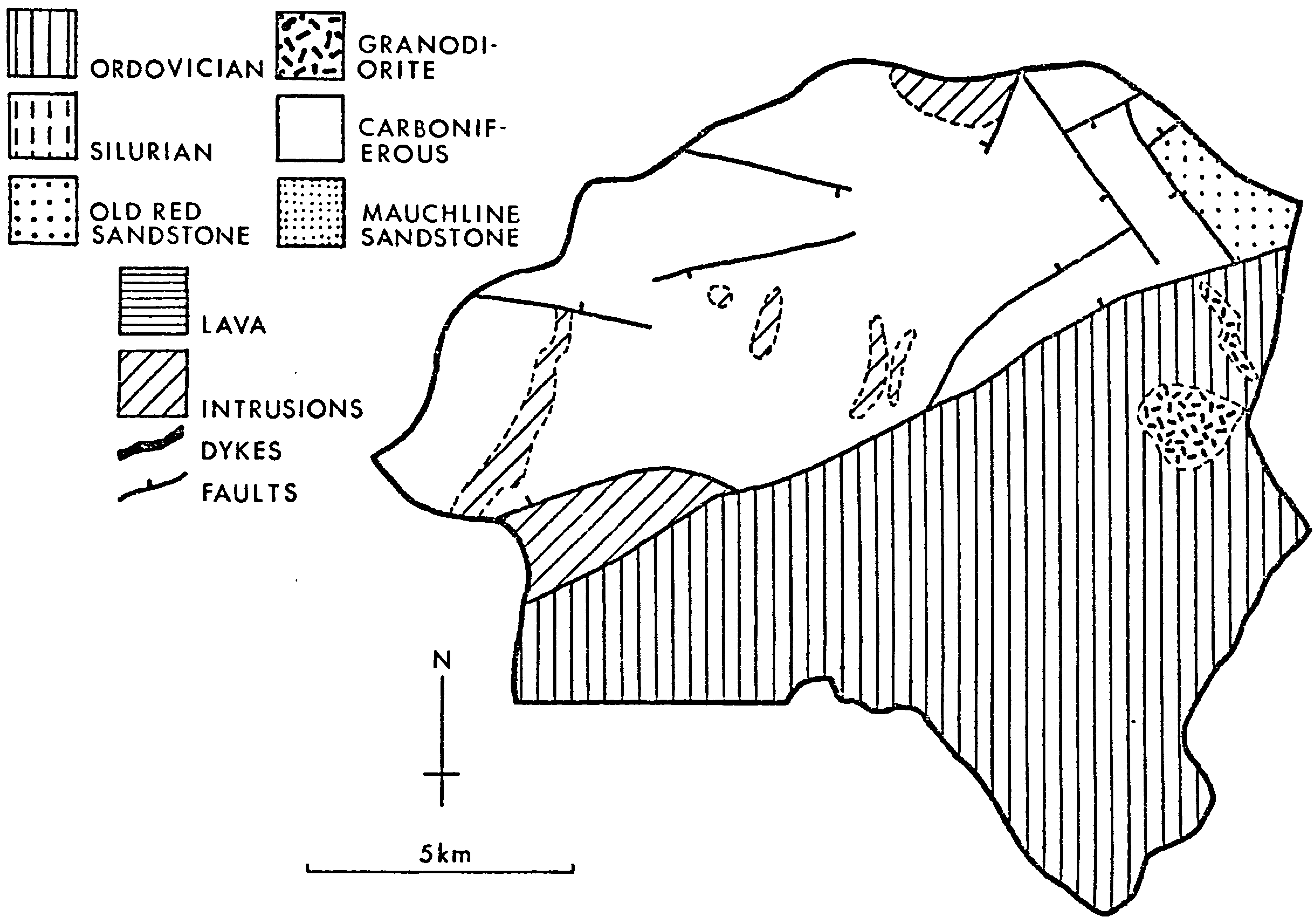


Fig. 6.3 Area V - Geology.

Plate 6A   Extensive Flood Plains associated with the River Nith and general view of Area V

The whole of this part of Area V lies to the south-east of the Southern Upland Fault. This means that the rock-types include resistant, highly contorted greywackes and granitic intrusions. Locally the intrusions support relatively high altitude summits; The Knipe (568m.) is one example (Fig. 6.2). The strike of all the folds in this part of the Southern Uplands is orientated in a north-east to south-west direction.

The drainage system in Area V is dominated by the River Nith which has its main catchment area to the south and east of the main stream (Fig. 6.2). The River Nith shares a generally south-west to north-east direction of flow with most of its main tributaries (e.g. Daleagles Burn, Connel Burn) (Fig. 6.2). However, the largest tributary stream to the Nith, the Afton Water, flows in a generally south-east to north-west direction. Most of the main tributary streams, therefore, have directions of flow which correspond with the geological grain of the area. The Afton Water, however, completely traverses the 'Calcdonian' grain of the country rock and comprises one of the most distinctive features in the whole area.

The resultant drainage pattern is one that is asymmetrically dendritic (Fig. 6.2). The valleys that contain the main drainage lines are deep and steep-sided with broad, open cross-sections. However, parts of the valleys of the River Nith and the Afton Water are characterised by very steep sides and broad, flat flood plains.

Area V, therefore, may be subdivided into 3 distinct parts on the basis of relief: the extreme north-east; the north-west and the south-east. The drainage pattern which is dominated by the River Nith, is asymmetrically dendritic - i.e. it receives most of its tributaries from the south and east. The relief and the drainage pattern strongly reflects the underlying rock-type and geological structure.

6.3: Glacial Erosion

Area V contains more features that have been produced by the erosive action of ice than any of the other four areas of central Ayrshire. The features identified include roches moutonées (stoss and lee topography), striations, a glacial trough and glacially-breached cols (Fig. 6.4).

Fifteen roches moutonées have been identified in Area V. The distinctive characteristics of these features "... an asymmetric hillock or hill with one side moulded and the other side steepened and often craggy." (Sugden and John, 1976, p. 171) make their identification in the field relatively simple. Their size varies from small (i.e. approximately 1.5m. high) to large (approximately 8m. high) as at Castle William (Fig. 6.4). All the roches moutonées in Area V are located in, or close to, the upper reaches of the Afton valley (Fig. 6.4). This is a part of the area which is characterised by a geological foundation of resistant, highly contorted greywackes that are completely devoid of overlying material. The roches moutonées are, without exception, elongated in a south-south-east to north-north-west direction. Their smooth, gentle slopes face towards the south-south-east and their jagged, steep slopes face towards the north-north-west. Roches moutonées are "the universal earmark of the invasion of an area by glacier ice" (Fluckiger, 1934) but more importantly they "can be used to indicate approximately the former directions of ice motion" (Embleton and King, 1975, p. 199). In this context, the implications of former ice movements from such a regular pattern is clear; the ice moved from the south-south-east in this part of Area V; the source region was to the south, in the Southern Uplands.

Approximately 25 striations have been recorded in Area V. Their main concentration is south of the Southern Uplands Fault, although a few others exist elsewhere in the area (Fig. 6.4). In the south-eastern part, the majority of striations have a south-south-east to north-north-west orientation. However, in the north-west the orientation is south-east to north-west, and in the north-east the orientation is south-west to north-east (Fig. 6.4). The maximum altitude of these striations is 530m. which suggests a minimum ice cover to this level; however the streamlined nature of summits suggests a total ice cover. The former directions of ice movement indicated by the study of these striations across Area V may be hypothesised. The proximity of many of these features to the roches moutonées indicates that the ice by which they were produced moved from the south-south-east out of the higher parts of the Southern Uplands. On reaching the lower ground to the north it splayed out and moved from the south-east in the north-western part of the area and from the north-western part of the area and from the south-west in the north-eastern part of the area. From the evidence of glacial erosion in Area V it is not possible to determine the cause of the diverse ice movements in the northern part of the area. However, considerations from other parts of central Ayrshire indicate that the Highland ice-mass, which lay to the north, influenced these movements to some extent and probably caused the deflection of the Southern Upland ice to the east and west. A similar deflection of Southern Upland ice was also suggested by Eyles et al (1949), but this related only to ice which radiated from the Loch Doon basin.

The largest feature produced by glacial erosion in Area V is the glaciated valley which now contains the Afton Water (Fig. 6.4). This valley has steep sides and a broad, flat floor along the whole of its length but these features are best developed along the upper 7 km. of its course (Fig. 6.4, Plates 6B, 6C, 6D). The over-steepened valley sides rise as much as 385m. above the flat valley floor which is 500m. wide at a maximum. Unfortunately, borehole records do not exist for this part of Area V and therefore a rock-head cross - or long - profile is impossible to construct. However, the broad, flat floor indicates that a considerable amount of infilling has taken place which masks the solid form of the valley. The ice by which it was occupied did not emanate from a cirque at the northward facing head of the valley, as may be expected. The head of the valley is represented by a glacially-breached col (Fig. 6.4). This strongly suggests that the ice "originated on upland plateau areas, forming the outlet (glaciers) of mountain ice caps" (Embleton and King, 1975, p. 245). However, it is curious that this valley is the only one in Area V which has such a characteristic glaciated form when there can be little doubt that other valleys did contain considerable thicknesses of ice.

The existence of glacially-breached cols in Area V is suggested not only by their morphology but also by the lack of corries. Twenty three glacially-breached cols have been identified in the area and their altitudes range from a mimimum of 297m. O.D. in the north-west to a maximum of 580m. in the south-east (Fig. 6.4). This suggests a minimum altitude of the ice cover in Area V, but, as suggested on p.152, the stream-lined nature of the surrounding summits indicates a total ice cover. The

Plates 6B, 6C Glacial Trough of the Afton Valley with its broad, flat floor and steep sides

Plate 6D   Oblique view of the Glacial Trough of the Afton Valley

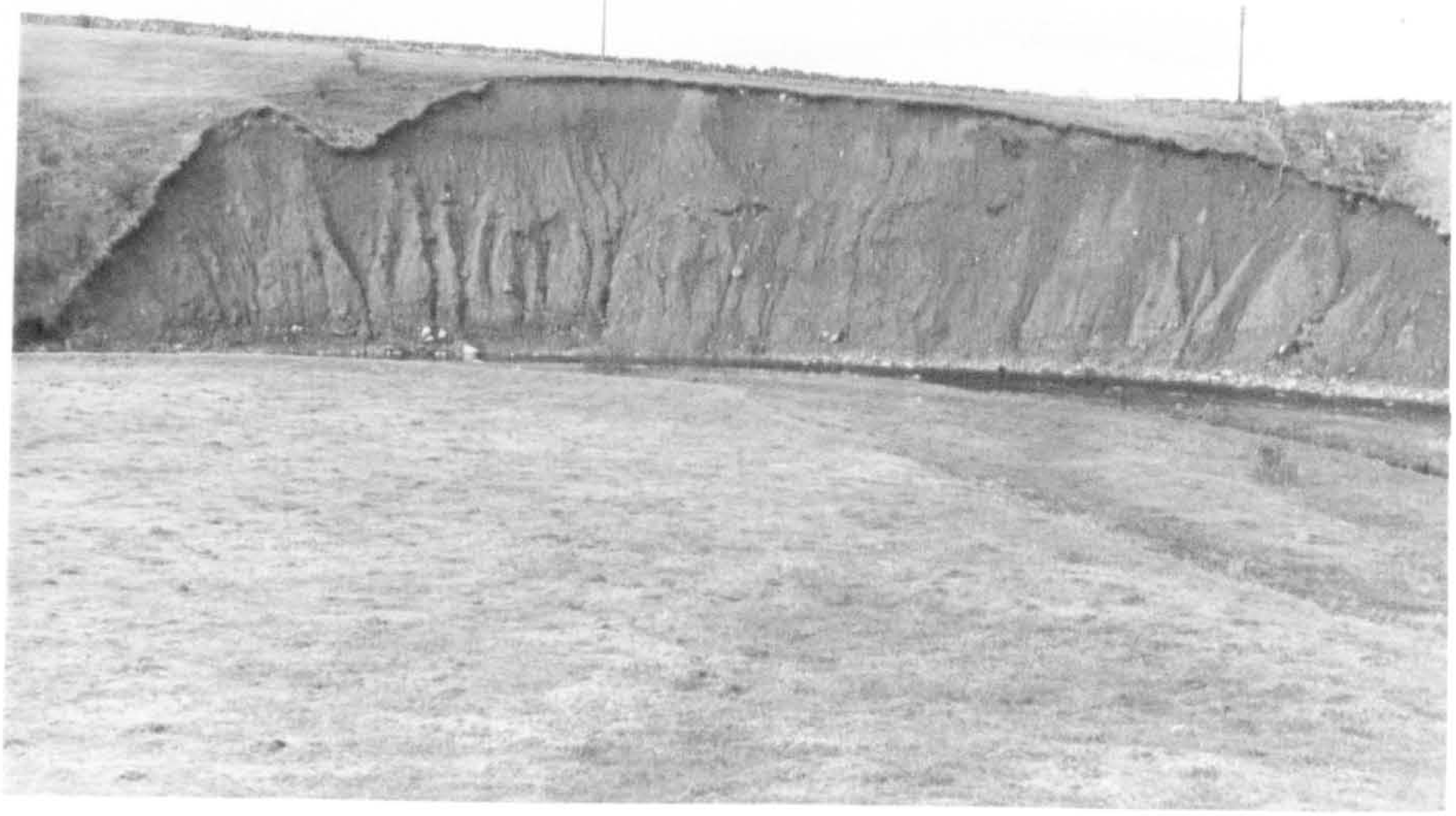


Plate 6E   Exposure near Fordmouth - Site 6c orientations of the glacially-breached cols are diverse and it is unlikely that they reflect the regional patterns of ice movement (Ch. 2, p.30). However, the concentration of 6 glacially-breached cols orientated at right angles to the (glaciated) valley of the Afton Water is interesting (Fig. 6.4). These cols, which decrease in altitude from south to north, may indicate glacial diffluence similar to that described by Price (1973): "If a valley becomes full of ice any pre-glacial col along the watershed between that valley and its neighbour will tend to carry ice across the pre-glacial watershed." (p. 54).

The existence of diffluence channels in Area V may also explain the selection of the Afton valley as a major ice routeway. Three large glacially-breached cols feed into the head of the Afton valley from higher ground to the south. If ice built up on the high part of the Southern Uplands around the head of the Afton valley, as suggested by A. Geikie (1901), it would be expected to spill over the nearest and lowest cols. These three cols are the only ones which traverse the watershed between the Afton drainage system and the Ken drainage system to the south. They are considered, therefore, to have been the major routeways for ice penetration into Area V before the ice-sheet phase which covered the whole of Area V.

From the study of the features of glacial erosion, it is clear that the ice which affected Area V originated mainly to the south in the Southern Uplands. The ice which generally flowed from the south gained access into the area (and across watersheds) through pre-existing cols. However, in the north-western part of the area the flow of ice was from the south-east while in the north-eastern part the flow was from the south-west. It is doubtful that this divergent flow was due to topographic constraints. When evidence of ice movements from the north in Area II are considered, it seems likely that ice which originated in the Highlands and generally flowed from a northerly direction deflected the movement of ice from the Southern Uplands and caused its divergent flow from the south-east and south-west.

If this is correct and ice with a Highland origin was in close proximity to the edge of the Southern Uplands, it may explain the lack of a well-developed glaciated landscape in the area. As Embleton and King (1975) explain: "In order to erode effectively ... there must ... be a free outlet for the ice to lower ground or out to sea so that its flow can be maintained" (p. 271).

This suggestion of former ice movements in Area V based upon the evidence of glacially-eroded features is at variance with the view of Eyles et al (1949). They suggested that the Loch Doon basin, which lies to the west of Area V, was the major ice centre in the north-west Southern Uplands. From this centre ice moved from the north-west, north-east and south-west (Fig. 6.5). It is implicit, therefore, that the ice which affected Area V moved from the south-west. Due to the overwhelming amount of evidence of a movement of ice from the south-east over most of the area, Eyles et al's suggestion must be strongly rejected. Only in the extreme north-eastern part of Area V does evidence exist for a movement of ice from the south-west. The dominant movement of ice from the Southern Uplands was from the south-east or the east-south-east. The ice which affected Area V, therefore, probably dispersed from several distinct centres that lay on the Southern Uplands (as suggested by Geikie (1901)). The centre which exerted most influence was around the head of the Afton valley.

6.4: Glacial Deposition

The glacial deposits of Area V are not as widespread as in other areas of central Ayrshire. Till outcrops at the northern, western, southern and eastern extremities but between these extremes its distribution varies considerably depending upon the amount of peat, alluvium or solid rock at the surface (Fig. 6.4). In the north-western part of the area, till is the most common surface material (Fig. 6.4). Very few outcrops of solid rock protrude through the till cover, and surface peat accumulations are of limited extent. However, extensive alluvium deposits are a characteristic feature of this part of Area V; the Nith and the Lane valleys are the main areas of alluvium accumulation (Fig. 6.4). Limited accumulations of sands and gravels also interrupt the surface distribution pattern of the till, though till is always found to underlie these sands and gravels. The main concentration of this mantle of sand and gravel is along the lower slopes of the valleys of the Blackloch Burn and the River Nith (Fig. 6.4).

Fig. 6.5 Ice Movements from the Southern Uplands - Eyles et al, 1949.

Till outcrops in the south-eastern part of the area are confined to the lower hill slopes and valley bottoms. The steeper and higher parts of the hills are, without exception, either peat covered or have no cover at all and the bare rock is exposed (Fig. 6.4). However, till is present in the valleys upto a maximum altitude of 580m. O.D. at which it thins out and eventually disappears.

The maximum thickness of till revealed by boreholes and exposures is I5m.. Till thicknesses of this magnitude are mainly confined to the north-western part of the area. Due to the abundance of greywackes, shales and igneous rocks which underlie Area V, the colour of the till is commonly grey or blue/grey. The grey till usually has a gritty texture, which is a reflection of the greywackes and igneous rocks from which it is derived. The blue/grey till is usually clayey, which is a reflection of the argillaceous texture of the Carboniferous shales from which it is derived. This gritty, grey till often contains large angular clasts over Im. long whereas the clayey blue/grey till rarely contains clasts over 20m. long. The only exception to the general grey colour of till is around Dalgig Quarry (Fig. 6.4). This is associated with a small outlier of Old Red Sandstone age sandstone which has given rise to a brick-red till in close proximity to the outlier.

Previous work in the area suggests that till is exposed everywhere as a single unit and that it was deposited by ice which originated in the Southern Uplands (Eyles et al, I949). However, a notable exception has been found near Fordmouth (Fig. 6.4, Site 6c) where not two but three, distinct till units have been identified. All other exposures of till in Area V are represented only by a single unit of till which rests directly on disintegrated bedrock.

Although the characteristics of the till found in Area V are less variable than in other areas of central Ayrshire, detailed examinations were completed at various sites in order to indicate the origin and former direction of movement of the ice by which it was deposited. Seven exposures of till were examined in detail for this purpose (Fig. 6.4, Sites 6a-6e) and the results are summarised in Figs. 6.4, 6.6, 6.8, 6.9, 6.IO and Table 6A. The sections where these analyses (which include particle-size analyses, preferred-stone orientations and erratic counts) were completed are upto I5m. thick and almost vertical. In all cases, except one at Dalgig Quarry, the exposures had been produced by stream erosion.

Site 6a is near the western extremity of the area in the valley of the River Nith (Fig. 6.4). This section is I5m. thick and composed entirely of grey, gritty/sandy till. A preferred-stone orientation, erratic count and particle-size analysis were completed at this site. A sample of 50 stones from this till had their orientation and angle of dip recorded. From these data a mean orientation of stones of 22° was calculated (Figs. 6.4, 6.6; Table 6A). A chi-square value of 6.89 was also calculated which, when tabulated with 8 degrees of freedom, is not statistically significant at any level of confidence. A dip-strength of 0.08 was also calculated from these data which, when tabulated with I dgree of freedom, is not statistically significant at any level of confidence. No suggestion of the direction of movement of the ice by which this till was deposited is indicated from these results. The erratic count may be of more use in indicating the direction of ice movement and the origin of the ice.

22% of the stones contained within this till are of local origin, which in this case is intrusive igneous rock. The remaining 78% of the stones are greywackes. These greywackes outcrop to the south of this site on the south-eastern side of the Southern Uplands Fault. The proponderance of Southern Upland rock-types contained in this till, which lies 2 km. north of the Southern Uplands Fault, is a strong indication that the ice by which it was deposited originated in the higher ground of the Southern Uplands and therefore moved from south to north.

The particle-size analysis results (Table 6A) show that over half the bulk weight of this till is within the sand size range. The proportion of gravel is relatively small for a Southern Upland till but this may be due to any one, or a combination, of four factors highlighted by Anderson (I957):- a) Lithological properties especially those affecting durability in the sand and pebble sizes; b) distance from source; c) rate of comminution; d) dominant type of bedrock erosion. However, there is no doubt that the till is of Southern Upland origin. This emphasises one of the major difficulties which arises when identifying the origin of the ice-mass which deposited any particular till from its internal characteristics; because of unknown processes, a particular characteristic may not be discernable. This should not rule out a precise origin for a till as

TABLE 6A

Till characteristics in Area V

	Nith Bridge Site 6a	Dalgig Quarry Site 6b	Fordmouth Till 1 Site 6c	Fordmouth Till 2 Site 6c	Fordmouth Till 3 Site 6c	Afton Water Site 6d	Muirfoot Burn Site 6e
Mean stone orientation	22^{o}	161^{o}	193^{o}	175^{o}	351^{o}	292^{o}	335^{o}
Chi square	6.89	12.27	19.5	18.29	14.77	24.92	19.5
Dip strength	0.08	6.48	0.32	9.68	0.8	3.88	5.12
% Gravel	12.35	8.92	15.07	23.21	46.52	39.89	9.44
% Sand	53.06	34.02	39.89	34.54	24.28	27.33	47.29
% Silt/Clay	34.59	57.06	45.23	42.25	29.20	32.78	43.27
% Local rocks	22	90	88	100	24	24	60
% Highland rocks	0	0	6	0	0	0	0
% Southern Upland rocks	78	10	0	0	76	76	40
% Unidentifiable rocks	0	0	6	0	0	0	0
Shell fragments	No	No	Yes	Yes	No	No	No

TILL FABRICS FROM AREA V

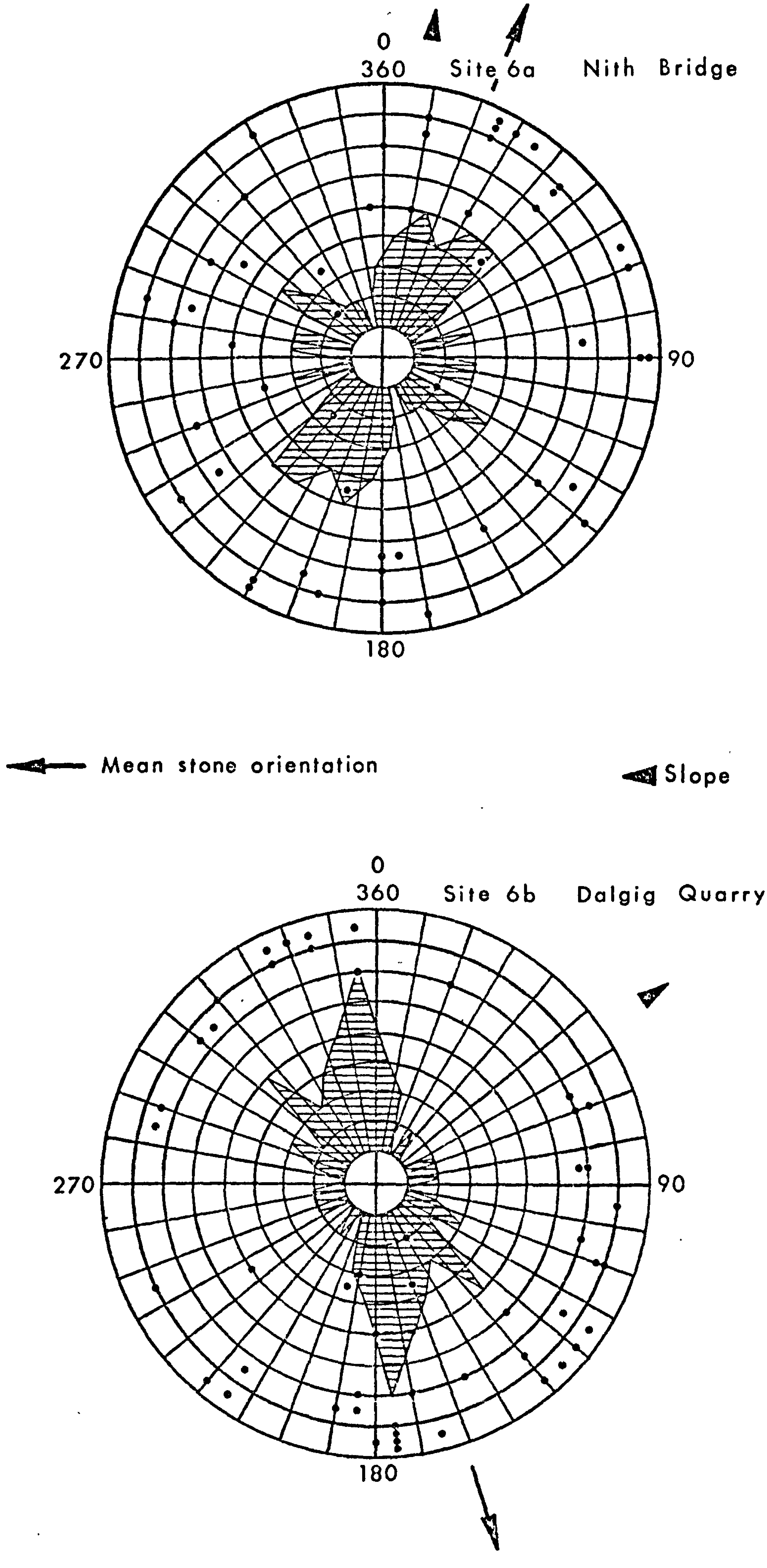


FIG. 6·6

a combination of characteristics will best indicate its origin. It is considered, therefore, unwise to suggest the origin of any till deposit upon the presence or absence of only one characteristic.

Site 6b is the only exposure of till in Area V which is not revealed by the erosive action of a stream. This IOm. thick section of brick-red, clayey till is at Dalgig Quarry in the north-western part of the area (Fig. 6.4). However, towards the bottom of the exposure, the till becomes increasingly blue in colour. Most of the clasts contained within this till are very small and rarely exceed I5 cm. in length. However, occasionally huge blocks of brick-red sun-cracked, Barren Red Measure micaceous sandstones, marls and shales are included. These blocks exceed 2m. in length. It is these Barren Red Measure sandstones, marls and shales which underlie this part of Area V that has given this till its brick-red colour.

From a preferred-stone orientation analysis a mean orientation of I6I° was calculated (Figs. 6.4, 6.6; Table 6A), for which a chi-square value of I2.27 was calculated which, when tabulated with 8 degrees of freedom, is not statistically significant at any level of confidence. A dip-strength value of 6.48 was also calculated from these data. When tabulated with one degree of freedom this shows that a statistically significant difference exists between the number of stones which dip towards the mean and the number of stones which dip away from the mean (at the 95% level of confidence) (Fig. 6.6, Table 6A). This evidence indicates that the ice by which this till was deposited generally moved from the south.

A count of the rock-type of the stones contained within this till, based upon a random sample of 50 stones, revealed that 90% are of local origin (i.e. Barren Red Measure sandstones, marls and shales) and the remaining IO% are of Southern Upland origin. These proportions are indicative of a Southern Uplands origin for the ice by which this till was deposited. However, a particle-size analysis shows this till to contain 57% silt/clay (hence the quarry for the Afton Brick Works), 34% sand and only 9% gravel (Table 6A). The proportions are not characteristic of Southern Upland tills - or even Highland tills - which ususally have higher gravel and sand contents. It is understood that the colour, the large proportion of local rock-types and silt/clay in this till emphasises the important control the underlying bedrock has upon the overlying till characteristics. Dreimanis and Vagners (1969) qualify this conclusion as follows: "... in areas of soft bedrock, and in situations where new material is added to the glacial drift after only short distances of transport and has therefore suffered little comminution, local materials may predominate in tills" (p. 97).

Site 6c is the most interesting in the whole of Area V. This section has been produced by the erosive action of the River Nith and is situated in the north-central part of the area 3 km. north-north-west of New Cumnock (Fig. 6.4). This exposure, which is 15m. thick reveals three till units (Fig. 6.7, Plates 6E, 6F, 6G, 6H). All three till units were examined in detail in order to highlight any differences between them and also to suggest the origin and direction of movement of the ice which deposited them (Figs. 6.8, 6.9; Table 6A). Two of the till units (Till 2) and Till 3)) outcrop at the surface and one till unit (Till 1)) exists below the surface (Fig. 6.7).

The two tills which outcrop at the surface have dissimilar appearances. Till 3), which overlies Till 2), (Fig. 6.7) is grey, has a sandy/gritty texture and contains many large sub-angular clasts. Till 2) is brown and has a sandy texture and although large clasts do exist in its mass, they are comparatively rare.

From the analysis of the preferred orientation of stones in Till 3) a mean orientation of 351 was calculated (Figs. 6.4, 6.8; Table 6A). A chi-square value of 14.77 was calculated for this mean orientation which, when tabulated with 8 degrees of freedom, is not statistically significant at any level of confidence. From these data a dip-strength value of 0.8 was also calculated. When tabulated with 1 degree of freedom this is also not statistically significant at any level of confidence. These results are of little use in indicating the former direction of movement of the ice by which this till was deposited.

A random sample of 50 stones was selected in order to identify rock-types. This analysis showed that 24% of the stones are of local origin and that the remaining 76% are of Southern Upland origin. No Highland rock-types or shell fragments exist in Till 3). These results are a strong indication that the ice which deposited this till originated

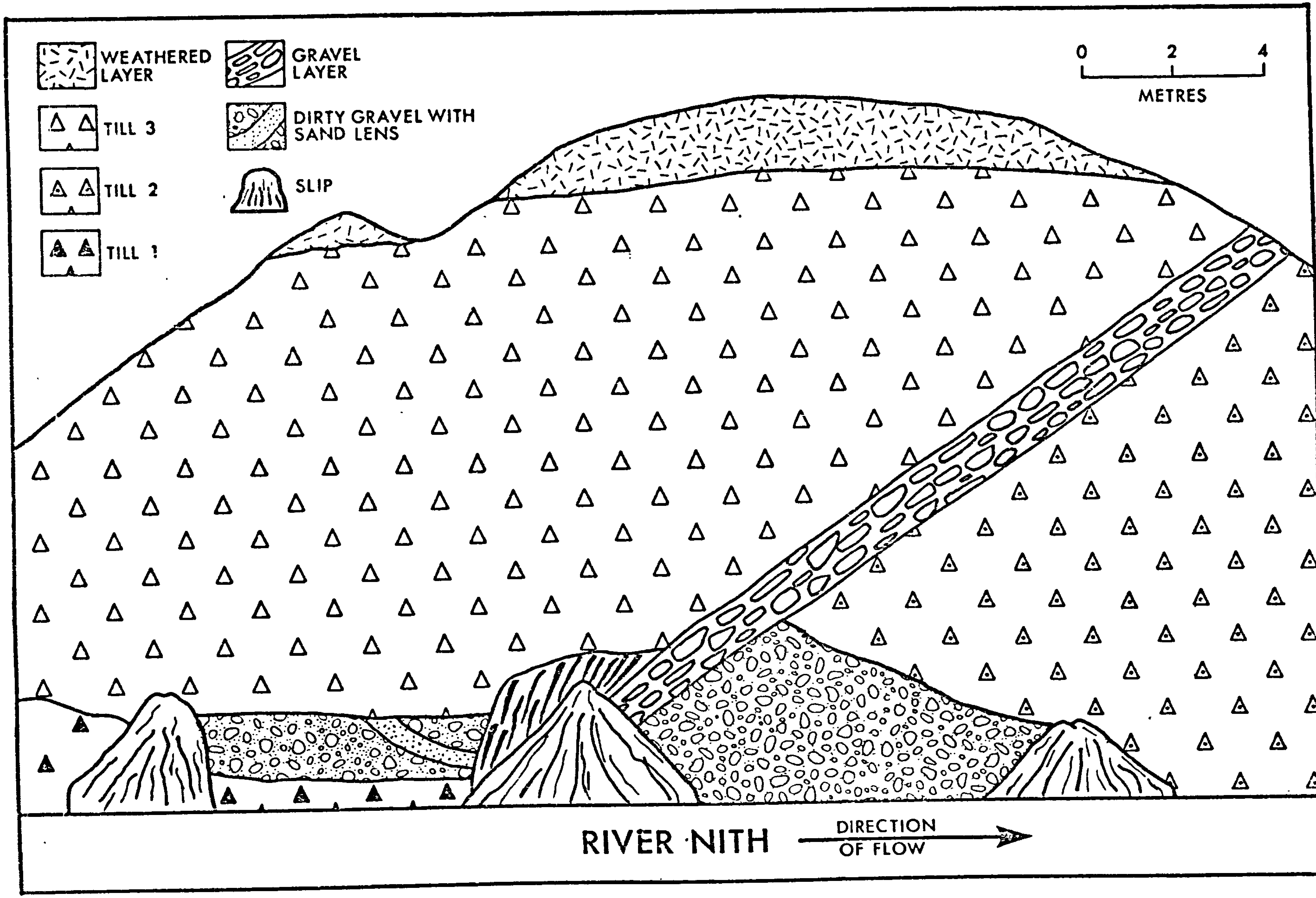
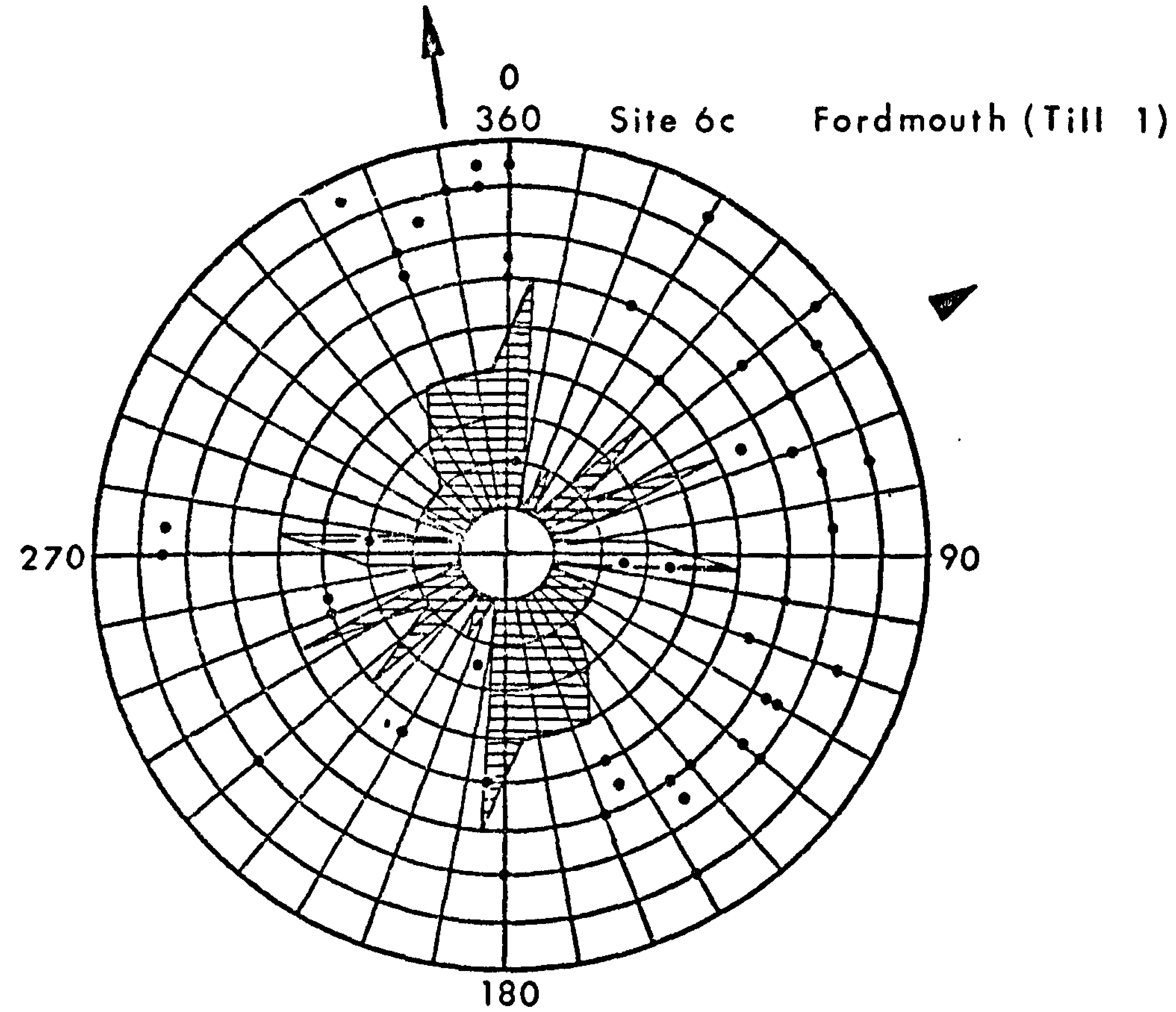


Fig. 6.7 Stratigraphy at the Fordmouth Exposure (Site 6c).

Plates 6F, 6G, 6H   Stratigraphy of the Exposure near Fordmouth - Site 6c

TILL FABRICS FROM AREA V



Mean stone orientation

Slope

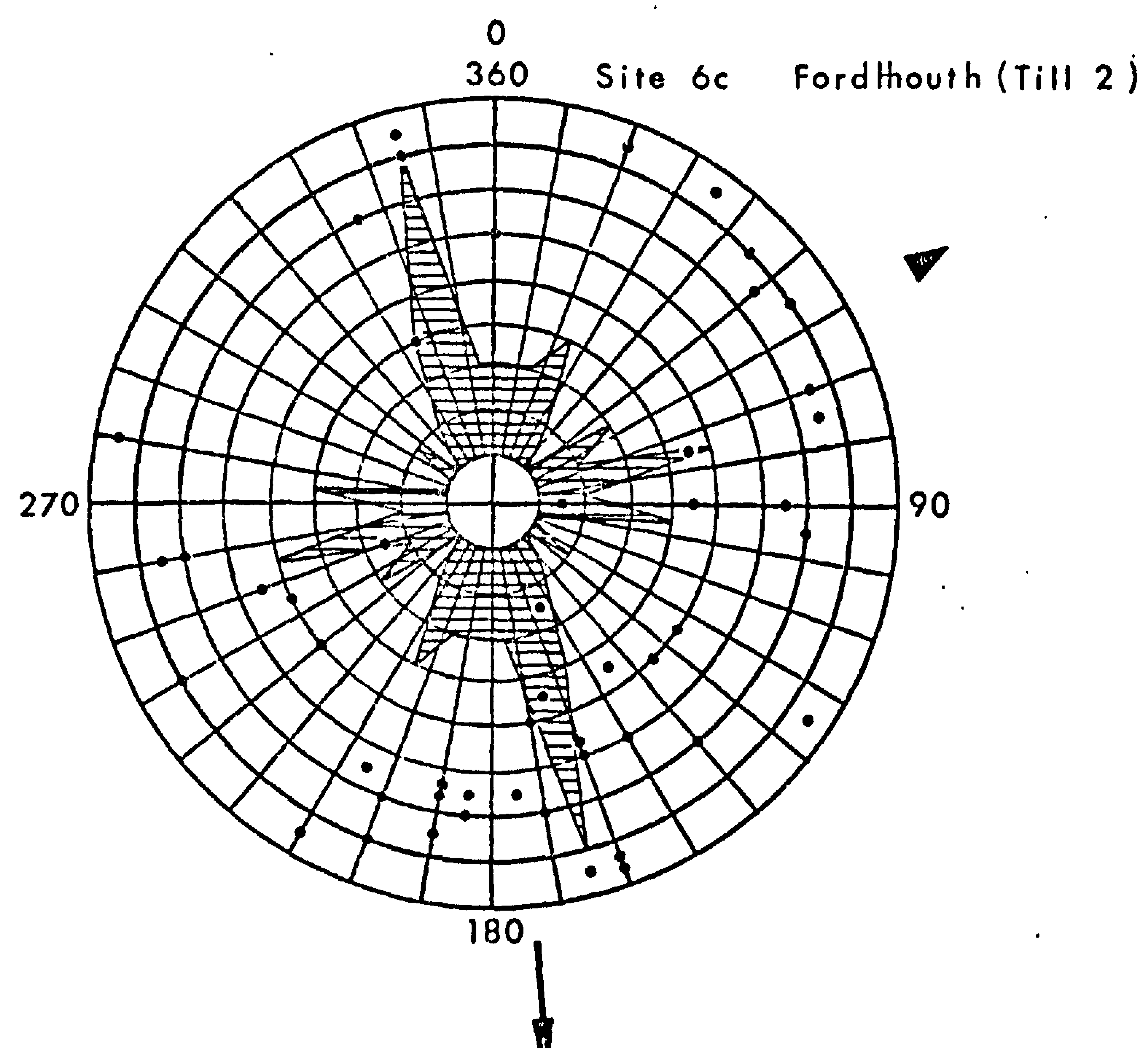


FIG. 6·8

in the Southern Uplands and so the ice would have moved from a generally southern direction.

The relative proportions of gravel, sand and silt/clay in Till 3) are 46.5%, 24.3% and 29.2% respectively. This high proportion of gravel is considered to be an indication of a Southern Upland till (Ch. 5).

The detailed study of Till 2) included a preferred-stone orientation analysis. From a sample of 50 stones a mean orientation of I75° was calculated (Figs. 6.4, 6.8; Table 6A). A chi-square value of I8.29 was calculated for this mean stone orientation which, when tabulated with 8 degrees of freedom, is statistically significant at the 95% level of confidence. A dip-strength value of 5.I2 was also calculated from these data. This value, when tabulated with I degree of freedom, is statistically significant at the 95% level of confidence. These results are a strong indication that the ice by which Till 2) was deposited moved either from the north or the south.

50 stones selected at random from the till were examined in order to establish their rock-type. The results of this analysis show I00% to be of the local Carboniferous rock-types. No Southern Upland or Highland rock-types exist in Till 2), but small scratched shell fragments are quite common. This evidence is interpreted as a clear indication that the ice by which this till was deposited originated to the north in the Highlands.

A particle-size analysis shows the relative proportions of gravel, sand and silt/clay to be 23.2%, 34.5% and 42.3% respectively (Table 6A). These proportions are significantly different from the particle-size proportions of Till 3). In fact, most of the characteristics of the two tills differ considerably. This strongly suggests that the two tills were deposited by separate ice-masses; Till 2) was deposited by an ice-mass of Highland origin which moved generally from the north, and Till 3) was deposited by a Southern Upland ice-mass which moved from the south. Based upon stratigraphical considerations, the Southern Upland ice-mass was the last to occupy this part of Area V, although it had previously been occupied by Highland ice. This is the only stratigraphical evidence in the whole thesis area which clearly shows the relative chronology of the movements of Highland and Southern Upland ice.

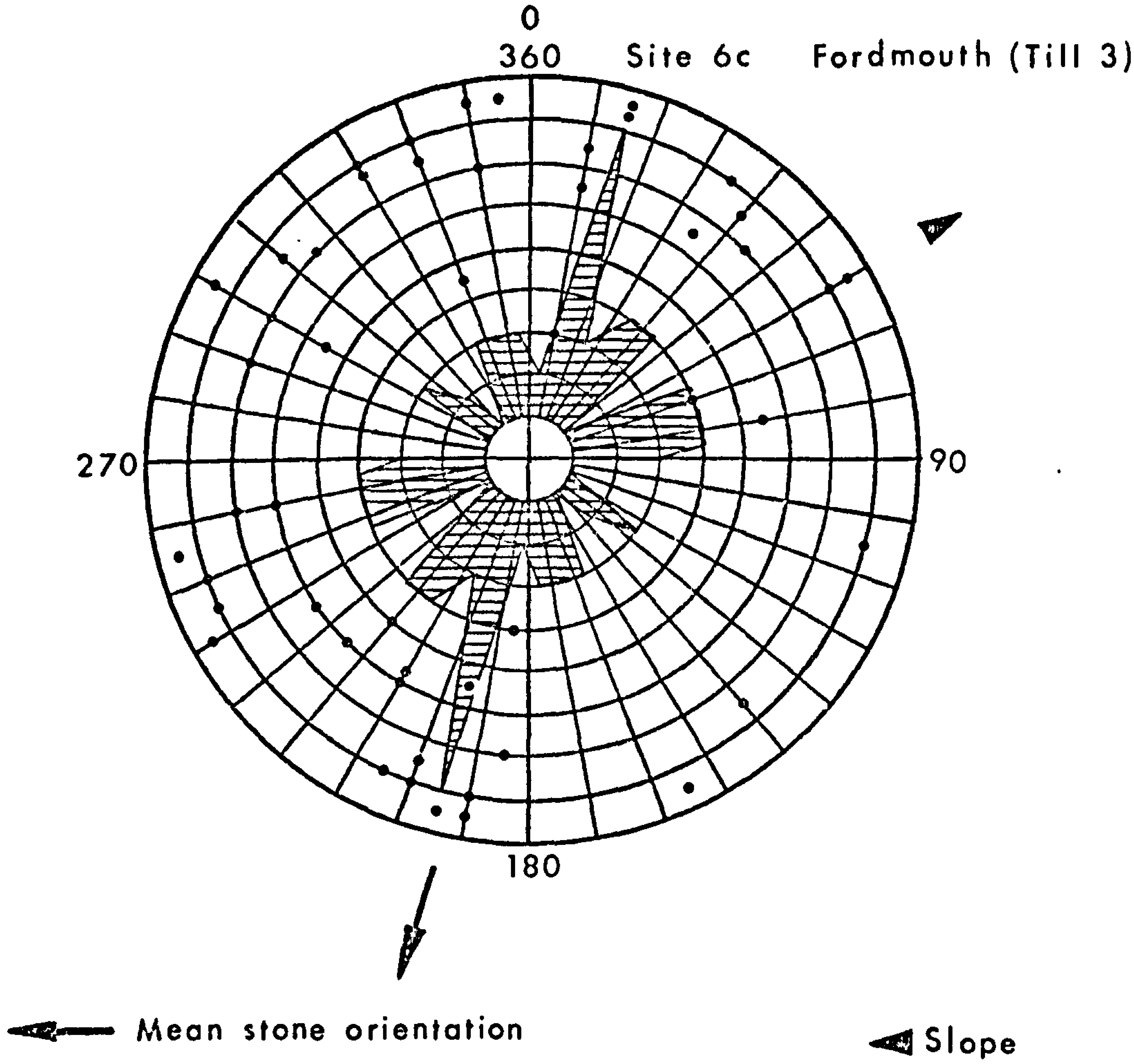
The oldest till unit (Till I)) exposed at Site 6c is purple in colour, very stiff and has a sandy texture (Fig. 6.7). Detailed analyses of this till were completed in order to highlight any differences it may have from Tills 2) and 3). These analyses were also completed in order to indicate the origin and direction of movement of the ice by which Till I) was deposited.

A sample of 50 stones was selected from this till of which the direction of orientation and angle of dip was recorded. From these data a mean orientation of stones of I93^{o} was calculated (Figs. 6.4, 6.9; Table 6A). This mean orientation has a chi-square value of I9.5 which, when tabulated with 8 degrees of freedom, is statistically significant at the 95% level of confidence. A dip-strength value of 0.32 was calculated from these data but, when tabulated with I degree of freedom, this is not statistically significant at any level of confidence. From these results it is likely that the ice by which Till I) was deposited moved from either the north or the south.

From a random sample of 50 stones selected from Till I) in order to identify rock-types, 88% are of local origin, 6% are of Highland origin and 6% are unidentifiable. This evidence strongly suggests that it was deposited by Highland ice which moved from the north. An analysis of the relative particle sizes of TillI) shows that I6.I% is gravel, 38.8% is sand and 45.I% is silt/clay (Table 6A). This relatively small proportion of gravel may be interpreted as an indication that this till is not of Southern Upland origin; it must therefore be of Highland origin. However, this evidence is not regarded as conslusivo.

A detailed analysis of a till deposit has also been completed at Site 6d which is I km. south of New Cumnock (Fig. 6.4). This exposure, which is in the valley of the Afton Water, is IOm. thick and composed entirely of grey, gritty/gravelly till. A preferred-stone orientation analysis, based upon a sample of 50, reveals that the mean orientation is 292^{o} (Figs. 6.6, 6.9; Table 6A). This has a chi-square value of 24.92 which, when tabulated with 8 degrees of freedom, is statistically significant at the 99% level of confidence. A dip-strength value of 3.88 was calculated from these data. When tabulated with Idegree of freedom this value is statistically significant at the 95% level of confidence. These results, therefore, strongly indicate that the ice by which this till was deposited moved from either the north-west or the south-east.

TILL FABRICS FROM AREA V



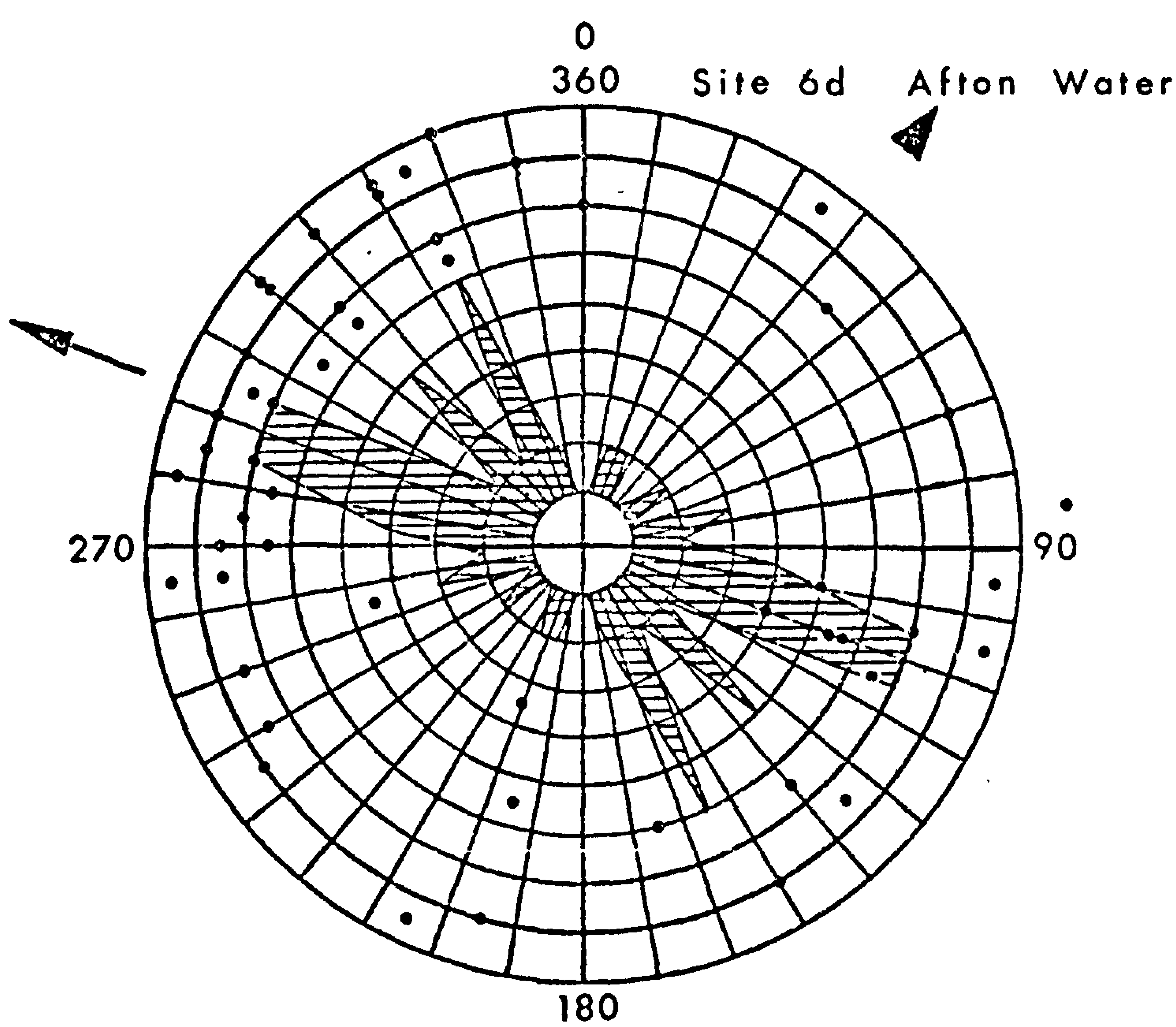


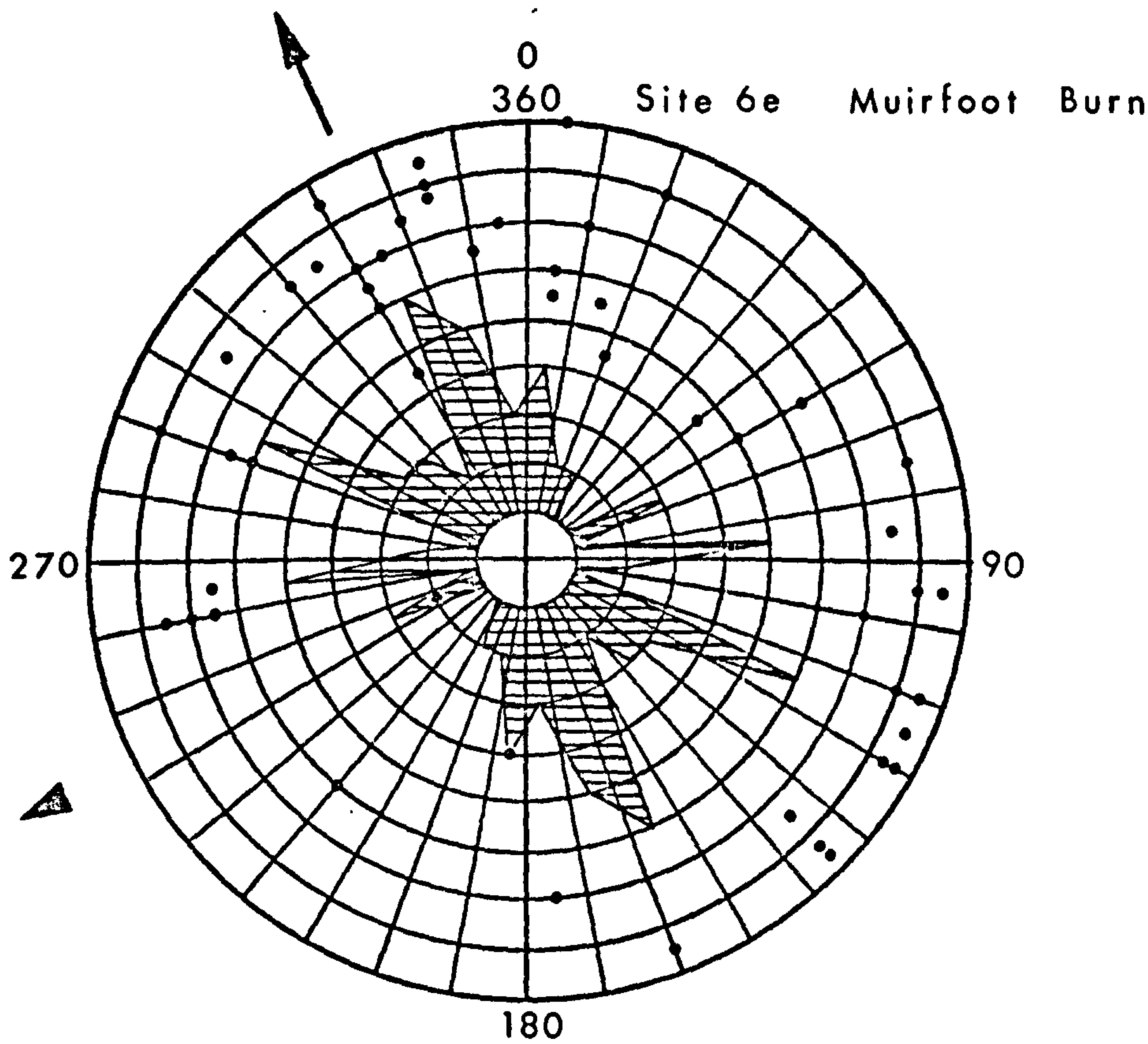
FIG 6.9

The identification of the rock-type of 50 stones contained within this till was completed in order to indicate the direction of ice movement. It revealed that 24% of these stones are of local origin and the remaining 76% are of Southern Upland origin. No Highland erratics or shell fragments are contained. An examination of the relative proportions of gravel, sand and silt/clay in the till shows them to be 39.9%, 27.3% and 32.8% respectively. The high gravel content, and the high content of Southern Upland rock-types, strongly suggest the ice by which this till was deposited originated in the Southern Uplands and moved from the south-east probably along the Afton valley.

The final detailed analysis of a till in Area V was completed at Site 6e 2 km. north-north-east of New Cumnock (Fig. 6.4). This exposure, which is in the valley of the Muirfoot Burn, reveals an 8m. thickness of blue/black till which has a sitly/sandy texture. A sample of 50 elongated stones was selected for a stone orientation analysis. From the resultant data a mean stone orientation of 335^{o} was calculated (Figs. 6.4, 6.10; Table 6A). This has a chi-square value of 19.5 which, when tabulated with 8 degrees of freedom, is statistically significant at the 95% level of confidence. From these data a dip-strength value of 5.12 was also calculated. This value, when tabulated with 1 degree of freedom, is also statistically significant at the 95% level of confidence. These results are a strong indication that the ice by which this till was deposited moved either from the north-north-west or the south-south-east.

An analysis of the rock-type of the stones in this till shows that 60% are of local origin and the remaining 40% are of Southern Upland origin. No Highland rock-types or shell fragments exist in this till. This is strong evidence that the ice by which it was deposited originated in the Southern Uplands and hence moved from a generally south-south-easterly direction. However, this conclusion is not supported by the examination of the particle-sizes which comprise the till. The proportions of gravel, sand and silt/clay are 9.4%, 47.3% and 43.3% respectively. This till, therefore, does not have the relatively large proportion of gravel which characterises other tills of Southern Upland origin (Sites 6a, 6c, 6d). However, this characteristic (which was also a feature of the till at Dalgig Quarry (Site 6b)) is considered to reflect the under-

TILL FABRICS FROM AREA V



Mean stone orientation

Slope

FIG. 6 10

lying fine-grained, dark-coloured shales typical of this part of Area V.

The examination of every other till exposure in Area V concentrated on establishing the presence or absence of Highland erratics and shell fragments and Southern Upland erratics. All other exposures reveal only grey, gritty till charged with Southern Upland erratics. Nowhere in Area V can Highland erratics or shell fragments be found in a till except at Site 6c. However, a notable trend in till characteristics does exist in Area V; the till becomes greyer, more gritty and more heavily charged with Southern Upland rock-types towards the south and east of the area. It is possible to indicate the origin and former movements of the ice which occupied Area V from the study of the internal characteristics of the till exposures (Fig. 6.4). All the area, except for a small part in a north-central position, was occupied by Southern Upland ice only, which moved generally from the south-east. The small part of the area in this north-central position was also occupied by Southern Upland ice, but only after it had been occupied by Highland ice which moved from a northerly direction. This pattern of movement is similar to that suggested for parts of Areas II, III and IV.

The till deposits in Area V do not display the drumlin landscape that is characteristic of some parts of the thesis area. This is hardly surprising because it is the area of central Ayrshire which has the highest altitude (lowest altitude = 185m. O.D.) and as Sugden and John (1976) suggest: "They (drumlins) occur for the most part in lowland situations ..." (p. 266).

Area V, however, does have a small part which is characterised by moundy morphology. This is located on the eastern side of the valley of the Craig Burn near the south-eastern extremity of the area (Fig. 6.4, Plates 6I, 6J). Individually,these mounds are steep-sided, sharply defined features upto 10m. high and 150m. in diameter. Their steepest side is confined to the western side of the mound - the eastern side often merging imperceptibly in the valley slope. Very few of these mounds are elongated in any particular direction. However, when taken as a whole,they have a distinct orientation parallel to the valley (i.e. north-north-west to south-south-east). This orientation is visible as two ridges at different altitudes:- the higher ridge begins at approximately 448m. and

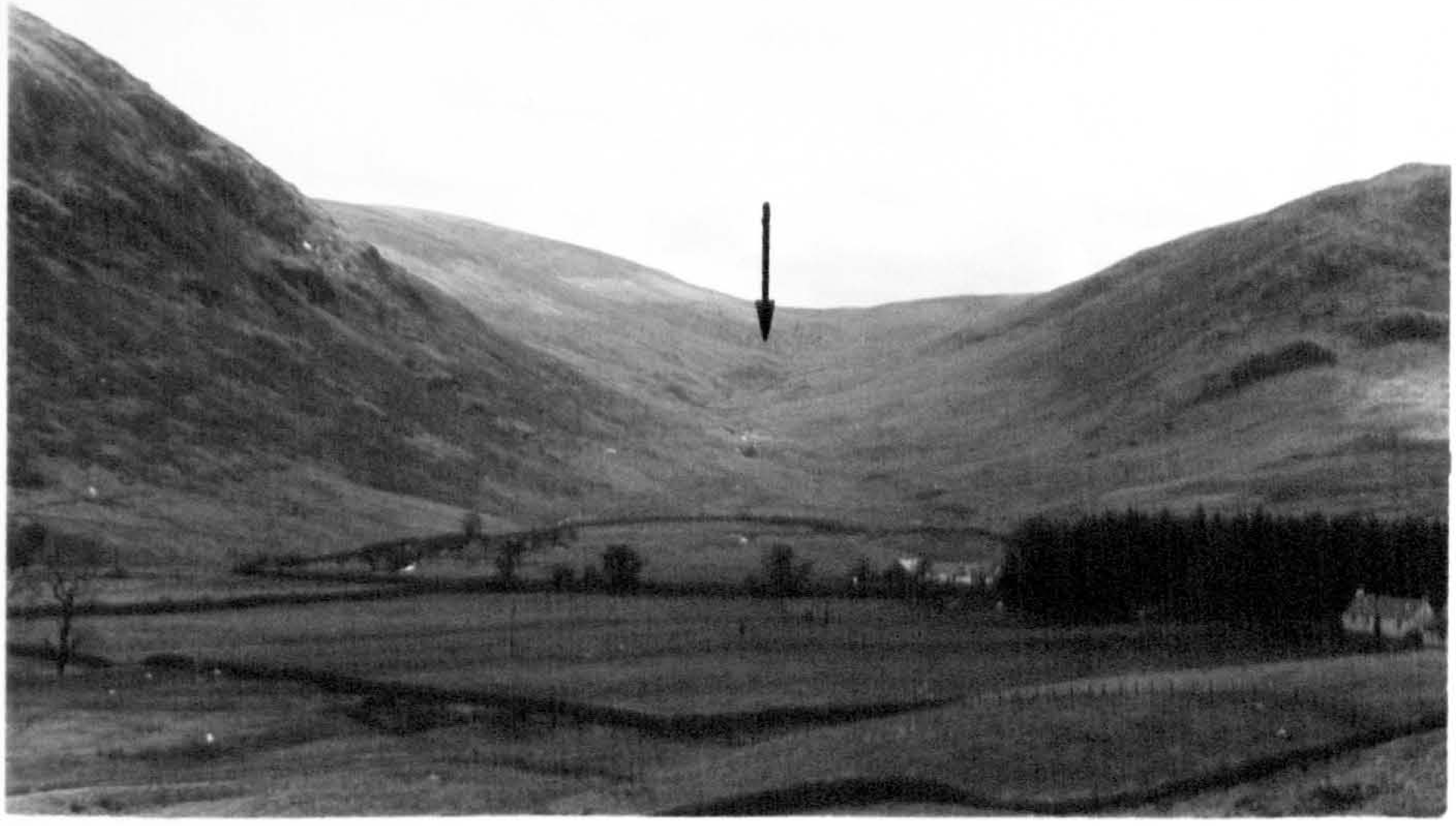


Plate 6I Position of the Lateral Moraines in the Valley of the Craig Burn

Plate 6J Detail of the Morphology of the Lateral Moraines in the Valley of the Craig Burn stretches down to approximately 375m.; the lower ridge begins at 430m. O. D. and terminates at 363m. O.D..

A part of Area V with a similar morphology was also mapped from air photographs, in the valley of the Montraw Burn south-south-east of this point. This could not be mapped on the ground due to the extensive forests that have been planted since the air photographs were taken. However, this 'moundy' spread was at a slightly higher altiude (approximately 460m.), but was again confined to the eastern side of the valley. A poorly developed moundy spread also exists in the Afton valley but, due to the construction of a dam and forestry planting, it is not clearly seen on the ground.

An exposure (Site 6f; Fig. 6.4; Plate 6K) at the northern extremity of the 'moundy' ridges in the Craig Burn reveals the following stratigraphy:-

Site 6f	Craig Burn	Fig. 6.4	I250'm. O.D.
2	Brown angular gravel. Weathered		2½m.
I	Grey till		½m.

The brown angular gravel is coarse, unsorted and unstratified. The clasts, which average 30 cm. in diameter but are commonly over 75 cm. in diameter, are entirely of Southern Upland rock-types and many are severely weathered. The lower stratigraphical unit is a Southern Upland till, grey, gritty and containing only Southern Upland rock-types. The clasts in this till are rarely weathered to any significant degree.

This description closely resembles the description of lateral moraines recorded by many workers (Sissons, I967b, Price, I973 and Sugden and John, I976): "... lateral moraines form successive parallel steps and ridges along the lower slopes of the valley side" (Sissons, I967b, p. 95). Although these ridges were probably formed along the lateral margins of the valley glacier which occupied the Craig valley, the process of formation is not clearly understood, as Price (I973) explains: "However, there is considerable debate about the percentage of material that is derived from weathering and mass movement on the rock walls above the glacier and material derived from the glacier itself. The increased steepness of the surface of the ice towards the valley wall is a common feature on valley glaciers and there is a natural zone of accumulation in the trough formed between the glacier and the valley wall. Dumping of

Plate 6K Exposure in the Lateral Moraines in the Valley of the Craig Burn material that has been transported on and in the glacier certainly plays a part in the construction of these moraines." (p. 84). This valley side, which has a westerly aspect, would have been conducive to the formation of lateral moraines by the dumping of material (Sissons, 1967b).

Whatever the process of formation of these lateral moraines, it is generally argued that similar high altitude moraines in the Southern Uplands are of Zone III (Loch Lomond readvance) age as Sissons (1967b) explains: "The glaciers of the Loch Lomond (Zone III) stage varied considerably in size and character ... Many in the northern Highlands, central and eastern Grampians, Southern Uplands and islands were a few miles long and flowed out radially from higher mountains" (p.139). There is no reason to disagree with this accepted view. In fact, the lack of corries at the head of the valleys of the Craig Burn, Montraw Burn and Afton Water and the presence of glacially-breached cols provides strong support for Sisson's (1967b) view (Fig. 6.II). The direction of ice movement during Zone III stage was probably similar to ice movement in earlier stages - though this is not necessarily the case (Sissons, 1967b).

Indications concerning the origin and former directions of movement of the ice which occupied Area V from the study of the glacial deposits is entirely consistent. Most of the area has only been affected by ice which originated in the Southern Uplands and moved from a generally south-easterly direction. However, at least one part of the area was affected by Highland ice, which flowed from the north, before the last advance of the Southern Upland ice. This is in the north-central part of Area V. In the south-eastern extremity, strong evidence exists to suggest that the Southern Upland ice movement consisted of two phases. In Area V, therefore, there may be evidence for four separate glacial stages during the last glaciation:-

I) Highland ice moved from the north and deposited the lowest till (Till I)) at Site 6c at Fordmouth.

2) Highland ice also deposited Till 2) at Fordmouth. This may represent nearby bedrock influence rather than a separate phase of ice movement.

3) The pressure exerted by the Highland ice-mass relaxed (or the pressure exerted by the Southern Upland ice-mass increased) and allowed the Southern Upland ice-mass to advance from the south-east and

Fig. 6.11 Loch Lomond Re-advance limits around the Head of the Afton Valley.

deposit till extensively throughout Area V. The exposure of Southern Upland till at Fordmouth (Till 3)) is one of the most northerly examples of this deposition in Area V and the only example where Southern Upland till and Highland till may be seen in direct association.

4) The Southern Upland ice-mass either halted during retreat and readvanced or it disappeared completely and advanced again in order to deposit the moraines in the valleys of the Craig Burn, Montraw Burn and Afton Water during Zone III times.

6.5: Fluvioglacial Erosion

Landforms produced by the processes of fluvioglacial erosion are not well represented in Area V. Only 9 channel systems have been identified in the area and they are all confined to the northern part (Fig. 6.4). These meltwater channels have a range of sizes from 200m. long and 5m. deep to over 800m. long and 15m. deep. The size of these features is often an indication of the material into which they were eroded; small channels were usually eroded into unconsolodated material and large channels were usually eroded into solid rock. Four of the channel systems were eroded into solid rock and the remaining five were eroded into unconsolodated material.

Channel system 9, which has the highest altitude of any of the meltwater channels in Area V (427m.), is located in the north-eastern extremity of the area to the north-east of Corsencon Hill (Figs. 6.4, 6.12). This meltwater channel system was eroded entirely into solid rock and as a result it has well-defined, steep sides 7m. deep and a broad, flat floor 6m. wide. The system has four constituent parts:-

a) a common intake channel 120m. long situated at its west-north-west extremity;

b)&c) this common intake channel bifurcates into two parallel channels approximately 530m. long;

d) a short tributary channel which leads into the northernmost parallel channel (Figs. 6.4, 6.12).

Fig. 6.12 Channel System 9 - Area V.

This system, which has a total length of 650m. and a west-north-west to east-south-east orientation, has a humped-profile. Its common intake channel begins at an altitude of 415m. O.D. and for 100m. of its course it slopes towards the west-north-west. It reaches a maximum altitude of 427m. O.D. close to its point of bifurcation. The remaining 550m. of the system (and hence the whole lengths of the two parallel channels) slopes towards the east-south-east and reaches a lowest altitude of approximately 381m. O.D.. The northernmost of the two parallel channels is joined approximately half way along its course by a small tributary channel which slopes to the south (Figs. 6.4, 6.12). This tributary channel is 3m. wide and 3m. deep and therefore it does not reach the floor of the main channel; it is, in effect, a "hanging" channel.

The description of channel system 9 shows many similarities to the description of subglacially eroded meltwater channels (Mannerfelt, 1945, 1949; Price, 1960, 1963; Clapperton, 1968). The direction of meltwater flow which eroded these channels was from a west-north-westerly direction. The humped-profile may be explained by subglacial meltwater which flowed under hydrostatic pressure. The study of the tributary channel also suggests that meltwater entered this system from the north.

The west-north-west to east-south-east slope of this channel system may reflect the ice gradient in this part of Area V, although this is not always reliable. What is reliable, however, is that ice filled this part of Area V upto a minimum altitude of 427m. O.D..

Channel system 3, which is 1 km. south-east of Burnfoot, was also eroded into solid rock (Fig. 6.4). This system comprises three individual channels, the maximum dimensions of length, depth and width are 480m., and 5m. respectively. The most westerly and central channels both slope towards the north-east and the most easterly in this system slopes towards the north (Fig. 6.4). Each of these channels displays the characteristic steep-sided, broad, flat-floored features of meltwater channels, and they are all dry. They all have their intakes around 259m. O.D. and their lowest points around 236m. O.D.. The direction of flow of the meltwater by which they were eroded was from the south-west and south.

Channel system 4, which is in a north-central position in relation to Area V as a whole, has part of its course eroded into solid rock and part eroded into till (Fig. 6.4). It is 800m. long, has a humped-profile and is orientated north-west to south-east. The humped-profile effectively cuts it into two distinct parts. The north-western half was cut into till and as a result it is not a sharply defined feature; it is 7m. deep and 6m. wide. This half of the channel system slopes towards the north-west to its lowest altitude of 700m. O.D.. The south-eastern half of the system was eroded into solid rock and its form is much more characteristic of a meltwater channel. It has sharply-defined, steep sides I5m. deep and a broad, flat floor which is, at a maximum, I5m. wide. Towards its south-eastern extremity the channel curves slightly to the south before it terminates at Lochill (Fig. 6.4). This terminus of the channel marks the beginning of a fluvioglacial spread of sand and gravel which occupies a considerable area of the lower slopes of the valley of the Blackloch Burn. The south-easterly slope of this part of the channel is from a maximum altitude of 223m. O.D. to a minimum of I98m. O.D..

The features of this meltwater channel system and the close proximity of its south-eastern extremity to a fluvioglacial spread suggest that it was eroded by meltwater which flowed subglacially under hydrostatic pressure from a north-westerly direction.

Channel 5, which is situated I km. south-west of New Cumnock, is the only other meltwater channel in Area V eroded into solid rock (Fig. 6.4). This channel is orientated in a north-east to south-west direction; it is 600m. long; it has a maximum depth of 7m. and a maximum width of 5m.. It has an asymmetrical cross-section with the south-eastern side upto 3m. higher than the north-western side. This feature slopes towards the north-east and at its lowest point terminates I00m. from the flood plain of the River Nith (Fig. 6.4). Channel 5 has an intake at an approximate altitude of I98m. O.D.. However, it has two points of outflow - one approximately half-way along its course at I92m. O.D. and the other at its north-eastern extremity at an altitude of approximately I86m. O.D.. Both these points of outflow face towards the north-north-east. From this evidence it seems likely that the meltwater which eroded this channel flowed from a south-easterly direction. It is not clear whether this flow was subglacial, submarginal or marginal.

Five channel systems have also been identified in Area V which were cut entirely into either till or sand and gravel (Channel systems I, 2, 6, 7 and 8, Fig. 6.4). Although the channels eroded into till are generally more distinctive than those eroded into sand and gravel, it is considered to be advantageous to group them together for description and discussion. The dimensions of these channels vary considerably but the maximum length is 600m.; the maximum width is 8m. and the maximum depth is 8m..

Three of the five channels have gradients which slope from south-west to north-east towards the floor of the valley of the River Nith or Blackloch Burn (Channels I, 2 and 8, Fig. 6.4). Channel 8 has a most distinctive form as it bifurcates and rejoins in its length of 400m.. Channel system 7, which lies on the northern side of the valley of the River Nith, has a gradient which slopes towards the south-east; again this is towards the floor of the Nith valley (Fig. 6.4). Channel 6 has a humped-profile with most of its length sloping towards the south-east and the floor of the Nith valley.

From these observations it seems highly likely that the meltwater which eroded all these channels into solid rock and drift, flowed from a generally western direction into the valley of the Nith.

6.6: Fluvioglacial Deposition

Evidence of fluvioglacial deposition in Area V is entirely confined to the lower slopes of the valleys of the River Nith and Blackloch Burn (Nith/Blackloch valley) (Fig. 6.4). The fluvioglacial deposits in the Nith/Blackloch valley are discontinuously exposed over a total length of 9.km.. Due to the lack of natural exposures, these deposits of sands and gravels have been delineated almost entirely upon morphological considerations and the examination of borehole records. The boundaries have been checked by the excavation of a series of pits which revealed the composition of the material which lies at the surface.

The deposits of fluvioglacial sands and gravels in Area V are entirely represented by IO individual spreads (Fig. 6.4). These spreads are upto I500m. long and rise to a height of IOm.. However, borehole records reveal that this height is no indication of the actual thickness of these deposits which average I6m.. The lower margin of each sand and gravel spread corresponds with the edge of the flood plain of the Nith/Blackloch valley. These steep lower margins are in contrast to the upper margins which merge, often imperceptibly, into the valley side. It appears, therefore, that these spreads of sands and gravels have been trimmed to some unknown extent.

The surfaces of the sand and gravel spreads have a nondescript form with an almost complete absence of the ridges and mounds which usually characterise fluvioglacial deposits (Embleton & King, I968; Price, I973; Sugden & John, I976). Only one of these spreads, which lies I km. east of New Cumnock (Fig. 6.4), includes an elongated ridge which is 250m. long and 5m. high at a maximum. This ridge, which may be described as an esker, is orientated in a west-south-west to east-north-east direction. This may indicate that the meltwater which deposited it flowed from either the west-south-west or east-north-east. With reference to the direction of meltwater flow revealed from the study of fluvioglacially eroded forms, it is considered more likely that the meltwater flowed from the west-south-west. However, a single esker ridge does not necessarily reflect the former direction of regional meltwater flow.

The patchy distribution and relatively limited extent of the sands and gravels in Area V may be due to a number of reasons:-

I) The fluvioglacial environment in Area V was not conducive to the deposition of characteristic sand and gravel forms. However, some of the characteristics of the meltwater channels which exist in close proximity to the fluvioglacial deposits in the Nith/Blackloch valley suggest that meltwater did flow in close association with the ice-mass. The esker ridge I km. east of New Cumnock proves this and that the meltwater was laden with debris. It seems likely, therefore, that environmental conditions were suitable for fluvioglacial deposition on quite a large scale - but only in the relatively low-lying Nith/Blackloch valley. Sugden & John (I976) suggest a reason for this:- "Generally .. these expanses of fluvioglacial landforms are related to mid-latitude ice-caps and ice sheets which have disintegrated rapidly by downwasting. They are less common in glaciated troughs in the uplands. This is partly because valley glaciers often remain active during retreat, inhibiting the survival of subglacial or englacial meltwater forms .." (p. 333).

2) If, as seems likely, extensive deposition of fluvioglacial features did occur on the lower slopes and floor of the Nith/Blackloch valley, subsequent erosion obliterated and altered its form and distribution considerably. Sugden and John (1976) describe the process: "Also meltwater features built on valley floors are often destroyed or buried by pro-glacial fluvial processes which have to operate on a relatively narrow floor." (p. 333).

This suggestion is particularly attractive because immediately downstream from Area V the flood plain is much narrower, and this is reflected in the extensive fluvioglacial forms above it on the lower slopes of the valley.

It is difficult to make firm conclusions concerning the former meltwater movements in Area V based upon the study of fluvioglacial deposits. One established point, however, is that the Nith/Blackloch valley did receive debris-laden meltwater which resulted in some deposition. It seems highly likely that this fluvioglacial material was considerably altered in form and distribution due to subsequent fluvial processes. Limited evidence in Area V does suggest that the general direction of flow of the meltwater was from west to east.

6.7: Conclusions

Evidence from the study of roches moutonées, striations, glaciated troughs, till deposits, meltwater channels and fluvioglacial deposits may be combined to produce a coherent pattern of the former ice movements across Area V. It is also possible from these studies to suggest from where the ice which affected the area originated and a relative chronology of events. Due to a lack of good evidence, conclusions concerning the mode of ice decay are more difficult to establish. The suggested pattern of events during the last glaciation for Area V are summarised as follows:-

1) Ice which originated in the Highlands and moved from the north occupied the north-central part of Area V and deposited Tills 1) and 2) at Fordmouth.

2) Ice which originated in the higher ground in the Southern Uplands, which lies to the south of Area V, built up and spilled over the

lowest pre-existing cols into the area. The lowest cols were at the head of the Afton valley. The ice eventually spillod over the watershed generally. This Southern Uplands ice then flowed from the south-east to occupy almost the whole of Area V before it met the Highland ice (Fig. 6.I3). The proximity of the Highland ice effectively prevented a free exit for the Southern Uplands ice. This caused it to thicken considerably and give rise to glacial diffluence - especially in the Afton valley. This "blocking" effect of the Highland ice also prevented severe glacial erosion by the Southern Uplands ice mass.

3) The pressure exerted by the Highland ice mass waned and the Southern Uplands ice mass advanced over part of Area V that had been previously occupied by Highland ice. The Southern Uplands ice extensively deposited the grey, gritty till characteristic of Area V, usually directly on top of bedrock but in the north-central part of the area near Fordmouth on top of Highland till.

4) Ice began to decay and, due to the relatively high altitude of the area, left very little evidence in the form of fluvioglacial deposits which help to establish the mode of decay of the ice. However, it seems highly likely that the Nith/BlackIoch valley was the only reception area for debris-laden meltwater which flowed from the west. Any extensive deposition of fluvioglacial sands and gravels which may have occurred as a result of this has been considerably altered in form and distribution due to the subsequent fluvial erosion and/or deposition.

5) Evidence exists which suggests a renewed phase of glacial deposition at high altitude in the south-eastern extremity of Area V. It is not certain whether this was during the last phase of glacial decay or whether ice had completely disappeared from the Southern Uplands and readvanced. It is considered that this renewed phase of glacial activity relates to the climatic deterioration which occurred in Zone III times (II,000 to I0,000 radiocarbon years B.P.) (i.e. Loch Lomond readvance times).

6) The ice completely disappeared from Area V.

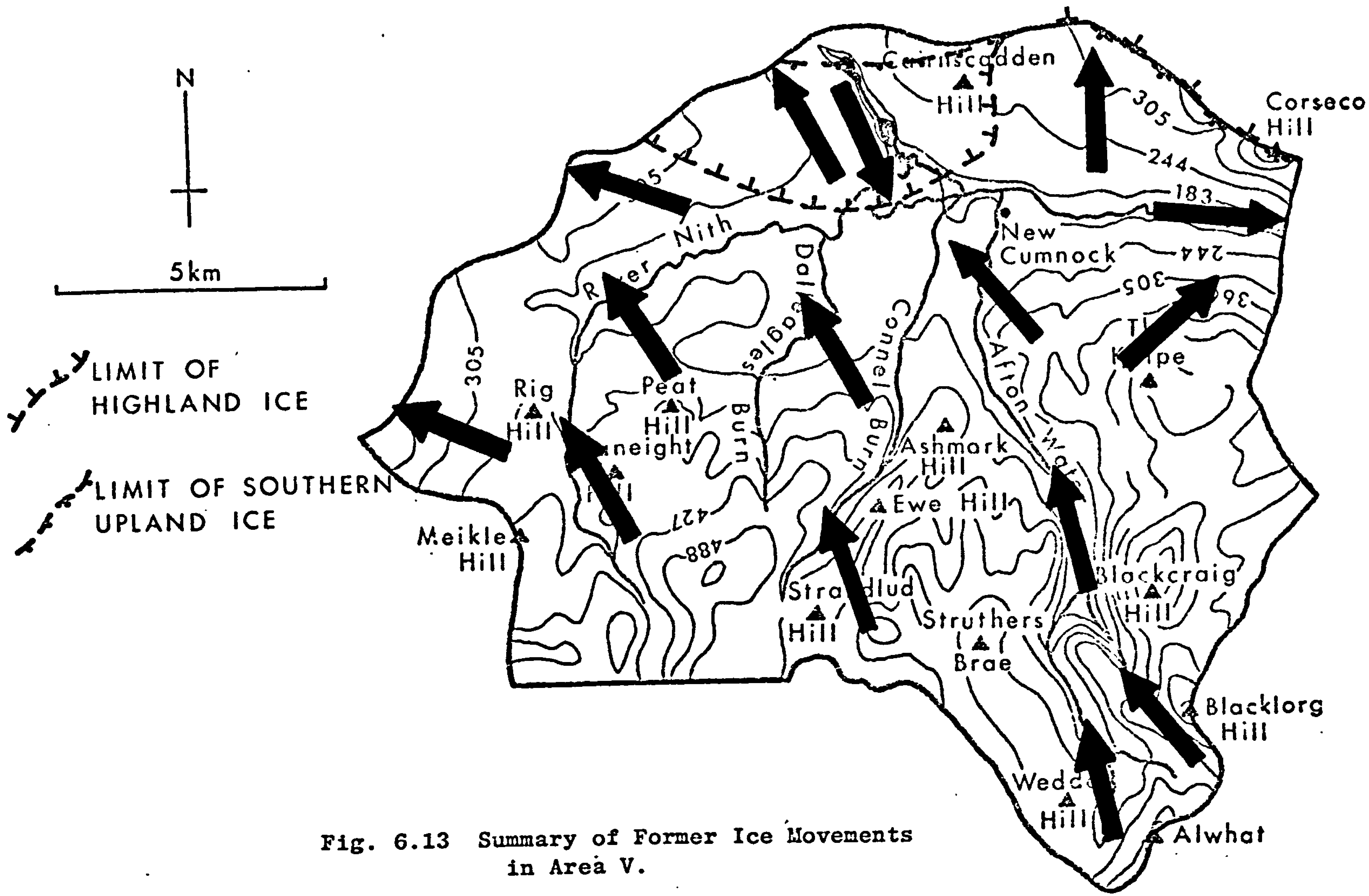


Fig. 6.13 Summary of Former Ice Movements in Area V.

CHAPTER 7

CONCLUSIONS

When the evidence obtained from the study of the glacial geomorphology and the superfical deposits in Areas I, II, III, IV and V is amalgamated and examined in relation to central Ayrshire as a whole a pattern of glaciation is discernable. It is reassuring to discover that although the 5 sub-areas have dissimilar bedrock foundations, landforms and deposits the indications of ice advance, movement and decay are entirely consistent across their boundaries.

Evidence from the study of features which have been produced by glacial erosion shows that central Ayrshire was affected by two ice-masses: one that moved from a generally northern direction and one that moved from a generally southern direction. The origins of these ice masses was suggested in 1869 by A. Geikie as being in the west Highlands and Southern Uplands respectively. No evidence exists in central Ayrshire to contradict this view. The Highland ice, which occupied the northern part of the thesis area, moved from a north-easterly and easterly direction across the north-western and west-central part (Fig. 7.I). This same ice stream also moved from the north-west and west across the north-eastern part (i.e. uphill) due to its deflection around Blackside (Fig. 7.I). In the central part of the thesis area Highland ice moved from the north before it met the Southern Upland ice (Fig. 7.I). No evidence of any movement of ice from the west (i.e. "recurved Highland ice" (McLellan, 1967)) in the north-western part of central Ayrshire is indicated. This is opposed to the views of Bell (1871), Craig (1873), Smith (1891), Richey et al (1930), Eyles et al (1949) and McLellan (1967, 1969) who accepted that "recurved" Highland ice swept across central Ayrshire from west to east.

The ice which originated in the Southern Uplands occupied the southern part of central Ayrshire. It moved from a generally south-eastern direction except where it was deflected by Highland ice to flow from the west in

Fig. 7.1 Summary of Former Ice Movements in Central Ayrshire.

the eastern part (i.e. the Nith valley) and from the east and north-east in the south-western part (Fig. 7.I). The general movement of Southern Upland ice from the south-east is at variance with suggestions by Richey et al (1930) and Eyles et al (1949) that the Loch Doon Basin was the centre from which the Southern Upland ice radiated; the ice in the south-eastern part of central Ayrshire is therefore considered to have moved from the west-south-west. This is an eroneous view. The Loch Doon Basin was an important accumulation area for Southern Upland ice but not the exclusive one. Other centres also existed to the south of central Ayrshire which fed ice into central Ayrshire from a south-easterly direction. The high ground at the head of the Afton Valley was one such accumulation area.

The meeting of the two ice masses in central Ayrshire caused ice to thicken and eventually submerge the whole landscape. Because the two ice masses did not have free outlets, their capacity to produce glacially eroded features was considerably reduced and this is reflected in the relative scarcity of such features in central Ayrshire.

The evidence concerning the origins, movements and mode of decay of the ice which occupied central Ayrshire revealed from the study of the features of glacial erosion is greatly enhanced by interpretations derived from the study of the internal and external characteristics of the glacial deposits.

A major dichotomy exists in the internal characteristics of the till in the northern and southern parts of central Ayrshire. In general terms, the till in the northern part is brown, sandy and contains erratics of Highland rock-types and fragments of shells. These characteristics indicate that the ice which deposited the till had a Highland origin. The southern limit of the presence of these characteristics represents the maximum extension of Highland ice into central Ayrshire (Fig. 7.I). The till in the southern part is generally grey, gritty and contains erratics of Southern Upland rock-types. These characteristics indicate that the ice by which the till was deposited originated in the Southern Uplands. The northern limit of the presence of these characteristics represents the maximum extension of Southern Upland ice into central Ayrshire (Fig. 7.I). Fig. 7.I shows that the influence exerted by the Southern Upland ice mass in central Ayrshire was relatively small, especially in the central and eastern parts. This is not in agreement with the views of J. Geikie (1894) or McLellan (1967, 1969) who both envisaged Southern Upland ice extending northwards into central Ayrshire beyond Muirkirk. These views are firmly rejected.

Between the maximum extensions of Highland and Southern Upland ice is an east-north-east to west-south-west orientated zone which contains evidence of occupation by both ice masses. This indicates that when the two ice masses met in central Ayrshire they waxed and waned, according to their contemporary strengths. This produced a "zone of crossing" or "debateable ground" (J. Geikie, 1894) that was affected by both ice masses. The ground to the north of this "zone of crossing" was only affected by Highland ice and the ground to the south was only affected by Southern Upland ice.

Till fabric analyses were useful in indicating the former movement of ice in central Ayrshire. These observations complement those indicated by the study of the features of glacial erosion. For this reason till fabric analyses are considered to be of greatest use when located in areas which are devoid of glacially eroded features. The mean stone orientations which were calculated from the fabric analyses indicate the general direction of ice movement. However, statistical analyses applied to these mean stone orientations do not always prove the actual direction of ice movement (i.e. the direction of movement could have been parallel and towards the mean, or parallel and away from it). Other characteristics of the till such as erratic content are more useful in this capacity.

Stratigraphical relationships within the glacial deposits show the pattern of ice advance and movement to be more complicated than indicated from the study of glacially eroded features. Near Fordmouth (Site 6c, Area V) an exposure shows three distinct units of till; the lowest unit is a compact, purple Highland till, the middle unit is a less compact, brown Highland till and the highest unit is a stiff, grey Southern Upland till. The lowest and middle units represent a facies change during the main phase of deposition by the Highland ice which moved from the north at this point. The existence of a Southern Upland till overlying the Highland tills clearly shows that as the ice masses waxed and waned the ice from the Southern Uplands was the last to occupy the "zone of crossing".

It is not certain whether this was due to an increase in the pressure exerted by the Southern Upland ice or a relaxation in the pressure exerted by the Highland ice.

In a small part of north-central Ayrshire, between Sorn and Muirkirk, a lower till unit which contains Highland erratics and shell fragments is overlaid by a considerable thickness of sand and gravel and an upper till unit which contains only local material. Ten years ago this sequence would have been ascribed to the "Perth readvance" (Sissons 1963, 1964); however, it is now agreed that "there is at present no satisfactory evidence in Scotland that the decay of the last ice-sheet was interrupted by a significant readvance" (Sissons, 1974b, p. 314). This multi-sequence exposure, therefore, represents a minor readvance of the Highland ice which occupied this part of central Ayrshire. It does not have any regional significance. There is no evidence, therefore, that central Ayrshire was affected by any more than one major advance of ice.

The morphological characteristics of the glacial deposits provide important evidence concerning the directions of ice movement and mode of decay. The concentration of drumlins which exists in the western part of central Ayrshire shows that the ice by which they were moulded moved from the north-east in the north-western part, from the east in the central part and from the north-east in the south-western part. This is entirely consistent with evidence derived from the study of glacially eroded features (Fig. 7.1).

Near the northern margin of the thesis area, there are a number of small drumlins, which are orientated in a north to south direction, in close proximity to the more common, larger, north-east to south-west orientated drumlins. One north-east to south-west orientated drumlin near Crossroads has three north to south orientated drumlins superimposed on its crest. This is clear evidence for two movements of ice in the northern part of central Ayrshire: a major one from the north-east and a secondary one from the north. This secondary movement may relate to the minor readvance of ice indicated by the multi-sequence exposures between Sorn and Muirkirk.

A spread of morainic morphology around the town of Maybole in the south-western part of central Ayrshire is characteristic of the "uncontrolled disintegration features" described by Gravenor and Kupsch (1959). This spread was formed when the Southern Upland ice which occupied this part of the thesis area was cut off from its source and became climatologically "dead". The block of "dead" ice then slowly decayed <u>in situ</u> to produce the ice-contact hummocky forms in the landscape.

The existence of small expanses of morainic morphology in the extreme south-eastern part of central Ayrshire in the Craig and Afton valleys is an indication of a halt, readvance or advance of Southern Upland ice during, or after, its general retreat. There is insufficient evidence available to indicate which of the three alternatives is correct. However, the altitude and situation of these moraines in relation to Southern Upland accumulation zone suggests that they relate to the Loch Lomond readvance, the limits of which are accurately known throughout Scotland (Fig. 7.2).

Although the characteristics of meltwater channels in central Ayrshire are varied and their distribution is uneven, careful examination and subsequent interpretation reveals a detailed pattern of meltwater flow. In most parts the direction of meltwater flow is remarkably similar to the direction of ice movements.

The finest and most extensive suite of fluvioglacially eroded forms is in the extreme north-eastern part of central Ayrshire north-east of Muirkirk. These channels were eroded subglacially by meltwater which generally flowed from west to east and eventually drained into the Douglas valley. The lowest point along the Ayr/Douglas watershed had a profound influence on the formation of these features as it regulated the level of the englacial water-table. When the level of the englacial water-table dropped below the lowest level of the Ayr/Douglas watershed,free drainage to the east (i.e. into the Douglas valley) was halted. This caused the reversal of the direction of meltwater flow beneath the ice and under the influence of gravity. However, the free drainage of this meltwater from the east was also impeded because the pressure exerted by the thick ice accumulations to the west rendered it impermeable. The result was fluvio-glacial deposition in subglacial cavities by meltwater that could flow a short distance to the west (i.e. down the Ayr valley to Greenockmains) and to the south-west (i.e. down the Boghead/Bellow valley to the Glenmuir valley). When the altitude of deposition had reached approximately 185m. O.D.,two "subglacial escape routes" (Sissons, 1958b) opened along the

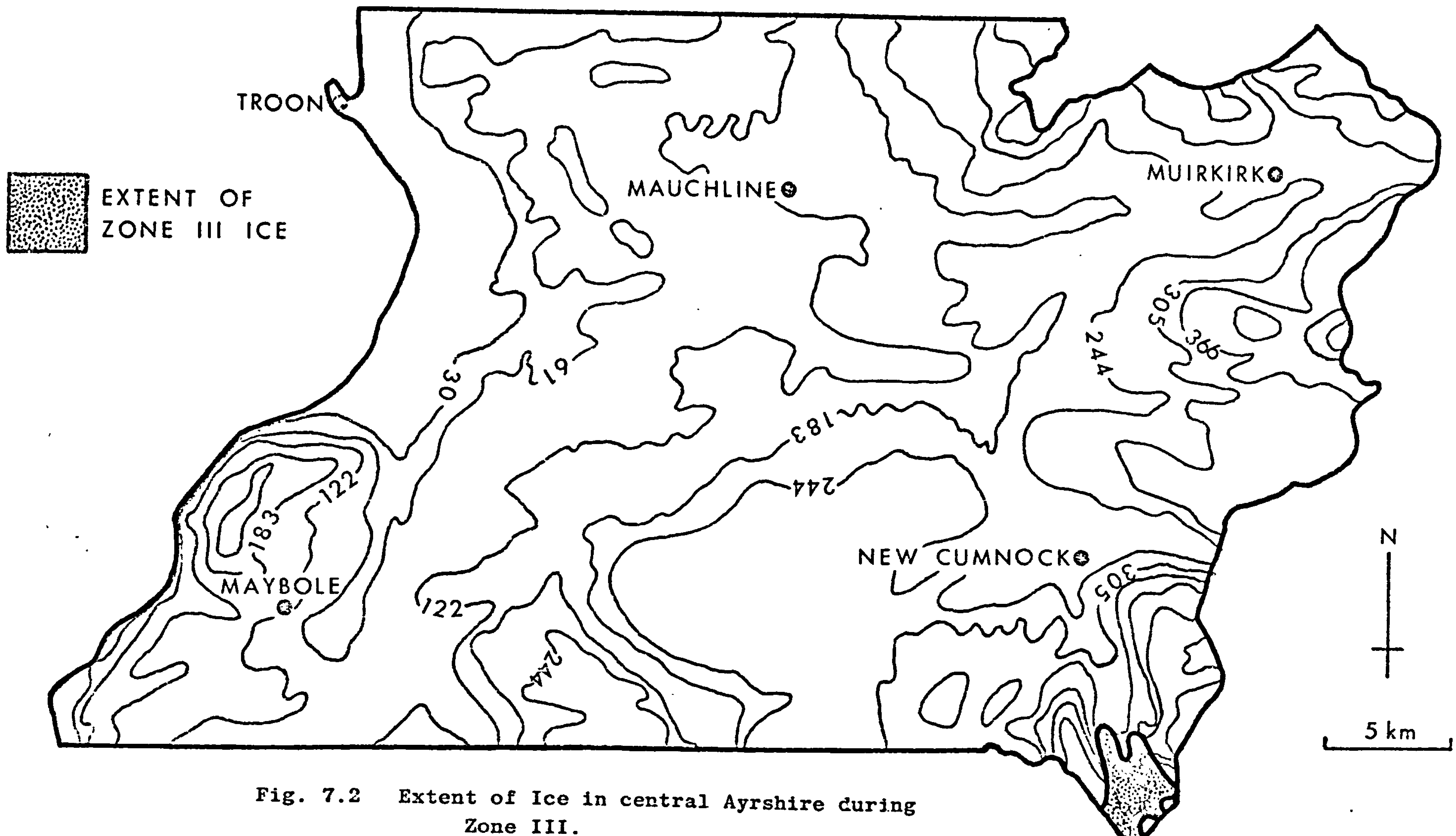


Fig. 7.2 Extent of Ice in central Ayrshire during Zone III.

Ayr valley and the Lugar valley which caused the rapid drainage of meltwater from the north-east and east-central parts of central Ayrshire (Fig. 7.3) and ended the formation of meltwater channels.

Meltwater channels eroded in fluvioglacial deposits on the flanks of Blackside in the north-central part of the thesis area indicate that this hill-mass emerged as a nunatak during deglaciation. In the north-western part of central Ayrshire evidence of fluvioglacial erosion is poor but it consistently indicates that meltwater flowed from the north-east.

The southern part of central Ayrshire was affected by ice which had a Southern Upland origin and this is reflected in the fragmentary meltwater channels which exist. Most of the channels generally have gradients sloping from south to north which feed, directly or indirectly, into either the Doon valley or the Nith valley. It is clear from this that the Doon valley was the main meltwater route for the south-central part of the thesis area and the Nith valley was the main routeway for meltwater from the south-eastern part (Fig. 7.3).

The examination and interpretation of the fluvioglacial deposits in central Ayrshire adds considerable detail to the pattern of meltwater flow that has already been suggested. The deposits of sands and gravels are widely distributed, though not very extensive, and display a variety of characteristic forms such as eskers and kames.

The fluvioglacial deposits in the upper Ayr valley and Boghead/Bellow valley prove that meltwater flowed from the east and north-east respectively. However, with the opening of the "subglacial escape route" along the Ayr valley, the source of meltwater (and debris) for the Boghead/Bellow valley was cut off. In order for meltwater from the east to reach the Ayr valley "subglacial escape route" it had to flow over fluvioglacial material that had already been deposited. This caused some alteration in form which is impossible to assess accurately.

The flanking of Meanlour Hill in the north-central part of the thesis area with fluvioglacial deposits in the form of kames suggests that it emerged as a nunatak during deglaciation. Charlesworth (1926b) regarded this spread as a kame terrace which was deposited on the margin of a lobe of ice (the Airds Moss Lobe) which moved from the north. No evidence exists

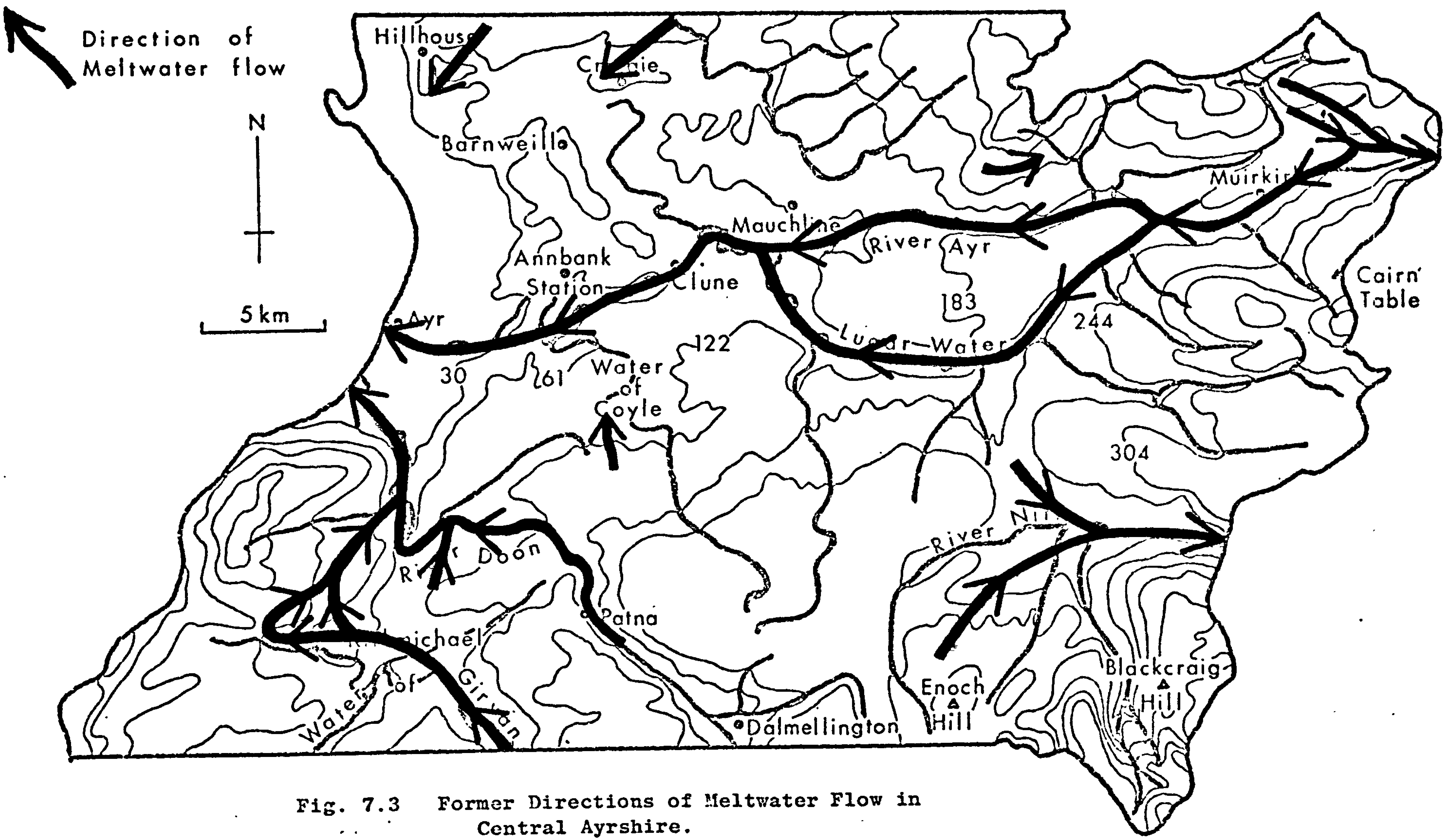


Fig. 7.3 Former Directions of Meltwater Flow in Central Ayrshire.

to support this interpretation.

Fluvioglacial deposits in the south-central part of central Ayrshire show that meltwater flowed from a generally south-eastern direction. Although the Doon valley was a major meltwater route, this is not true of other major valleys. The valley of the Water of Girvan for instnace, only contains fluvioglacial deposits along the part of its course which is parallel to the direction of meltwater movement (i.e. south-east to north-west). The crossing of interfluves by eskers shows that meltwater did not always flow under the influence of gravity. Some of the activity, therefore, was subglacial under hydrostatic pressure. The close association between the fluvioglacial deposits and morainic morphology around Maybole indicates that meltwater activity persisted throughout the whole deglacial phase.

The Nith valley in the eastern part of central Ayrshire was also a main meltwater route for areas occupied by Southern Upland ice. However, the deposits on the valley floor have been altered to a considerable degree as a result of pro-glacial activity. Such alteration limits their usefulness when an attempt is made to determine the direction of meltwater movement. However, a few forms are preserved which indicate that meltwater flowed from the west (Fig. 7.3).

The raised beach features which flank a large proportion of the western margin of central Ayrshire reveal that, since deglaciation, sea-level has stood at a maximum of 26m. above its present level. This upper limit of marine penetration is usually marked by a poorly defined fossil cliff. The highest raised beach varies in altitude between approximately 24m. and 26m. O.D. and is upto 2 km. in width. Two other raised beaches also exist between approximate altitudes of 10-12m. O.D. and 5-7m. O.D.. By correlating the altitudes of these raised beaches with others recognised in close proximity to central Ayrshire and in Scotland as a whole, their time of formation can be assessed; the highest raised beach is Lateglacial and the other two raised beaches are Post-glacial in age.

Deposits of marine, shelly, silty clay exist in the west-central part of the thesis area at Afton Lodge and Catrine at an approximate altitude of 90m. O.D.. The shelly clay is horizontally bedded in its upper layers and these layers generally become coarser towards the top of the deposit. The shells and foraminifers contained in the silty clay are typical of the species found offshore around Britain today at a depth of between I5m. and 50m.. Eyles et al (I949) concluded that this shelly clay was picked up, and subsequently deposited, as a frozen block of sea bed carried by the Highland ice which moved out of the Firth of Clyde and swept from west to east across this part of central Ayrshire. However, it has been clearly indicated that the Highland ice in this part of the thesis area moved from the north-east. Eyles's (I949) suggestion is therefore untenable It is unlikely that a marine deposit at this altitude (90m. O.D.) could have been deposited in situ during Lateglacial times. Besides, the faunal assembage of the silty clay does not resemble a Lateglacial fauna. The most likely explanation is that the shelly clay was deposited in situ in central Ayrshire at some time before the last glaciation (Late-Devensian). Its position at the base of a north-west to south-east orientated lava ridge between Barnweill and Clune is ideal for preservation from ice which moved from the north-east.

A shelly clay with remarkably similar characteristics also exists below a till unit north of Campbelltown, Kintyre. The analysis of curves derived from the Hypsographic Survey of Scotland by Halstead (pers. comm., 8/7/I977) indicates that the two deposits of shelly clay were probably related to the same high stand of sea level between I05m. and I50m. O.D..

Chronology

Due to the "errors in radiocarbon dating, the relatively few dates available, and the standard deviations associated with them" (Gray and Lowe I977, p. I80) absolute dates given in this section should be regarded as extremely tentative.

I) There is no evidence anywhere in central Ayrshire to indicate that the area was glaciated before approximately 27,500 years B.P. when the last ice-sheets (Late-Devensian) built up to submerge the area.

2) At some time before the onset of the last glaciation sea level in central Ayrshire (and across the Firth of Clyde in Kintyre) was approximately I05m. to I50m. above present sea level.

3) Between 27,500 years B.P. and 18,000 years B.P. the ice masses from the Highland and the Southern Uplands, which occupied central Ayrshire built up to their maximum extent and completely enveloped it.

4) From 18,000 years B.P. to 10,000 years B.P. the deglaciation of the area was completed.

5) The highest raised beach (24-26m. O.D.) was deposited at approximately 13,000 years B.P..

6) Between 11,000 years B.P. and 10,000 years B.P. ice with a Southern Upland origin advanced/readvanced and affected a limited part of central Ayrshire in the extreme south-east.

7) Between 8,400 years B.P. and 6,600 years B.P. the two lowest raised beaches (10-12m. O.D. and 5-7m. O.D.) were deposited.

APPENDIX 1

PARTICLE- SIZE ANALYSIS OF SEDIMENTS

Basic Aim. To aid the description of tills in order to help indicate the origin and direction of movement of ice by which they were deposited.

Field Sampling. An exposure of till which is to have a sample removed for particle-size analysis must be at least 3m. thick. The exposure is cleared and five points are selected at random. With the aid of a pick, a sample weighing at least IO kg. is obtained from each point. This is weighed with a spring balance to confirm that a total sample weight of 50 kg. is exceeded. The sample of till is labelled and taken back to the laboratory for particle-size analysis.

Laboratory Techniques. Because chemical methods are used to aid the disintegration of the till to produce discrete clasts which can then be sieved, it is generally accepted by geomorphologists that wet sieving is a more accurate method of analysis than dry sieving. For this reason, wet sieving (according to British Standard BSI377) was used for the fraction coarser than, and including, 63 m (200 mesh sieve, B.S.S.) with sieves at the British Standard Size Range (63μm, I25μm, 250μm, 500μm, I200μm, 200μm, 3350μm, 6350μm, I2700μm and 25700μm). The hydrometer method is used for the fraction finer than 75μm.

Procedure.

I) The whole sample is oven dried at I05-II0°C until no further reduction in weight is observed.
2) The samples are broken into pieces smaller than I5mm. diameter with a rubber-headed pestle and mortar. Great care is taken not to crush individual particles.
3) Samples are split into their respective sizes using the standard quartering procedure:-

a) Sample size for sieving the gravel fraction (2000μm).

The minimum weight is determined from the following scale taken from British Standard I377 (I.4.4.2):-

If IO% of sample exceeds	Minimum sample weight
64000µm	50 kg.
32000µm	IO kg.
24000µm	5 kg.
I6000µm	2 kg.
8000µm	0.375 kg.
4000µm	0.IOO kg.

b) Sample size for sieving the sand fraction (2000µm - 63µm).

Not less than IOO gms.

c) Sample size for hydrometer analysis of the silt/clay fraction (>63µm).

Not less than 20 gms.

4) Particle-size analysis of the gravel fraction.

i) The oven dried sample is weighed to 0.0I gm..

ii) The sample is placed in glass beakers and covered with distilled water and dispersing agent (sodium hexametaphosphate or hydrogen peroxide). This is then warmed and manually stirred for 30 minutes.

iii) Clasts with a diameter greater than 25700µm are carefully picked out, washed with distilled water from a squeeze bottle to remove smaller particles, and placed in a tray. The sample left in the beakers is then washed through a nest of sieves (2000µm, 3350µm, 6350µm and I2700µm) using wet sieving apparatus connected to the sink. Great care is taken not to flood the apparatus which would ruin the analysis.

iv) The sieves are then removed and together with the tray containing the largest clasts are oven dried at 50°C, the sieves resting on a sheet of paper to collect material falling through. When dry, the largest clasts (from the tray) are mechanically shaken through a nest of 42 cm. diameter sieves (3.8I cm., 5.08 cm., 6.35 cm. and 7.62 cm.) for 20 minutes. Also when dry, the sieves are nested and shaken mechanically for 20 minutes. With some of the more friable clasts shaking is done by hand and individual particles are examined to see if they will pass through the respective sieve mesh.

The sample in each sieve is then carefully brushed onto a sheet of paper, emptied onto the balance and weighed to 0.0I gm.

i) The oven dried sample is weighed to 0.0I gm.

ii) The sample is placed in a glass beaker and covered with distilled water and dispersing agent. This is warmed and stirred for I5 minutes then stirred with a mechanical stirrer for another I5 minutes.

iii) A nest of sieves between 63µm and 2000µm (63µm, I25µm, 250µm, 500µm, I200µm and 2000µm) is placed on the wet sieving apparatus and the sample is washed through.

iv) The sieves are oven dried at 50°C resting on a piece of paper to collect material passing through, nested, and mechanically shaken for 20 minutes. The samples are then carefully brushed from the sieves onto a large piece of paper, emptied onto the balance and weighed to 0.0I gm.

5) Particle size snalysis of the silt/clay fraction.

i) The hydrometers are calibrated (B.S. I377, p. 67) and graphs constructed.

ii) The oven dried sample is weighed to 0.000I gm.

iii) The sample is placed in a 500 ml. beaker and I00 mls. of dispersing agent added. The mixture is gently warmed and stirred for I5 minutes. It is allowed to cool to room temperatures and then mechanically stirred for one hour.

iv) The suspension is then transferred to a I000 ml. measuring cylinder. Great care is taken to transfer all the mixture with the aid of a squeeze bottle of distilled water. The mixture is made up to I000 mls. with distilled water.

v) A rubber bung is placed in the open end of the measuring cylinder which is then vigorously shaken until all the sediment is in suspension. The cylinder is then placed upright and the bung withdrawn. A stop clock is started and readings are taken at suitable intervals; similtaneously the temperature of the suspension is recorded for each reading.

vi) The hydrometer used for the readings is washed in distilled water after each recording.

vii) The short-stem hydrometer is used when the reading on the long-stem hydrometer approached I.008.

The results are calculated using the method shown in B.S. I377 and are used in conjunction with the wet sieving results to give an accurate assessment of relative particle size. The important, and most obvious, differences between samples was found to be between the relative proportions of gravel, sand and silt/clay. The results of the particle analyses therefore have been simplified in order to emphasise these important differences (Tables 2A, 3A, 4A, 5A, 6A).

APPENDIX 11

PREFERRED- STONE ORIENTATION

Basic Aim. The purpose of the preferred-stone orientation analyses on tills in this study is to indicate the direction of movement, and maybe the origins, of the ice-mass/es by which they were deposited.

Field Procedure.

i) An exposure is selected for examination based upon its potential usefulness for the determination of former ice movements in a regional context.

ii) The exposure is cleaned and excavated. The sampling is undertaken only on vertical exposures (i.e. river cliffs or quarry faces) which means that the outer 0.3m. must be removed in case of disturbance (Andrews, 1971).

iii) Five trenches are cut into the vertical face at random intervals, though the upper 0.5m. of the exposure is avoided in case of disturbance, in order to provide horizontal working faces. These are then slowly excavated with a knife/trowel until a suitable stone is located. A suitable stone is one which has an a axis / b axis (i.e. length/breadth) ratio of at least 3:2. It is usual for there to be sufficient silty/clay in the matrix of the till for the stone to be carefully removed leaving its cast. The stone is examined (for size) and reinserted for measurement. It is common practice to avoid stones that lie adjacent to large boulders or touch each other. Ten stones are measured from each of the 5 pits thus giving a total sample of 50.

iv) The orientation of the stones is measured with a Suunto fabric compass. It is considered that even with the most cautious measurement the readings are only accurate to $\pm 5^{\circ}$. The measurements therefore were recorded to the nearest 5° orientation.

v) The measurement of the dip is completed by replacing the stone by a non-magnetic rod which exactly duplicates the dip of the a axis. The dip is then read on an inclinometer and recorded.

APPENDIX 111

ANALYSIS OF RESULTS FROM PREFERRED-STONE ORIENTATION

I) Graphically. The results of the preferred-stone orientation analyses are displayed by constructing rose diagrams. They are easy to construct and convey a strong visual image. The orientations are grouped into 20° class intervals from $0^{\circ}/360^{\circ}$. The 20° class intervals are also grouped through I80 to give a "mirror-image plot" (Andrews, I97I).

2) Statistically. A mean stone orientation is calculated from the results of a preferred-stone orientation analysis by using the following formula:-

$$\bar{X} = Xa + C\,\frac{uf(x)}{f(x)}$$

where Xa is the middle point of the distribution, and C is the interval between classes. An example from Chapter 6 (Till 2) at Site 6c) is completed in order to aid understanding. In this example the modal frequency is just west of south, and the data will be tabulated from 80° to 260° with opposite 20° cell units summed together (Table 111A).

TABLE 111A

Mean Orientation of Till 2) at Site 6c

Class (Degrees)	Frequency (f(x))	u Scale	uf(x)
80- 99, 260-279	6	-4	-24
I00-II9, 280-299	I	-3	- 3
I20-I39, 300-3I9	3	-2	- 6
I40-I59, 320-339	6	-I	- 6
I60-I79, 340-359	II	0	0
I80-I99, 360- I9	6	I	6
200-2I9, 20- 39	6	2	I2
220-239, 40- 59	4	3	I2
240-259, 60- 79	7	4	24
	50		I9

$$\bar{X} = 167.5^{\circ} + 20.\frac{19}{50}$$

$$= 167.5^{\circ} + 7.6$$

$$= \underline{175.1^{\circ}}$$

Chi - square is commonly used by geomorphologists to provide a numerical value for the orientation - strength and the dip - strength. It provides a test against a uniformly distributed fabric by setting up a null - hypothesis that no significant difference exists between the observed distribution (O) and the expected distribution (E). The expected distribution in this case is uniform. To be a meaningful test the expected frequencies (E) have to be at least equal to 5 (Andrews, I97I). The orientations, therefore, are divided into 9 X 40° classes, 20° - 59°, 60° - 99° , I00° - I39° , ..., and the frequency of observations recorded for each class (Table CB). The expected uniform distribution for each class is, therefore, 50/9 (i.e. total number of observations / number of class groups) or 5.55 pebble orientations for every 40° division. Chi - square is then calculated using the following formula:-

$$X^2 = \frac{(O-E)^2}{E}$$

TABLE 111B

Chi-Square for Orientation of Till 2) at Site 6c

Central value	(O)	(E)	(O-E)
0	3	5.55	2.55
40	5	5.55	0.55
80	7	5.55	2.45
I20	3	5.55	2.55
I60	I3	5.55	7.45
200	9	5.55	3.45
240	5	5.55	0.55
280	3	5.55	2.55
320	2	5.55	3.55

$$X^2 = \frac{114.98}{5.55} = 18.29$$

There are (n-I) degrees of freedom, where n is the number of class groups. In this example the tabulated value with (n-I) degrees of freedom (i.e. 8) the 95% level of confidence is I5.5I. The calculated value is I8.29. As the calculated value is greater than the tabulated value this is, in statistical terms, a significant difference between the observed distribution and expected distribution. The null hypothesis that there is no difference between observed and expected value is, therefore, rejected.

A chi-square test is used to give a dip-strength value of the stones in the fabric. It is obtained by dividing the observed stone fabric into halves at right angles to the mean orientation. The null hypothesis is that no significant difference exists between the number of observations in each half. The expected distribution of the dips of the stones would be n/2, where n equals the number of stones with a dip. If there are no horizontal stones the expected value is 50/2 = 25, if 3 horizontal stones exist the expected value is 47/2 = 23.5. In the case of Till 2) at Fordmouth (Site 6c) no stones are horizontal. The expected distribution (E) is, therefore, 50/2 = 25. There are I7 stones dipping towards the mean and 33 stones dipping away. The chi-square value is:-

$$\frac{(17-25)^2 + (33-25)^2}{25} = \frac{128}{25} = 5.12$$

With (n-I) degrees of freedom the tabulated value is 3.84. The calculated value is greater than the tabulated value, the null hypothesis is, therefore, rejected (i.e. there is a significant difference between the observed and expected distributions).

APPENDIX 1V

AFTON LODGE MICROFAUNA

FORAMINIFERA.

Species present:-

TABLE 1VA

	%
Ammonia beccarri (Linne)	34
Quinqueloculina seminulum (Linne)	30
Elphidium excavatum (Terquem)	9
Elphidium articulatum (d'Orbigny)	2
Elphidium clavatum Cushman	2
Various Elphidium species (approx. 5)	2I
Fissurina cf. lucida (Williamson)	I
	99

Ammonia beccarri has a "southern" distribution around the coasts of Britain, France, Spain, as far north as Denmark. The similar A. batavus (Hofker) is characteristic of the North Sea and post-glacial deposits of Denmark and southern Norway, where it often forms a large part of the foraminiferal fauna. Murray regards the latter as one of several variants of A. beccarri. The specimens from Afton Lodge are not of the batavus variety however. Environment: inner shelf, I4-I38m; estuarine records are probably of A. aberdoveyensis Haynes.

Quinqueloculina seminulum has a widespread distribution in glacial and post-glacial deposits, but this may be due to wrong identifications of glacial material. Living specimens, in connection with Britain, are described as having a southern distribution by Murray. Environment: inner shelf, I4-IOOm.

Elphidium articulatum sensu Murray (= E. *williamsoni* Haynes) indicates hyposaline lagoons, estuaries and intertidal sand flats.

Elphidium clavatum is a typical cold water species, living specimens having an arctic-boreal distribution; probably commonest Recent foram in shallow arctic waters. Present off N. America and Arctic Europe. In Quaternary common throughout northern Europe, where it often forms more than 50% of glacial foraminiferal fauna. Also present in post-glacial deposits of Scandinavia, but forms less than 5% of fauna.

Elphidium excavatum sensu Murray (= *E. selseyense* (Heron-Allen & Earland) sensu Haynes). According to Murray, a "southern" species, characteristic of inner shelf shallow waters, 0-18m.

OSTRACODS.

Only two specimens, one of a moult stage of *Cyprideis torosa* Jones an estuarine species, the other *Cytheropteron latissimum* (Norman) shallow marine.

Conclusions: The fauna represents water temperatures similar to those of today. Marine conditions, depth probably in the range of 15-50m. Somewhat similar assemblages can still be found in the Firth of Clyde today.

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