

LATE- AND POST- GLACIAL CHANGES
OF SHORELINE ON THE NORTHERN
SIDE OF THE FORTH VALLEY AND ESTUARY

by

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PREFACE

In 1962, Dr. J. B. Sissons began an investigation into the development of raised marine phenomena in an area south of the Forth. The initial results of his work suggested that the current descriptions of the pattern of ^{raised} late- and post-glacial/shorelines in Scotland were at variance with the sequence of features in the Forth area.

The writer became interested in Scottish raised shorelines when, as an undergraduate in 1960, he spent several weeks examining these features on the west coast. Later, when the opportunity arose to carry out research at Edinburgh, the writer found Dr. Sissons' theories extremely interesting and determined to examine sea level change on the north side of the Forth.

In submitting this thesis, the writer is deeply aware of the considerable debt of gratitude he owes to Dr. Sissons for his advice and encouragement. He would also particularly like to thank Professor J. W. Watson for the support he has given. Several other names must also be mentioned. The methods used in this investigation required considerable help, particularly the levelling, and for this the writer is greatly indebted to Mr R. A. Cullingford, Mr I. A. Morrison, Miss K. McClumpha, Mr R. P. Kirby, Mr R. Dickson, Mr P. Levein, Mr J. D. Walter, Mr H. Nichols, Mr J. A. T. Young, and Mr C. M. Clapperton, as well as Dr. Sissons.

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TABLE OF CONTENTS

PART I

		Page
	PREFACE	ii
CHAPTER I:	Introduction	1
CHAPTER II:	The development of present opinion on late- and post-glacial climatic change and sea level fluctuation in Scotland	7
	<u>1a Climatic change in the late-glacial period</u> .	7
	<u>1b Climatic change in the post-glacial period</u> .	17
	<u>2. Movements of sea level</u>	19
CHAPTER III:	The investigation of raised shorelines	34
	<u>1. Previous investigations</u>	34
	<u>2. The present investigation</u>	38
CHAPTER IV:	The area between Aberfoyle and Stirling	45
	<u>The carse</u>	45
	<u>The glacial features around the Lake of Menteith</u>	62
	<u>The valley of the river Teith, Lanrick Castle to Blairdrummond</u>	75
	<u>Terrace features and glacial morphology of other areas</u>	82
	General conclusion	86
CHAPTER V:	The area between Stirling and Alloa, including the Lower Devon valley	88
	<u>The carse</u>	88
	<u>The glacial deposits at Airthrey</u>	96
	<u>The Devon valley</u>	99
	<u>The Tullibody-Alloa area</u>	108

	Page
General conclusion	109
CHAPTER VI: The area between Alloa and Kirkcaldy	111
<u>The area between Alloa and Culross</u>	111
<u>The carse</u>	111
<u>Glacial landforms</u>	115
<u>Other shorelines</u>	117
<u>Conclusion</u>	121
<u>The area between Culross and Rosyth</u>	122
<u>The Bluther Burn valley</u>	122
<u>The coast, Culross to Crombie Point</u>	124
<u>The coast, Crombie Point to Rosyth</u>	126
<u>Inland, Cairneyhill to Dunfermline and</u> <u>Rosyth</u>	127
<u>Conclusion</u>	129
<u>Rosyth to Kirkcaldy</u>	131
<u>The Inverkeithing Depression</u>	131
<u>The coast between Inverkeithing and</u> <u>Kinghorn</u>	132
<u>The coast between Kinghorn and</u> <u>Kirkcaldy</u>	134
<u>Conclusion</u>	137
<u>General Conclusion</u>	138
CHAPTER VII: The coast between Kirkcaldy and Fife Ness	139
<u>The area between Kirkcaldy and Methil,</u> <u>including the lower Ore valley</u>	139
1. <u>Glacial features</u>	139
2. <u>Raised shorelines</u>	140

	Page
<u>The Leven valley below Markinch and the coast of Largo Bay</u>	141
1. <u>General description</u>	141
2. <u>The evolution of the glacial features</u>	142
3. <u>Raised shorelines</u>	155
4. <u>Conclusion</u>	157
<u>The coast between Drumeldrie and Fife Ness</u>	157
1. <u>General description</u>	157
2. <u>Evolution of the Glacial features</u> ...	158
3. <u>Raised shorelines</u>	161
4. <u>Conclusion</u>	171
<u>General Conclusion</u>	172
CHAPTER VIII: Conclusion to Part I	173
PART II	
CHAPTER IX: Introduction to Part II	178
CHAPTER X: The evolution of present concepts on sea level changes	180
<u>Development of theories on world sea level change</u>	180
<u>Development of theories on local sea level change</u>	187
CHAPTER XI: Shoreline displacement on the northside of the Forth	202
1. <u>Shoreline height analysis</u>	203
a. Accuracy of the data	203
b. Methods of analysis	205
c. Results	209

	Page
MAPS AND DIAGRAMS	
2. <u>Shoreline pattern analysis</u>	225
a. Cause of the displacement	225
b. Aspects of theisokinetic theory.....	228
c. Application of the isokinetic theory to the displaced shorelines in the area under study	233
3. <u>The sequence and formation of displaced shorelines on the northern side of the Forth valley and estuary</u>	240
CHAPTER XII: Conclusion	242
APPENDICES:	
I A note on Carbon 14 datings	246
II Boreholes made during this investigation.....	247
III Levelled heights made during this investigation .	253
IV A note on linear regression analysis.....	297
BIBLIOGRAPHY	298
PHOTOGRAPHS	at the end of chapters IV,VII.

MAPS AND DIAGRAMS

	Following Page
FIGURE 1 The Forth valley and estuary.	2
2 Stages in the retreat of the Würm ice sheet in Scotland, after McCallien (1937), Movius (1942), Charlesworth (1926 and 1955), Synge (1953 and 1956) and Sissons (1964).	12
3 Isobases for raised shorelines, according to Wright (1914), Movius (1942), Donner (1963) and Sissons (1964).	27
4 Location of the principal morphological maps shown.	39
5 The principal glacial and post-glacial features in the area between Flanders Moss and Stirling.	45
6 The location of some whale skeletons found in the carse, according to Clark (1947).	48
7 Surface morphology beneath Gartreerich Moss.	55
8 The carse section near Blairdrummond, taken from Blackadder (1824), Drummond (1824) and Milne-Home (1871).	56
9 Cross-section of the carse, A-B, Figure 5.	57
10 Cross-section of the carse, C-D, Figure 5.	57
11 Cross-section of the carse, E-F, Figure 5.	57
12 The morphology and stratigraphy beneath Flanders Moss.	59
13 Compaction of the sub-carse peat at Littleward.	60
14 Compaction effect upon the carse "wedge" at Flanders Moss.	60
15 The principal glacial and post-glacial features at the Lake of Menteith.	62
16 Section by the Goodie Water, X-Y-Z, Figure 15.	66

		Following Page	
FIGURE	17	Glacial outwash and associated features at the western end of the Lake of Menteith.	72
	18	The principal glacial and post-glacial features in the Teith Valley from Lanrick Castle to Blairdrummond.	75
	19	Slope of the glacial outwash and river terraces in the Teith valley between Lanrick Castle and Blairdrummond.	76
	20	The principal glacial and post-glacial features in the area between Stirling and Alloa.	88
	20a	Continuation of Figure 20. The principal glacial and post-glacial features in the area between Alva and Cowden Castle.	90
	21	Cross-section of the carse, K-L, Figure 20.	92
	22	Features at Tillicoultry (1) and Cowden Castle (2), with a sketch of a section in the Tillicoultry sand pit.	100
	23	52 varves and their constituent layers, Dollar.	102
	24	The Morphology of the bedrock surface in the buried Devon valley, according to Soons (1960).	104
	25	The principal glacial and post-glacial features in the area between Alloa and Culross.	111
	26	Cross-section of the carse, M-N, Figure 25.	114
	27	Slope of outwash terraces in the Kincardine-Culross area.	116
	28	Probable limits of the Perth Readvance in the Tillicoultry-Kincardine-Dollar area.	119
	29	The principal glacial and post-glacial features in the area between Culross and Rosyth.	122
	30	Slope of the terraces in the Bluther Burn valley.	122
	31	Cadell's "buried river channel" in Torry Bay, viewed in the light of recent borehole information.	129

		Following Page	
FIGURE	32	The principal glacial and post-glacial features on the coast between Rosyth and Kirkcaldy.	131
	33	The principal glacial and post-glacial features on the coast between Kirkcaldy and Methil.	139
	34	The principal glacial and post-glacial features on the coast between Leven and Drumeldrie, together with the Leven valley as far west as Markinch.	141
	35	Slope of the glacial outwash and river terraces in the Leven valley.	153
	36	The principal glacial and post-glacial features on the coast between Drumeldrie and Fife Ness.	157
	37	The inclination of a lake flat by Pittenweem.	161
	38	Tidal range between Stirling and Dunbar.	204
	39	Graph of all the raised shoreline and possible raised shoreline heights along a W-E axis.	205
	40	The method of calculating the distance of each point from the origin point.	207
	41	Heights taken on the main Perth Readvance shoreline, plotted along a NW-SE axis, and the regression line.	208
	42	Heights taken on the main Perth Readvance shoreline, plotted along a WNW-ESE axis, and the regression line.	208
	43	Heights taken on the main Perth Readvance shoreline, plotted on a W-E axis, and the regression line.	208
	44	Heights taken on the main Perth Readvance shoreline, plotted on a WSW-ESE axis, and the regression line.	208
	45	Heights taken on the main Perth Readvance shoreline, plotted on a SW-NE axis, and the regression line.	208

		Following Page	
FIGURE	46	Graph of all raised shoreline and possible raised shoreline heights along a NW-SE axis.	209
	47	Graph of all raised shoreline and possible raised shoreline heights along a WNW-ESE axis.	209
	48	All raised shoreline and possible raised shoreline heights in East Fife, from Leven to Fife Ness, plotted along a WNW-ESE axis, with regression lines.	210
	49	All raised shoreline and possible raised shoreline heights in East Fife, from Leven to Fife Ness, plotted along a W-E axis, with regression lines.	210
	50	Alternative regression lines for the WNW-ESE east Fife plot.	216
	51	Heights taken on the main Perth Readvance shoreline, ^{and} associated outwash terraces, plotted on a WNW-ESE axis. Regression line for the shoreline, estimated lines for the outwash terraces.	219
	52	The carse shoreline heights, plotted on a NW-SE axis.	221
	53	The carse shoreline heights, plotted on a WNW-ESE axis, and regression lines. (see text).	221
	54	The carse shoreline heights, plotted on a W-E axis.	221
	55	A regression line profile of the carse, along a WNW-ESE axis. The alternative regression line through all the sections is shown.	222
	56	The relationship of the steps in Figure 53 to a map of the carse, and stages in the evolution of the carse.	224
	57	Late-and post-glacial shorelines as defined by regression lines for the northern side of the Forth valley and estuary.	225

FIGURE	58	Eustatic change during late-and post-glacial time, according to (1) Shepard and Suess (1956), (2) Godwin, Suggate, and Willis (1958), and (3) Shepard, 1960; and (4) eustatic change before 7,000 B.P. according to Curray (1960). (Taken from Jelgersma, 1961).	226
	59	Eustatic change during the post-glacial period, according to (1) Schofield (1960) and (2) Fairbridge (1961). Relative sea level change in the Netherlands (3) according to Jelgersma (1961).	226
	60	The formation of a raised shoreline during a steady rise of the land and decelerating rise of the sea, assuming central uplift.	229
	61	The formation of a raised shoreline during a steady rise of the land and decelerating rise of the sea, assuming peripheral uplift.	229
	62	The formation of a raised shoreline during decelerating subsidence of the land and steady subsidence of the sea.	229
	63	Figure to illustrate that in theory during isostatic and eustatic movement there is only one point along a radius from the centre of uplift where the land and sea can be in equilibrium.	230
	64	The formation of raised shorelines during wave uplift.	231
	65	Theoretical limits to the area over which a shoreline may be formed during steady rise of the land and decelerating rise of sea level.	231
	66	Theoretical limits to the area over which a shoreline may be formed during dome uplift.	231
	67	Metachronous shorelines as deduced from the successive positions of the highest marine limit.	232

		Following Page	
FIGURE	68	Isostatic uplift at Stirling since 12,000 B. P., according to Sissons (1962).	232
	69	Interruption of the shoreline pattern caused by a readvance.	232
	70	Regression lines for late- and post-glacial shorelines on the northern side of the Forth valley and estuary (WNW-ESE axis).	233
	71	The inclination of the supposed East Fife late-glacial shorelines on the formation of LG6.	236
	72	All shoreline regression lines, projected to a common base level.	237
	73	Relative sea level change during the late-glacial period on the northern side of the Forth valley and estuary.	237
	74	Eastward projection of the regression lines for PG3 and PG4.	238

CHAPTER I

INTRODUCTION

The coastal landscape of Scotland contains abundant evidence that the sea has relinquished considerable areas of territory in geologically recent time. Most Scottish coasts possess, to a greater or lesser degree, many features of the former sea margin now raised above the reach of the waves.

Scottish geologists have always found these features particularly interesting, and the development of opinion as to their origin followed a course which had many parallels, first advocating catastrophic change, then agreeing upon less violent events. By the early years of the present century the problem of formation of the features appeared solved, and writers felt confident in describing the Scottish "raised beaches", as the features were generally called, in terms of a particular scheme.

With the trend towards a more quantitative approach in geomorphology, recent years have seen the recognition that not enough measurement of these features has been carried out, and accordingly Donner (1959, 1963), McCann (1961) and Sissons (1963) attempted to remedy the situation. The result was that a fundamental controversy arose as to the origin and nature of the features.

This account is a direct outcome of the controversy. It was decided to examine displaced marine features in an area small enough to permit detailed examination but large enough to test current theories. The aim of the investigation was to ascertain the distribution and height of the features in a particular area and attempt to account for the pattern revealed. The area chosen was the northern side of the Forth valley and estuary.

The Area

The Area

The area extends in a broadly east-west direction between latitudes 56° and $56^{\circ} 11'$ North and Longitudes $2^{\circ} 30'$ and $4^{\circ} 30'$ West.

The Forth valley and estuary (Fig. 1) are one of the major features of central Scotland, though the river after which they are called is by itself a very humble stream. In the shadow of the Menteith Hills in the western extremity of the area, a small burn, the Ducray Water, takes the name of Forth after passing eastward through the town of Aberfoyle. Two miles to the east of that town, the river Forth breaks through the ridge of which the Menteith Hills are a part, in a narrow declivity, and crosses the Highland Boundary Fault to enter a broad lowland. Near the head of this lowland lies the Lake of Menteith, surrounded by morainic mounds, but eastward of this the lowland is a near flat plain, the Carse of Stirling. These carse-lands attain a width of some three miles, most of which lies north of the river, while in length they exceed twelve. The carse does not generally exceed 50 feet O.D., and the contrast with the surrounding country is marked. To the south rises the steep northern face of the Campsie Fells, some 1,500 feet high, and although the immediate landscape of gently rolling country to the north is less dramatic, behind it lies the southern edge of the Highlands, where Ben Ledi and Ben Vorlich exceed 2,800 feet O.D.

Through this landscape the Forth meanders slowly and almost unobtrusively, keeping to the south side of the valley; but near Stirling it receives the waters of the Teith, a larger river, and also the Allan Water, and in consequence greatly increases in size. The character of the low-

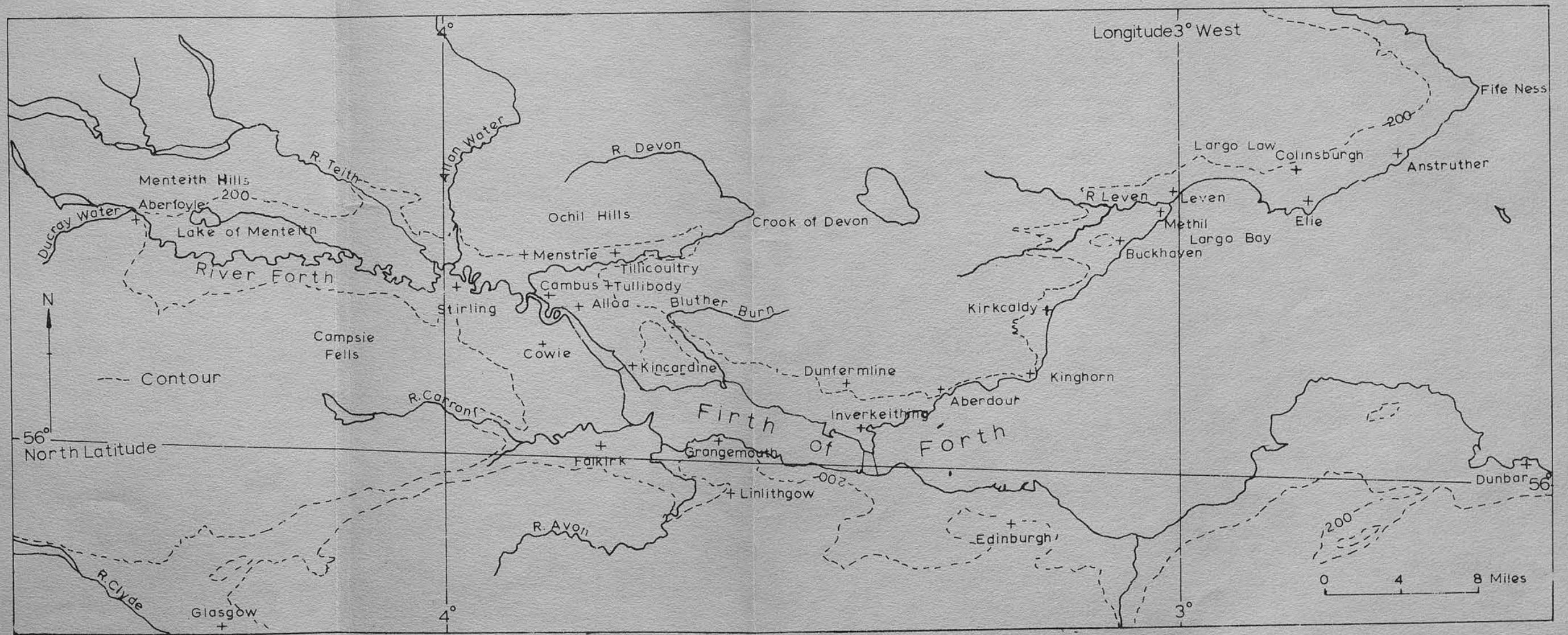


FIGURE 1 The Forth valley and estuary.

land also changes here, but not because of the river. At Stirling, hills of dolerite close in from north and south, so that the lowland narrows in width to less than one mile.

East of Stirling the carse broadens again to achieve a width of four miles between Menstrie and Cowie. The Forth flows through it in large meanders, and is now a tidal river. Away to the north, the Ochil Hills provide the most dramatic scenery of the region, rising almost sheer from the carse to heights in excess of 1,800 feet O.D. The south side of the lowland is now less dramatic for here low hills and extensive glacial deposits characterise the landscape. At Cambus the Forth receives the Devon, which has been flowing westwards along the south side of the Ochils since the Crook of Devon. West of Tillicoultry, the floor of the Devon valley is formed of similar carse deposits to those of the Forth lowland.

At Tullibody, on the north side of the Forth, low ridges of glacial material intrude amongst the carse-lands, and by Kincardine there is very little carse north of the river. As the carse here narrows, the river widens and assumes a different character. Here the Firth of Forth begins.

From Kincardine to Kinghorn the Firth lies along a west-east line and varies between one and five miles in width. Throughout this section the north shore is bordered by a belt of strongly ice-moulded country, and the coastline is generally steep, heights of 250 feet O.D. being generally achieved within a mile of the shore. The coastal landscape is however a varied one. The ice-moulded country is interrupted by such features as the valley of the Bluther Burn, which contains extensive

terraces; and by ancient lake flats as at Dunfermline and Inverkeithing. The landscape is clothed in extensive growths of woodland, which give it a pleasant appearance.

The most salient features of the coast between Kincardine and Kinghorn are however provided by the geology. At Inverkeithing, the occurrence of dolerite sills occasions a constriction in the width of the estuary and provides a bridging point. Between Aberdour and Kinghorn volcanic vents give rise to an exceptionally steep coastline and inland form the Binns of Burntisland, which rises to 632 feet O.D.

At Kinghorn, the north shore of the Firth turns northward, and the estuary opens out to admit a greater influence from the open sea. As a result, the coastline from Kinghorn as far as the industrial towns of Methil and Buckhaven is for the most part steeply cliffed, except at Kirkcaldy, where wide terrace features, on which the town stands, occur.

Behind the coastline in this section, the land has a distinct west-east grain, this being emphasised by the dolerite sills in the Raith Park area. Such streams as the Tiel and Dronachy Burns are subordinate features of a topography reflecting the paramount influences of glaciation and geology.

At Leven the coast changes in character. Here the rivers Leven and Ore combine to distribute their waters in the Firth, and eastward of this point the wide sweep of Largo Bay commands attention. Its shores, fringed by a multitude of sand dunes, are overlooked by the slopes of Largo Law, rising to 952 feet O.D. Here a great complexity of fluvio-glacial features may be seen.

Largo Bay terminates at Ruddons Point, and here the coastline turns first southward, then eastward, then north-eastward, to follow a north-eastward line as far as Fife Ness, at the mouth of the Firth. This last stretch of coastline is backed by a variety of scenery. North of Kinncraig Point, the land as far as Colinsburgh is low and extremely varied because of numerous fluvioglacial forms. This character is maintained as far east as Anstruther, where however it dies out and the landscape inland is almost featureless as far as Fife Ness. The coastline itself comprises alternate bays and steep rocky headlands, with cliffs generally exceeding 70 feet in height. Comparing this with the coastline at the head of the Firth, it is apparent that the transition from an estuarine to an open sea coast is complete.

Form of the Thesis

This thesis is divided into two parts. The first part describes the groundwork. In this, considerable attention is paid to the effects of glaciation and deglaciation in the area, since previous investigations have suggested that these events were often closely connected with local sea level changes. Chapter II, a study of literature on glaciation, deglaciation, and sea level change in Scotland, is followed by a discussion in Chapter III of the failings of previous methods of investigating sea level change in the light of which new methods are drawn up. There follows an examination of the effects of glaciation, deglaciation, and local sea level change in the area divided into four parts: Chapter IV deals with the area between Aberfoyle and Stirling; Chapter V with the area between Stirling and Alloa, including the lower Devon valley; Chapter VI treats

the coast from Alloa to Kirkcaldy; and Chapter VII the coast from Kirkcaldy to Fife Ness. Chapter VIII summaries the salient points of Part I.

The second part is concerned with the pattern of marine and associated features in the area as a whole. After an introduction (Chapter IX), the development of thought on shoreline movements is analysed (Chapter X), and following this the pattern of shoreline displacement on the north side of the Forth is discussed and interpreted (Chapter XI). The work is then concluded in Chapter XII, which comprises^a recapitulation of the principal results.

The measurements and formulae used in this work are recorded in the appendices.

CHAPTER II

THE DEVELOPMENT OF PRESENT OPINION ON
LATE- AND POST-GLACIAL CLIMATIC CHANGE
AND SEA LEVEL FLUCTUATION IN SCOTLAND1a. Climatic Change in the Late-Glacial Period

Despite the abundant evidence of very recent glaciation in Scotland, agreement upon a chronology of glacial retreat stages is wanting. Since A. Geikie (1863) first indicated that the recession of the ice sheet had been succeeded by an advance of valley glaciers, many writers have attempted to unravel the complexities presented within the broad picture.

During the nineteenth century, evidence accumulated to show that considerable variations of climate had taken place in both glacial and post-glacial time. A number of discoveries were made in central Scotland of organic deposits lying between two tills. Sections were observed where a considerable thickness of sand and gravel, indicative of deglaciation, was overlain by a thick bed of till, implying renewed glaciation. In 1866, J. Geikie showed that the stratification of peat bogs demonstrated climatic changes, and early in the present century, Lewis (1905, 1906, 1907, 1908, 1909) identified a period of cool climate from a layer of arctic plant remains found in many bogs. Evidence of renewed glacial conditions was usually termed "glaciation", and the intervals of climatic amelioration were called "interglacials", despite the fact that the organic deposits often indicated no more than tundra conditions (e. g. Hailes quarry section, J. Geikie, 1881) as Sissons (1964) has pointed out. It was usually assumed that during an "interglacial" the land was completely freed of its ice cover.

By the third decade of the present century however, investigators in north

Britain came to the conclusion that evidence of renewed glaciation need not be interpreted in such a radical way. They conceived of large-scale oscillations of a retreating ice-sheet, calling them "readvances". In 1924, Dwerryhouse and Charlesworth described a readvance in north-east Antrim. In 1926, layers of peat overlain by till were interpreted as evidence of a readvance near Carlisle (Dixon, Maden et al.). In the same year, Charlesworth described "a readvance of uncertain yet probably considerable magnitude" to a line running from the Lammermuir Hills across the Southern Uplands to Stranraer.

In 1933, Simpson recognised two important readvances in central Scotland. "The Perth Readvance" had extended to the vicinity of the site of Perth in the Tay Valley, and was manifest by the large "morainic accumulations" in both the Earn and Tay valleys. In the banks of the River Almond, north of Perth, "morainic deposits" (sands and gravels), 15 feet thick, were seen to overlie 40 feet of varved clay, presumed to be marine. It was estimated that 640 varves appeared in the section. Since the top of the varves lay at 90 feet O.D., he concluded that sea level lay at that height before the readvance; but since meltwater channels in the "morainic accumulations" descended to 50 feet O.D., he believed that sea level had fallen to that level by the time of retreat.

"The Loch Lomond Readvance" was marked by conspicuous moraines about Loch Lomond and in the upper Forth valley. Here, sections showed clay with marine shells overlain by sand and gravel. Since the top of the clay at the Lake of Menteith lay at 65 feet O.D., Simpson correlated the readvance with a sea level at that height. He believed that this readvance was of a later date than the Perth Readvance.

About this period, several writers underlined the validity of Geikie's conclusions with regard to an advance of local valley glaciers in various parts of the Highlands (e.g.: Bremner, 1920, 1921, 1934_a, 1934_b, 1936; McCallien, 1937; Wright, 1937). Now, however, it was termed a "readvance" and the names given to it were "Valley Glaciation", "District Glaciation" or "Morainic Glaciation". Figures were obtained for the sea level considered to be contemporary with the readvance. Phemister (1936) noted that a well marked shoreline at about 100 feet O.D. near Loch Hourn and Loch Duich was absent from the heads of the lochs. He concluded that the readvance which occupied the heads of the lochs was therefore contemporary with a sea level at 100 feet O.D. Wright (1937) arrived at similar conclusions after examining the area of the Inner Sound, between Skye and the mainland, where a marked shoreline at 100 feet O.D. could not be traced in the heads of Lochs Carron and Kishorn. Wright found similar evidence in Mull, where investigations showed that sea level was at least as low as 30 feet O.D. before the disappearance of the glaciers. In Lochs Don and Spelve, McCallien found that a sea level at 85 feet O.D. had cut a notch in the outer face of the moraines of local valley glaciers.

With the accumulation of evidence that the withdrawal of the ice sheet from its maximum in Britain was marked by definite stages, early attempts to interpret the glacial sequence in general terms were made by Antevs (1928) and Charlesworth (1931). A more detailed interpretation was made by McCallien (1935) (see Fig. 2). He recognised three important readvances in succession: "The North-east Antrim - Isle of Man - Cumberland Readvance"; "The Lammermuir-Stranraer Readvance"; and finally "The District Glaciation". McCallien considered

that Simpson's Perth Readvance was contemporaneous with Charlesworth's Lammermuir-Stranraer Readvance. He equated this with the Finiglacial phase of the Baltic on the basis of 59 varve measurements at Dunning in Strathearn. These varves, overlain by "morainic deposits" of the Perth Readvance were compared with the Scandinavian varve chronology by De Geer (1935), giving a time span of 11,048 - 11,106 B.C.

In 1936, Phemister recognised two stages during the retreat from the maximum glaciation in the north-west Highlands. These were

- (i) the stage of confluent glaciation, when glaciers radiated from several centres, and many peaks stood out as nunataks; and
- (ii) the valley glacier stage, when glaciers were entirely restricted to valleys.

By implication the retreat of the great ice sheet was not a continuous process, but was interrupted by phases when the ice reasserted itself locally. Phemister, however, did not attempt to draw any limits for the stages he described.

It had long been apparent that the development of man in Britain was intimately connected with the recession of the last ice sheet, and in consequence, as a basis for his book on the Irish Stone Age, Movius (1942) attempted to draw a general map of the retreat stages of the last glaciation. (see Fig. 2.) He considered that the maximum of the Würm in Britain was represented by the line of the "Old Drift"; that the "Newer Drift" was a readvance after an important interstadial, and that the withdrawal of the ice front into Scotland was interrupted by a major readvance to a line incorporating Simpson's Perth Readvance limit and the eastern part of Charlesworth's Lammermuir-Stranraer Kame-moraine. In England this line

was continued to Carlisle and the Isle of Man, thence to link up with the north-east Antrim moraine. This was called "The Highland Glaciation". Subsequent to this stage, a final readvance occurred after ice had retreated far up the Highland valleys, carrying ice back down to form the conspicuous moraines described by Geikie. He preferred the name "Valley Glaciation" for this stage.

In Scandinavia, palynological studies of the late-glacial period were progressing at this time, and by 1947 it was clear that considerable variations in climate had occurred there in late-glacial time (Godwin, 1947). Three cool phases were being recognised, and two periods of climatic amelioration were becoming apparent. In 1951, Manley tried to assess the degree of late-glacial climatic change in Britain. His map of the glacial stages since the maximum closely followed that of Movius, but he termed the Valley Glaciation of Movius "The Perth Readvance".

Undoubtedly the most comprehensive work has been done by Charlesworth (1955). Drawing upon his earlier work in Ireland and the Southern Uplands, and presenting a considerable amount of evidence from the Highlands and Islands, he recognised three principal stages in the retreat of the last ice sheet from its maximum - now considered to be the southern boundary of the Newer Drift. Each was marked by an important readvance, succeeding a climatic amelioration of some magnitude. (see Fig. 2.) First came "The North British Readvance". Then followed "The Highland Glaciation", at the maximum of which ice covered all areas to the north of a line running from the Lammermuir Hills to Stranraer, except for "Moraineless Buchan". Finally "The Moraine Glaciation" marked the last readvance of the ice, corresponding to the District or Valley Glaciation of other writers. Between the maximum of the Highland Glaciation and the Moraine

Glaciation (stage M), Charlesworth recognised 11 substages, and between the Moraine Glaciation and the final dissolution of the ice he recognised 9 substages, of which the third, P, was a minor readvance. Charlesworth correlated Simpson's Loch Lomond Readvance with his Moraine Glaciation, but he ascribed less importance to the Perth Readvance, which he represented as substage L.

In a wider sphere, Charlesworth saw his Moraine Glaciation as a contemporary of that which produced the central Swedish and Salpausselkä moraines in Scandinavia, while the climatic amelioration which preceded it he believed to be the Allerød oscillation, a warmer phase within the late-glacial period by then widely recognised. He equated stage M with a sea level at 100 feet O.D. and substage N with one at 50 feet O.D.

Synge (1956), working in north-east Scotland, defined three stages in the retreat of the ice sheet. (see Fig. 2). "The Moray Firth-Strathmore Glaciation" corresponded to the maximum, during which Buchan was ice-free. "The Aberdeen Readvance" was believed to be the equivalent of Simpson's Perth Readvance, and the final stage was "The Dinnet Readvance", a contemporary of Simpson's Loch Lomond Readvance. Sea level at the time of the Aberdeen Readvance was considered to be at 100 feet O.D., but by the time of the Dinnet Readvance it had dropped to 30 feet O.D..

Since Erdtman wrote in 1929, palynological investigations in Scotland have grown, particularly during the last decade. The late-glacial period is commonly divided into 3 zones after the British pollen zonation. The bog or lake deposit stratigraphy of these zones, as established by Donner (1957, 1958, 1960) and Mitchell (1952) is commonly (base upwards): Zone I - soliflucted material, with

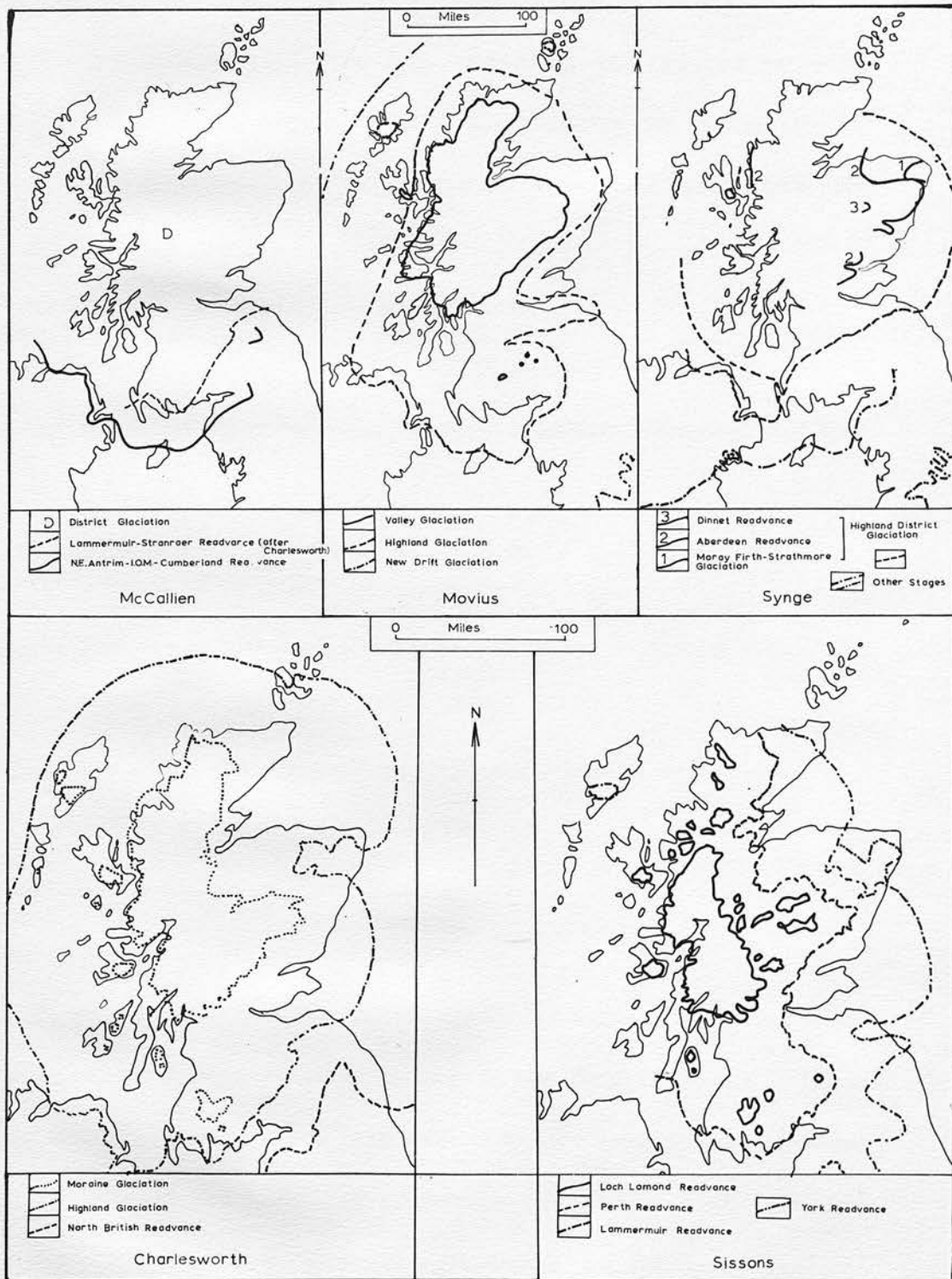


FIGURE 2 Stages in the retreat of the Würmice sheet in Scotland, after McCallien (1937), Movius (1942), Charlesworth (1926 and 1955), Synge (1953 and 1956) and Sissons (1964).

a very low pollen content, if any; Zone II - muds charged with organic material, more rarely a peat layer, the pollen showing a high percentage of scrub vegetation and a much smaller percentage of tree pollen, mostly birch and pine; Zone III - a layer of silty clay or sand very poor in pollen, interpreted as being soliflucted material. The pollen content of Zone II is usually characteristic of an Allerød deposit. Carbon 14 assay of the zone boundaries in England has given the following results (Godwin, 1960):

Zone III/IV boundary	10,300 B. P.
Zone II/III boundary	10,800 B. P.
Zone I/II boundary	12,000 B. P.

At Garral Hill, Banffshire, Carbon 14 assay of Zone II showed (Godwin and Willis, 1959):

Q-104 Zone II, top	10,800 \pm 230 B. P.
Q-101 Zone II, near base	11,880 \pm 225 B. P.

Thus it would appear that the Scottish sequence is probably in accord with that found elsewhere in Britain.

The bog stratigraphy of the late-glacial period in Europe is as follows:

Younger Dryas	Zone III
Allerød	Zone II
Older Dryas	Zone Ic
Bølling	Zone Ib
Oldest Dryas	Zone Ia

Carbon 14 assay has established that the end of the Older Dryas, together with the Allerød and Younger Dryas correspond closely to the British Zones I, II, and III. Consequently British investigators may expect to find equivalents of Zones Ia and Ib, and indeed at least two locations may have (Kearney, 1963, Kirk and Godwin, 1963). Yet unfortunately no general agreement has yet been reached on the absolute date of the Bølling oscillation. Fairbridge (1961) gives 13,000 -

12,500 B.P. However, Tauber (1960) gives:

Zone 1b, Bølling, top	K542	12070 ± 140	B.P.
Zone 1b, Bølling, base	K544	12410 ± 140	B.P.

from a site at Usselo, Netherlands, where the complete late and post-glacial stratigraphy is present. On the other hand, Vogel (1963) agrees with Fairbridge:

Zone 1b, Bølling, top	GrN 12,670 ± 130	B.P.
Zone 1b, Bølling, base	GrN 13,170 ± 135	B.P.

for a site at Poueyferré in the Pyrenees. Location of the Bølling is here based entirely on pollen stratigraphy, since no solifluction layers are present.

Though a subdivision of Zone I has yet to be achieved in Britain, the application of pollen analysis was and still is of direct concern in the elucidation of a late-glacial chronology in Scotland. In 1957, Donner began a number of publications on this topic. (1957, 1958, 1960). Analysing the stratigraphy of sites in Central Scotland he found that Zone II did not exist in the sites he examined within the Loch Lomond Readvance limit of Simpson, but Zone II was found inside Simpson's Perth Readvance limit. He concluded that the Loch Lomond Readvance took place during Zone III and that the Perth Readvance took place during Zone I. He disagreed with Charlesworth in that he equated the Loch Lomond Readvance with a sea level at 50 feet O.D. (as against Charlesworth's 100 feet O.D.), and he introduced a different term for this stage, calling it the "Highland Readvance". In 1962, Donner obtained a complete post-glacial pollen sequence from a corrie facing north-east near the summit of Ben Lawers (3984 ft. O.D.). If any glaciers had existed after Zone III, this would have been one of the most favourable locations. Thus it is likely that the glaciation of Scotland terminated at the end of Zone III.

Since 1955, the glacial retreat sequences put forward by McCallien and Movius

have lost favour in the face of Charlesworth's scheme. Recent work in Scotland and Ireland, however, has been critical of Charlesworth's conclusions. Sissons (1961) has shown that the central part of the Lammermuir-Stranraer "moraine" was not formed along the edge of Highland ice, so invalidating Charlesworth's readvance in this region. Synge and Stephens (1963) have questioned the validity of the continuation of this line in Antrim, and have equated the readvance there with Simpson's Perth Readvance. Charlesworth (1963) has replied, re-affirming his views. McCann (1963) has cast doubt on the reality of stage M on the west coast by Applecross. The validity of this latter stage has been further questioned by the discovery of a marked layer of organic material beneath sands and silts in the deposits of Loch Droma, a small loch in Sutherland, ^r near the head of Loch Broom (Kirk and Godwin, 1963). A Carbon ¹⁴ date of $12,810 \pm 155$ B. P. has been obtained, though the circumstances of the stratigraphy would suggest an Allerød date. At any event, this deposit, clearly formed in situ, and not overlain by till or contorted by glacial advance is well within Charlesworth's Moraine Glaciation limit ascribed by both himself and Donner (1957) to Zone III. Thus whether Allerød or Bølling, extensive modifications need to be made to line M in Sutherland.

Very recently, Sissons (1964) has suggested an alternative picture of the glacial retreat. (See Fig. 2.). He recognises three principal stages in Scotland, each of them an important readvance. His "Aberdeen-Lammermuir Readvance" extends to a line from the Lammermuir Hills, where Charlesworth's Highland Glaciation limit was, to Aberdeen and thence to Caithness. On the west of Scotland the limit lay in the sea. Sequential to this stage, he ascribes considerable importance to the Perth Readvance of Simpson, extending the limit drawn by

the latter at Perth south to encompass the central and western Southern Uplands; north around the Cairngorms, and upper Spey valley, and thence to Inverness. The District, Moraine, or Valley Glaciation of earlier writers is given a more limited extent, corresponding in some areas with Charlesworth's stage N.

Current opinion on the chronology of the late-glacial stages in Scotland would perhaps acknowledge the importance of the Perth Readvance first recognised by Simpson. Synge (1956), Donner (1957) and Sissons (1964) affirm this, while McCallien and Movius both considered it a salient point in their schemes. An important readvance in the area of the Highlands is generally accepted, but after the work of Kirk and Godwin it seems probable that this was less extensive than at first thought, at least in the north-west. It is probable that the Perth Readvance took place at some time during Zone I, and it is likely that the Loch Lomond Readvance took place during Zone III of the pollen sequence.

Beyond these points opinions diverge. It is unfortunate that no glacial stage in Scotland has been dated by Carbon 14. Moreover, the application of pollen analysis to the problems of late-glacial chronology has been limited, and because of the stratigraphical context of the sites so far, its results have been negative. Thus, because Zone II is absent from two sites behind the Loch Lomond Readvance moraine, it does not necessarily follow that the readvance is Zone III. Because of a lack of positive dating, writers have resorted to sea level evidence as a method of dating their ice limits in a relative sense. They have used an assumption of "100 foot" and "50 foot" synchronous sea levels, in connecting readvances in different localities not linked by overland morphological evidence. (e.g., Charlesworth, 1955; Donner, 1957). Sea level would appear to be a useful

yardstick, yet it is here that opinions are most divergent. Charlesworth correlates stage M with "The 100 foot Raised Beach", but Donner equates this stage with "The 50 foot Raised Beach". Such radical differences of opinion are not encouraging, as Sissons (1962) has pointed out.

Summary

Research into the retreat stages following the maximum of the last glacial period in Scotland, generally correlated with the Würm in Europe and the Wisconsin in North America, has led to the concept of the readvance, which is thought to interrupt every period of major ice-sheet dissolution. Limited agreement has been reached on two conspicuous readvances in central Scotland, but further agreement must wait upon more extensive use of the techniques of Carbon 14 assay and pollen analysis. A more detailed chronology of "raised beaches" would certainly be of value.

1b. Climatic Change in the Post-Glacial Period

Opinion on the events and chronology of the post-glacial period in Scotland is far less divided, though it is important to recognise that less work appears to have been done in this sphere than on the late-glacial period.

The work of J. Geikie and Lewis established that peat bogs record climatic changes, and subsequently pollen analysts became able to recognise changes in climate over the post-glacial period from the stratification of pollen grains in peat and lake deposits. The pioneer in Scotland was Erdtman (1928, 1929, 1931), but considerable work has been done recently by Durno (1956, 1958, 1961) and by Donner (1958, 1962).

The beginning of the post-glacial period in Europe is put at 10,300 B. P.,

(Erdtman, 1931). These variations of climate have been held to affect geomorphic processes (Smith, 1963), as well as sea level (Fairbridge, 1961).

Summary

Although climatic change in the post-glacial period was less radical than in the previous late-glacial period, the technique of pollen analysis has enabled the recognition of certain phases of climate. This chronology provides a useful yardstick by which to catalogue post-glacial sea level changes.

2. Movements of Sea Level

The fact that the sea had once covered large areas of the land in Scotland must have been common knowledge for a very long time. In the carse-lands of central Scotland, beds of marine shells are turned up with great regularity, while on the west coast and on many islands the only lands available for cultivation are often the narrow spreads of sand, shingle, and shells, which lie at intervals up to about 100 feet above the present sea.

Records of marine fauna having been found in deposits far inland and well above sea level go back at least to the early eighteenth century (see Chapter IV). They appear to have been of two types. From an early date, records of shells found in the carse show that the habitat was similar to that of the present day (Statistical Accounts, 1794, 1845). On the other hand, a very different fauna was obtained from the clay pits excavated as industry expanded towards the middle of the nineteenth century. Shells from the well known "Clyde Beds" collected by Smith (1936) and from Portobello (Martins, 1851), Elie and Errol (Brown, 1867),

together with numerous seal skeletons found in Stratheden (Page, 1859), by St. Andrews (Walker, 1863) and Kirkcaldy (Allmann, 1858), were principally of an arctic character. The clay in which this arctic fauna was found often lay at a higher altitude than the carse, which rarely exceeds 45 feet O. D.

Side by side with evidence of one or more falls of sea level came indications of a rise of sea level. "Submerged Forests" had for some time been recognised in England, and Fleming in 1823 and 1830 described instances in the Firths of Tay and Forth. Blackadder (1824) and Drummond (1824) showed that a peat layer existed in places beneath the Forth carse-lands. It became very difficult to reconcile the evidence of both elevation and depression of sea level, and some curious explanations were advanced. (e. g.: in Statistical Account, 1794 and Fleming, 1823).

In 1851, the discovery of a bed of arctic shells 30 feet above the sea at Portobello by Edinburgh had prompted Martins to suppose that the deposit had accumulated while much of the land was covered by ice and the rest was depressed beneath the sea. Subsequently the land had risen on the melting of the ice and the shell bed had attained its present position. In 1861, A. Geikie concluded that the carse and other features with a more recent fauna were a product of an elevation of the land. The full sequence was explained by Jamieson, whose classic paper in 1865 became the foundation for work on sea level change not only in Scotland, but also in other glaciated areas. He observed the various beds described above in close relationship at three principal sites in Scotland: Blair-drummond in the Forth valley, Errol in the Tay valley, and Ellon by the estuary of the Ythan north of Aberdeen. At these sites the sequence from the base up-

wards was (a) Till (b) Marine clay with arctic shells (no shells at Blairdrummond) (c) Peat, containing birch and alder remains (d) Carse clay, with marine shells similar to those of today, and (e) Peat (though only at Blairdrummond). He concluded that during glaciation the land was depressed and that as the ice retreated the sea invaded the depressed areas depositing clay sometimes with arctic shells. Next, while the final retreat of the glaciers was taking place, the land was elevated, and subsequently peat grew upon the surface of the arctic clays. Then a depression of the land occurred, submerging the peat and allowing the carse clays to be deposited. Finally another elevation took place, raising the carse to its present position above sea level and allowing the great mosses of the Forth valley to grow. To account for these movements he proposed depression beneath the weight of the ice sheet first, then recovery as it melted, but he did not explain the second depression in the sequence. He considered that the carse clays were the estuarine facies of a conspicuous low raised shoreline on the east coast, which, he observed, became lower towards the north-east. He did not propose any names for the features he described.

Jamieson had proposed a scheme which at first sight looked simple: two raised shorelines around the coasts of Scotland, separated by a peat bed indicating low sea level. Yet in reality the scheme was more complex. He had recognised that uplift of the land was not everywhere equal; therefore the shorelines could not be expected to be horizontal if his theory was correct.

Most investigators of that time do not appear to have recognised the full implications of Jamieson's theory. Indeed, it was difficult to accept such up and down movements of the land, particularly when they were not adequately explained. Moreover, other theories were being widely canvassed. To most workers in the field one raised shoreline at a comparatively low level stood out. Hull described it in Kintyre in 1866, and from its extent and width in resistant metamorphic rocks, believed that the sea must have remained at that level for a considerable period of time. He called it "The Thirty foot Raised Beach". This appears to be one of the earliest expressions in Scotland of the term "Raised Beach". Other investigators recognised a similar terrace at a similar level in other parts of Scotland. It became known as "The 25 foot Raised Beach", since its inner edge generally corresponded to the 25 foot contour on Ordnance Survey maps. It was generally considered to be of recent origin. Gradually "The 25 foot Raised Beach" became established as a raised shoreline about the coasts of Scotland.

The other high sea level which Jamieson had described was less obvious, though extensive marine deposits did exist at higher levels than "The 25 foot Raised Beach". Moreover, investigators were misled by marine shells existing at several hundred feet O.D. in the Glasgow area, Caithness, and elsewhere, later shown to be glacially transported. Eventually evidence was gained which showed that not one but two other raised shorelines existed in one area. In 1879 the Geological Survey published sheet 31, embracing an area round Falkirk. On it, 3 "raised beaches" were represented: "The 25 foot Raised Beach", "The 50 foot Raised Beach" and "The 100 foot Raised Beach", corresponding to three

marked terraces in the area, whose heights were approximated. Later, other maps which included coastal areas were published with a similar legend, though sometimes "The 75 foot Raised Beach" and "The 125 foot Raised Beach" were introduced. Officers working on the West coast identified moraines which appeared to have been formed at the same time as or subsequent to "beaches" at about 50 feet O. D. and 100 feet O. D. (Hinxman, 1892). Consequently the arctic marine clays described above were considered to be contemporaneous with either of these features.

The use of this terminology by the Survey presupposed that the features were horizontal remnants of former sea levels, yet some officers were themselves clear that the shorelines they represented as "The 100 foot Raised Beach", "The 50 foot Raised Beach", and "The 25 foot Raised Beach", were tilted. Peach expressed this opinion in a letter to Nansen (Nansen, 1904). He observed that "The 100 foot Raised Beach" sloped upwards towards the heads of estuaries; that "The 50 foot Raised Beach" was often as low as 35 feet O. D. in the western islands; and that "The 25 foot Raised Beach" rarely attained 20 feet O. D. in the west.

In 1906, Jamieson appealed against the practice of mapping "beaches" at 25, 50, and 100 feet O. D., calling it an "article of faith". In 1908 he further emphasised his point about the slope of a feature equivalent to "The 25 foot Raised Beach", giving figures for its height along the east coast. Jamieson's objections were in some degree substantiated. The Forth carse-lands, which had always been regarded as a continuous morphological feature sloping up towards the west from about 30ft.O. D. to near 50ft.O. D. (Jamieson 1865, Milne-Home 1871) were in 1881

divided into "The 50 foot Raised Beach" and "The 25 foot Raised Beach" (^{J.}Geikie).
 Later, in 1927, they were called "The 50 foot Raised Beach", ^(Dinham) and later still in
 1959, they are referred to as "The 25 foot Raised Beach" ^(Read). / On the western sea-
 board, considerable confusion was evident between these two "beaches". Some
 writers regarded "The 50 foot Beach" as an especially clear feature - Peach
 (1904) says "This marks a long pause in the upheaval process, shown by the great
 notch planed out by the sea at this level". Yet others (e.g. Wright, 1914) believed
 it was of much more limited development.

Discussion as to the age of "The 25 foot Raised Beach" was reopened in 1904,
 when Munro produced evidence to indicate that the date of upheaval of a feature at
 a similar level in the Firth of Forth lay in the Bronze Age. About this time,
 archaeologists began to refer to it as "The Neolithic Raised Beach".

Investigations into the origin and development of Scottish raised shorelines
 owe much to the work of Wright. It was he who lent credibility to the theory of
 Jamieson. British geologists had always found it hard to accept such movements
 of the earth's crust as Jamieson had proposed, to explain the sequence of for-
 mation of the various beds. Now Wright (1914) showed that such an apparent
 alternation of upheaval, then subsidence, then upheaval, could be explained by
 variations in the eustatic rise of sea level as the ice melted, combined with a con-
 stantly rising land. Henceforth the theory that the land reacted to the weight of
 an ice cap by trying to maintain isostatic equilibrium (see Chapter X) was widely
 applied in glaciated areas. Having put Jamieson's theory on a firmer basis, Wright
 tried to substantiate it, showing that "The 25 foot Raised Beach" rose to a level
 of 35 feet "above the present shore" near Loch Linnhe, and descended to present sea

level in Ireland, England, and North Scotland. He drew a "zero isobase" for the shoreline; that is to say a line joining all points where the shoreline is at present sea level (see Fig. 3). He attempted to show that its central portions had emerged first, and its distal portions last, due to a wave-like pattern of emergence, basing his argument on archaeological evidence (1925). He said that the name "25 foot Raised Beach" was not a happy one, and suggested that it be called "The Early Neolithic Raised Beach" (1928). He believed that its emergence had taken place at the same time as the Littorina shoreline in Scandinavia.

He was sceptical of "The 50 foot Raised Beach", saying that "Neither is it obvious that what has been termed the 50 foot Raised Beach is everywhere the same shoreline". "The 100 foot Raised Beach", however, he accepted in full measure, saying that "it maintains, as far as available measurements go, an approximate horizontality within this area" (i. e.: its area of distribution), although in a footnote he added "These measurements were made mainly in the peripheral area and are of small number and no great accuracy". He concluded "It would seem as if nothing but faulting could explain the anomaly". Wright agreed with previous observers that both "The 100 foot Raised Beach" and "The 50 foot Raised Beach" were contemporaneous with valley glaciers.

During this period, many Scottish Geological Survey one-inch sheets, and accompanying memoirs, were published for the first time. A study of these indicates the measure of success which the concept of a trilogy of raised beaches had attained. On some sheets raised beaches were described as "Raised Beach", "Higher Raised Beach", "Highest Raised Beach" (sheets 44, 45, 37), and on

others "Main", "Intermediate" and "100 foot Raised Beach" (sheet 43) or "Raised Beach" "Older Raised Beach" and "Oldest Raised Beach" (sheet 81), but on the majority "The 25 foot Raised Beach", "The 50 foot Raised Beach" and "The 100 foot Raised Beach" prevail.

In 1927, Dinham estimated the maximum height of "The 100 foot Raised Beach" at Stirling to be 145 feet O.D. This figure was subsequently frequently quoted as the maximum height of "The 100 foot Raised Beach" in Scotland.

In 1936, another "Raised Beach" was added to the sequence officially recognised around the coasts of Scotland. Phemister described a "distinct shelf" at 15 feet O.D. in Sutherland, which he considered to be later than "The 25 foot Raised Beach".

The likely connection between archaeology and the emergence of raised shorelines, especially in post-glacial time, prompted Movius in 1942 to attempt an analysis of the literature then available on the subject. He proposed the name "Littorina Raised Beach" for "The 25 foot Raised Beach", adding that the latter name could hardly be appropriate in view of the fact that its height varied from 0 to 50 feet above sea level. He believed that the Forth and Tay carse lands, which were thought to attain 50 feet O.D., were the estuarine facies of this "beach". He rejected the term "The Early Neolithic Raised Beach" of Wright (1928) along with "The Mesolithic Raised Beach" of McCallien (1937).

Movius put a different interpretation on the records of "raised beaches" at higher levels than had hitherto been supposed. Wright had observed (1911) that a conspicuous raised wave-cut platform at 100 - 135 feet above H.W.M. in Mull, Islay, Colonsay, and the Tresnish Islands bore evidence of having been overridden

by ice, and therefore believed it to be pre-glacial. Møvius asserted that it was probably late-glacial in age, having been overridden by an ice sheet contemporary with the Perth Readvance. Observing that different readvances were associated with raised shorelines, he concluded that "Late-glacial raised beaches are not necessarily the same age in all parts of the country". He then drew an isobase map (see Fig 3) based on the height information then available on shorelines considered to be late-glacial, and found that the isobases lay within Wright's zero isobase of "The 25 foot Raised Beach"; consequently he deduced that the pattern of uplift was similar to that in Scandinavia. His map indicated that the greatest amount of isostatic uplift had taken place about Rannoch Moor. Møvius' approach was very different to anyone before him. He was aware that a terrace at 75 feet O.D. might well be contemporary with one at 100 feet O.D., but he also believed that many of the higher "beaches" might well be metachronous - the product of a continuously rising or falling sea level. Nowhere does he use the term "100 foot Raised Beach" preceded by the definite article.

Despite the strictures of Wright and Møvius, developments in the last decade underline a general acceptance of four "raised beaches" around the coasts of Scotland. The names "15 foot", "25 foot", "50 foot" (or 75 foot), and "100 foot" have been retained on Geological Survey maps and in memoirs, though many writers accept that they are tilted. In 1953 for instance, Charlesworth observed that "The late-glacial 100 foot Raised Beach" probably lay at 50 feet in Northern Ireland, which suggests that raised shorelines are tilted there. / In 1956, Stephens ^{has been done.} showed that "The 'early post-glacial raised beach' has a decided tilt between Dublin Bay and North Antrim, averaging 1/10th of a foot per mile". In 1963, the same

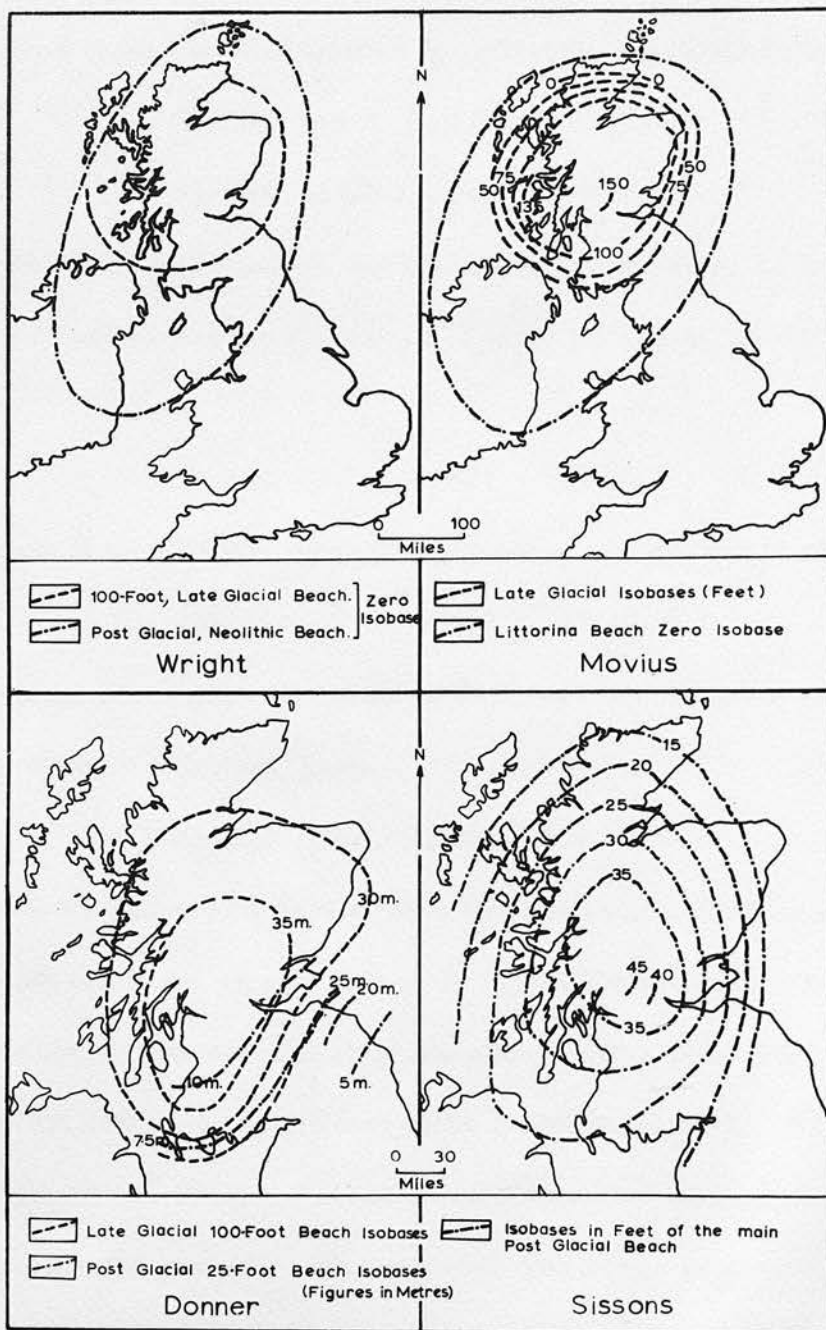


FIGURE 3 Isobases for raised shorelines, according to Wright (1914), Movius (1942), Donner (1963) and Sissons (1964).

author attempts to demonstrate a tilt for 'a' late-glacial "raised beach".

Recently, Carbon 14 assay has added to the knowledge of sea level changes in Scotland. At Airth colliery, near Stirling, the following dates were obtained from the peat buried beneath the carse (Godwin and Willis, 1961)

Q-280 top $8,421 \pm 157$ B. P.

Q-281 base $11,024 \pm 199$ B. P.

though Q-281 was regarded as having been contaminated by inactive carbon.

A sample of buried peat in the carse of Strath Earn by Eastfield of Dumbarney gave:

Q-421 $8,421 \pm 157$ B. P.

and one from Broombarns, near Forgandenny, in the same district gave:

Q-422 $8,354 \pm 143$ B. P.

In 1962, a date from near the base of Flanders Moss, where it overlies the carse clay west of Stirling, gave:

Q-533 $5,492 \pm 130$ B. P.

Hence the dates allow of a period of 3,000 years for the formation of the carse lands considered to be an equivalent of "The 25 foot Raised Beach", and establish that a transgression took place about pollen Zone VIc,¹ ending in Zone VIIa, a possibility already envisaged by Erdtman (1929). Thus the carse, and, by implication "The 25 foot Raised Beach" appear to have been built essentially in the Atlantic period. The picture, however, is not so simple, since buried peats from south-west Scotland have yielded dates varying between

Q-639 $6,159 \pm 120$ B. P.

at Newton Stewart, to

¹ A late period of Zone VI

Q-642

9,620 \pm 150 B. P.

at Irvine, Ayrshire. (Godwin & Willis, 1962).

Recent years have seen two papers by Donner (1959, 1963) on Scottish raised shorelines. In 1959, working principally in Kintyre, but also at other places on the west coast, he determined the height of terraces he described as "raised beaches" located from Geological Survey maps, by aneroid measurement and levelling using the upper limit of the banacle, Balanus balanoides as his datum. He found that the highest shoreline sloped down towards the south-west, and estimated the centre of isostatic uplift causing this to have been at Callander. He could not demonstrate any tilt for the other shorelines, however, and accordingly supposed them to be horizontal. He did not depart from established terminology, identifying the shorelines he measured as 100 foot, 50 foot, 25 foot, and 15 foot. In 1963 he extended his observations to cover east, north-east, and south-west Scotland as well. This time he was able to demonstrate that "The 25 foot Raised Beach" was tilted away from a centre of uplift at Callander, but that its isobases differed slightly from those drawn for "The 100 foot Raised Beach", except possibly in their marginal areas. (see Fig. 3).

The majority of present opinion on Scottish "raised beaches" recognises the following pattern. Probably at the time of the Perth Readvance, land which is now below about 100 feet O.D. was transgressed by a rising sea level. Subsequently the isostatic rise of the land became greater than the eustatic rise of the sea, and a marked shoreline was revealed. Its deposits range from sands and gravels to clays with abundant faunal remains, the clays

usually being a bottom deposit. During this period of regression, the land-sea relationship was occasionally stabilised, so that less marked features, now at about 75 and 50 feet O.D. were formed. Glacial conditions still prevailed at this time. The land continued rising, however, and outstripped the eustatic rise until at some time when sea level lay lower than at present, conditions were probably stabilised. By that time, the climate was more genial and extensive peat bogs grew particularly around the Clyde, Forth, and Tay estuaries. Pollen analysis suggests that this began around Zone V (Durno, 1958). Eventually the eustatic rise overtook the isostatic, and the peat mosses were submerged. This event probably took place during Zone VIc. Sea level continued to rise until it attained nearly 50 feet O.D. in some places, during which time coarse clays were deposited in estuaries and more coarse deposits on open coasts. Then the sea retreated again, and peat bogs began to grow on many of the surfaces revealed at about 5,500 B P. A brief halt in the regression of the sea sufficed to form a terrace at about 15 feet O.D. before the sea assumed its present level. Opinion is divided on whether it shows any tendency at present to depart from this. (Valentin, 1953, Hafemann, 1954).

A considerable body of opinion believes that "The 100 foot Raised Beach" slopes away from a centre of uplift in the Southern Grampians, and that "The 25 foot Raised Beach" is inclined in a similar manner. There are those, however, who assert that both these shorelines are horizontal (e.g. Read, 1959).

Although argument has been considerable about the slope or otherwise of "raised beaches" in Scotland, no-one in recent years except perhaps Møvius, has doubted that four synchronous raised shorelines were formed in late and

post-glacial times. In 1962, however, the concept was challenged by J. B. Sissons. The following is a resumé of this important paper:

After an account of the literature, and an outline of the present position, Sissons attempts to show the lack of definition of "The 100 foot Raised Beach". He recalls accounts which describe it as principally a depositional feature, feebly developed in many areas, and notes that the deposits of arctic marine clays cannot usually be connected morphologically with it. He observes that the late-glacial "beaches" are especially poorly developed in peripheral areas, and notes the differences of opinion of those who attempt to correlate "beaches" with readvances.

Discussing the amount and rate of isostatic recoil in Scotland, he constructs a provisional graph of isostatic uplift at Stirling since 12000 B. P. This shows that uplift was more rapid in late-glacial than in post-glacial times. Considering the Firth of Forth, he shows how present opinion has the late-glacial "raised beaches" less steeply sloping than post-glacial ones by drawing a graph of "raised beach" heights from data given principally in Geological Survey memoirs. He then indicates that the pattern is incompatible with the supposition of more rapid uplift in late-glacial times.

Since the upper shorelines are not continuous morphological features along the coastline, but are very fragmentary, the practice of correlating features over a wide area simply on the basis of similar height is shown to be open to question by the following reasoning. In Scandinavia, a region where isostatic uplift is still going on, and where raised shorelines have been well studied, late-glacial shorelines slope as much as 9 feet per mile away from the centre

of uplift. Assuming that uplift in Scotland were a quarter that in Scandinavia, a late-glacial shoreline might slope $2\frac{1}{4}$ feet per mile. Consequently if the centre of uplift in Scotland is near where Wright, Movi^us, or Donner suggest, a shoreline of 145 feet O.D. at Stirling would be the equivalent of one of 15 feet O.D. at Dunbar.

Like Movi^us in 1942, Sissons asserts that "The 100 foot Raised Beach" is probably a time-transgressive feature, adding that it is probably younger towards the centre of uplift. After discussing the practical application of this reasoning to the Forth area, he concludes that the terms "100 foot Raised Beach" and "50 foot Raised Beach" as normally used should be abandoned.

This paper was criticised by Earp, Francis, and Read, in 1962, and Sissons has replied (1962^a) reaffirming his views. Earp, Francis, and Read had asserted amongst other things that the carse level and the late-glacial levels were horizontal, and in a later paper Sissons (1963) produces the results of accurate levelling of some of these features, demonstrating that they slope eastwards down the Forth valley. Read has publicly retracted his criticism (British Association for the Advancement of Science, Aberdeen Meeting, 1963). Sissons (1963) has criticised the work of Donner on two points. Firstly, he claims Donner's measurements do not have the desired degree of accuracy; Donner mentions discrepancies of up to 3 metres between aneroid readings at the same point, and he was often unable to locate the banacle line. Secondly, Sissons shows how one of Donner's measurements on "The 100 foot Raised Beach" in the Forth area, showing it to be 134 feet O.D., is in fact taken on a glacial outwash feature, disregarding a well marked shoreline at 90 feet O.D. nearby.

He concludes "One therefore hesitates to attach any significance to the isobases for the "100 foot beach" drawn by Donner for the Forth area".

Summary

The history of raised shoreline investigation in Scotland is dominated by the concept of three raised shorelines: "The 25 foot Raised Beach", "The 50 foot Raised Beach" and "The 100 foot Raised Beach", sometimes with three others added: "The 15 foot Raised Beach", "The 75 foot Raised Beach" and "The 125 foot Raised Beach". Most observers believe at least some of these shorelines to be tilted away from a common centre of uplift located in the southern Grampians, but some are on record as believing that they are horizontal features. It has been noted that these concepts developed in the face of opposition from Jamieson, originator of the glacial isostatic theory.

In recent years the long-established opinions have been challenged by Sissons, ~~1952, 1953~~ who has raised substantial objections. It may be fairly concluded that the development of Scottish raised shorelines is as yet only imperfectly understood.

CHAPTER III

THE INVESTIGATION OF RAISED SHORELINES

Previous Investigations

An examination of the character and methods of previous investigations of Scottish raised shorelines suggests several sources of error. These may be grouped under seven headings, six of which were recognised by Johnson in 1931.

1. The inherent difficulties of the problem. Johnson has said "it may be stated that the correlation of former marine levels is one of the most difficult and delicate of geomorphic problems". Yet correlations in Scotland in the past have been carried out by those whose main interest lay in quite different subjects. For instance, by archaeologists, anxious to establish a yardstick by which to correlate various cultures - McCallien (1935, 1937), Movius (1942), and Lacaille (1946, 1950).
2. The search for evidence in support of a single working hypothesis. The classic example is the 25 foot, 50 foot, 100 foot scheme introduced in 1879. Johnson remarked that "coastal regions usually preserve so many traces of real or supposed shorelines that a sufficient number of benches, cliffs, gravel deposits, or other features may be found, sufficiently near to any given level, to lend support to almost any theory favoured by an investigator". As long as terraces are approximated to the nearest 25 foot contour, the 25 foot, 50 foot, 100 foot interpretation will prevail.
3. Failure of authors to state the precise significance of the figures given for terraces described by them. Scottish Geological Survey memoirs, on which most of the figures for raised shoreline heights are based, are guilty of this

error. For instance, "a well-defined feature cut mainly in the boulder clay, between 120 and 130 feet above present sea level" (Allan and Knox, 1934, p189) could mean

- (a) that the terrace is horizontal, but so imperfectly formed that the surface varies between 120 and 130 feet;
- (b) that while as a whole it is horizontal, the front margin is at 120 feet and the back is at 130 feet;
- (c) that the terrace is warped, sloping from 130 to 120 feet along its length.

4. Basing correlations on barometric determinations of altitude. Donner (1959, 1963), King and Wheeler (1963) and Ogilvie (1923) have used aneroids for determining raised shoreline heights. Although measurement is to be welcomed in a field where too many approximations have been made, there are considerable errors inherent in this particular method, especially in Scotland, because of the very variable atmospheric conditions. Donner (1959) claimed an accuracy of ± 1 metre, making two traverses to check each point, although he mentioned discrepancies up to 3 metres. Apparently no checking instrument was used, nor any regard paid to weather conditions, though he emphasised the short time (7 minutes) taken for each traverse. King and Wheeler (1963) claimed an accuracy of ± 4 or 5 feet. Their procedure was the same as Donner's. Ogilvie does not give as much detail, but he claims his measurements were "unusually accurate". When features as low as 15 feet O.D. are being investigated, and when correlations are being attempted over a wide area between small fragments, these methods have important limitations. Moreover, when time is so limited, the careful measurement of various breaks of slope in the shore profile must be rendered difficult.

5. Employing the elevation of non-significant parts of terraces. An example of this is Donner's measurement of a point mid-way along an outwash plain in the Forth area, and subsequent use of this measurement in calculating the slope of "The 100 foot Raised Beach" (see Chapter II). Another example may be drawn from Dinham (1927). Although recognising that sand and gravel deposits north of Stirling may be outwash, he quotes an estimate of their height made part way along the feature as the height of "The 100 foot Raised Beach".
6. Attempting correlations on the basis of marine levels reported in the literature. It is 33 years since Johnson said "studies of ancient marine levels have not yet reached that degree of precision and uniformity in methods of investigating and reporting field observations, to make dependence on the literature a safe basis of correlation". There is no reason to suppose that the above statement is out of date with regard to investigations of Scottish raised shorelines in view of the diversity of methods used.

In addition to the above causes of diversity of opinion, another may be mentioned:

7. No standard datum has been used. The following datum lines have been used for measuring raised shoreline heights in Scotland:
- (a) Ordnance Datum, Liverpool (Ogilvie, 1923).
 - (b) High water mark of ordinary spring tides (McCann, 1961).
 - (c) The upper limit of Balanus balanoides (Donner, 1959, 1963).
 - (d) Sea level at the time of observation, subsequently related to Ordnance Datum, Newlyn, by tide tables. (King and Wheeler, 1963).

The following datum lines have been quoted for raised shoreline heights

apparently obtained by estimation:

- (i) Present Sea level (Allan and Knox, 1934).
- (ii) The present shore (Wright, 1914).
- (iii) Ordnance Datum (Read, 1959).
- (iv) High water mark (Wright, 1934).

The possibility of correlating the height information available with any precision is rendered impossible on the following account:

- (a) The differences between the various datum lines are not only great, but are very variable. Thus both the tide levels and the upper limit of Balanus balanoides increase in height in estuaries. The high water mark datum may range up to 15 feet above Ordnance Datum, and precise figures for it may only be obtained at old established harbours.
- (b) Such vague terms as "present sea level" or "the present shore" can only convey a height approximated to a figure equal to the distance between high water mark of ordinary spring tides and low water mark of ordinary neap tides. This may vary up to 20 feet.
- (c) The validity of one of these datum lines must surely be questioned. Donner has occasion to remark of the Balanus balanoides line: "The barnacle line was used as a base-level for the measurements, but in some areas it is missing, and the base-level is therefore less accurate". (1963, p. 5).
- (d) Many accounts (Dinham and Haldane, 1932; Wright, 1914, 1934; Read, 1959; Earp, Francis, and Read, 1962) contain no indication that the features have been instrumentally measured. In this context, such datum lines as Ordnance Datum and present sea level suggest that the height of the feature has been interpolated

from contours or spot heights. This information must in consequence be treated with the greatest reserve.

In view of the limitation of past investigations, it is perhaps not surprising that there should arise fundamental differences of opinion concerning the development of Scottish raised shorelines. An examination of the methods and results of previous investigations indicates the need for detailed, careful investigation based on the following principles:

- (i) Each clear feature caused by former sea levels should be accurately instrumentally heighted at as many points as are reasonably possible.
- (ii) Ordnance Datum should be used in height measurement.
- (iii) Care should be exercised in identifying features as marine, and all possible origins should be considered.
- (iv) Correlations should take account of differences in composition and morphology of the features.
- (v) The limitations of the methods used should be adequately stated.

The Present Investigation

(a) The Area

The Forth valley and estuary (see Fig. 1) are a critical area in the study of Scottish raised shorelines. Important conclusions about the late and post-glacial geomorphology of the country have been drawn from evidence in the area (see Chapter II). In particular, two important late-glacial readvances have been recognised there and may be expected to show relationship to contemporary fluctuations of sea

level (Simpson, 1933; Sissons, 1963a, 1964). Moreover, the numerous sections recorded showing clays with marine fauna well above present high water mark, together with the general agreement among observers that well marked marine terraces exist, suggest that raised shorelines might be profitably examined here.

(b) Methods

The present study began with an investigation of the literature on the area. Then followed a programme of mapping all identifiable raised marine features, together with glacial features, in the area below 200 feet O.D., and sometimes up to 400 feet O.D. In this way, 250 square miles were covered. After this, borings were made at selected sites in the carse clays to establish the carse stratigraphy. 61 boreholes were put down, an aggregate of 740 feet, averaging 12 feet per borehole. Further stratigraphical information was obtained by consulting National Coal Board records. Finally 2,200 levelled heights were obtained on clear raised shorelines and associated features. Further details of these techniques are as follows:

Mapping. All field mapping of glacial and marine landforms was done on a scale of six inches to the mile. The symbols adopted were chosen for their clarity and descriptive merit. These generally correspond to those currently used by Dr. J. B. Sissons. A key to the principal morphological maps of the area is provided in Figure 4. The more instructive sections discovered were levelled (see Chapters IV and VI).

Boring. To obtain a stratigraphy of the top 25 feet of carse, a standard

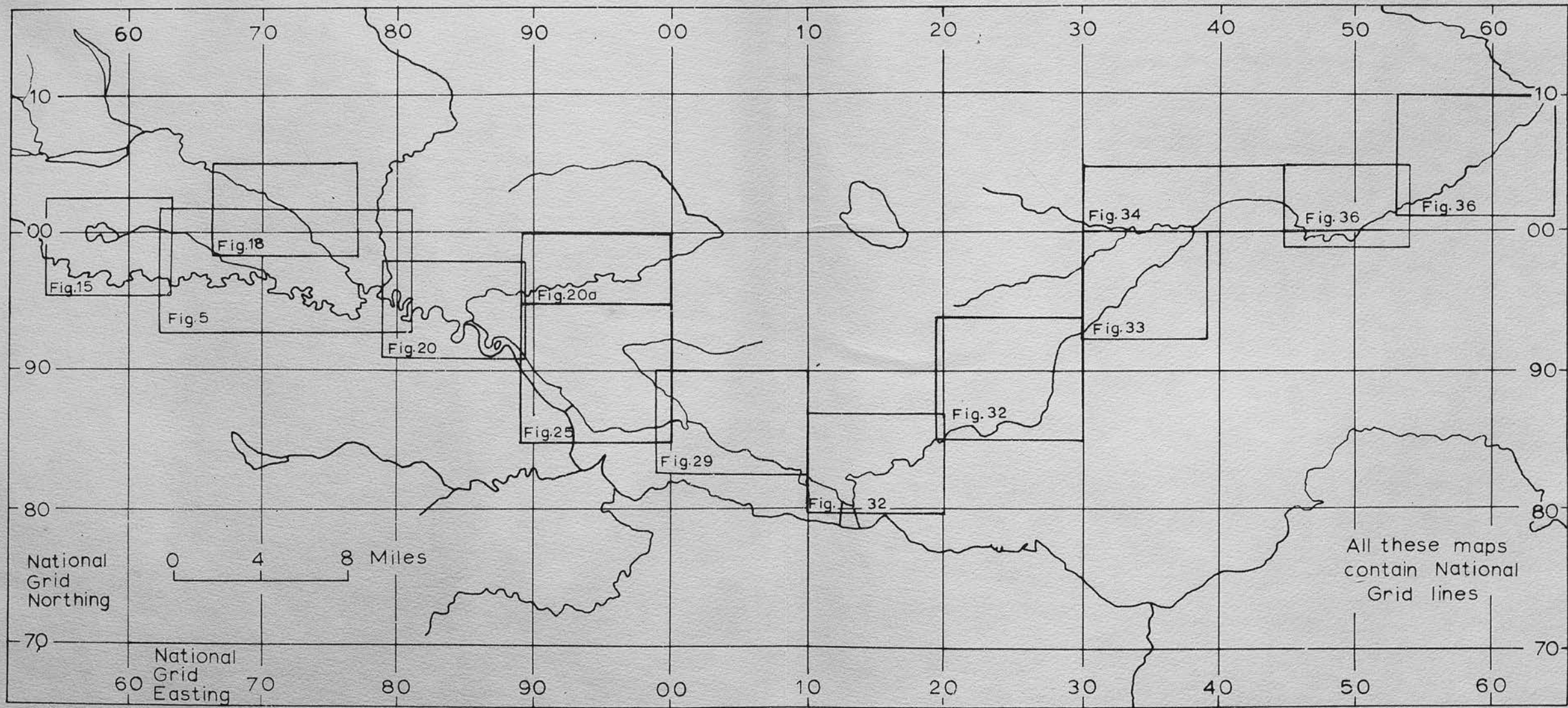


FIGURE 4 Location of the principal morphological maps shown.

Hiller peat borer with a chamber half a metre long was used. This instrument would penetrate any material finer than coarse sand without much difficulty. In 50 of the boreholes, sampling was made every third of a metre, thus giving a complete stratigraphy. In the rest, samples were taken at intervals, and these are indicated. In every case, sampling was carried out only where the horizon to be sampled was at the bottom of the borehole. This eliminated the possibility of contamination and distortion of layers and consequent inaccuracy. After boring, every borehole was levelled, with the exception of six which are mentioned.

Levelling. Measurement in previous investigations has been compromised by three sources of error: instrumental errors, variable datum lines, and (not always mentioned) the difficulty of selecting the point of measurement. In this investigation, an effort was made to reduce these errors as far as possible. In the case of the first two, accurate instrumental levelling from bench marks of the Newlyn Ordnance Datum reduced the error to negligible proportions. In the case of the third, certain precautions were taken.

Instrumental and datum accuracy. The area contains a large number of Ordnance Survey bench marks, and the heights of these were obtained in feet to the second decimal place corrected to the Second Geodetic Levelling (the Third Geodetic Levelling is not yet complete for Scotland) from bench marks of the secondary and tertiary levelling networks, that is, flush brackets and carved marks. Most of these are accurate, relative

to each other, to ± 0.03 feet (R. G. Curtis, personal communication).

Every traverse was closed, and no levelling was carried out when the wind was strong. Four traverses with closing errors of +1.14, +0.90, +0.73 and -0.67 feet were accepted, but otherwise any traverse with a closing error of over ± 0.5 feet was rejected and repeated, and most closing errors lay between 0.00 and ± 0.10 feet. The closing error of each traverse is indicated in the appendix.

Care was taken to minimise the effect of coal mining subsidence. Between Stirling and Cambus, near Alloa, there is a considerable amount of subsidence, and bench marks have subsided by as much as 1.54 feet since the last levelling. Consequently all lines of levelling in this area were tied to the Fundamental Bench Mark at Menstrie, which is re-levelled at frequent intervals by the Ordnance Survey.

Some intermediate sights, which were made over long distances, were read with surveying poles marked only in feet. It was found possible in practice to estimate the reading to the nearest tenth of a foot.

Selecting the point of measurement. The point at which a feature is measured is clearly of the utmost importance, and an attempt was made to achieve standardisation in choosing this point. Measurement at the inland margin was decided upon in the case of terrace features, though lines of heights at right-angles to the inland margin were also made in some instances, especially on the carse. On some outwash and on flat-topped features, various lines (described in the appropriate chapter) were taken. Heights were spaced at intervals of 80 yards along features, though on some very small features more frequent intervals were chosen.

Although the precise inland margin of a terrace is usually obscured by movement of material downslope from the cliff behind, it was found that a short way out from the former cliff a marked break of slope occurred. It could usually only be seen by looking along the ground towards the former cliff from some distance away. This break of slope is thought to be the limit of slopewashed material, and this is suggested by borings along it (BH 47, 48, 50) and sections. It was always measured. This technique obtained for possible shorelines, glacial outwash features, and river terraces alike, though sometimes in the case of the latter features care had to be taken to avoid meander scrolls. It is felt that the generally consistent nature of the measurements obtained justified the method, though the variations that do ensue from measuring similar points at intervals along the same marine terrace serve to cast doubt upon the conclusions of those who have only measured one point. (Donner, 1959, 1963; King and Wheeler, 1963).

The question naturally arises as to what point is being measured compared with a terrace or platform in an active state of formation. King (1959) has indicated the variability of beach profiles, but does imply that the high water mark of ordinary spring tides, coincides with an important break in the profile (p. 200). It is certain that the point measured on the cause is not the limit of wave action or deposition (Chapter IV). Hills (1949) has drawn attention to the fact that erosional platforms are not developed to a common water level. Most marine features in the Forth area are, however, depositional. Study of the present sea shore in the Firth of Forth indicates a marked break in the profile, particularly

on mudflats. This has been levelled at several points from Kincardine to Aberdour, and the results will be discussed later.

Although, therefore, this method of measurement involves only very small instrumental and datum errors, the error in selecting the point of measurement cannot be assessed. All that can be said is that the results suggest that it is small, probably less than two feet (see Chapter XI). Sources of error which arose during interpretation of the results are discussed in Chapter XI.

(c) Terminology

The term "raised beach" is most frequently used to describe such features as are the object of this investigation. It is unfortunate. It has been used to describe both features that may be wholly erosional and mudflat features. Objections to this term have been made by Movius (1942, p. 85) and Zeuner (1959, p. 277). In this study, "raised shoreline", a term already in frequent use, is used, unless referring to specific elements of the former shore, since the measurements taken approximate to the shoreline position. Otherwise, the terminology of Johnson (1919) will be used.

(d) Boring and Levelling Records

Borehole records are detailed in metric units, because of the graduation of the instrument used. They are recorded in full in Appendix II. All levelled heights will be found in Appendix III, where both British (feet and tenths of a foot) and metric (metres, to two places of decimals) units are given, together with the National grid reference for each point,

and the closing error of each traverse. In the text, heights are recorded in feet, and specific heights made during this investigation are given with the reference number in brackets, but without the unit, thus: 114.1

(S702). All other heights, including abbreviated heights of this investigation, are given in full.

THE CASE (see Page 5, 13)

1. The Composition of the Deposit

The material that characterizes the catchment appears to be a clay-silt. Its texture seems to vary in different areas, perhaps being in general more clayey in the central and western areas, and more silty near the Forth and in the east. This is probably the reason for the contrasts in the agricultural use of various parts of the deposit. The deposit is composed of two layers, the upper layer of which is a hard, compact, brownish-grey clay-silt, and the lower a more silty, brown, sandy deposit, often containing small pebbles and possessing a fine texture. The lower strongly resembles the present

CHAPTER IV

THE AREA BETWEEN ABERFOYLE AND STIRLING

The valley of the Forth between Aberfoyle and Stirling has in the past been the subject of a considerable amount of literature on both sea level changes and glacial features. Most previous investigations, however, have been concerned in addition with much greater areas, and the Forth valley has lacked the detailed attention it deserves. This account, concerned only with the north side, is the product of an investigation which included mapping an area of 60 square miles, measuring carse and other terrace features at 750 points, and putting down 48 boreholes. For the purposes of description the area is divided into four morphological units. The most conspicuous unit - the carse - is taken first.

THE CARSE (see Figs. 5, 15)1. The Composition of the Deposit

The material that characterises the carse-lands appears to be a clay-silt. Its texture seems to vary in different areas, probably being in general more clayey in the central and western areas, and more silty near the Forth and in the east. This is probably the reason for the contrasts in the agricultural use of various parts noticed by Drysdale (1909). The deposit is composed of two layers, the upper layer or crust being a harder, mottled grey-brown colour with much vegetable débris, and the lower a more blue-grey, softer deposit, often referred to as "sleech", and possessing a fetid smell. The latter strongly resembles the present

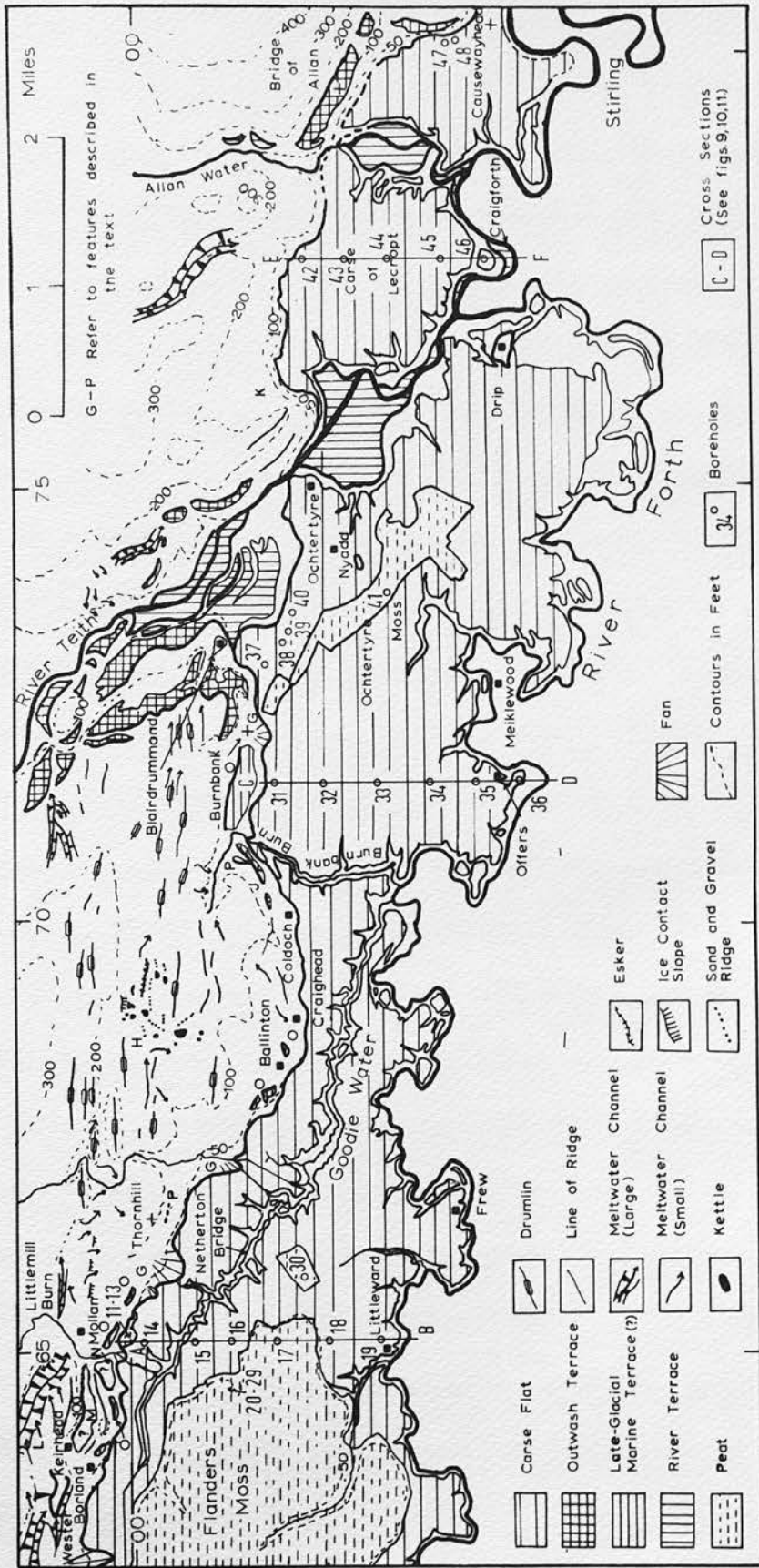


FIGURE 5 The principal glacial and post-glacial features in the area between Flanders Moss and Stirling.

mudflats about the Forth banks in the Alloa area. It is probable that both layers had a common origin, the upper part being subsequently changed by subaerial agency. The total thickness does not usually exceed 12 feet, the upper layer being nowhere more than 5 feet, but in places near the Forth, carse deposits have been proved to a depth of at least 25 feet (B. H. 19, 33-36, 46). Milne-Home (1871) observed that the carse was a finely laminated deposit, a view endorsed by the writer's observations. This indicates quiet depositional conditions.

A variety of material is found in the carse. The presence of vegetable matter near the surface may possibly be explained by the initial method of cultivation, which entailed mixing the carse with dry peat (Farmer's Magazine, 1817, Walker, 1803), but lower down it is probably due to the growth of vegetation as the deposit accumulated. Several instances are known of large tree trunks embedded in the carse (Statistical Account, 1794 - Kilmadock, Kincardine; Tait, 1794; Carmichael, 1835), one of which was in such a fine state of preservation as to be suitable for furniture making. The writer has observed numerous tree trunks in the carse along the banks of the Forth between Cardross and Drip, in the banks of the Goodie Water, and the Teith. Beds of marine shells have been observed in many places from Frew to Stirling. These were described as early as 1707 by Sibbald, and have been noted by Nimmo (1777), Tait (1794), Walker (1803), Forsyth (1806), Blackadder (1824), Carmichael (1835), Haswell (1865, 1870), Jamieson (1865), Smyth (1866), Milne-Home (1871), Tait (1884), Foord and Kidston (1889), and Morris (1892), as well

as the writers of both (1794, 1845) Statistical Accounts among others. Haswell asserted that the shells were restricted to the lower layer. He observed that they showed no signs of disturbance, and were usually arranged in layers. He deduced that they lay in their former position of growth. Milne-Home noted that they generally declined in altitude towards the east. The writer has observed shells along the Goodie water between Netherton Bridge and its confluence with the Forth, and in the Forth banks by Frew. The opinion of all those who have examined shells in the carse is that they indicate climatic conditions slightly warmer than at present, for although the species are all common in the present firth, those that are also common in more southerly latitudes are especially well developed. Foord and Kidston, investigating a site near Bridge of Allan, gave the following list:

<u>Molluscs:</u>	<u>Lamellibranchs</u>
	<u>Ostrea edulis</u>
	<u>Mytilus edulis</u>
	<u>Cardium exiguum</u>
	<u>Tapes virginia</u>
	<u>Macra subtruncata</u>
	<u>Scrobicularia prismatica</u>
<u>Gasterpods:</u>	<u>Buccinum undatum</u>
	<u>Ocenebra erinacea</u>
	<u>Pupura lapillus</u>
	<u>Littorina littorea</u>
	<u>Littorina obtusata</u>

The carse has yielded numerous other faunal remains. In this area five whale skeletons have been dug up since 1824 (see Fig. 6): at Cardross (Clark, 1947), at Ballinton (Drummond, 1824), at Wood Lane near Blairdrummond (Morris, 1892), at Cornton, near Bridge of Allan (Lothian, 1863), and at Causewayhead (Munro, 1898). Clark (1952) believed the most predominant species to have been the Rorqual. Implements were found with the Ballinton Whale (Drummond) and the Cornton whale (Milne-Home). The implement associated with the former was considered to be Mesolithic (Clark). Near Coldoch, the writer has found numerous parts of a whale skeleton on the dryfield beside the carse, but there is doubt as to whether its antiquity is beyond the nineteenth century, when many local inhabitants joined whaling fleets. Haswell (1865) recorded the discovery of other faunal remains during the construction of Stirling new bridge. These included remains of shark, horse, wolf and domestic cattle. Milne-Home noted the discovery of the bones of a small fish with the Cornton whale, and Dinham reported that seal skeletons had been got from the carse.

It has long been recognised that the character of the carse is one of a shallow estuarine deposit.

2. Extent

The carse forms a level area. The deposit is found over a wide area from Stirling to where the Forth breaks through the gap by the Menteith Hills, east of Aberfoyle. Here, at a farm called Carse of Shannochill, carse is seen overlying gravels at several sections in the river bank.

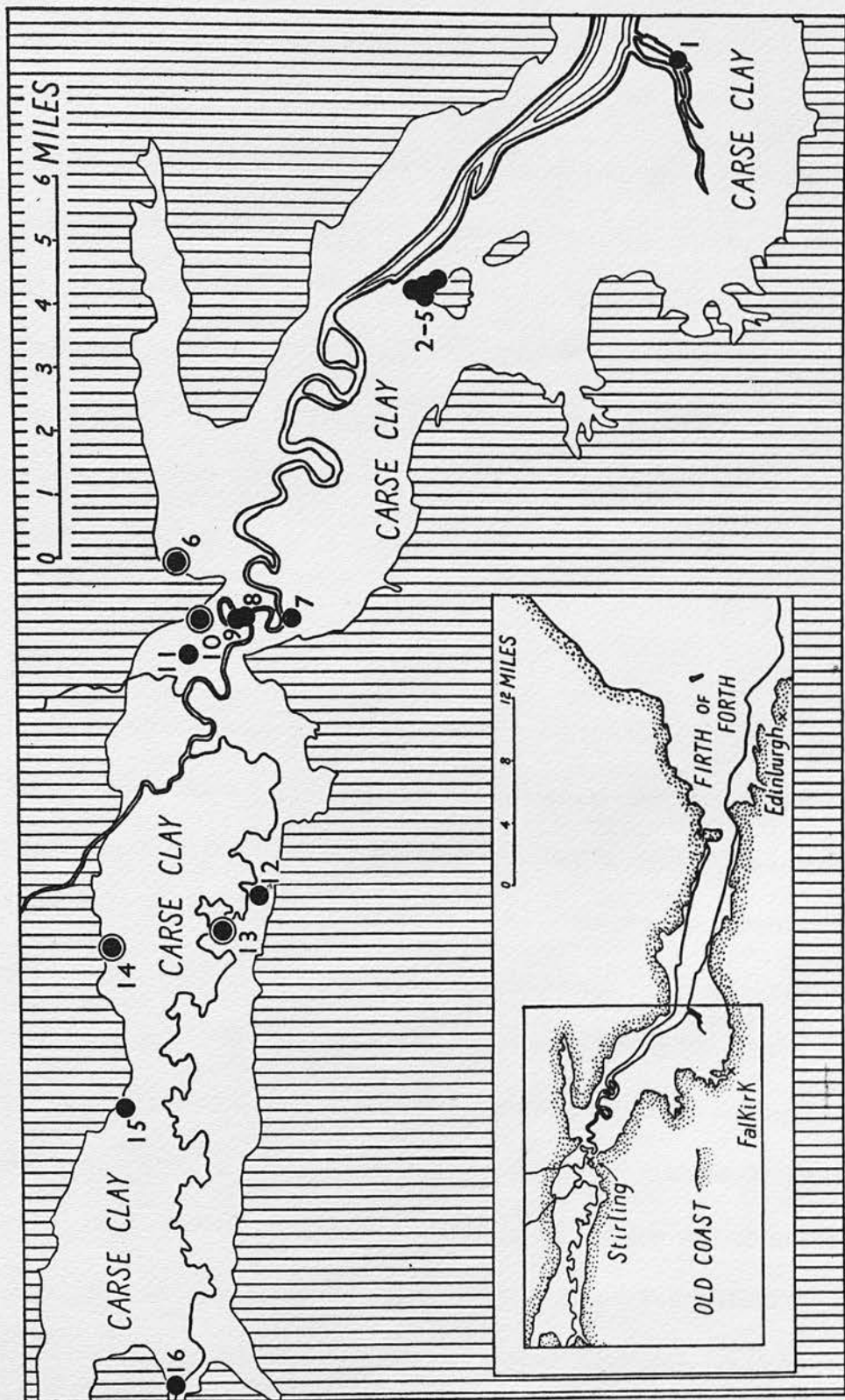


Fig. 3. DISTRIBUTION OF REMAINS OF WHALES STRANDED ON THE SHORES OF THE FIRTH OF FORTH DURING THE STONE AGE
 NOS. 6, 10, 13 AND 14 WERE ACCOMPANIED BY IMPLEMENTS OF DEER ANTLER
 no. 1 Grangemouth; nos. 2-5 Dunmore; no. 6 Airthrey; no. 7 Forthbank; nos. 8-9 Cow Park, Stirling; no. 10 Causewayhead;
 no. 11 Cornton; no. 12 West Carse; no. 13 Melkewood; no. 14 Blair Drummond; no. 15 Ballinton; no. 16 Cardross
 (Based on Turner, Munro and Morris)

FIGURE 6 The location of some whale skeletons found in the carse, according to Clark (1947).

West of this area, gravels and alluvium characterise the sections, while to the east the gravels disappear, and only carse is noticeable in the Forth banks. The area extent of the deposit is at first restricted in the west, and obscured by thick growths of peat (see Fig. 7), but east of Flanders Moss it opens out to attain a width of some two miles at Thornhill. At Craighead the plain narrows, but soon regains its former extent near Burnbank, and maintains this as far as Bridge of Allan before the dolerite mass of the Abbey Craig all but terminates it at Causewayhead. Everywhere the junction of the carse with the "dryfield" of the valley side is marked (see Plate 1), though occasional stream fans effect a more gradual junction.

3. Clearances

It is well known that Flanders Moss and the peat bogs by the Lake of Menteith are remnants of a once much more extensive peat moss that probably covered most of the carse. The Statistical Account of 1794 indicates that the Carse of Lecropt, near Bridge of Allan, was once extensively covered by peat, while the removal of 1800 acres of peat 3 - 10 feet thick from the Blairdrummond estate during the years 1766 - circa 1832 is well documented. (Tait, 1794; Statistical Account, 1794; Walker, 1803; Farmer's Magazine, 1817; Carmichael, 1835; Cadell, 1913; and others). Records are also extant for the clearing of the moss along the upper part of the Goodie Water (New Statistical Account), at Littleward, by Thornhill (New Statistical Account), at Ochertyre (New Statistical Account), and Micklewood (Graham, 1832). The only sizeable

areas where it is uncertain that peat ever grew are at Craighead (New Statistical Account) and by Causewayhead. Morris (1892) was however of the opinion that the whole area was covered. The Statistical Account of 1794 infers that the Carse of Lecropt was clear before the other areas, and in accordance with this, the top grey-brown layer is thicker here than elsewhere (see BH. 42-46). A small moss in Lecropt, a small moss by Thornhill, and Ochtertyre Moss, are remnants of the old cover, left at the termination of the clearances in 1865 (Cadell, 1913).

4. Surface Form

There is evidence that the surface of the carse revealed by the clearances was different to that today. The writers of both Statistical Accounts, also Carmichael (1832, 1835) and Smyth (1866) referred to the "carse ridges" and the difficulties they presented to cultivation, inhibiting drainage. Most of the ridges were levelled by the mid nineteenth century, but the writer has mapped numerous slight undulations on the carse of Blair-drummond estate, and more pronounced features may be seen at South Flanders, south of Flanders Moss. Their amplitude does not exceed two feet.

The contrast between the level carse of the present day and the valley side has led some to describe the carse as being featureless (Tait, 1884). Although the ridges are now levelled this is far from being the case, for although the surface is generally level, it is frequently furrowed by streams and deep ditches, while occasionally small enclosed depressions may be found, especially at the margin. The size of many ditches is

out of proportion to their present use. This is because they were once used in clearing the moss, being fed by large reservoirs on the uncleared sections of the moss so that the peat could be floated away. Other irregularities in the surface are caused by the windings of the River Teith and the Allan Water, which, have formed flood plains 20 feet below the carse level (see Plate II). Small islands of sandstone protrude from the carse at Drip and Nyadd farms. Rock approaches the surface at Craigforth, where it may be seen in the river bed, and possibly at Offers and Craighead, where the Forth appears to flow over rock.

5. Age

The age of the moss would clearly give a minimum age for the surface of the underlying carse. It has been the subject of much discussion.

The stratigraphy of the moss revealed by the clearances was commonly:

- "4. Heath and bent-grass, about one foot.
3. Various kinds of mosses, principally sphagnum palustre, about three feet.
2. Grass; black and heavy - three feet.
1. Many large tree trunks and stools, mainly oak, birch, hazel, alder, and willow."

(Tait, 1794; Farmer's Magazine, 1817).

During the clearance of Blairdrummond moss and Drip Moss (a part of Blairdrummond estate), a trackway composed of logs and birchwood was found at the base leading north-west from the ford at Drip. It seems that before the moss grew, the carse surface was very boggy, as perhaps it would be now, but for the extensive artificial drainage network and



levelling of the ridges. On some of the large tree trunks at the base of the moss, Tait (1794) found axe marks. Reference to the literature on the Roman occupation of southern Scotland convinced him that the trees had been felled by the Romans to deprive native tribes of their opportunity for ambush. As this event was said to have taken place in A. D. 81, and one of the trees had 314 circles in one of its roots, the age of the forest was put at at least 233 B. C. Tait believed the trackway to have been part of a Roman road to the Ardoch fort. Three Bronze Age cauldrons, one found at the base of Ochertyre Moss, one under Blairdrummond Moss, and one found in a small camp at the edge of Flanders Moss, were supposed to have been used by the Romans as camp kettles.

More recent opinion, however, inclined towards the belief that the Ochertyre cauldron was left by the people who fashioned it (Munro, 1904; Erdtman, 1928), and also by implication the Blairdrummond cauldron, which was almost identical. This in turn suggested that the trackway might have been a good deal older than Roman. Further support for a Bronze Age date came when a Bronze Age axe was found beneath the moss at Nyadd in 1908, and when two Bronze Age swords were found "in" Flanders Moss.

If it is supposed that the moss began growing at about the same time everywhere (whether due to cutting down of the forest or - much more likely - the inclement drainage conditions) - and this seems likely in view of the widespread characteristic profile - then the results of pollen analysis carried out in recent years add further support for a Bronze Age

date. In 1929, Erdtmann showed that part of Ochtertyre Moss began growing in zone VIIa, which has been Carbon 14 dated at 7,445 - 4,925 B. P. in Britain (Godwin, 1960). Although Erdtmann's technique has been criticised by Godwin (1934), this particular result has not been opposed. In 1962, Godwin and Willis Carbon 14 dated a sample of "wood peat" from 4 inches above the base of Flanders Moss, near South Flanders, at $5,492 \pm 130$ B. P.

6. Height

The carse has been variously described as part of "The 50 foot Raised Beach" (J. Geikie, 1884; Dinham and Haldane, 1932), "The 25 foot Raised Beach" (Anderson, 1940; Read, 1959), "The Early Neolithic Raised Beach" (Wright, 1937), "The Mesolithic Raised Beach" (McCallien, 1937), and "The Littorina Raised Beach" (Movius, 1942). Accepting the term "The 50 foot Raised Beach", J. Geikie, believing in horizontal raised shorelines and aware that glaciers had been interpreted as contemporaneous with "The 50 foot Raised Beach" in the west of Scotland, sought to show, as Milne-Home had done (1871) that the carse was deposited during a cold climate. His opinion contradicted the shell evidence, but gained the acceptance of Peach (Nansen, 1904) and Dinham (1927). Later, however, Dinham and Haldane (1932) concluded that the carse, which they called "The 50 foot Raised Beach", was contemporaneous with terraces which they called "The 25 foot Raised Beach" further east in the estuary. This introduced confusion into Scottish Geological Survey terminology, which recognised "The 50 foot Raised Beach" and "The 25 foot Raised Beach" as being

separate features formed at different times. This was eventually resolved in 1940, when it appears that the carse became accepted as the estuarine facies of "The 25 foot Raised Beach" (Anderson). This view is held in the most recent Scottish Geological Survey publications (Francis, 1956; Read, 1959). The term "The Mesolithic Raised Beach" is a refinement of "The Early Neolithic Raised Beach". It is in harmony with published archaeological opinion on the antiquity of the implement found with the Blairdrummond whale. The term "The Littorina Raised Beach" arose from the correlation by Movius of the deposit with the Littorina Sea in Scandinavia on the basis of Erdtman's archaeological and palynological evidence. It is, however, not widely used.

Most authorities are agreed that the height of the carse surface increases towards the west. Carmichael observed this in 1835; later Milne-Home (1871) and Morris (1892) stated it, the latter suggesting a slope of $1\frac{1}{3}$ feet per mile. Jamieson acknowledged the slope in 1905, and Dinham in 1927. Maximum heights in the west of 30 to 40 feet "above the present level of the sea" (Milne-Home), 30 feet "above sea level" (Jamieson) and 49 feet "above sea level" (Dinham) have been quoted. Both Milne-Home and Jamieson attribute the slope to the rise in height typical of mudflats in estuaries, due to the increasing tidal range towards the head. Earp, Francis, and Read, however, have recently asserted (1962) that the carse level is horizontal. Accurate levelling south of the Forth by Sissons (1963) has shown that in that area at least the main conclusion of Carmichael, Milne-Home, Jamieson, Morris, and Dinham were fully justified.

Sissons recognises a consistent slope of 0.25 feet per kilometre eastward.

Accurate levelling has been carried out by the writer along the inner angle of the Carse at 80 yard intervals, and heights have been obtained at the same interval across the carse lands at right angles to the axis of the valley on 3 lines. The results of levelling the inner angle show a rise in height towards the west, but this is by no means uniform. At Causewayhead, the inner angle lies at circa 32 (S610-617). By Bridge of Allan this has risen to circa 33 (S618-627), and in the Carse of Leocroft it rises towards the west from 35.1 (S1373) to a maximum near Keir of 38.1 (S1418 - 1438). Near the Teith, river gravels descend beneath the carse and the junction is very subtle. Two breaks of slope are noticeable: one rises towards the west from 37.4 - 38.3 (S1295 - 1296) to 39.9 - 40.2 (S1277-1294); the other is present on the former delta of the Teith (see below) at circa 46 and near Burnbank at circa 45 (S87-95). West of Burnbank there is no evidence of two separate levels, and the height of the inner margin rises steadily from circa 41 (S43-59, 1250-1276) at Coldoch to circa 48 (S20-24) at Borland. Westward of this point the inner margin is obscured by peat, but borings (BH 37-40 and Fig. 16) indicate that it rises further, and a section by Rednock shows carse at 50.5 (S322). Beneath Gartrenich Moss, at the head of the carse-lands, Department of Agriculture for Scotland (Peat Section) borings have revealed a surface most probably of carse at around 48.0 feet O.D. (see Fig. 7).

It is possible that the irregular rise towards the west is the result of

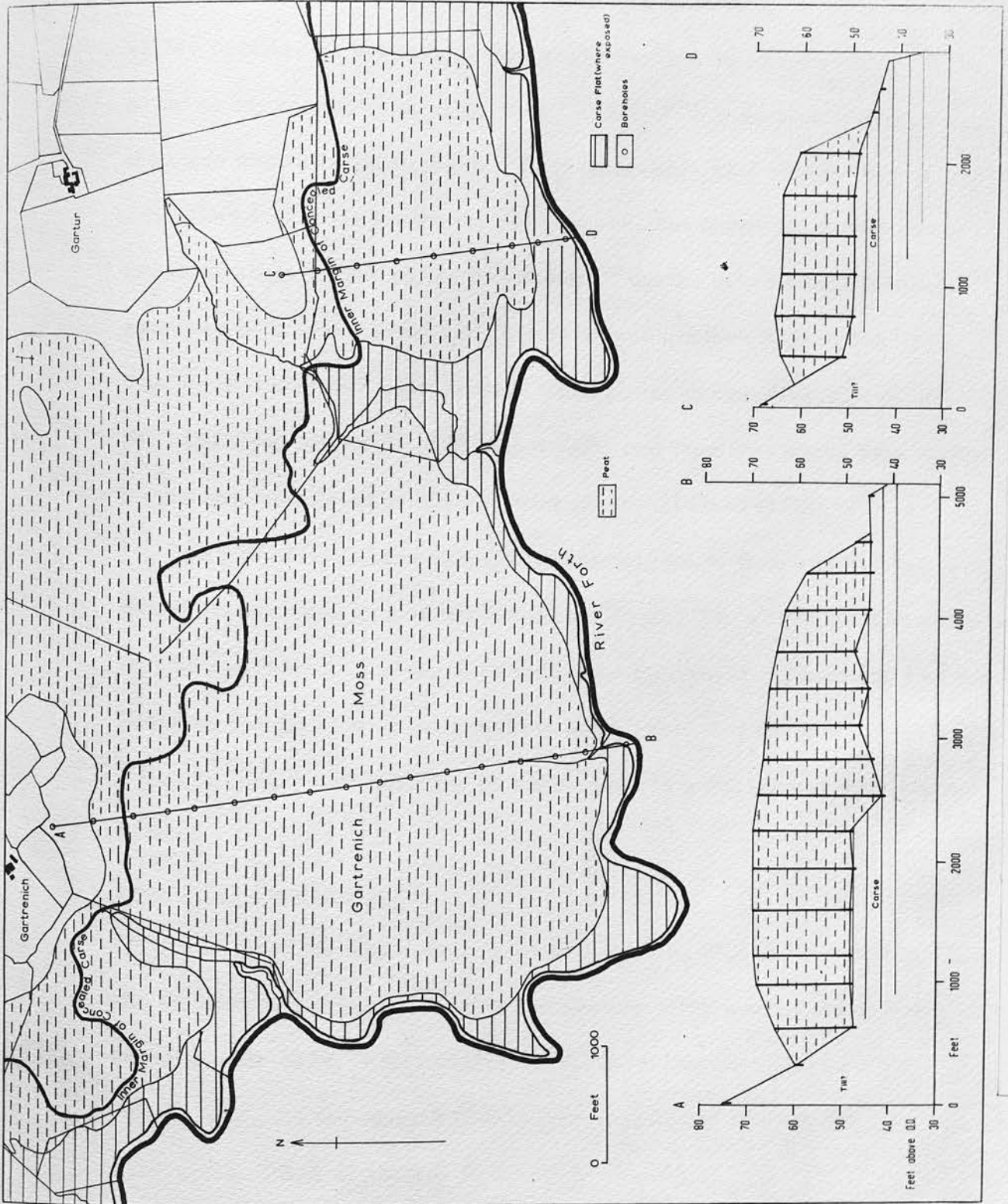


FIGURE 7 Surface morphology beneath Gartreirich Moss.

the carse having been formed by more than one sea level. This is suggested by the two levels near the Teith and Burnbank. The cross-valley profiles do not add further confirmation, however. The location of these cross-profiles, A-B, C-D, and E-F is indicated in Figure 5, and they are shown in Figures 9-11. It is noticeable that profile A-B is smoother and more gentle than the others, but there is no noticeable break of slope on the carse flat in any. On the other hand, there is evidence of a lower level near the rivers in another part of the area. The Teith and Forth have formed flood plains descending eastward from 24.1 (S1299-1306) to 16.4 (S1406-1408), and four feet above this feature a step has been levelled at one point (21.0, S1416-1417).

The likelihood of the carse representing more than one marine level will be considered at greater length in Chapter XI, where further evidence will be considered. Here it is sufficient to state that precision has been added to the views of most previous observers, and the suggestion of Earp, Francis, and Read, namely, that the carse is a horizontal surface, is refuted.

7. Sub-Carse Stratigraphy

When the first whale skeleton was found, at Blairdrummond in 1824, the excavations revealed a most interesting stratigraphy beneath the carse (Drummond, 1824; Blackadder, 1824; Milne-Home, 1871) (see Fig. 8):

4. Carse clay, 4 feet, containing bones of a whale
3. Bed of shells, 4-5 inches
2. Peat, 6 feet, dipping gently eastwards
1. Blueish sand

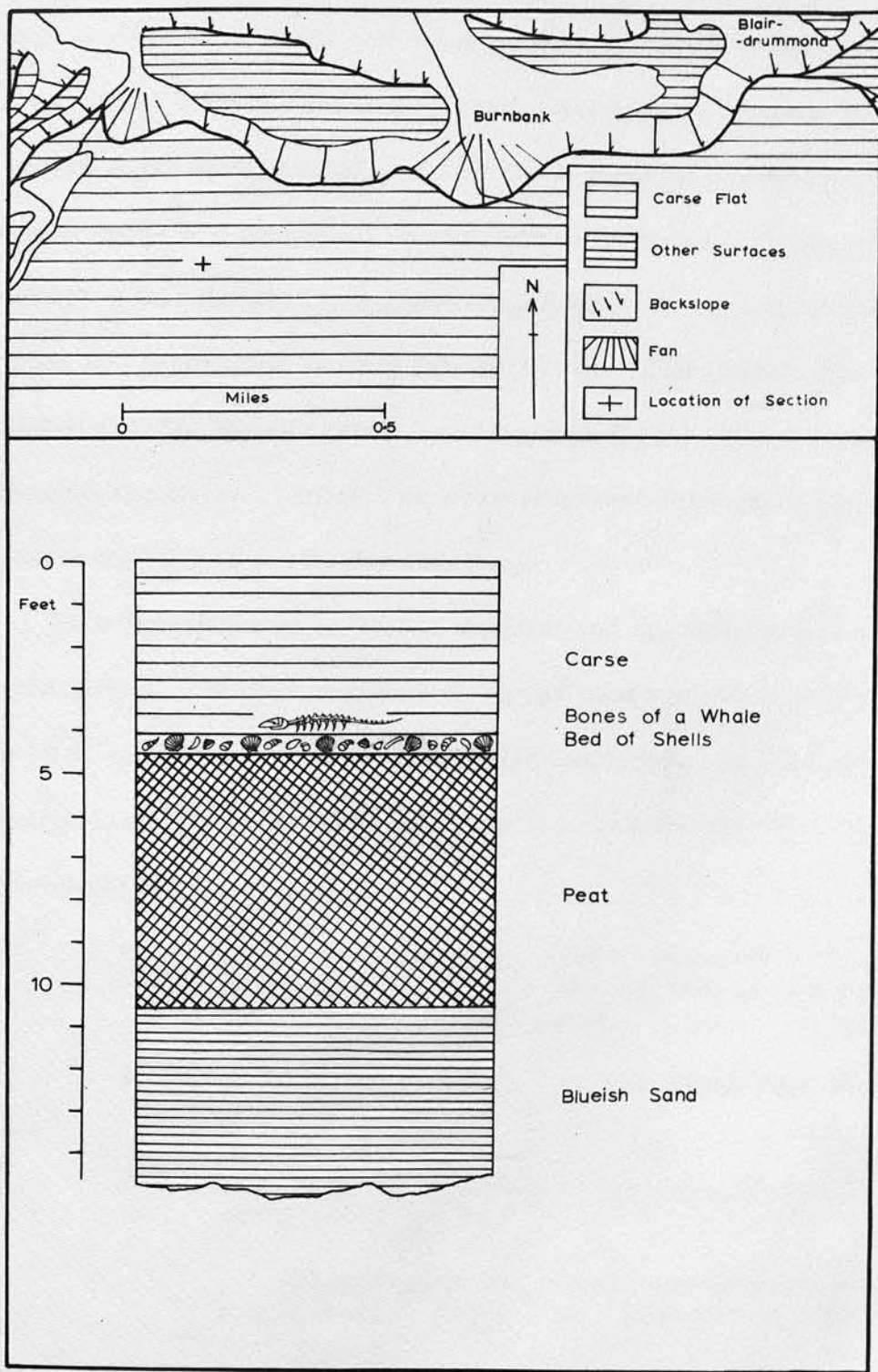


FIGURE 8 The carse section near Blairdrummond, taken from Blackadder (1824), Drummond (1824) and Milne-Home (1871).

Later, Carmichael (1835) and Lothian (1863) described similar sections. Writing in 1865, Jamieson referred to the Blairdrummond section, adding hypothetical beds of till and solid beneath. He observed that there was insufficient evidence for a continuous peat layer. Smyth, however, observed more instances of a layer of peat beneath the carse in 1866, noting that it contained no human implements or remains. Milne-Home (1871) asserted that the peat was probably drifted. Several peat sections were noted by Maconochie in 1874 (Peach 1914). Tait (1884), Morris (1889), Cadell (1913), Peach (1914), and Erdtman (1929) refer to a layer of peat beneath the carse. Instances were scattered throughout the area and not concentrated in a particular location.

This investigation indicates ^{that} the peat and the fine sand beneath are widespread. In open sections along the banks of the Forth the stratigraphy is very well shown between Littleward and Frew. At the former place a particularly clear section (see Plate III) revealed the following: (Top of section 41.2 feet O. D.)

4. Brown carse silty clay. Vegetable remains in upper part; many reeds in a vertical position throughout. 4.9 ft. seen, rest obscured.
3. Blue silty clay. Reeds. 0.5 ft. Transition 3-4 vague and varied.
2. Peat - (b) wood peat, large branches, very tough and compressed 0.8 ft.
 - (a) layered moss, sphagnum, eriophorum, compressed. 0.2-0.3 ft. (Base at 25.5 feet O. D.)
1. Fine blue-grey silty sand.
 - (b) Mixed with peat - 70% sand 30% peat. 0.2 ft.
 - (a) Laminated - coarse and fine layers, coarser

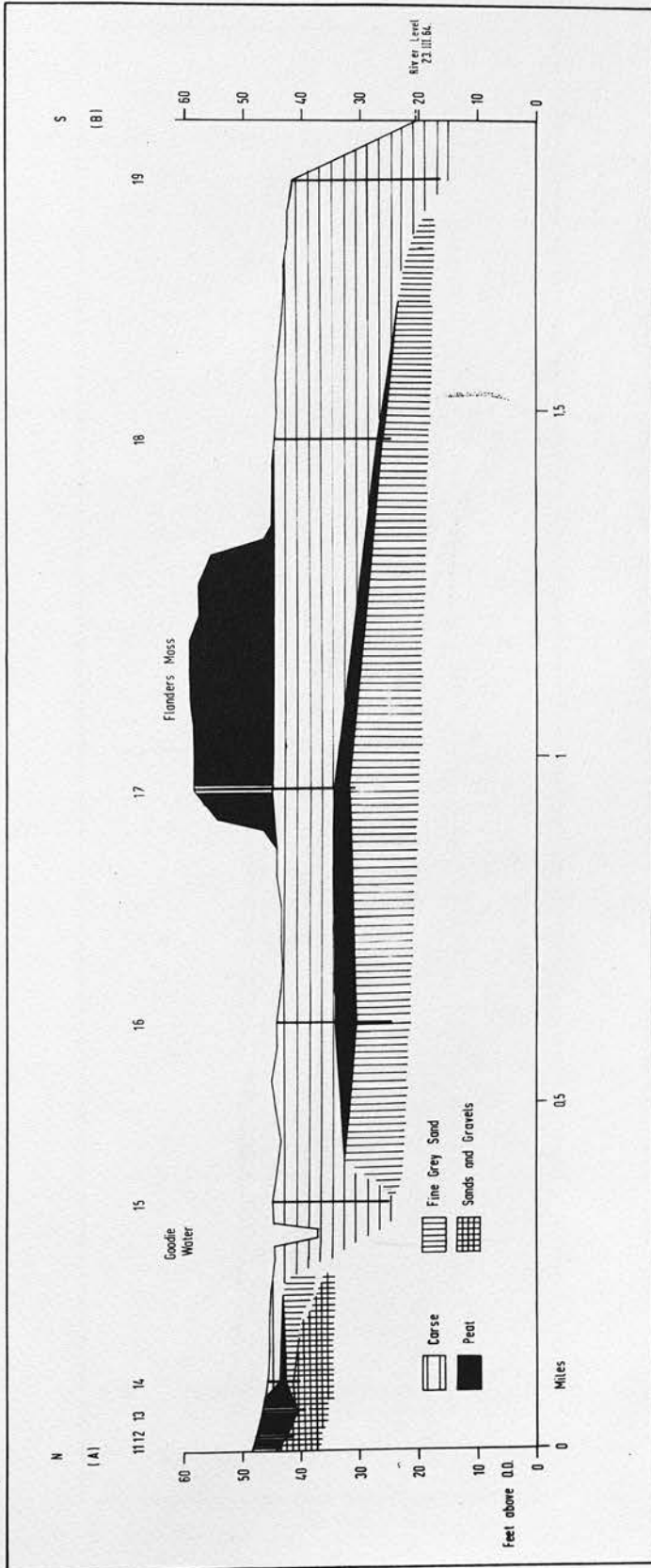


FIGURE 9 Cross-section of the carse, A-B, Figure 5.

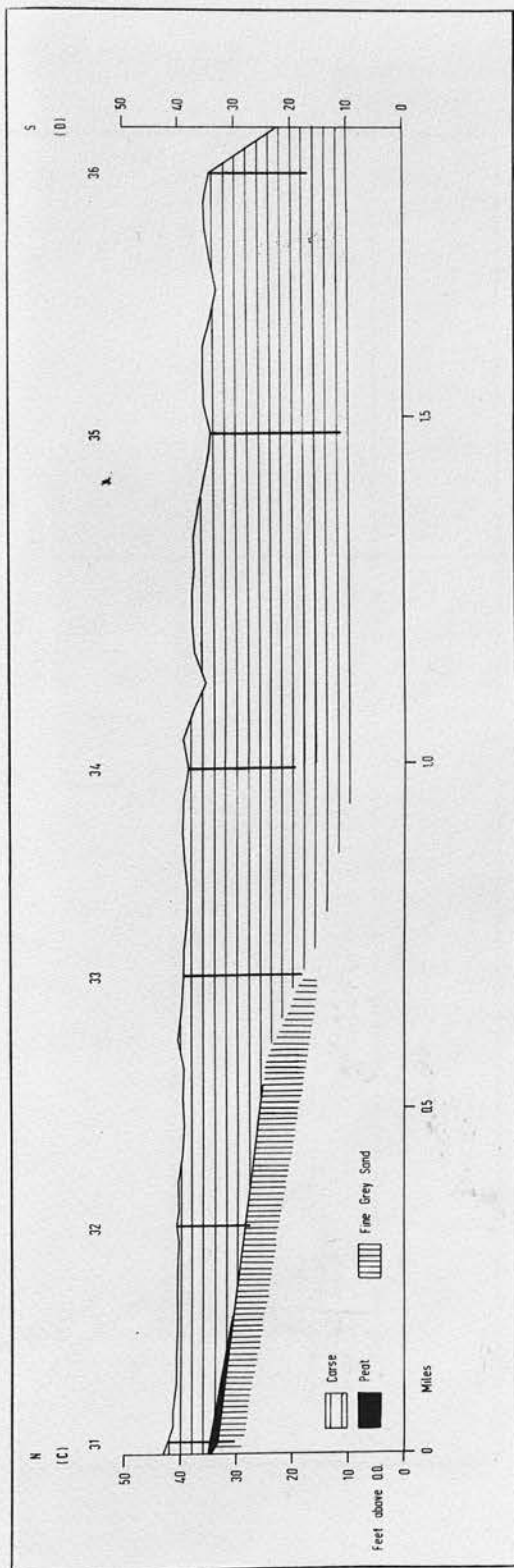


FIGURE 10 Cross-section of the carse, C-D, Figure 5.

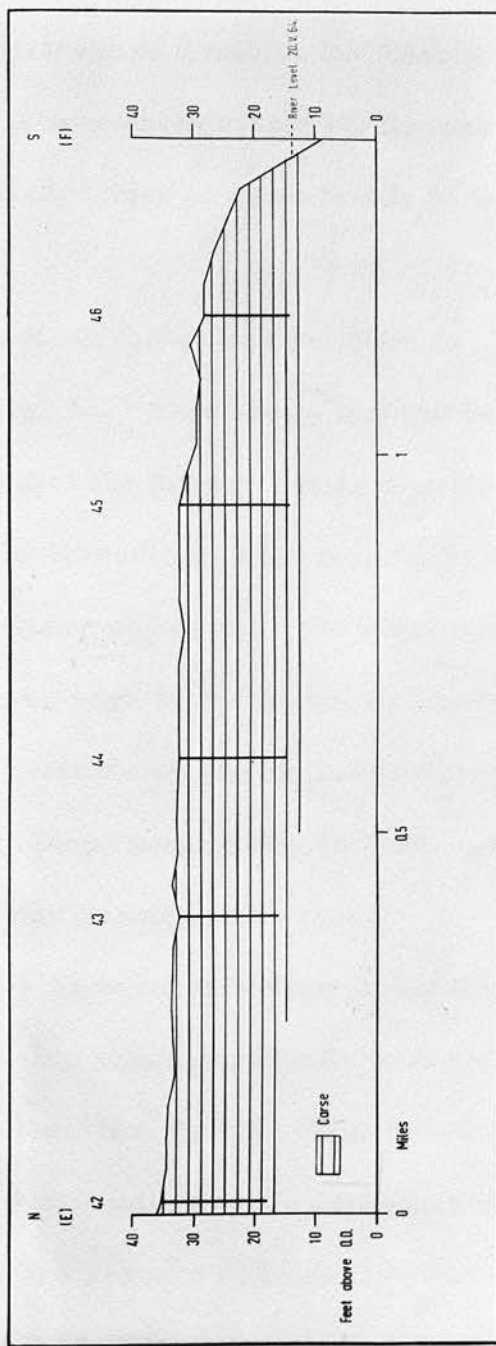


FIGURE 11 Cross-section of the carse, E-F, Figure 5.

with depth. Reeds, especially near top 5.0 ft.

layer 1(a) contained a stone, sub-angular, sandstone.

Between Netherton Bridge, by Thornhill, and its confluence with the Forth, a distance of 3 miles, the Goodie Water flows continuously on a bed of peat, above which oyster shells may be seen. Moreover, farmers at Burnbank, and Bridge of Allan testify to the existence of peat beneath the carse.

A network of boreholes was put down to establish the stratigraphy more clearly (see Fig. 5). This shows that the peat and sand beneath are widespread, but that the former varies considerably in thickness, and neither could be traced beneath a large part of former Blairdrummond Moss and the Carse of Lecropt (see Figs. 10, 11). The peat is more often found at the inner edge of the carse, where it often outcrops from beneath the carse (for instance at Thornhill, Borland and Coldoch, BH 11-14, see Fig. 9). Drummond noticed this in 1824, and referred to the difficulty this caused in cultivating these areas.

Levelling of the boreholes showed that the surface of the fine sand is generally uniform, sloping gradually towards the east and also towards the valley centre (see Figs. 9, 12). The broadly uniform level, together with the widespread nature of the deposit, suggest that it may be a marine surface, but in the absence of faunal evidence this cannot be proven. The Littleward section indicates quiet depositional conditions, in harmony with a quiet estuarine environment. It is interesting to note that on drying out, the fine sand has a very micaceous appearance, suggestive of

a rock flour deposit.

The relationship of Flanders Moss to the buried peat layer is extremely interesting. In 1884, Tait noticed that Flanders Moss "begins abruptly, suggesting the idea that improvers in former ages have proceeded with the removal till, for some reason or another, a sudden halt was made, and the work never resumed". The reason for the premature halt of the clearances was never completely clear, but it is now evident for a large part of Flanders Moss. In 1950, the Department of Agriculture for Scotland (Peat Section) surveyed Flanders Moss, and determined the thickness of peat on a closely spaced grid of boreholes. Their resulting map showed a steep sided "depression" beneath, its base flat at circa 31 feet O.D. (see Fig. 12). Clearly the surface beneath the moss was very unlike the carse outside, and it is evident that the clearances had proceeded to the edge of the "depression", then stopped. Durno took pollen samples from the peat in the "depression" in 1958. His analyses showed that a complete spectrum from Zone V upwards was present - significantly earlier than Erdtman's Ochtertyre peat. Accordingly Durno suggested that the transgression in which the carse was deposited ended east of Flanders Moss, and he identified the deposit under the moss in the "depression" as similar to that described by Drummond at Blairdrummond.

It is difficult, however, to reconcile Durno's suggestion with the known presence of carse north and south of this area, beyond the margins of Flanders Moss. Accordingly 11 boreholes were put down on the edge

of the moss in a line part way across the "depression". These showed (see Fig. 12) that the carse wedges out between the peat (the "wedge" warped due to differential compression (see Fig. 14)), and indicate that in this locality a peat moss stood out as an island during the transgression which deposited the carse around it. It is generally supposed that the carse transgression took place during Zone VIc - VIIa, and it is probable that the peat island was able to maintain itself particularly at this time since, as Durno has shown (1961), the period of most rapid post-glacial peat growth in Scotland was during Zone VI. Elsewhere beneath Flanders Moss, the sub-peat surface is uniform at about 45 feet O.D., the height of the carse in the area, and since Godwin and Willis' (1962) Carbon 14 date was taken from such an area, its implications are in no way altered by the present findings. The surface below the sub-carse peat and the base of the "depression" does not vary in height outside 30-32 feet O.D. It is everywhere composed of a fine blue-grey sand with a micaceous appearance, similar to the deposit which underlies the sub-carse peat in boreholes and sections to the east.

8. Compaction

The following remarks apply equally to those areas of carse east of Stirling.

Studies in other areas suggest that compaction may have been an important factor influencing the present altitude and thickness of the carse and peat. In similar situations in the Netherlands, Jelgersma (1961) observed that while compaction in fine sand is negligible, compaction in

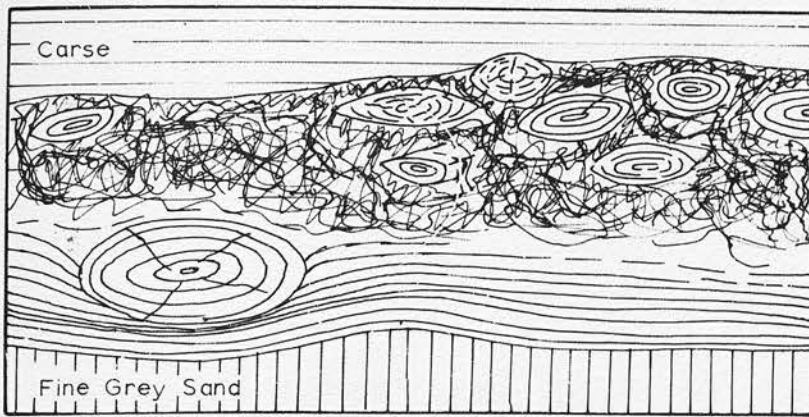


FIGURE 13 Compaction of the sub-carse peat at Littleward.

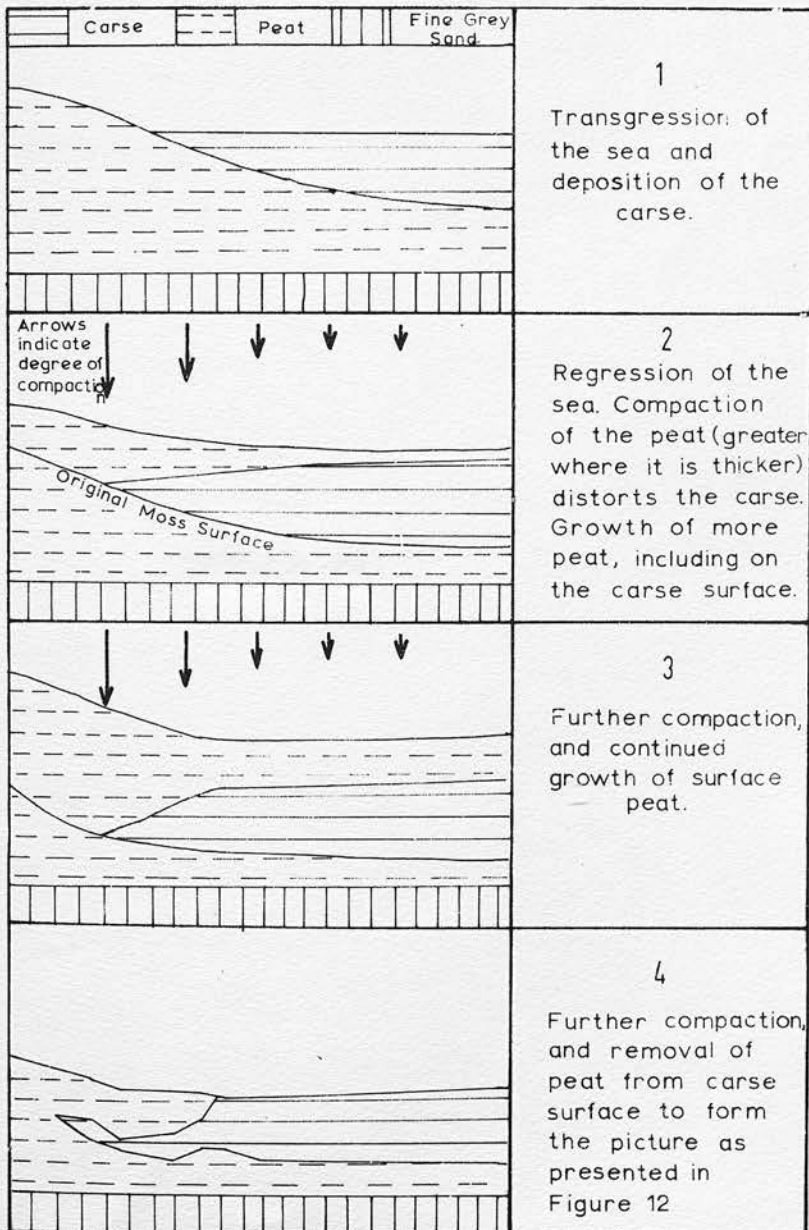


FIGURE 14 Compaction effect upon the carse "wedge" at Flanders Moss.

peat, silt, and clay is considerable, whether by weight of a superincumbent layer or by gravitation alone (autocompaction). In North America, Kaye and Barghoorn (1964) have very effectively illustrated the effects of autocompaction in peat.

There is little doubt that the peat beneath the carse in the Forth area has compacted. In the section at Littleward, the logs in the peat have been compressed to an oval shape, while the stratigraphy of the moss layer is irregular, according to whether or not it presented some resistance to compaction (see Fig. 13). The "wedge" of carse at the edge of the "depression" in Flanders Moss shows the effects of compaction. This wedge probably developed in the manner depicted in Figure 14, due to compaction in the peat. If the inference about the Flanders Moss wedge is correct, then at least some of this compaction took place after the deposition of the carse.

With the methods of the present investigation, there is no way of telling when compaction in the peat took place, or how much compaction has taken place in the carse. The break of slope heights, however, were taken where the carse and peat thickness is generally small, so it is assumed that at the break of slope compaction is least effective, and that the heights obtained bear as close a relationship to the former sea level as is possible.

Conclusion

In 1865, Jamieson published his interpretation of the stratigraphy of the Forth valley carse and sub-carse deposits. Further investigation

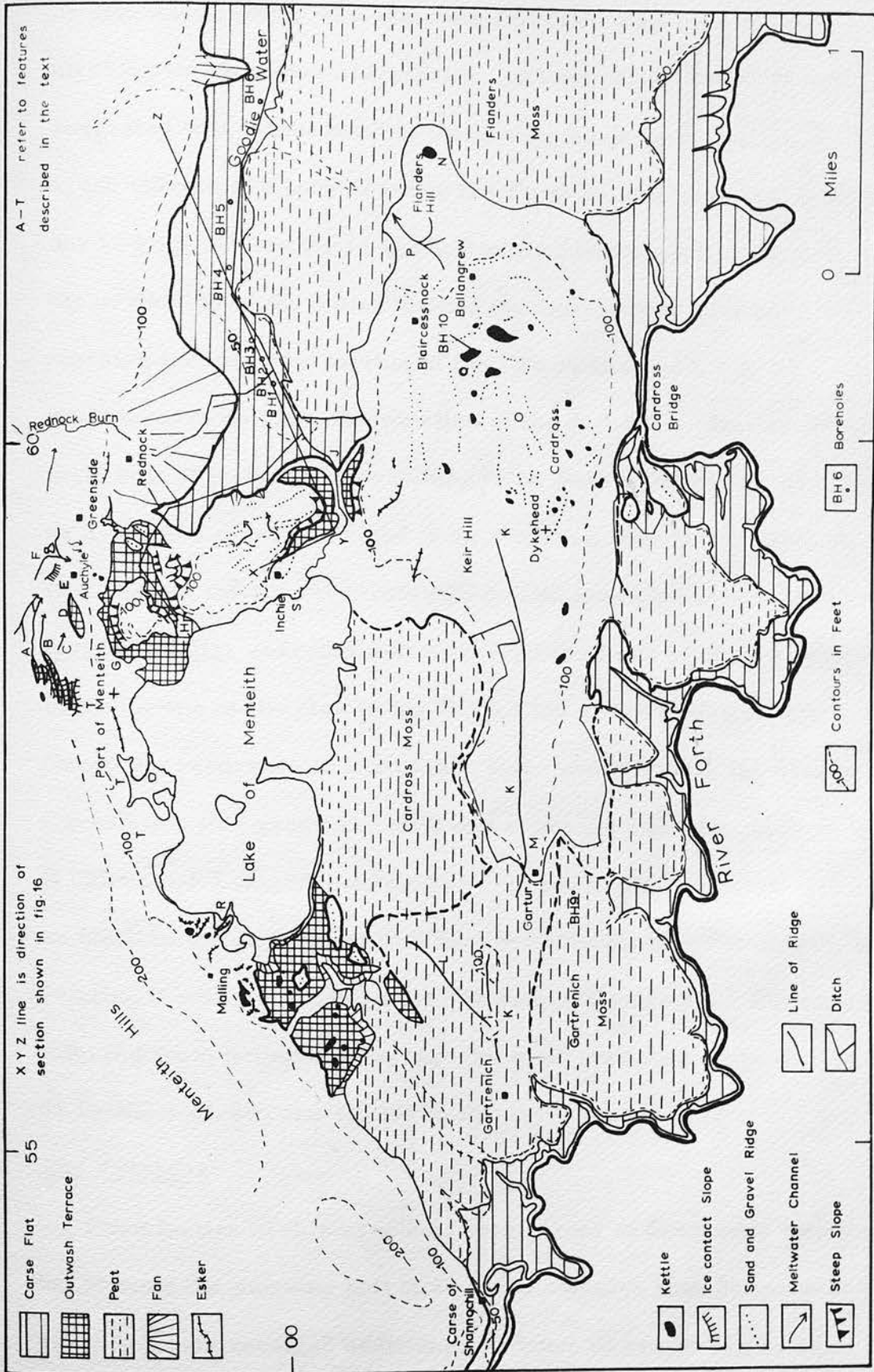
now permits modification of Jamieson's scheme:

1. The fine sand surface beneath the sub-carse peat possibly represents a marine surface.
2. Recession of the sea permitted the growth of peat on this surface. Examined closely, the peat shows a gradual transition from marshy conditions to a deposit in which sizeable trees grew.
3. A transgression of the sea took place, possibly partially eroding the peat. An island of peat was left on the site of Flanders Moss. The sea was shallow, and in the mud deposited in it reeds were able to establish themselves; thus most of the deposit was probably inter-tidal. Débris from the submerged peat bed was incorporated in the mud.
4. The sea receded, probably in stages, so that more than one level of mudflats were revealed. Peat began to grow on this, the carse, surface. Pollen analysis and Carbon 14 assay, together with the majority of archaeological evidence, suggest a date of Zone VIIa for the base of this superficial peat layer. Most of the peat mosses were cleared from the carse by improvers in the late eighteenth and early nineteenth centuries. Measurement has shown that the carse surface increases in height towards the west, where it attains a maximum of 50.5 feet O.D.

THE GLACIAL FEATURES AROUND THE LAKE OF MENTEITH (see Fig. 15)

Introduction

The western end of the Aberfoyle to Stirling area is characterised by conspicuous glacial deposits (see Fig. 15). These were first described



by Jamieson (1865), who asserted that they were "glacier-moraines" marking the terminus of a glacier. Later, Renwick and Gregory (1909) suggested that "moraines" at Buchlyvie, south of the Forth, were formed at the margin of a lobe of ice in the Forth valley, contemporaneous with one at Loch Lomond. In 1927, Dinham remarked that the deposits on the north side of the valley around the Lake of Menteith were "kames" marking the site of a portion of the "Forth Glacier". In 1933, Simpson made a more detailed examination of the deposits. He described the main belt of features, stretching from Port of Menteith to Buchlyvie, as a "frontal moraine," and from a section near Inchie farm where 30 feet of sand and gravel overlay 10 feet of grey clay with fragments of Mytilus edulis, asserted that it marked the limit of an important readvance. Since the top of the clay in the section lay at about 65 feet O.D., he believed the readvance to have taken place while the sea lay at that height. Correlating this readvance with one at nearby Loch Lomond, he called it "The Loch Lomond Readvance". In 1955, Charlesworth also recognised an ice lobe here, terming it "The Aberfoyle Piedmont Glacier", and correlating it with his stage M, or "Moraine Glaciation". Donner (1957) has inferred from pollen studies that the readvance took place during Zone III, or between 10,800 and 10,300 B. P.

The Features

Examination of this area confirmed many of Simpson's conclusions, but showed the moraine belt to be more complex than Simpson had supposed, and revealed additional evidence of sea level change.

The lower slopes of the Menteith Hills, below 250 feet O.D., by the farm of Auchyle, are marked by 4 well developed kame terraces, one below the other, each with a perceptible eastward slope. Two of these (A, B, Fig. 15)^{are} associated with marginal or sub-marginal glacial drainage channels, which rapidly descend to below 150 feet O.D. by the farm. Below the lowest terrace a sub-glacial chute (C) occurs; below this in turn is a fifth terrace (D), less well developed. About 100 yards north-east of the farm is a well marked ice contact slope in sands and gravels (E), and east of this is a short channel system linking with the uppermost marginal or sub-marginal channel and turning west of south downslope like a sub-glacial chute (F). The depositional forms have been collectively described as part of the "distinct frontal moraine" by Simpson. They are interpreted here as having been formed at the lateral margin of a retreating ice mass.

South of this area, a belt of hummocky material, apparently composed entirely of sand and gravel, stretches between Port of Menteith and the Goodie Water. In form it is composed of innumerable small ridges and elongated depressions, aligned north-south, and attains a maximum height of 130 feet O.D. near Inchie farm. Its east-west cross-section shows an asymmetric form, with a steep western side and a more gentle eastern side, the latter furrowed at intervals by sinuous dry valleys, interpreted as pro-glacial channels. There is a notable lack of material which could be considered ablation moraine; the deposit is not "fed" by any notable sub-glacial channel. Moreover, though most sections re-

veal sand and gravel, and only one, till; at Greenside, a trench, 100 yards long and in places 6 feet deep, revealed a chaotic mixture of sand, gravel, and till. These facts suggest that the feature might be a push moraine, or stauchmoräne, although there is no evidence of overriding by the ice.

The feature is beached at 3 points (G, H, J, Fig. 15), each gap occupied by a terrace of coarse gravel, becoming finer towards the east and likewise declining in height in that direction. The terrace in the most southerly gap, though incised in part by the Goodie Water, where it leaves the Lake of Menteith, slopes from a height of 77.0 (S298) southwards then eastwards uniformly down to 53.7 (S309), before a step is cut into it at 51.0 (S311) (see Figs. 15, 16). At its western end, the terrace is joined by a short ridge of sand and gravel, on which stands Inchie farm; east of this the terrace is joined by a deep channel 20 feet deep, now dry, which leads south-eastwards uphill into the terrace. It is concluded that the terrace is an outwash feature, formed at the margin of an ice lobe which lay slightly west of the moraine.

The relationship between the outwash material of these gaps and the stratigraphy of the carse lands has been investigated in a number of sections in ditches and by boring. In the centre gap (H) the gravels are mostly covered with a peat layer, 1 - 3 feet in thickness. West of Rednock, peat covers all the outwash deposits, but further south it is in turn covered by alluvium of the fan of the Rednock Burn. 300 yards south of this point carse deposits overlie the peat above gravel, the sur-

face being 50.5 (S322) and the gravel surface being 46.5 (S318, S319).

A more instructive section is revealed in the banks of the Goodie Water. This stream leads east-north east away from the most southerly channel, in a straight artificial cutting recently enlarged. Continuous exposures along its sides for a distance of over one mile show the outwash gravels dipping gradually beneath the carse with a bed of peat interposed between the two deposits. Remnants of a superficial peat layer are scattered on the surface of both carse and gravel. East of the place where the gravels and peat disappear beneath the bed of the stream, they were located by a line of boreholes (BH 1 - 6). The boreholes and the various elements of the sections were levelled and the results are shown in Figure 16. They indicate that:

- (a) The surface, omitting the irregular peat cover, slopes regularly upwards towards the west-south-west from BH6, at Tarr (46.3, S1064) to a notch at 50.7 (S328), on the outwash slope. This surface is composed mostly of carse, except at the western end, where it is gravel. There is no morphological break along its length.
- (b) The outwash gravel dips uniformly east-south-eastwards in general accordance with the outwash slope to the west, and the lowest point at which it was reached is 37.2 (BH3).
- (c) Above the gravel lies the deposit of fine grey sand so characteristic of sub-carse deposits elsewhere. Its surface is at 42.5 (BH 1) in the west, declining eastwards to 34.5 (BH 6).

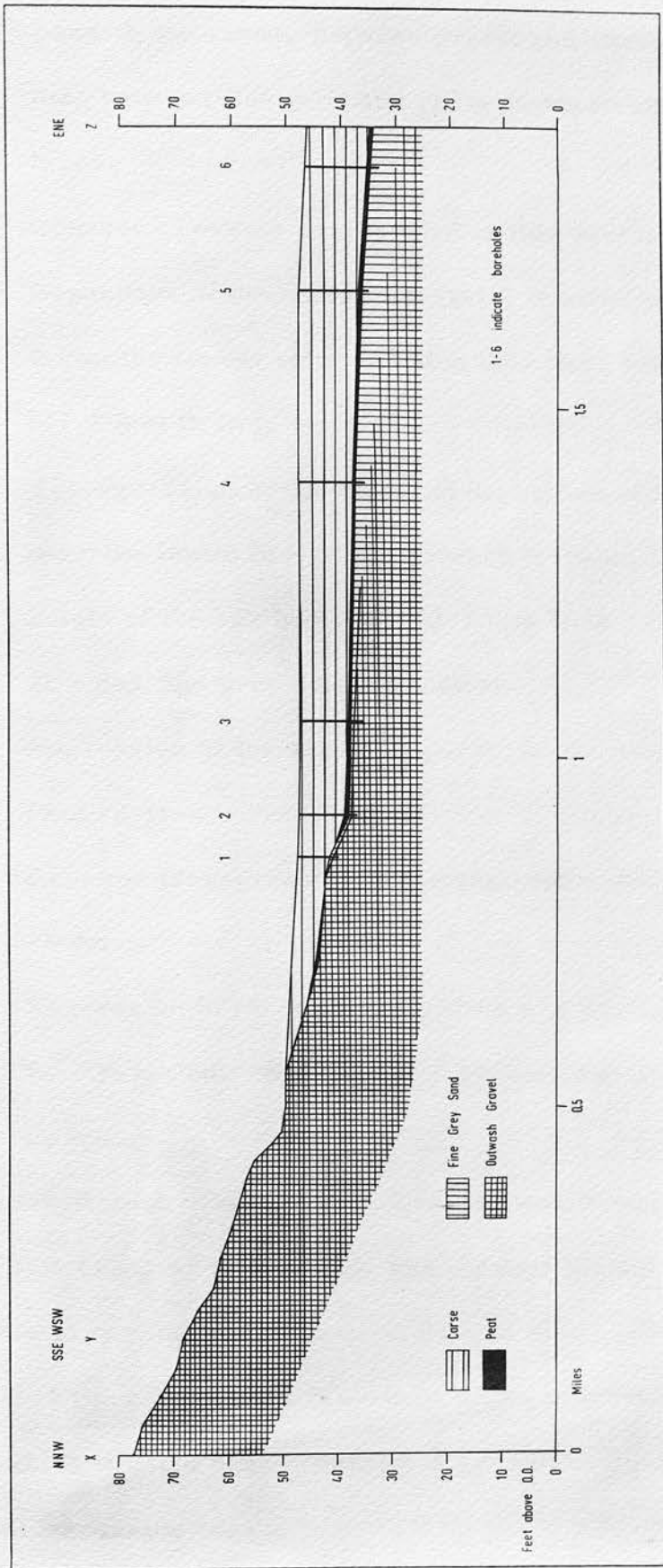


FIGURE 16 Section by the Goodie Water, X-Y-Z, Figure 15.

(d) Beneath the carse, between gravel and carse in the west, then between fine sand and carse further east, occurs a peat layer.

The sequence of events represented in this section is thus:

1. Deposition of the outwash gravels, controlled by a base level below the lowest point at which they were found to be sloping (37.2 feet O.D.).
2. Transgression of the sea, and deposition of fine grey sand over the lower part of the outwash terrace. The minimum height of the sea level was 42.5 feet O.D., the highest point at which fine grey sand was found.
3. Regression of the sea, and growth of the peat on the resultant land surface.
4. Renewed transgression of the sea, and deposition of the carse clays.
5. Regression of the sea, and growth of a peat cover on the surface revealed. Subsequently this peat was partially removed by man.

The stratigraphy thus records a transgression not hitherto recognised in the Forth area, or in Scotland, namely that which led to the deposition of the fine grey sand. The earliest date at which this event could have occurred is the cessation of deposition of the outwash, while the latest date at which it could have occurred is the end of Zone VIc, when the carse transgression began.

South of this area the character of the landscape changes markedly. An extensive broad ridge (K, Fig. 15) runs parallel to the axis of the valley from Gartrenich in the west to Flanders Hill in the east, a distance of 3 miles. The feature is 1 mile wide at its widest point, near Cardross, and attains a maximum height of 198 feet O.D. at Keir Hill. Its character changes along its length. The western end comprises a main ridge and a smaller offshoot (L) together $\frac{1}{2}$ mile wide and rarely over 100 feet O.D., covered for the most part in peat moss. East of the farm Gartur, however, it opens out to much broader dimensions. Here, a 20 foot section shows a thin veneer of sand and gravel overlying sandstone (M). For some distance east of this point extensive plantations prohibit the examination of individual features, but by Dykehead and Cardross the surface of this ridge is composed of sand and gravel, and some enclosed depressions, all trending west-east. At Ballongrew, however, the forms curve round to complete a noticeably symmetrical arrangement. East of Ballongrew the land decreases in height, to end at Flanders Hill, where lies a large but shallow enclosed depression (N). A number of exposures in this area show stratified sands and gravels, and examination of the top soil indicates that the material may be finer towards the eastern end. Near the east Lodge of Cardross an old quarry examined by Peach in 1914 showed solid rock beneath a cover of sand and gravel (O). A notable dry valley (P), probably a subglacial channel, runs north-east past the farm of Blaircessnock, to end abruptly at about 60 feet O.D. (spot height). The depositional forms of this area appear to be characteristic of forms

produced in sub-glacial or en-glacial conditions. Yet the ridges lack the sinuosity of form or the resemblance in plan to stream systems generally adduced as evidence of deposition in sub- or en-glacial tunnels. There is also a notable lack of ablation material, though the location is especially favourable to this, with steep hillsides to the west and north-west. These facts, combined with the symmetry of the forms suggest that the features may be crevasse infillings. It may be noted that this area, which far exceeds in extent that of the moraine north of the river, was not even considered by Simpson, while Dinham dismissed it as a "rock ridge". The latter however, did mention its influence in preserving the deposits north of it from subsequent erosion by the Forth or its pro-glacial equivalent.

These numerous fluvioglacial forms east of Dykehead and Cardross lie eastward of the line of the moraine. It would seem, therefore, that they were formed at an earlier period. This possibility is supported by two lines of reasoning. Firstly it is undoubtedly the case that the features of the ridge area are less distinct and less fresh than those of the moraine to the north. Secondly, the stratigraphy in a large shallow kettle hole (Q) by Ballangrew farm is remarkably similar to that obtaining in Loch Mahaick (Donner, 1958), suggesting that the feature was formed in zone I. Boring showed:

Section	cms	Interpretation
Sphagnum peat	0)	post-glacial
Compressed peat, marshy	166)	

Section	cms.	Interpretation
Soft pink clay, no vegetation	202)	Zone III
Grey clay, plant remains	213)	
Marshy peat	221)	Allerød
Transition	343)	
Soft Grey Clay, no vegetation	349)	Zone I
Grey-pink clay	378)	
Pink clay	388)	
Pink silt with stones	400)	

The similarity to Loch Mahaick is very close, excepting only the thickness of the supposed Allerød deposit, which here is much greater.

Though no firm conclusions may be drawn from this evidence until pollen analysis has been applied, the present interpretation means that the kettle hole formed sometime before Zone II. Since the moraine has been dated by Donner as Zone III, this means that the kettle is part of an earlier deposit than the moraine.

South of these features the remainder of the eastern part of the deposit is composed of small ridges and mounds of sand and gravel near the river. These look more fresh than the main ridge feature, and some of them adhere to its sides as if they had been deposited on it after its formation. Here there is no evidence that the ridge is wholly rock, and on its surface sand and gravel may be seen. At Cardross Bridge and for a short distance downstream the bed of the Forth is composed of large cobbles, suggesting outwash from a nearby ice front.

The Lake of Menteith itself lies between the ridge described above and the push moraine described earlier. Around its shores, sands and gravels are everywhere in evidence. The deposits are most coarse in the north,

and finest in the south-west. Knolls and ridges of sand and gravel surround the Lake on the north, west, and south-east sides; some are rock-coved in the north, but there is one very fine eskerridge (R, Fig. 15) near Malling. At the south-east corner of the lake, Simpson's section (S) is still extant, (see Plate IV). Here, 30 feet of stratified sands and gravels overlie at least 5 feet of grey silty sand with shells. A species probably of Yoldia was obtained from the deposit; other shells were present, but were badly crushed. No shell was found entire, and none appeared to have lain undisturbed since its decease. The top of the section lies at about 65 feet O.D., but because of the disturbed nature of the grey silty sand and the fact that glacial deposits overlie it, it would appear that the suggestion of Simpson that this figure represented the sea level at the time of deposition, is erroneous. Other similar exposures have been seen. A deep trench cut along the north shore of the lake in March 1964 (near T) revealed 3 feet of stratified sands and gravels overlying 2 feet of shelly silty sand. Again the shells were crushed and none was entire. The section was only available for 24 hours and could not be levelled, but the top of the shelly material was estimated at 70 ± 10 feet O.D. The deposit which contained the shells assumed a white colour on drying out, resembling glacial rock flour. Another instance of a similar section is available, for the 1845 Statistical Account for Port of Menteith records that

"in driving a level in a ditch, . . . the exuviae of the marine mussel, the periwinkle, and other shell-fish, were thrown up from seven feet below

the surface of the incumbent soil, consisting of from three to four feet of gravel, and, next, of a substance resembling pipe-clay".

The ditch in question is by the Church at Port of Menteith. Dinham (1927, 1932) took the passage to mean that carse occurred in this locality. This is plainly highly unlikely, for had the carse sea reached this point, the Lake of Menteith would have been filled in with carse deposits. It is possible that Dinham was misled by the shell information - mussels and periwinkles are often found in the carse - but it is difficult to see how he could have interpreted the stratigraphy as evidence of carse conditions, for the report clearly indicated that gravel overlay the pipe clay. The present writer has not seen or read of any section in the carse lands where gravel overlay carse clay, except near stream fans and there is no such fan here. Therefore, the section probably shows a different kind of deposit. It is interesting that this section is less than 100 yards from the trench section referred to above at T, Figure 15, and it is suggested that it shows a similar stratigraphy, which is interpreted as further evidence of a re-advance. Other evidence is available at Greenside, where a 2.5 ft. section showed sand and gravels overlying laminated clay.

West of the Lake of Menteith, a fine outwash terrace occurs. This was mapped by Peach (1914) as part of "The 100 foot Raised Beach", but subsequently interpreted by Simpson as outwash marking a stage in the retreat of the ice that produced the moraines to the east. A map of this feature appears in Figure 17. 40 heights were obtained on it (S338-377) along three lines. These show a general decline in height towards the

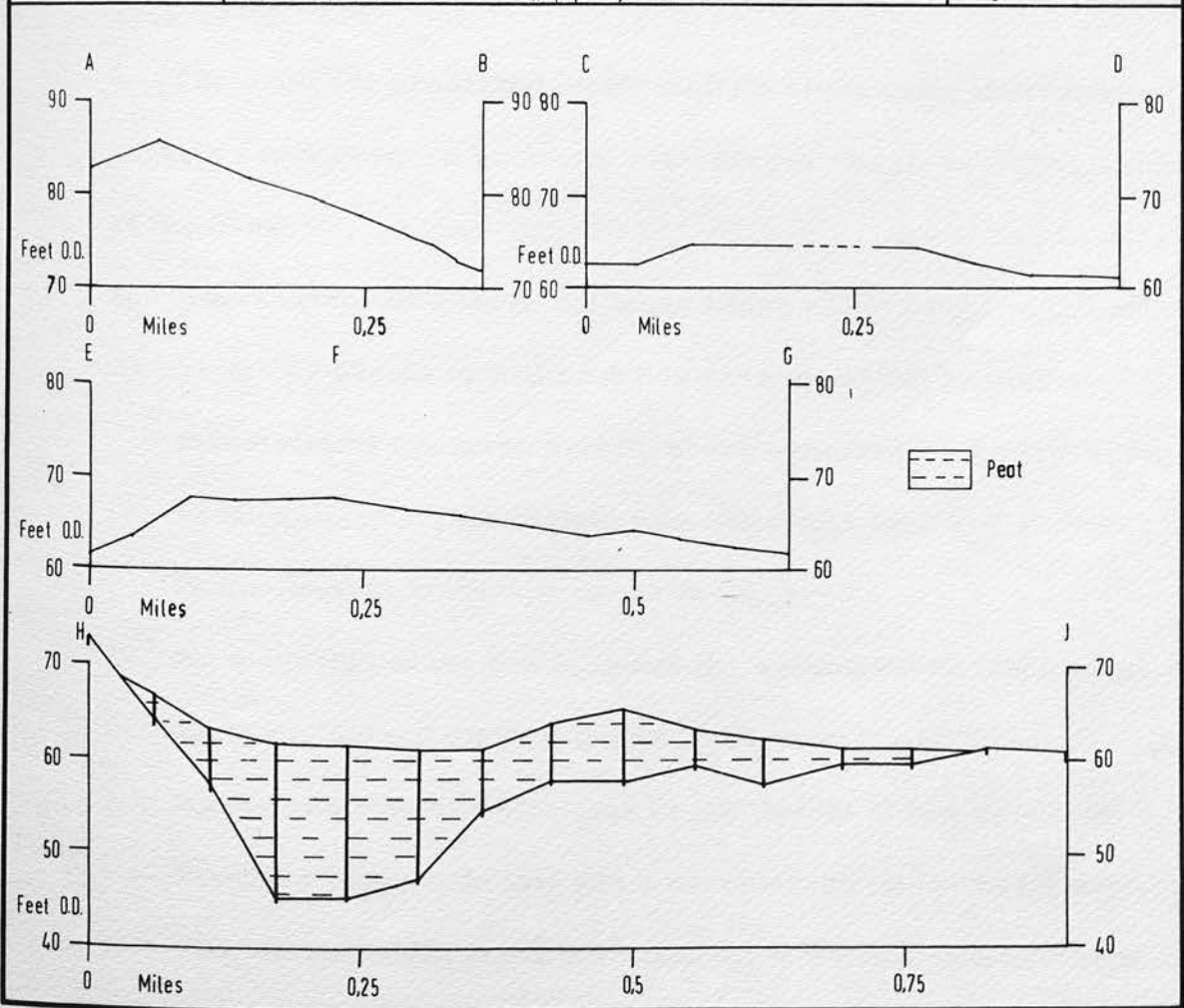
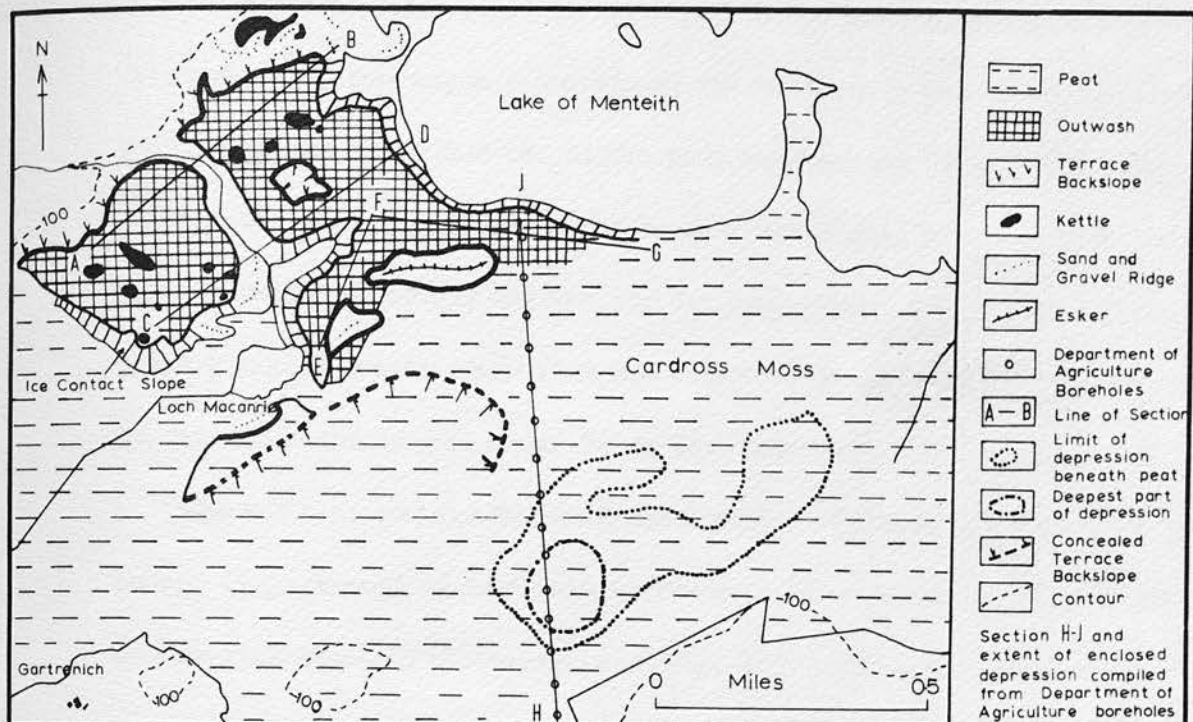


FIGURE 17 Glacial outwash and associated features at the western end of the Lake of Menteth.

east and north-east, more pronounced at the lateral margins of the terrace. An interesting feature of the terrace is the short reverse slope at its western end, that is, at the part nearest the former ice front. This could be due to the terrace having been built in this region on top of ice which subsequently melted and let down the terrace. Ice-contact slopes near the lake show that the site of Lake of Menteith was occupied by ice while the terrace was being formed.

The terrace passes beneath the surface of Cardross Moss, to the east. Here, Department of Agriculture borings have revealed a large enclosed depression beneath the moss (see Fig. 17). This is probably a kettle hole.

Conclusion

The evidence presented in the vicinity of the Lake of Menteith permits certain conclusions to be drawn regarding the late-and post-glacial history of the area:

1. The wastage of a large ice mass which occupied the valley at least as far as Flanders Hill probably occasioned the formation of a symmetrical crevasse system about a marked rock ridge in the centre of the valley. This system was filled with sand and gravel, resulting in the present landscape forms in this area.
2. An incursion of the sea followed the withdrawal of this ice mass, but certainly did not attain a height of above circa 50 feet O.D., for no terrace marks the ridge area at that height either outside or beneath Flanders Moss. In this sea a considerable fauna was established. The ice was sufficiently far removed to permit abundant deposition

- of fine material.
3. A readvance of the ice occurred, probably partially overriding the ridge west of Keir Hill, and forming push moraines to the north. At the maximum of this stage, pro-glacial channels flowed down the front of the moraine to at least as low as 50 feet O.D., so the contemporary sea level lay at least as low as this.
 4. Three pro-glacial channels breached the moraine. A minor retreat of the ice front coincided with the formation of outwash through these breaches in the moraine belt, and its continued slope traced down to 37.2 feet O.D. means that the contemporary sea level lay at least as low as this.
 5. The ice front retreated to Malling, but the site of the Lake of Menteith was still covered by an ice mass, around which outwash was deposited.
 6. Ice melted out from the Lake of Menteith, and retreated back from the Malling outwash an unknown distance. Sea level rose and a deposit of fine grey sand was laid down up to 42.5 feet O.D. on top of the outwash of (4).
 7. The sea receded, the climate ameliorated further, and peat grew upon the surface of the fine grey sand and uncovered outwash.
 8. A transgression of the sea again occurred, burying the peat. In the area of the moraine it attained circa 50 feet O.D. In this sea the carse was deposited.
 9. The sea again receded, and peat grew upon the surface of the carse as well as the exposed lower parts of the outwash gravels. Colonisa-

tion by man eventually resulted in partial clearance of the peat cover for agricultural purposes.

THE VALLEY OF THE RIVER TEITH, LANRICK CASTLE
TO BLAIRDRUMMOND (See Fig. 18)

Introduction

The Teith, a much larger and swifter river than the Forth, with a steeper gradient, is confined within a much narrower valley.

From Lanrick Castle to Blairdrummond the valley is characterised by numerous fluvioglacial forms, which nevertheless have received scant attention. Charlesworth (1955) stated that a glacier contemporaneous with the one at Lake of Menteith extended to within 2 miles of Doune during the Moraine Glaciation. He called it "The Callander Piedmont Glacier". Donner (1958) obtained a complete pollen sequence from Zone II to the present from the clays and silts of Loch Mahaik, 3 miles north-north-west of Doune, and inferred that Perth Readvance ice covered the area, but not Loch Lomond Readvance ice.

This investigation was concerned with determining the relationship, if any, that these forms might have to changes in sea level. A morphological map of the area appears below, in Figure 8, and a graph of terrace heights appears below, in Figure 9. Similar reference letters in the two Figures refer to the same features.

The Features

Between Lanrick Castle and Doune Lodge a multitude of very fresh fluvioglacial depositional forms are confined within the valley

between hillsides furrowed by fluvio-glacial channel systems (Dickson, 1964). Several marked esker ridges are apparent, also well defined kettle holes, while west of Burn of Cambus a fine ice contact slope extends over 200 yards, parallel to the axis of the valley (K, Fig. 18). This latter feature margins an important ridge feature, which from its straightness may have been crevasse guided. Most of the other ridge forms in this area are surmounted by large angular blocks of ablation moraine. The ice contact feature lies exactly 2 miles west of Doune, but it is unlikely that it marks an important ice margin as Charlesworth implies, since besides lying parallel to the axis of the valley, there is no change of form either side of it.

By Doune Lodge, the fluvio-glacial features pass by degrees into an extensive outwash terrace, which continues past Doune burgh (L). Lacaille (1948) has described this feature as being the highest remnant of "The 100 foot Raised Beach" in Scotland. In fact the feature was described as outwash by Buckland as long ago as 1840, and possesses all the classic characteristics of an outwash deposit as described by Davis in 1889. At its western end are numerous kettles, and esker ridges lead into it. Here too it fingers up a conspicuous glacial drainage channel leading north west past Doune Lodge. Lacaille described it as lying at 155 feet O. D. Levelling showed a slope of some 40 feet per mile from 158.3 (S200) to 125.7 (S931) towards Doune. Here however the picture becomes more complex, for a slight rise towards the east is observed, culminating in 131.8 (S970) north of the town. A second fall in height

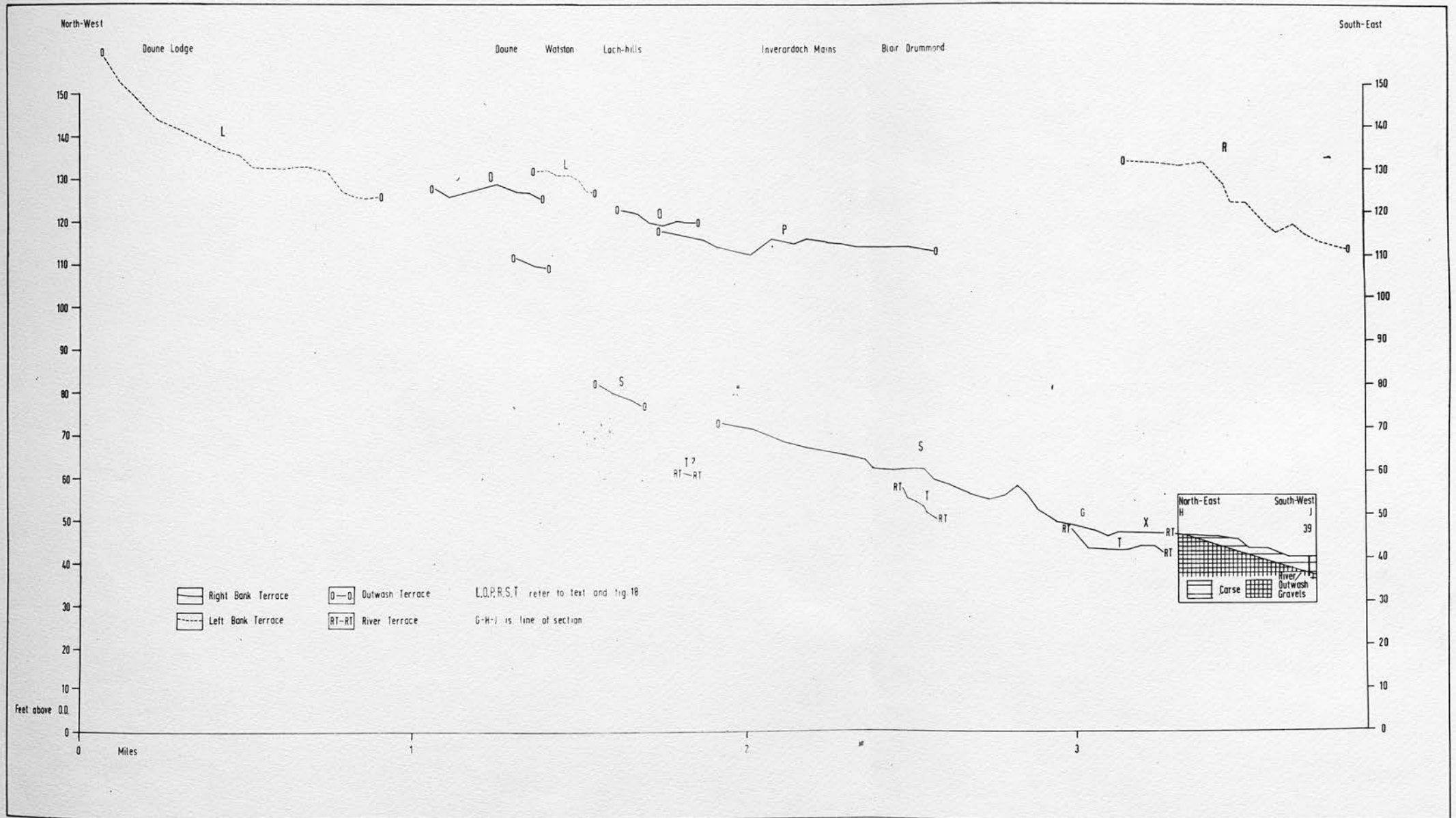


FIGURE 19 Slope of the glacial outwash and river terraces in the Teith Valley between Lanrick Castle and Blairdrummond.

east of Doune (to 126.1, S975), terminates in a very steep drop of some 60 to 70 feet (M). A small burn runs at the base of this slope but is evidently not capable of having cut it. It seems that the feature is an ice-contact slope, for east of it lies a valley floor with kame ridges and a small channel, below the height of the terrace. Clearly these features would have been buried had not ice remained to protect them. Moreover the slope of the eastern end of the outwash is in conformity with the suggestion.

Extensive quarrying has removed part of the outwash near Doune railway station and also by Clarkton. Sections at the former place revealed 10 - 12 feet of sands and gravels overlying till. In places the sand was very fine. A conspicuous kame once stood out from the centre of the deposit here. At Clarkton rolled stones present an inclination characteristic of a water borne deposit coming from the west. The outwash is not homogeneous, nor does it show a gradual size gradation; although the area of coarsest material lies to the west, there are also beds of fine sand visible which are generally overlain by coarser deposits.

The outwash terrace can be followed south past Watston, where it might have been fed by a large channel system from the west (N), into Blairdrummond estate. (132.0, S938). Here a multitude of very fine terraces may be observed. On the western side of the river the highest terrace (O) ends near Meldrum at 119.1 (S944), but a terrace only two or three feet lower (P) borders it and passes through the gardens of Blairdrummond House, declining from 117.0 (S951) to 113.8 (S985).

Although these higher terraces look uniform, levelling suggests that they may be compound features. Their long profile is concave, decreasing in rate of declination towards the east and south. Because of morphology and accordance of height, whether one, two, or more features, they are considered to be products of one period. Their profiles cannot be linked with any others in the area. The feature that is manifestly a single terrace, and has been traced above (S951, S985) ends abruptly near Blairdrummond House where a meltwater channel (Q) leads away from it. The front of the terrace near Blairdrummond House appears to be an ice-contact slope. It would therefore appear that during formation of the terrace, ice lay in this area.

Across the Teith valley, on the eastern side or left bank, south of Greystone, a high terrace (R) is seen to lead away from a presumed subglacial channel. The terrace declines from 133.9 (S952) to 110.7 (S968), and from its position relative to the other terraces (see Fig. 19) would appear to be an older feature.

The terraces described above lie on the edge of the valley, far removed from the present river. In the valley proper, however, a much more extensive terrace, S, composed of coarse gravels, begins at 81.2 (S989) by Loch Hills, and continues past Blairdrummond House to level out at 47.0 (S776). Three terrace fragments (T) are etched into this, descending from 60.9 (S990) to 43.2 (S1010). It is not certain that these fragments all belong to one level, since they do not fall well in line with one another (see Fig. 19). Below these is the present flood plain of the Teith (U).

Intimately associated with these terraces is a magnificent gorge (V), a former channel of the River Teith, fully 60 feet deep. This passes from the Bridge of Teith round the western side of High Daira to the bank of the present river north of Blairdrummond House. Its freshness (were it not for the vegetation one could easily suppose it to have been vacated a few years ago) has inspired legend: the 1794 Statistical Account recalls the tradition that the building of Doune Castle (11th - 14th century) involved the removal of great quantities of stone causing the river to be diverted to its present course. Blackadder (1824) calls the channel an "ornamental river". Milne-Home remarks on its size. The 81.2 ft. O.D. to 47.0 ft. O.D. terræ passes along the sides of this former channel which also contains a terrace at 60.9 to 60.1 (S990-991). The present river flood plain appears to be slightly lower than the bottom of the channel.

It is interesting to note that for water to pass through this channel, the Teith would have to turn through 100 degrees at Doune Bridge. In view of the lack of any remnant of an obvious barrier along its present course, it seems most strange that it should have carved this channel. The problem is resolved, however, when the valley side of the present course is examined. Here, as observed above, 3 sub-glacial chutes descend to well below 100 feet O.D. (W). This means that ice occupied the site of the present river channel east of High Daira while the outwash terraces were being formed at Doune and down the valley to Blairdrummond. The proglacial Teith then cut down through the outwash and by the time the present channel was opened up by the melting of the ice, was sufficiently established in its course not to change. In any case the present channel

was probably partially obscured by sand and gravel deposits. The river probably maintained its western channel until increased volume and load, leading to the deposition of the large terrace beginning at 81.2 feet, permitted it to cut through the insubstantial barrier to the east. From then on it probably occupied both channels until the easterly route proved easier.

The lower terraces in the Teith valley (below 81 feet O. D.) are very clear, but south-east of Blairdrummond, where the terraces approach one another in height, and where the carse appears, the morphology is more complex. The position is best described approaching the landscape from the south.

The upper carse break of slope is well defined and easily perceptible. It lies in this region at between 42.7 (S763) and 43.4 (S758). Beneath the carse, gravel is reached at between 3.0 and 5.1 feet (BH 37 - 40), but there is no peat layer. Behind the break of slope, the land rises gradually. A fortunate ditch section (section H-J, Fig. 19) shows gravel approaching the surface of the carse, and finally appearing at the surface, the carse fingering out, but no peat between. The carse, however, climbs up the gravel slope almost 3 feet (45.5, S767) above the break. The slope then flattens out at 45-46 ft. O. D. and a large flat gravel area ensues (X). This is probably a former delta of the Teith. It is furrowed in places by meander scrolls; old levées may also be recognised, and it is cut into by a terrace fragment referred to above (T) which descends to 43.2 (S1010). By Blairdrummond House the deposit increases in altitude, at first slowly, then rapidly, to merge without a morphological break with the terrace

described above as attaining 81.2 (S989) (Terrace S).

The interpretation put upon these latter features is as follows:

- (a) Because of its wide extent and coarse gravelly composition, the terrace beginning at 81.2 is considered to have been formed by the pro-glacial Teith while ice remained somewhere north-west of Lanrick Castle.
- (b) A rise of sea level caused re-sorting of the lower end of this terrace, and the creation of a large gravel delta, graded to 45 - 46 feet O. D. The carse and the lowest of the river terrace fragments (T) were graded to a level about 2 - 3 feet lower.
- (c) Subsequently sea level fell to create the present morphology.

Conclusion

The presence of ice at both ends of the Doune outwash terrace (L) during its formation suggests that the terrace was formed during the retreat of an ice sheet which formerly extended east of Doune. This feature was not the product of the Loch Lomond Readvance, but of some earlier and more extensive ice mass.

There is in fact no evidence that ice of the Loch Lomond Readvance penetrated into the part of the Teith valley studied. The statement of Charlesworth that this readvance reached to within two miles of Doune has no support in the field.

It is possible to infer the following sequence of events from the assemblage of features in this part of the Teith valley:

1. During the retreat of a large ice sheet, large masses of ice lay detached from the main mass, for example east of Doune and in the lower Teith valley. Meltwaters issuing from the main ice front, lying at about Doune Lodge, formed extensive terraces developed in relation to a falling base level.
2. The meltwaters rapidly cut down through the outwash while the ice stagnated. A pro-glacial stream established itself in a deep gorge south-west of the present town of Doune. Base level was falling, and more ephemeral terraces were formed.
3. A renewed supply of material, possibly occasioned by a readvance of the ice, caused an extensive terrace to be formed (81.2 - 47.0 ft. O.D.). The barrier to the more easterly route of the stream was cut and two distributaries functioned. Eventually only the easterly route was used.
4. A rise of sea level caused a re-working of the lower end of the 81.2 - 47.0 feet O.D. terrace into a large delta, with a surface at 45 - 46 feet O.D. The river terrace and the carse deposits of this locality were graded to a level 2 - 3 feet lower than the delta surface.

TERRACE FEATURES AND GLACIAL MORPHOLOGY OF OTHER AREAS

(See Fig. 5)

Apart from the area by the moraines at Lake of Menteith, and the terrace areas by the Teith, the northern side of the Forth valley away from the carse is composed largely of strongly ice moulded country. The

features trend west-east, and are composed for the most part of a reddish till. The picture presented is one of strong west-east ice movement. There is also, however, evidence of ice decay. A short distance east of Thornhill is a belt of fluvioglacial forms (H, Fig. 5): kettles, ice-contact slopes, kames and eskers. Kame terraces are apparent west of Burnbank (J, Fig. 5). Near the Carse of Lecropt a small area of fluvioglacial deposits occurs (K, Fig. 5). On either side of the lower Teith valley, subglacial meltwater channels cut into the symmetrical drumlinoid landscape.

The most striking evidence of ice decay in these areas lies west of Thornhill. Here a huge system of meltwater channels furrows the landscape, cutting across the west-east trend in a north-west-south-east direction. One channel (L, Fig. 5) achieves a depth of 100 feet; two approach that figure. All were probably begun subglacially, since they are all linked in a system most of whose components are up and down channels or run obliquely to the contours. They generally possess a sinuosity of form. It is possible however that part of this system may have also operated pro-glacially. By Keirhead, a large channel appears to lead into a flattish area composed for the most part of fine sand, rather like rock flour (M). Levelling of this feature, however, revealed that it was less convincing than it first appeared, for after sloping regularly away from the channel from 99.6 (S1119) to 86.4 (S1126) it then rose again to 93.2 (S1159). The most easterly channel of the system may or may not have functioned as a route for material supplying a fan (N Fig. 5)

at its end. The apex of this fan lies at near 72.7 (S1148), and it declines to 66.9 (S1146) before ending in an abrupt slope, the cliff of the carse. The fan is composed of coarse material: rolled stones up to 4 inches in diameter. A small burn, the Littlemill Burn, could have been its supplier. Peach described both these terraces as remnants of "The 100 foot Raised Beach" in his map of the area (1914).

At intervals along the slope north of the carse between Wester Borland (west of Thornhill) and Blairdrummond, there occurs a distinct terrace feature between 60 and 70 feet O.D. (O Fig. 5). Generally a slope towards the east from 68 down to 66 feet O.D. is observed, but locally variations in the order of 5 feet are observed. 2 fragments occur at Wester Borland (68.7, S1129, to 65.9, S1130), 2 at Mollan (67.9, S28, to 65.8, S27), 2 at Ballinton (69.6, S1065, to 63.8, S1068), 1 at Craighead (69.3, S1071, to 61.2, S1069) and 1 at Burnbank, near Blairdrummond (67.3, S82, to 65.3, S85). The Burnbank feature is composed of fine gravel, but one Mollan feature showed fine grey sand. The 2 Ballinton fragments convey the impression more of a marginal kame terrace than a beach, for they decline in height uniformly towards the east at a rate of 2 feet per 100 yards. 4 other terraces also exist, 3 of them near Coldoch (P). One declines regularly north-eastwards from 86.0 to 70.5 (S1240 - 1242, S1247 - 1249). Two others attain heights of 80.1 (S62) to 79.8 (S63) and 60.6 (S66) to 60.0 (S70). A terrace by Thornhill has been levelled at 89.6 (S1072) to 88.5 (S1073). All these features were mapped by Peach (1914); he considered them collectively as rem-

nants of "The 100 foot Raised Beach". Dinham (1927), however, recognised some, and suggested that they might be "marginal drainage terraces".

The upper terrace near Coldoch is very likely an outwash feature. The 2 lower terraces could well be parts of successive fans of the Burnbank Burn, which emerges from a very wide depression nearby. The Thornhill terrace is extremely vague, and unconvincing. The other terraces however, cannot be dismissed as due to local effects. Their generally accordant height, albeit with a slight easterly slope, is significant. If they are allowed as ice marginal features, then it is surprising that there is a lack of marginal channels, chutes, or ice contact slopes, while no terrace possesses kettle holes. Though the evidence is not convincing, it is suggested here that they may be marine features.

It may be significant that no terrace fragment exists west of Wester Borland, though the gentle slopes of the carse margin would seem to be favourable. In view of the fact of the subglacial channel ending abruptly at 60 feet O.D. by Blaircessnock noted earlier, it may be that the terrace gives the maximum possible level of the sea outside the lobe of ice which covered the Blaircessnock area and referred to above (P.)

Conclusion

The conclusions to be drawn from the morphology and stratigraphy of this area therefore appear to be:

1. A strong west-east flow of ice.
2. Decay of the ice sheet, with subglacial and englacial fluvial activity.

3. A sea level of 68 - 65 feet O.D., declining eastwards, but only found as far west as Wester Boreland, west of which there was probably still ice.
4. A fall of sea level, revealing the terrace.

GENERAL CONCLUSION

The results of this investigation into the late- and post-glacial morphology and stratigraphy of the Aberfoyle to Stirling area enable the following general sequence of events to be traced:

1. A strong west to east ice flow covered the area, during which a well marked ice moulded topography was formed. This ice was probably that of the Perth Readvance.
2. The ice sheet began to decay, and sub-glacial meltwaters carved deep gashes in the landscape. Constructional subglacial forms were also produced, and large extra-glacial outwash features were formed. The impression conveyed by all these forms is that base-level was steadily falling.
3. When the ice had retreated as far west as Borland, sea level lay higher than now and marine terraces were produced up to 68 feet O.D.
4. The ice retreated at least west of the Menteith Hills, and the sea lay in the western end of the valley. To this point there is no evidence of any interruption of continuous recession.
5. During Zone III of the pollen sequence (10,800 - 10,300 B.P.), a re-advance of ice occurred, forming push moraines in the upper Forth valley and causing the formation of large outwash deposits in both the Teith and

Forth valleys.

6. After the following recession of the ice, which ushered in the post-glacial period, a rise of sea level occurred and a widespread deposit of fine grey sand was laid down.
7. A fall of sea level followed, and peat and woodland began to grow on the marine surface revealed, during Zone V.
8. A second rise of sea level took place during Zone VIc, submerging much of the peat and woodland on the former marine surface, and laying down a silty clay, the carse.
9. A further fall of sea level, probably in stages, revealed the carse deposits, and on the surface of these, peat mosses started to grow in Zone VIIa, at about 5,500 B. P. Subsequent clearance of the peat by man has considerably modified the landscape.



PLATE I

The inner edge of the carse, Thornhill.



PLATE II

The inner edge of the Teith flood plain, Ochtertyre. Carse surface on the left.



PLATE IV
Section at Inchie farm,
Lake of Menteith. Below
spade - silty sand with
shell fragments. Above
spade - stratified sands
and gravels.



PLATE III
The section in the Forth
bank at Littleward.

CHAPTER V

THE AREA BETWEEN STIRLING AND ALLOA,
INCLUDING THE
LOWER DEVON VALLEY

Accounts of this area have not occupied much space in Scottish geomorphological literature. Yet both the morphology and stratigraphy are complex and record interesting late-and post-glacial events. In an attempt to elucidate the late-and post-glacial record, 40 square miles were mapped, 8 boreholes were put down and 400 levelled heights were obtained. An examination of National Coal Board borehole records proved enlightening. As with the previous chapter, the area is described in separate morphological units. A map of the area appears in Figures 20 and 20a.

THE CARSE1. Composition

The carse here is very similar to that of the preceding area. It appears to exhibit a variable texture, being probably more silty towards the Forth, and more clayey along the Ochil scarp. This fact is underlined by the considerable disparity in the value of the farm land; farms by the Forth are in general more valuable, since the land is more easily worked. Within the deposit, two marked layers are present; these are referred to in the New Statistical Account (1845). The upper layer is a mottled brown-grey clay-silt, showing laminations and containing vegetable remains. In all 8 boreholes it was uniformly 190 centimetres thick. The lower layer is a laminated blue clay-silt. It occasionally contains vegetable remains, and is of variable thickness, attaining 450

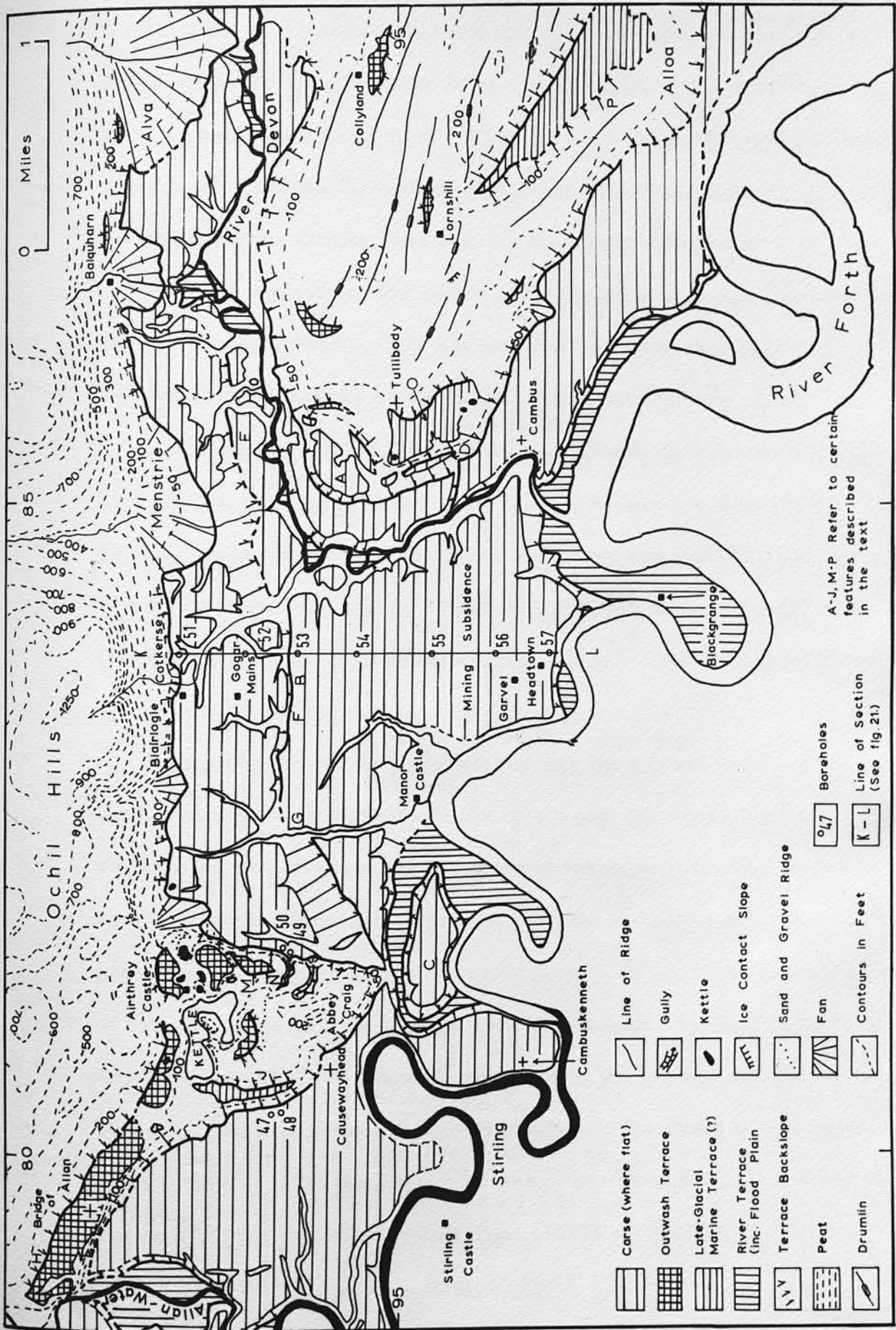


FIGURE 20 The principal glacial and post-glacial features in the area between Stirling and Alloa.

centimetres in thickness near the Forth. Both layers appear to be distinctly more silty than the carse west of Stirling, and occasionally have a glistening appearance. Throughout the deposit lenses of sand and gravel occasionally occur, particularly near the alluvial fans issuing from the Ochils, and also by the Devon and Forth.

Detailed analysis of the carse in the Devon valley was made by Parthasarathy (1954). This showed that the carse is a highly variable deposit, in some areas highly plastic but in others very sandy. In general the silt (0.002-0.05mm) ^{particle size} and sand (0.05-2mm) fractions are highest, but the clay fraction (less than 0.002 mm) is important. Salinity tests showed that the carse has a low salt content, this paradox being explained by leaching. High percentages of the mineral illite, and fairly high percentages of kaolinite and chlorite were interpreted as evidence of a marine environment.

A considerable variety of material has been found in the carse. The scattered vegetable remains in the upper part may possibly have a like explanation to that advanced for those in the deposit further west - a combination of admixture of peat to improve fertility and tillage and the growth of reeds in a shallow water deposit. Large tree trunks, usually of oak, are recorded by both Statistical Accounts, by Bald (1811) and Milne-Home (1871) as having been got from the carse, and the writer has observed numerous trees firmly embedded in the carse of the Devon banks. Great numbers of shells have been seen; both Statistical Accounts record shells by Logie and Alloa, while Bald (1811) recognised:

Ostrea edulis

Mytilus edulis

Cardium edule

Turbo littoreus

Donax trunculus

Patella vulgata

in the carse near Alloa. He noticed that *Ostrea* was very large and thick. The writer has observed shells in a ditch by Garvel and near Cambus; on both occasions the predominant species was *Ostrea*, and individuals were of considerable size. In 4 boreholes (BH51-54), shell fragments were located at varying depths. Though some have sought to identify the shells with the sleet layer alone (New Statistical Account), it is evident that they occur indiscriminately throughout the deposit.

Whale skeletons have also been found. Clark (1947) only listed one in this area (see Fig. 6), but the writer has found reference to three. One was found near the east gate to Airthrey Castle in 1819 (Lothian, 1863). It lay 5 feet below the surface, wholly in the sleet, and was one of the largest found in the Forth, attaining 72 feet in length. 2 pieces of antler were found with it, one being perforated to take a handle. Clark considered them to have been Mesolithic implements. A second whale was found by Clackmannan sometime before 1817 (Bald, 1821), and a third at Blackgrange (near Cambus) in 1869 (note in the Transactions of the Alloa Society of Natural Science). Several records are available of whales recently stranded as far up the Forth as Cambuskenneth, by Stirling (Neill, 1811, Barclay and Neill, 1821, Clark 1947), and it is generally believed (Clark

1947), that the carse whales are of similar species.

The only records of other fauna being found in the carse here are of crabs (Bald, 1811, New Statistical Account).

2. Extent

East of Stirling the carse opens out to form a broad plain of some two miles width. Within a mile, however, it narrows again, fingering up the Devon valley as far as Tillicoultry, and extending in a narrow strip to Alloa. On its southern margin the Forth swings in long meanders, while to the north the steep scarp face of the Ochils rises abruptly straight from the carse, dramatically stressing the low relief of the carse-lands. On east and west the carse is confined by belts of glacial deposits of differing origin.

3. Surface Form and Height

In the Devon valley the carse is strongly dissected by the river, while large alluvial fans at the foot of the Ochils spread out and restrict its extent. At Tillicoultry it ends, merging with a river terrace formed of sand and gravel. Extensive mining subsidence in the valley has warped its surface in many places, and spoil heaps preclude accurate delimitation of its former extent in many areas.

The carse is more profitably examined west and south of Menstrie. Here, although dissection is still extensive and mining subsidence widespread, 3 distinct levels may be recognised. Along the Ochil scarp, the surface lies at circa 39 (S132-141, S487-491, S1099-1101), and by Tullibody a surface/circa 41 (S395-401) (A, Fig. 20) would seem to correspond. At Gogar, however, a marked step occurs (B) and a lower sur-

face appears at circa 30 (S548-584). The upper surface is broadly horizontal, but the lower one declines towards the east. The lower surface ends in a steep bluff near Causewayhead, south of which is an abandoned meander of the Forth, wholly in carse and lying at circa 15.5 (S102-106). Within the core of the meander is another surface, however, at circa 19.5 (S598-605) (C) and declining eastwards. A north-south profile (K-L, Figs 20, 21) east of this last area, with points levelled every 80 yards, from Cotkerse to Headtown revealed the first and second surfaces but failed to reveal the possible third indicated by the meander core, for it remained above circa 22 (S450-488) with only two conspicuous breaks, at 30.2 (S475) and 38.4 (S488).

Continuing eastwards, the highest level is present by Cambus at circa 43 (S114-117) (D); in the Devon valley by Menstrie at also circa 43 (S1091-1095) and Tillicoultry at circa 42 (S1080-1085), so after a slight rise from 39 feet O.D. west of Menstrie the surface is almost horizontal. The second level is present in the Devon valley only as far east as Menstrie (E), where it attains 31.8 (S416), but it is well developed from Cambus to Alloa, where it forms the entire carse land. In this section it declines from circa 30 at Cambus to circa 26 by Alloa, (S107-111, S378-394, S1104-1110, S127-131). Below this level the flood plain of the present river Forth lies at circa 7 (S440-447).

Some of these heights may be affected by subsidence, though areas where subsidence hollows could be recognised were avoided, and precautions were taken with the bench marks (see Chapter III).

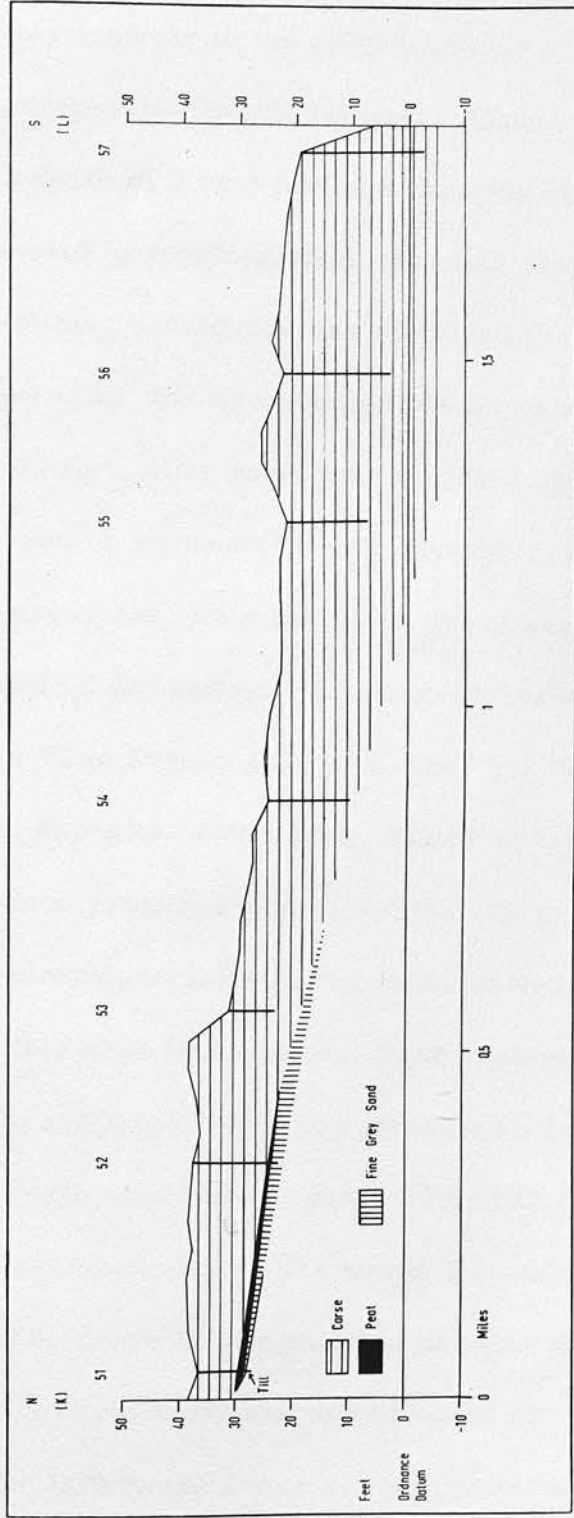


FIGURE 21 Cross-section of the carse, K-L, Figure 20.

There is a clear distinction, in degree of dissection, between the highest and the second terrace. The highest terrace is extensively dissected, particularly in the neighbourhood of Menstrie, but the second terrace is comparatively undissected. Channels which furrow the upper terrace to a depth of 7 or 8 feet end abruptly at the break of slope (F), or are continued by much smaller channels across the lower terrace (G).

Though mining subsidence has distorted the carse surface in part, stream patterns on the carse resemble those of streams developed on comparatively flat, silty surfaces described by Morisiwa (1964). The writer has seen no written evidence that the carse was ever covered by peat in this area, excepting for small areas near the east gate to Airthrey Castle and near Tillicoultry. (Statistical Account, 1794).

The term "The 50-foot Raised Beach" has been commonly adopted for the carse deposits of this area, though of late "The 25 foot Raised Beach" has been proposed (Read, 1959). Earp, Francis, and Read (1962) have lent apparent precision to the views of Read (1959), by asserting that the carse in this area is horizontal in an east-west direction at around 42 feet O.D., and Read (1959) has identified a lower surface in the carse south of the Forth near here at circa 30 feet O.D. Accurate levelling by the writer, described above, has shown the assertion of Earp et al. to be incorrect. The carse is composed of at least two levels, neither of which is wholly horizontal, and one of which has a marked declination to the east. The latter, the lower surface, is assumed to correspond with Read's circa 30 feet O.D. level. In view of these facts, the use of the terms "The 50 foot Raised Beach" and "The 25 foot Raised Beach" is singularly inappropriate.

4. Age

Stone and bronze axes, together with funeral urns found at the inner edge of the highest surface near Blairlogie (New Statistical Account) were probably left when the surface was dry land, but their age is not known. If they are similar to those found at Blairdrummond, described by Munro and the author of the New Statistical Account for Kincardine parish, then they may be Bronze Age. A Roman ford and fort once existed near Manor Castle (New Statistical Account, 1845, Milne-Home, 1871).

More positive evidence of the age of the carse has recently been obtained. In 1962, samples of sub-carse peat from Airth colliery, south of the river at Alloa, were dated by Carbon 14 assay at $8,421 \pm 157$ (top) and $11,024 \pm 199$ (base). The second result was thought to be inaccurate for reasons given above (Chapter II) (Godwin and Willis). If this peat layer corresponds to that beneath the carse on the north side, then the figure 8421 ± 157 represents a maximum date for the rise in sea level which began the deposition of the carse clays.

5. The Sub-carse Surface

In this section, comments are restricted to the upper 20 feet of deposits, for consideration of the deeper deposits will be given in the next section. Boreholes 49-52, all on the highest carse surface, revealed a layer of peat beneath the carse, varying in thickness from 6 inches to 2 feet. Boreholes 49-51 were all very close to the old cliff line, and in the case of 50 and 51 probably struck the material of this descending beneath the carse. BH49 reached a detrital deposit and is discussed separately

later. BH 52, however, reached a layer of fine grey silty sand identical in appearance to the deposit which underlies the sub-carse peat west of Stirling. The top of the deposit lay at 24.0 feet O.D. This poses the question as to whether it forms an extensive level surface beneath the carse and peat, as west of Stirling. Accordingly National Coal Board borehole records, very detailed for this area, were consulted. Many were of no use, for the height of the boreholes had not^{always} been levelled, but a good number between Balquharn and Tillicoultry had, and they revealed interesting facts. Beneath the carse, peat was only occasionally reached, and usually the bore struck a layer of "grey silt", "grey sand", or "grey clay". Sometimes this was overlain by a thin layer of gravel (particularly near the river or near the alluvial fans), and occasionally the colour was referred to as "blue". At all events, the surface of this deposit or deposits lies over a wide area between 32 and 25 feet O.D. It would appear, therefore, that a surface exists beneath the upper carse level (no boreholes revealed it beneath the lower level). Parthasarathy's work shows that the deposits of this surface are noticeably saline, and possess the minerals illite, kaolinite, and chlorite in quantity. He concludes that they are of marine origin. It follows that this is a marine surface.

The lack of any comparable deposit beneath the second carse level could be interpreted as evidence that this level was formed as a result of a transgression. It is considered more likely, however, that in this area the extent of the grey deposit was not modified very much by the carse sea, and that the upper carse level derives its extensive development from the distribution of the grey deposit.

Conclusion

Examination of the carse has permitted the following sequence of events to be interpreted:

1. At some time unknown, a deposit of fine grey sand, was laid down in the sea standing at about 24-32 feet O. D. in this area.
2. Sea level fell, and the peat grew upon the surface revealed at around 8,400 B. P.
3. Sea level rose, and achieved 39-43 feet O. D., permitting the accumulation of a shallow estuarine deposit. The carcass of a stranded whale was despoiled by Mesolithic people. Climate was somewhat warmer than at present.
4. Sea level fell to 26-30 feet O. D., and a similar estuarine deposit was laid down.
5. Sea level fell again, probably by stages, a halt occasioning the creation of a surface around 20 feet O. D.

THE GLACIAL DEPOSITS AT AIRTHREY

North-west of Bridge of Allan a sub-glacial meltwater channel of immense size cuts through the landscape of Keir estate to assume an ice marginal aspect, leading on to a marginal kame terrace north of Lecropt Church. Bridge of Allan itself stands for the most part on a similar terrace (H, Fig. 20) which descends from 151.9 (S1439) by the entrance to Strath Allan to 134.3 (S1118) near the west lodge of Airthrey Castle. The steep slope below both terraces is probably an ice contact feature, but extensive building precludes examination. The Bridge of Allan terrace is kettled and possessed of two marked dry channels. Both terraces were probably formed along an ice margin, and were probably

fed by meltwaters and detrital material passing along the big channel and Strath Allan.

The Bridge of Allan terrace is continued by an extensive area of sand and gravel deposits in the policies of Airthrey Castle. This takes the form of level surfaces alternating with deep enclosed depressions, interpreted as kettle holes. On its northern margin lies the steep slope of the Ochils, while to the south the rock of the Abbey Craig protrudes.

Dinham (1927) has described these deposits as part of "The 100-foot Raised Beach" and estimated their height at 145 feet O.D. Many have quoted this height as the highest point of "The 100-foot Raised Beach" in Scotland. Dinham however also asserted that it could be an outwash feature. How therefore it could be one and the same with "The 100-foot Raised Beach" is not readily understandable. The writer's measurements in fact confirm Dinham's supposition of outwash. It declines eastward from 134.3 (S1118) to 114.1 (S233), and there is no level area such as might support a suggestion of marine origin. Moreover, the component sands and gravels are markedly coarser in the west, the area proximal to a likely ice front, a feature characteristic of an outwash deposit.

Sissons (1963) in fact believes that an important ice limit lay here, occasioned by the constriction of the valley at this point due to the existence of the Abbey Craig and Stirling Castle Rock. The writer is in agreement with this opinion. A section in these deposits observed by Peach (1914) near Bridge of Allan showing sands and gravels overlying "gutta-percha" clays suggests the possibility of a readvance but is not supported by any other evidence.

Two lower terrace-like features are present in this deposit. On the west, a considerable feature at circa 74 (S212-220) stands out (J), the break of slope showing no particular inclination. On the east, an equally marked feature (M) was revealed by levelling to possess the characteristics of a fan, 85.2 (S224) at the apex, declining to 81.7 (S221) and 83.4 (S227) at the distal parts. The apex lies exactly at the end of a deep trough in the sand and gravel deposits which is in part a shallow enclosed depression. This latter feature has been described as a kettle (Dinham), and may in part be such, but it is probable that it also functioned as a pro-glacial channel, and that the fan was related to a sea level somewhat lower than its present distal margin. Thus this outwash area was probably formed at a time of falling sea level in view of this schotter-like arrangement.

The Airthrey deposits are furrowed by three sinuous dry valleys on the eastern flank. Two possess small fans at their mouths where they meet the carse; the third, the most northerly (N) is different. It is the largest, and attains a depth of some 30 feet. Unlike its neighbours it descends to the level of the carse, which is found in the mouth of the valley. A borehole in the mouth (BH49) showed carse overlying peat beneath which a red clay with angular stones was reached. A second borehole north of the first, at the carse beak of slope (BH50) showed carse over peat over gravel. The presence of a peat layer at the mouth of a channel of such size implies that the channel was excavated prior to the growth of the peat. Some slight deepening of the channel may have occurred after the growth of the peat, since there is a small channel in the carse at this point. The red clay with stones in BH49 is interpreted as detritus from the channel. The character of this latter deposit, in

an area of sand and gravel, supports the view that the dry valley was excavated during periglacial conditions sometime after the retreat of ice from this place.

THE DEVON VALLEY

The principal characteristics of the Devon valley are the massive scarp face of the Ochils and the great alluvial fans issuing from deep ravines in the hills. But the passage of ice along the valley from the west has left remarkable features both above and below ground.

Along the face of the Ochils below about 400 feet O.D. are numerous marginal kame terraces. These occur particularly near the large valleys, where a plentiful supply of material was no doubt available. A marked terrace at Balquharn has been extensively quarried, and sections reveal a chaotic assortment of cobbles, gravel, and sand. Other terraces occur at Alva, Tillicoultry, and near Dollar. By Tillicoultry they are both kettled and associated with meltwater channels. Staircases of terraces occur at both Alva and Tillicoultry.

On the south side of the valley, kame terraces are less numerous. The best example occurs near the village of Collyland. Levelling at five points showed a continuous slope towards the east from 114.7 (S1078) to 107.4 (S1079) in 400 yards.

Taken together, these forms indicate the retreat of an ice tongue westwards.

More important features lie west of Dollar and at Tillicoultry. At the former place, near Cowden Castle, the valley becomes constricted, and a steep hill face opposes its north-eastward line. Here the Devon spills out of a narrow gorge in which it has been confined since the Crook. At the foot of

the hill, a large arcuate moraine has been formed. From near Cowden Castle to Arndean farm a high ridge (circa 100 feet) of sand and gravel (Fig. 22, and A, Fig. 20a) is almost continuous, breached only by the Devon and its tributary, the Back Burn. Quarry sections at Arndean show over 100 feet of sands and gravels, growing finer towards the top, but generally poorly sorted. On the side of Law Hill, to the north-west of the feature, a marginal kame terrace gives way to a sub-marginal drainage channel, which develops into a gorge some 120 feet deep containing the smallest of streams. This is eventually entered by Cowden Den Burn at Holeburn farm, and the deep valley proceeds around the margin of the arcuate ridge, until it manages to breach the feature at Muckhart Mill, where it joins the Devon.

Sub-glacial chutes on the hill face to the east testify to the former extent of ice, though whether of this period is uncertain. Chutes and channels in the western slope of the moraine point to the subsequent establishment of a system of subglacial drainage which followed the regional slope of the subglacial ground surface.

In view of the arcuate form and great size of the ridge, it is considered that it marks an important ice limit, probably influenced by the topography. It is likely that the formation of the moraine took place at a time when the Devon was still flowing to the east from the Crook (Soons, 1958), for there is no evidence of ice marginal lake deposits, and no evidence in the immediate vicinity, of diversion of the Devon.

At Tillicoultry a similarly dramatic feature occurs. A high (circa 100 feet) ridge (Fig. 22 and B, Fig. 20a) of sands and gravels crosses the valley on a north south line, breached only by the Devon. Dinham and Haldane remarked

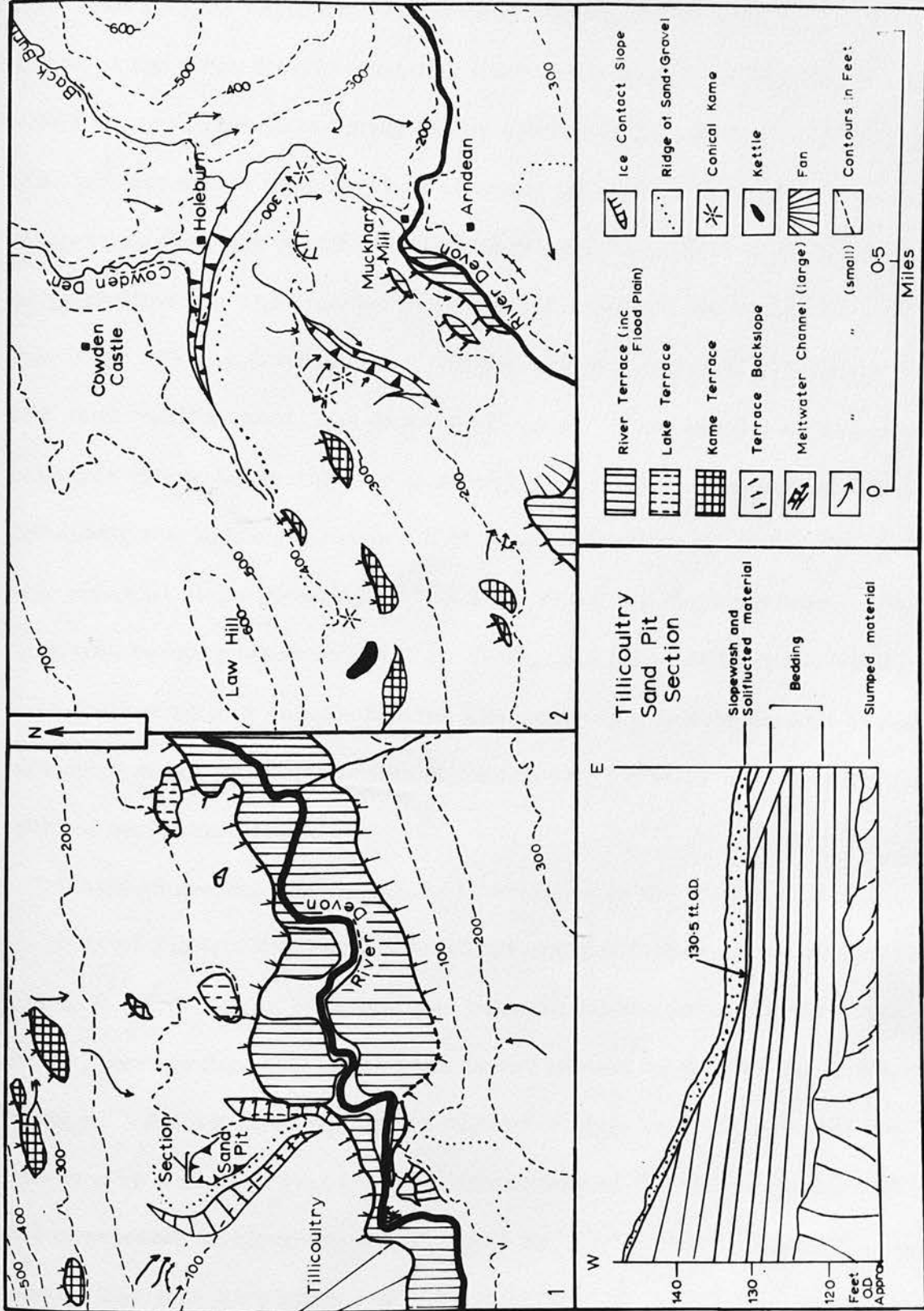


FIGURE 22 Features at Tillicoultry (1) and Cowden Castle (2), with a sketch of a section in the Tillicoultry sand pit.

upon this feature in 1932. They believed it to mark a former ice front, and observed that the deposits were bedded, dipping 10 degrees east or east by north. The writer's observations show the feature to be asymmetric, with a steep western face resembling an ice contact slope and a more gentle eastern face (except where the river has undercut it). This is in conformity with the suggestion of origin postulated by Dinham and Haldane. An extensive sand pit permitted the examination of an almost complete west-east cross-section (see Fig. 22) in 3 dimensions. In the west the material comprises gravel and sand, well bedded, and dipping 10° east. Towards the east the material becomes finer, becoming fine sand with a lens of chocolate coloured silty clay. Gradually the bedding flattens out to become horizontal, and at this point there is a break of slope (levelled at 130.5 (S1041-2) in the landscape. Further east, the bedding takes on a deltaic form, and fore-set beds are visible. The eastern part of this deposit has the character of a deltaic deposit having been laid down under quiet depositional conditions; probably in standing water in front of an ice margin.

A second ice limit is therefore in evidence in the Devon valley.

East of Tillicoultry certain terraces and flat topped areas occur around 100 feet O.D. (C-F, Fig. 20a). Sections in these show a pink, plastic clay. At Dollar, one terrace feature (F) has been extensively worked for brick clay in the past. A fortuitous section showed over eight feet of laminated clay overlain by a veneer of gravel from the fan nearby of the Dollar Burn. The clay was composed of alternate layers, pink and grey, separated by wafer thin layers of sand. The pink clay appeared to be finer than the grey, and contained traces of vegetation. These characteristics suggested that the deposit was one of

varved clay, and accordingly the layers were measured and counted by the method suggested by Sauramo (1929). 105 layers, or 52 varves, were present (see Fig. 23). Near the surface the layers became thinner and more regular, a characteristic usually interpreted as indicative of a climatic amelioration or retreating ice.

The top of the clay lay at 104.4 (S1031). Other terrace and flat topped features composed of a similar deposit ranged from 95.6 (S1039) to 112.3 (S1035). Allowing for the fact that on no occasion was the probable upper limit of the clay measured, and also that all the features were greatly dissected, it is thought not unlikely that they may be deposits of the same body of water which lay in front of the ice at Tillicoultry and in which the Tillicoultry sands were laid down. The difference in size of the component materials was probably due to the difference in proximity to the ice front. Drainage of the lake was probably effected towards the westward, after deposition of the clay, as the ice wasted back further.

The existence of a proglacial lake, in which such fine material was deposited, suggests calm water conditions. When this, together with the gradation in grain size of the material, smaller towards the east, and the absence of a delta in the east is considered, it seems likely that the Devon did not flow westwards at this time. Accordingly it is supposed that it still pursued its course eastwards from the Crook.

West of the Tillicoultry ridge there is some evidence of a level above the carse. Where the Devon breaks through the ridge it has formed a terrace, at 63.2 - 65.1 (S1087-S1090) (G). Several of the fans (Balquharn, Alva, Burnside, Menstrie) show a flattening off around this height, but due to building it was only possible to measure that at Menstrie, where figures of 62.0-65.7

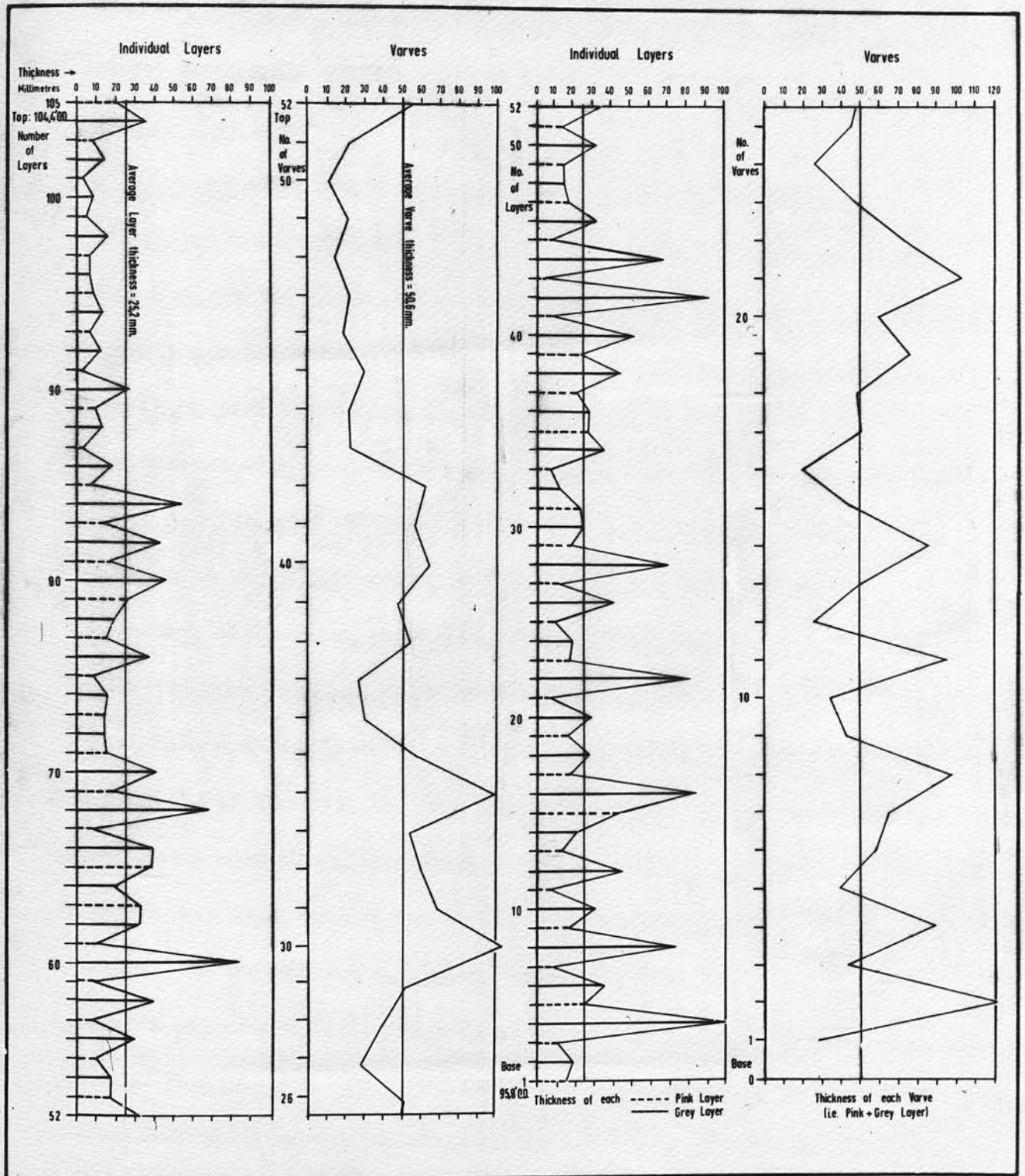


FIGURE 23 52 varves and their constituent layers, Dollar.

(S1096-1098) were obtained. West of Tillicoultry there is even less evidence, though the fan of the Melloch Burn seems to have been developed to a higher base level at one time. It may be that these features indicate a marine level, but they are far from conclusive.

Borehole Evidence

Since the early nineteenth century, the Devon valley has been an area of intensive mine workings. The unfortunate effect of mining subsidence on many features in the valley has already been mentioned, but it should be admitted that much information has been obtained from the borings of the mine companies and the National Coal Board. A close network of boreholes has established the existence of remarkable depths of drift in the valley, and recorded the presence of important superficial deposits.

From an early date it was known that bedrock lay over 300 feet beneath the surface of the carse near Alva, but Cadell in 1913 was the first to try to interpret the evidence of the boreholes. He conceived of a preglacial Devon Valley, 300 feet below sea level, which joined with an even deeper preglacial Forth valley, 600 feet below sea level. His trace of these valleys was adopted on Geological Survey 6 inch maps. The borehole evidence was by no means conclusive, however, for between Stirling and Cambus, across the line where the supposed Devon preglacial valley joined the supposed Forth pre-glacial valley, no borehole revealed more than 216 feet of drift. In 1954, Vincenz showed that at least part of the buried Devon valley was not a simple river valley. His resistivity survey by Alva showed the buried valley to be U-shaped and to possess a marked hollow near Kersiepow. In 1960, Soons, apparently without knowledge of

Vincenz' work, but with the advantage of more recent borehole information, proposed that the "pre-glacial valley" was in reality a series of glacially overdeepened hollows (see Fig. 24). This view was contested by Francis (Soons, 1960), but remains more plausible from two points - firstly, ice has passed over the area in considerable quantity, and secondly a sea level 600 feet lower is so considerable as to require much more regional evidence before acceptance.

The superficial deposits are also of considerable interest, and an attempt has been made by the writer to interpret the evidence their record presents. It should be pointed out, however, that this is based only on the evidence of 60 boreholes kindly made available by the National Coal Board. Many more records are held by the Scottish Geological Survey, which does not allow extensive consultation of its records.

The stratigraphy of the Devon valley deposits is as follows:-

- 7 Carse - usually described as "Yellow clay".
 - 6 Peat - though only occasionally present.
 - 5 Gravel/silt/sandy clay, grey, blue or "dark".
 - 4 Sand and gravel.
 - 3 Brownish or reddish clay, sometimes sandy, more often plastic and laminated.
 - 2 Sand, sometimes mixed with clay, also boulders.
 - 1 Till, of a reddish colour.
- Bedrock.

The greatest difficulty in interpreting this succession concerned the meaning put on the term "red clay". In this area the till is of reddish colour,

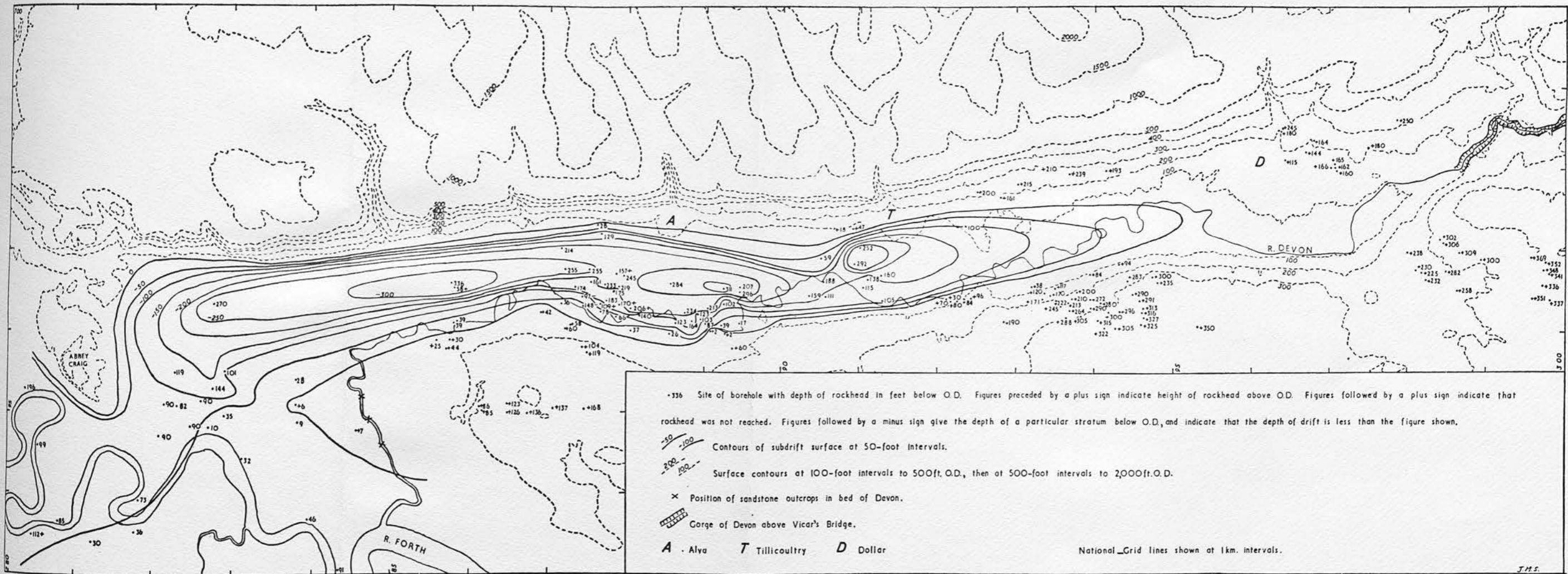


FIGURE 24 The Morphology of the bedrock surface in the buried Devon valley, according to Soons (1960).

and it was found by comparing neighbouring boreholes that "red clay with boulders" was synonymous with "till". Similar successions, usually omitting (2) and (4) and specifying (5) as "gravel" have been quoted by Cadell (1913) and Parthasarathy and Blyth (1959). These authors interpret the "brownish or reddish clay" as contemporaneous with "The 100-foot Raised Beach". Cadell has remarked upon the widespread character of the "brownish or reddish clay" in the Forth valley and described it as an arctic marine deposit. Sissons (1963) has suggested that in the Forth valley the deposit was laid down prior to the Perth Readvance.

The sub-peat and carse deposits will be discussed under four sections:

(a) The fill and sand, (1) and (2).

The till is presumably the ground moraine of an ice sheet, and the sands above the product of the retreat. The "boulders" probably indicate the proximity of an ice front.

(b) The "brownish or reddish clay", (3)

Parthasarathy (1954) has obtained samples of this from 40-45 feet beneath the surface at Kersiepow, and determined that it has a high salinity. Resistivity survey by Vincenz (1954) has shown that throughout a layer corresponding to these deposits, resistivity values are low, suggesting high salinity. Though this can in part be due to leaching from above, it is believed that this shows the deposit to be marine.

In addition, Parthasarathy has shown that the deposit is of much more uniform composition than the carse, and is a silty clay. The fine laminations recorded in many boreholes show that it accumulated

under calm conditions.

In view of these facts, it might be expected that the deposit should show a uniform upper surface. This is not so, however, for in boreholes within 300 yards of each other the surface varies as much as 123 feet. No interpretation of the borehole records would permit the delimitation of a surface. It must be concluded that either the deposit was heavily dissected by running water or else ice has passed over it.

(c) The sand and gravel (4).

This deposit is less regular in occurrence than the "brownish or reddish clay". It is also variable in texture, sometimes containing boulders. In view of the fact that it does not present a regular surface such as might suggest buried river terraces or fans, it is considered that it is a glacial deposit. Thus it would appear that a readvance has occurred, laying down this deposit on top of the "brownish or reddish clay". It must be admitted, however, that conclusive evidence of a readvance is not available, since no till layer has been found above the "brownish or reddish clay".

(d) Horizon (5)

The deposits of this horizon are mostly the "grey" or "blue" material underlying the carse and suggesting a marine level. Some "grey" or "blue" deposits probably have a different origin, however, for beneath the Tillicoultry and Alva fans, deposits of "blue mud" occur up to 60 feet O.D. and 39 feet O.D.

Alluvial Fans

Borings like the two quoted above made through the alluvial fans at Alva and Tillicoultry show considerable depths of clays beneath a superficial covering of gravel. This shows that at least parts of the fans were formed later than the deposition of the clays. This disproves the contention of Dinham and Haldane that they were contemporaneous with "The 100-foot Raised Beach Period" during which the clays were supposed to have been deposited. Dinham and Haldane also believed that the fans were now fossil features, being eroded by the streams that formed them. The observations of the writer do not support this belief. All the streams on the fans are dyked to restrain them from migrating across the fan surface, while the junction of the carse surface with the fan is very difficult to perceive, no nick being present. The evidence indicates that the fans were being actively extended until human beings took a hand.

Conclusion

The observations recorded above permit an outline of late and post-glacial history to be drawn for the area.

1. At an early stage an ice sheet moved eastwards depositing a reddish till. Subsequently it retreated, leaving a deposit of sand and gravel on top of the till.
2. During a considerable period of time, when ice was far removed from the area, a deposit of brownish or reddish clay was laid down in a sea which extended at least to Tillicoultry.
3. A readvance of the ice occurred, probably reaching just east of Dollar, where there is a marked moraine.

4. The ice retreated and became stabilised about Tillicoultry, where it formed a marked ridge and held up an extensive proglacial lake.
5. The ice retreated further, probably to Airthrey, where it formed the deposits referred to earlier, and at this time the sea probably lay around 65 feet O. D., flooding the Devon valley.
6. Sea level fell to around 24-32 feet O. D., at which level a deposit of greyish sandy material was laid down.
7. The subsequent pattern of events followed that described for the carse.

THE TULLIBODY-ALLOA AREA

Between the Devon valley and the Forth lies a landscape of drumlins and ice moulded ridges, trending W. N. W. -E. S. E., composed of a sandy till, and fringed by terraces of sand and gravel. Most interesting evidence is contained within this area concerning the late-glacial period.

There is strong evidence that the last ice which passed over this area was a readvance, though its magnitude is uncertain. North of Alloa lies a large drumlin through which a borehole was put sometime before 1811. In that year, Bald recalled that it showed 162 feet of till overlying 6 inches of material which

"appeared to have been deposited from water in the most quiescent state, as it was divided into the finest laminae" (p.482-3)

and in 1871, Milne-Home described a boring "west of Alloa" which revealed:

Surface soil

Boulder clay 104 feet

Sea sand and shells (a few feet thick)

Rock

In addition, borehole records consulted by the writer show a similar picture to the Devon valley. Reddish or brownish clay, finely laminated and greatly varying in depth, is overlain by up to 25 feet of sand and gravels.

There is evidence too of the gradual retreat of the ice. Near Cornhill the side of a Drumlin is covered by a kame terrace, bedded, and sloping down towards the east. Ice contact slopes in sand and gravel exist in two places near Tullibody. In this town, excavations for a housing estate revealed a deposit of large cobbles, over 1 foot diameter, in a large area.

Retreat of the ice westward was possibly accompanied by the incursion of a sea to circa 70 (S207-211). This is suggested by a large spread of sands and gravels at this height at Tullibody (O, Fig. 20), the break of slope showing no inclination in any particular direction, and also by the extensive flat area between drumlins on which much of Alloa is built (P). This surface here lies at circa 70 feet O.D. also, according to numerous spot heights. Measurement was impossible because of building. During the accumulation of this deposit, the ice front was probably not far away, since the Tullibody feature possesses three kettle holes.

GENERAL CONCLUSION

Late glacial events in this area are dominated by the readvance and consequent retreat of a large ice sheet. It advanced to beyond Dollar in the Devon valley, and during its retreat lingered for some time about Tillicoultry. Further recessions led to a second halt about Airthrey, probably occasioned by the constriction of the valley at that place. The readvance was probably the Perth Readvance.

Considerable changes of sea level took place. Before the readvance, sea level is not known, though extensive ^{marine} deposits were laid down. On the retreat, a sea level circa 70 feet O.D. was achieved. The features at circa 65 feet O.D. in the Devon valley were probably formed contemporaneously with those at Tullibody. The marked feature on the western side of the Airthrey outwash at circa 74 feet O.D. was probably also a contemporary. If so, this means that the ice edge at the time of this sea lay somewhere west of Airthrey.

The next event in this area was the formation of a marine surface at 24-32 feet O.D. There is no evidence here as to whether this belongs to late or post-glacial time.

The events of the post-glacial period appear to be more complex in this area than west of Stirling. Sometime before 8,400 B.P. sea level fell, and peat grew upon the 24-32 feet O.D. surface. Sometime later, sea level rose to a height of 39 to 43 feet O.D., and the carse was deposited. Subsequently it fell, and a lower carse level accumulated, around 31 to 26 feet O.D. This has a strong slope down towards the east. A further fall of sea level down to the present level may have been interrupted by a still stand at about 20 feet O.D.

CHAPTER VI

THE AREA BETWEEN ALLOA AND KIRKCALDY

East of Alloa the Forth ceases to be merely a tidal river and assumes the characteristics of an estuary. By the time Kirkcaldy is reached, 30 miles to the east, the aspect of the coastline is more that of an open sea coast. Throughout this distance, the north shore is bordered by extremely well developed terraces, while inland the glacial land forms take on a special significance. Detailed investigation of this area, which involved mapping, levelling, and boring, included consultation of National Coal Board and South of Scotland Electricity Board borehole records. In the following account, the area is arbitrarily divided into three parts: The area between Alloa and Culross; the area between Culross and Rosyth, and the coastline from Rosyth to Kirkcaldy. In the Alloa-Culross area, features are particularly well developed and in consequence the area is described according to the principal features, of which the most important, the carse is described first. The accounts of the other areas are divided regionally. The three areas are portrayed in Figures 25 (Alloa-Culross), 29 (Culross-Rosyth) and 32 (Rosyth-Kirkcaldy).

THE AREA BETWEEN ALLOA AND CULROSS (See Fig. 25)The Carse

1. Composition. In composition the carse in this area differs little from that of areas further west. Again it possesses the texture of a silty clay, perhaps this time with a higher silt content, and comprises two layers. The upper layer is a mottled grey-brown colour, some 180 cms. thick, containing fewer vegetable remains than further west, while the lower

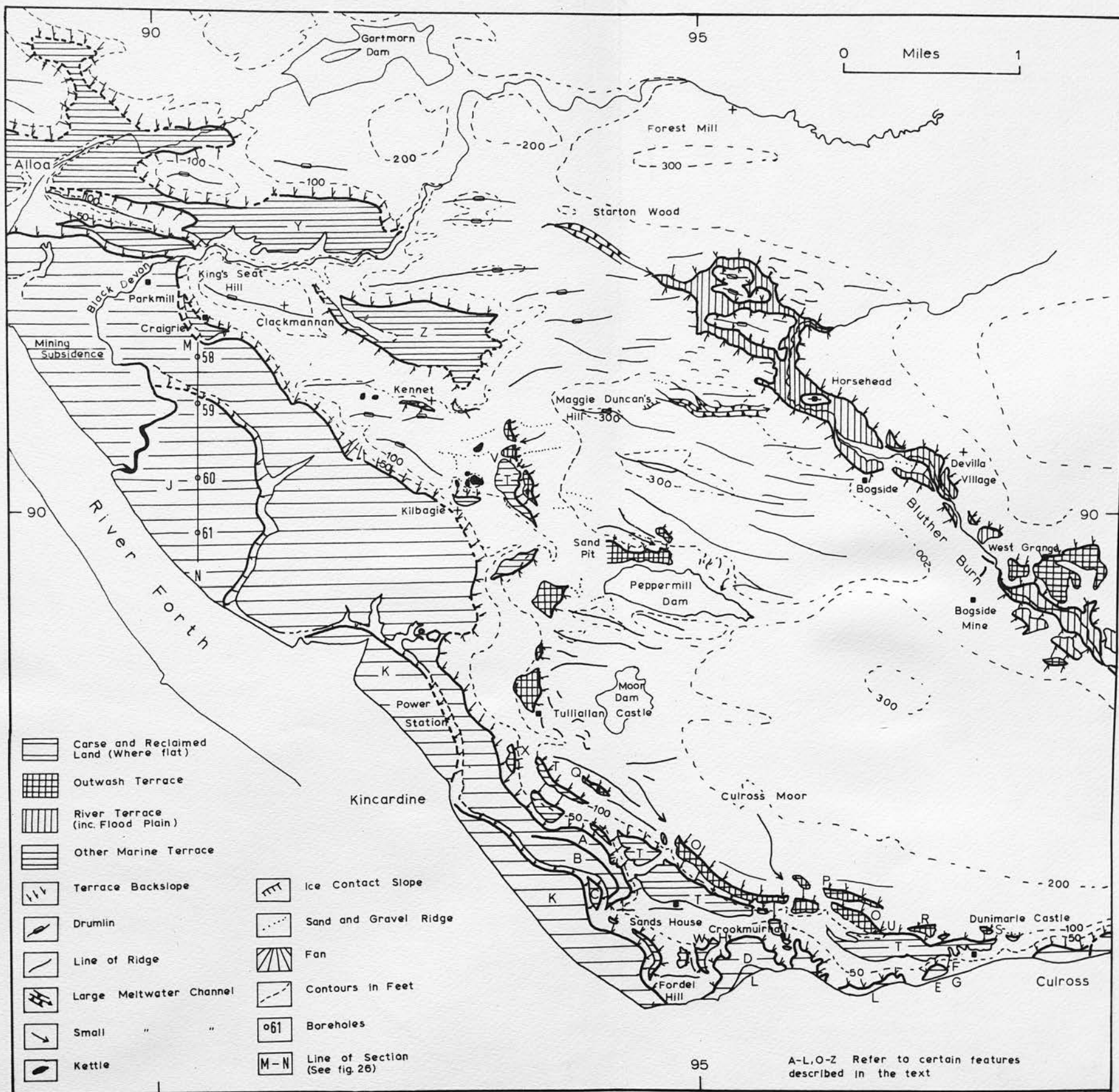


FIGURE 25 The principal glacial and post-glacial features in the area between Alloa and Culross.

is a blue-grey colour, somewhat coarser but well laminated and achieving at least 100 cms. in thickness. The lower layer has a distinctly fetid smell and is commonly called "sleech".

The carse in this area has not yielded so many faunal remains as further west. However, shells were found by Bald (1811), while the writer has observed several beds of shells in the banks of the Forth below Alloa, and occasional specimens in the banks of the Black Devon below Parkmill. In each instance the most abundant remains appeared to be those of Ostrea, which achieved a considerable size. BH 58, near Craigrie, passed through a bed of shells 35 cms.thick at 180-215 cms. and this lay upon a bed of sand 33 cms.thick, below which came sleech. In the Forth bank section the shells were mostly entire, and appeared to have been buried in their position of growth.

A whale skeleton 30 feet long was found in the carse at the foot of Clackmannan Hill sometime before 1817 (Bald, 1821).

2. **Extent.** The carse forms a broad plain south of Clackmannan and a narrow one east of Kincardine. It is terminated in the east by a ridge of solid rock on which stands Sands House, and except for small fragments near Fordel Hill and Culross, is no longer an important element of the landscape east of that place.
3. **Surface Form.** Extensive subsidence has distorted the carse surface over the whole of this area. Moreover, colliery waste has been tipped over much of the surface. It is noticeable, however, that the carse in its natural state contains remarkably few stream depressions, except near the seaward edge. As pointed out above (p. 93), this was a feature of

the second carse level between Stirling and Alloa, contrasting with the upper level. "Ridges" in the carse have been a characteristic of this area as with so many areas further west, according to the Statistical Accounts. It seems that they were levelled during the late eighteenth century and are no longer to be seen.

About 10 feet above the inland margin of the carse, remnants of a high level occur. This terrace is usually composed of sand, and is only well preserved where rock approaches the surface.

Height. Levelling the inner margin of the carse showed that between Alloa and Kincardine it maintains a consistent level from 21.9 (S1316) to 23.7 (S1307), although there are indications of coalmining subsidence nearby. A faint notch above this was measured in various places at 24.2 (S1321) to 26.8 (S1336). East of Kincardine, mining subsidence is more widespread, and consequently no safe conclusions may be drawn from the heights revealed: In the embayment at Inch, the carse appears to be composed of three surfaces; 17.8 to 19.1 (S652-655) (A, Fig. 25), 12.0 to 16.0 (S638-651) (B) and 10.0 to 10.8 (S117-120) (C). The two lower features are clearer, and gave generally consistent results along their lengths (if the single reading 16.0 (S643) on the upper level, B, is excluded, the spread is 12.0 to 14.8). East of Sands House, still in the subsidence area, small remnants gave heights of 13.9 to 14.7 (S528-534) (D), 15.1 to 15.8 (S680-681) (E), 10.3 (S678-679) (F), 17.4 to 19.4 (S682-683) (G) and 15.3 to 17.7 (S535-536) (H). It could be that these figures represent more than one marine surface, in view of their range; the three "steps" at Inch certainly suggest this.

4. Age. There seems little doubt that the carse was formed during a broadly similar time to the carse further west, since it contains a similar fauna, is of similar texture, and is very likely morphologically continuous through Alloa with the second carse level of the previous chapter (though it cannot be measured because of the built-up area). There is no independent evidence in this area, however, for arriving at an estimate of its age. The writer has seen no written archaeological evidence pertinent to the age of the carse here, and in particular there appears to be no evidence that the carse was ever covered by peat. In view of this latter fact, the vegetable content of the upper carse layer is probably due to the growth of salt marsh vegetation during the latter stages of formation of the carse.
5. Sub-carse Stratigraphy. B.H. 58, the only bore put down by the writer in the carse of this area, showed a layer of fine grey silty sand at 261 cm., identical in appearance with that found beneath the carse in boreholes further west (see Figure 26). In the few National Coal Board and South of Scotland Electricity Board boreholes however, a similar layer was not recognised. Rock is present within 20 feet of the surface of much of the carse.
6. Reclaimed Land. Considerable areas of mudflats in this area have been reclaimed from the waters of the Forth estuary. These are located around the mouth of the Black Devon (J, Fig. 25), east and west of Kincardine (K) (the Tulliallan Reclamation - Menzies, 1839) (Cadell 1913), and west of Culross (L). It is suspected that the last named area, still partly inundated at high tide, is only an accident resulting from the building of a railway across the mouths of four muddy inlets. A study of these areas is instructive in illustrating the likeness of the carse to former mudflats.

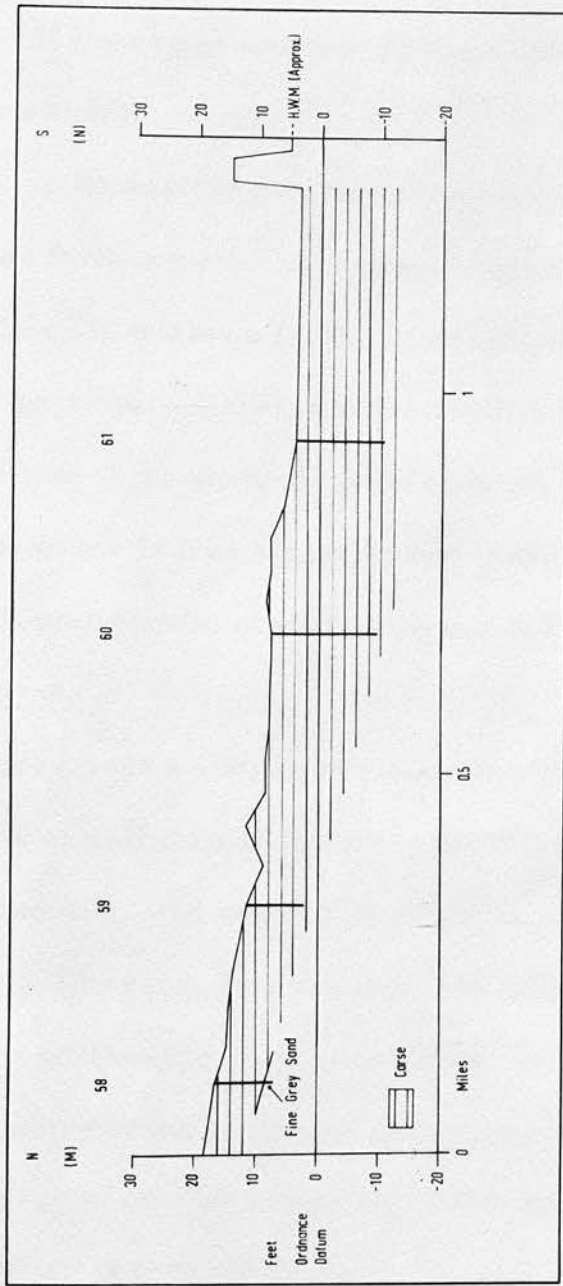


FIGURE 26 Cross-section of the carse, M-N, Figure 25.

The reclaimed areas lie at 3.5 - 8.4 (S664-677, S1344-1355 and Fig. 26). 3 boreholes (BH 59-61) put through the surface by the Black Devon showed a stratigraphy differing from the carse only in that it had a thinner upper layer and fewer vegetable remains. Otherwise, areas that were mudflats only 130 years ago are now distinguishable from the carse only by their lower altitude.

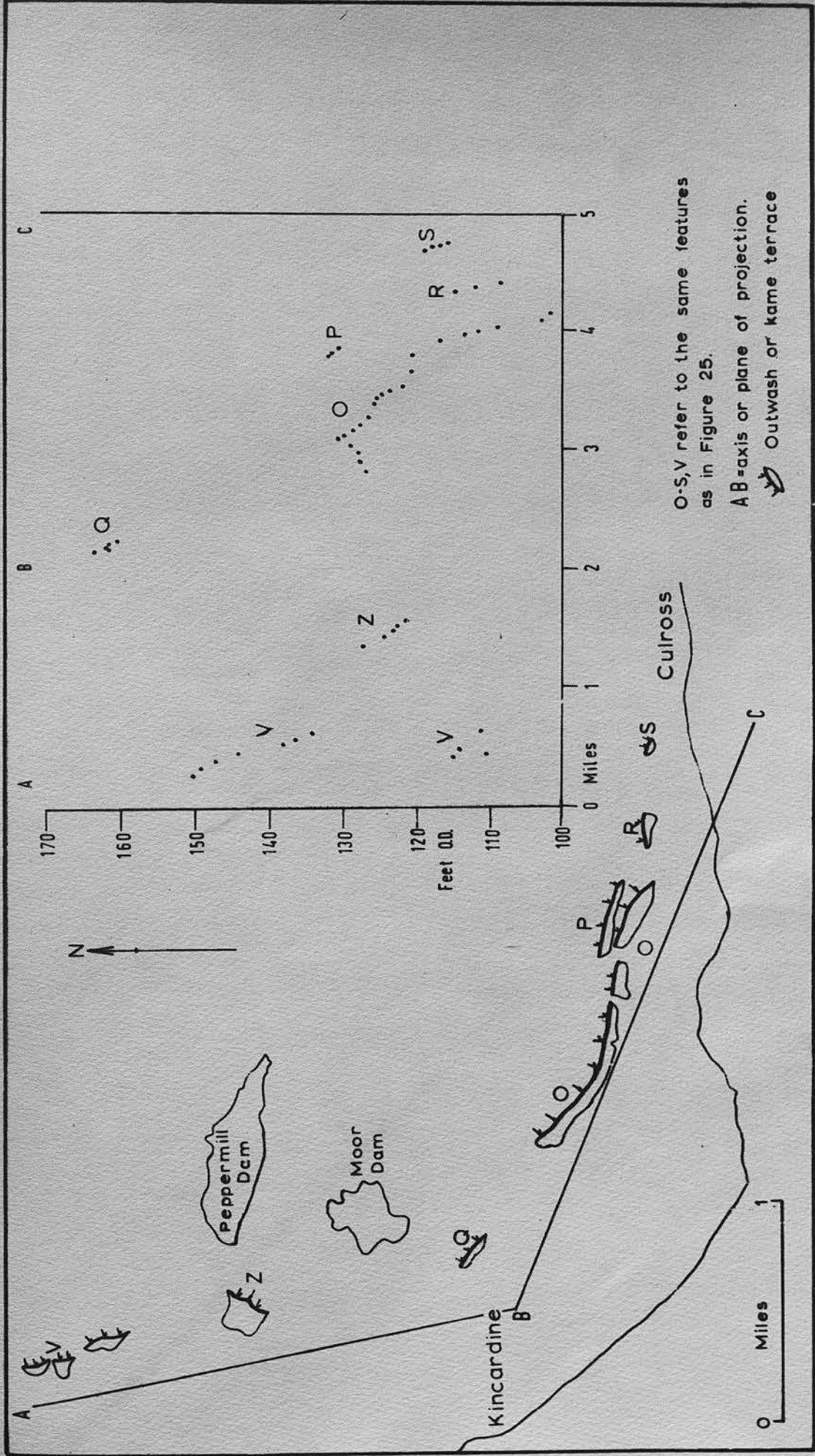
Conclusion. In its eastern extremity the carse is thus ^{different} little from the greater expanse further west. In common with the second level between Stirling and Alloa, it retains a fresh, undissected appearance, and is not underlain by a peat bed. Between Alloa and Kincardine, levelling of the carse does not reveal the easterly slope common in other areas. East of Kincardine, the carse is less extensive and badly affected by coal mining subsidence. It may consist of more than one level in this latter area.

Glacial Landforms

This area possesses a variety of glacial landforms. The basic morphology consists of well formed drumlins and till ridges, all trending a little south of due east, and coalescing into a broad, undulating till plain behind Culross. However, in a belt some $1\frac{1}{2}$ miles wide and extending from Kincardine northwards at least to Forest Mill (the limit of the mapped area), the symmetry of the landscape is interrupted, and there occurs a chaotic assemblage of mounds composed of till with large angular blocks. Most of this country is covered by plantation and bog, being of little use for tillage or pasture, and is difficult to map accurately. It seems that there is no distinct lineation to the mounds, except where large meltwater channels cut through them in an easterly direction. These channels, at

Starton Wood and Maggie Duncan's Hill, lead on to spreads of outwash, which follow the valley of the Bluther Burn, and are described in the next section. A proglacial function is thought most likely for these channels particularly that at Maggie Duncan's Hill, where an ice contact slope in sands and gravels is present near the beginning of the channel. Near the bank of the Forth, in Tulliallan estate, a well developed meltwater channel leads directly on to an outwash terrace (O, Figure 25) which extends over a distance of a mile, declining regularly from 130.5 to 102.9 (S291-S243). The terrace is composed of coarse gravel at its western end, but of fine sand at its eastern extremity. Other outwash terraces also occur in this locality (P-S), particularly to the east of the large terrace, and one (P) is connected with a large meltwater channel leading from Culross Moor. They were all levelled, and are shown in the accompanying diagram (Fig. 27).

Along the hillside east of the A977 road from Kincardine to Kennet, numerous outwash terraces occur. They have been levelled, and slope consistently east or south-east. One contains a well developed kettle hole. In this area further evidence of ice decay occurs. Peppermill Dam is a large artificial lake occupying a large part of a depression between two rock ridges, trending west-north-west - east-south-east. On the northern side of this depression a fine outwash terrace occurs, fed partly by a meltwater channel, and dipping eastwards. An extensive pit in this revealed 45 feet of bedded sands and gravels showing faults, contortions and slumping. Below this occurred 2 feet of laminated silt lying on a blue till, beneath which rock was occasionally seen. Further east, the terrace is terminated by small, irregular hillocks composed of a yellow, plastic, till, very



O-S, V refer to the same features as in Figure 25.
 AB-axis of plane of projection.
 C Outwash or kame terrace

FIGURE 27 Slope of outwash terraces in the Kincardine-Culross area.

different from the till beneath the sands and gravels in the section or from the characteristic till of the area, which is brownish and sandy.

At Kennet, a landscape of drumlins is covered on the east by deposits of sand and gravel with well formed kettle holes.

The above evidence indicates that an important readvance of ice sheet has occurred in part of this area; a condition that ^aSissons (1963) has suggested. The till plain and drumlins in the eastern part show that ice once extended over the whole area. Upon the retreat of this ice a readvance occurred, destroying the drumlinoid forms left by the previous ice as it advanced, and recreating drumlinoid forms within its main body. Around its margin, however, it merely gave rise to chaotic mounds of till, probably formed of the débris of the old drumlins. Thus the drumlins in the area between Alloa and Culross are of different ages; those to the west of the belt of chaotic mounds are of a later date than those to the east. There is also stratigraphic evidence which suggests that a readvance has taken place. As noted in Chapter V there are records cited by Bald (1811) and Milne-Home (1871) of laminated clay and sea shells lying beneath till. These observations indicate the reworking of earlier deposits by an advancing ice sheet.

Other Shorelines

Between Kincardine and Culross, a distance of 4 miles, there exists a very well developed terrace (T), which is morphologically continuous throughout the area except for two breaks, each of 300 yards length. It was levelled at 34 points. It declines gently in altitude eastwards, from 103.7 to 106.2 (S1020-1024) at Kincardine to 96.8 to 100.9 (S497-504) at

Culross. The feature is also present near Kilbagie, north of Kincardine, where it attains 105.9 to 108.5 (S684-689). It is everywhere composed of sand and gravel, usually fine. No marine organic remains were found, but from its widespread occurrence, gentle inclination, and generally uniform composition, it must be considered marine.

This major feature displays an interesting relationship to the outwash features. Frequently they appear to have been cut off by the marine feature. At Crookmuirhall, the largest outwash feature descends regularly down to 102.0 (S 274), at which point the marine feature is present, and here the two meet at an angle (U). At Kilbagie, an outwash terrace declining in height from 123.0 (S701) is cut off at 108.5 (S 687) by the marine feature (V). These and other less perfect relationships strongly suggest that the outwash terraces were developed to a lower base level than the sea level that existed at the time of the construction of the major shoreline. This implies that the latter was associated with a transgression.

Although a vague step was levelled in one locality circa 3 feet above the major shoreline (S495-6), there is no satisfactory evidence of the existence of a shoreline above the major one, and this is in conformity with the deployment of the outwash features. Below the major feature, however, other terraces do occur. None are steeply inclined or suggest ice in proximity. Above the carse, at 40.6 to 41.5 (S 537-539, S 546-547) by Fordel Hill is a terrace of fine white sand (W); by Kincardine Church a clear feature at 45.1 to 48.4 (S 1015-1019) (X) stands out. At Crookmuirhall a less well developed feature attains 55.1 to 56.7 (S 510-513). At Clackmannan, two inter-drumlin depressions (Y, Z) are filled with a brown, plastic, clay,

which attains a height of 70.7 to 73.6 (S 1356 - 1365) in one and a similar height in the other. This deposit was described by Dinham and Haldane (1932). It is of importance to note that here, although the area would seem to be the most favourable of all for a development of the major shoreline, no vestige of any terrace above 73.6 ft. O.D. is to be seen. In addition, the lips of kettle holes by Kennet descend to well below the height of the major shoreline in this latter area. Evidence has already been presented to show that an important ice limit lay in this area. Accordingly it is supposed that the major shoreline was formed at the same time as ice lay up to this limit. The fine development of the shoreline can then be explained by its formation in proximity to a large supply of glacial detrital material.

It has been shown above that the major shoreline was transgressive and later than the outwash terraces described above. Therefore 3 ice limits are recognisable, the first, when ice produced the chaotic mounds; the second, when outwash poured away from the ice into the Bluther Burn valley, and when the Peppermill Dam and other terraces were produced; and the third, when the major shoreline was produced (see Fig. 28). There cannot have been a great distance between the second and third limits, so because of this, and because of the development of the major shoreline, it is likely that the ice front remained stable about this area for some time.

Borehole Evidence

A number of boreholes have been put down in this area for the National Coal Board and the South of Scotland Electricity Board. These do not give much assistance in interpreting the geomorphological record. National Coal

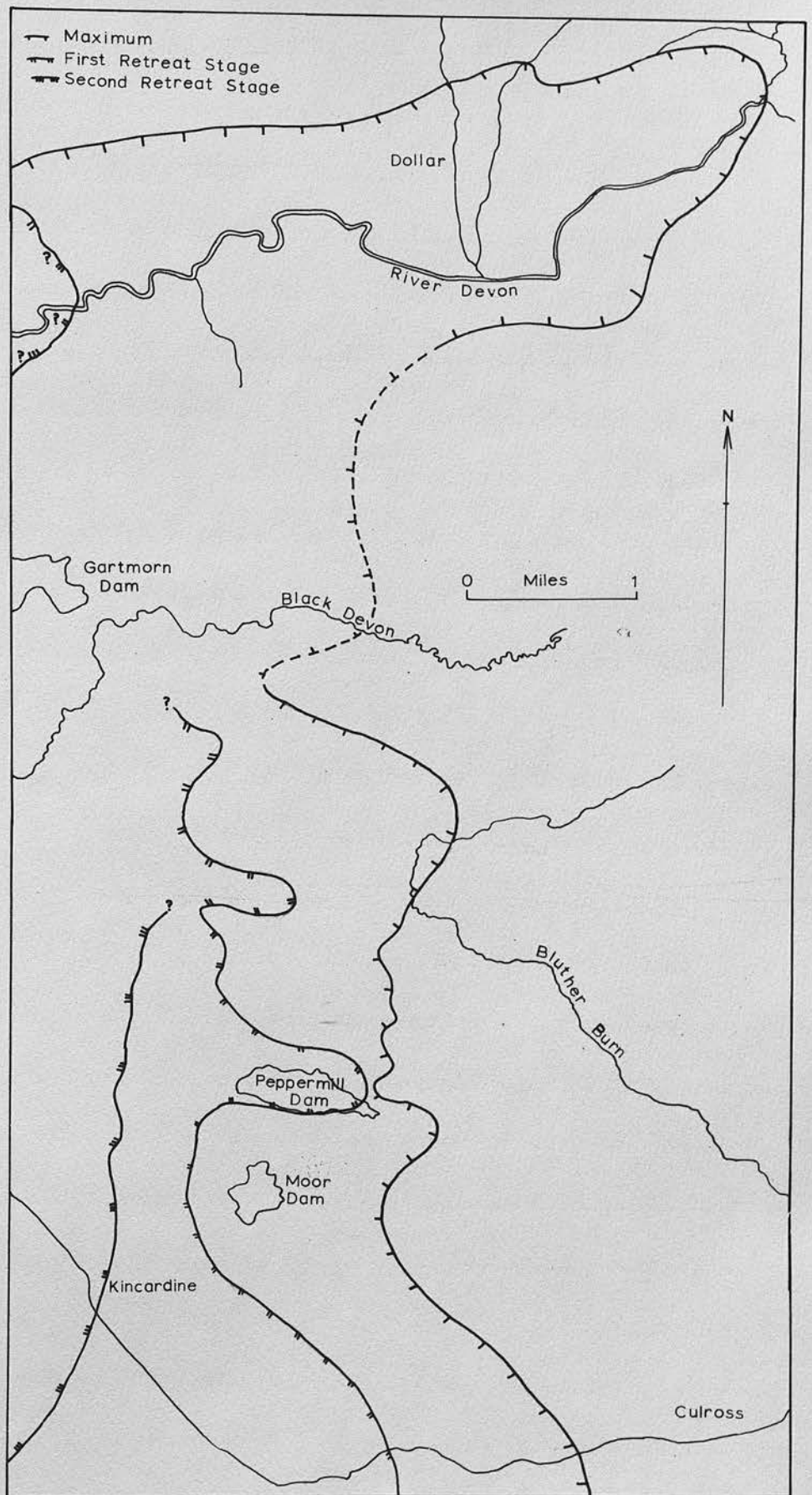


FIGURE 28 Probable limits of the Perth Readvance in the Tillicoultry-Kincardine-Dollar area.

Board boreholes near the Black Devon show a similar succession of superficial deposits to that recounted before further west: a brown, finely laminated clay often of great thickness being underlain by till and overlain by gravel. This clay is irregular in appearance, and has an irregular surface. In one place, the till overlies 8 feet of gravel. Both successions suggest readvance conditions, but the absence of a definite till layer above the brown clay precludes a definite inference. South of Scotland Electricity Board bores for Kincardine power station reveal a brown plastic clay overlain by gravel, and here the surface of the clay is more regular, declining towards the river, but the site is too restricted in extent to allow conclusions about possible buried marine surfaces. It is certain, however, that here ~~the general stratigraphy~~ the general stratigraphy of superficial deposits near the Forth is

4 Carse clays or muds

3 Gravel

2 Laminated brown plastic clay

1 Till

Important questions are raised by the widespread nature of the stratigraphy. As already seen, **Sissons** has suggested that the brown clay was laid down prior to the Perth Readvance, and the writer has supported this contention. It seems highly likely that the readvance described in this section is equivalent to that described on the south side of the river by **Sissons**. How therefore, ice could create such an expressive topography inland, forming drumlins 100 feet high, shaping rock ridges, and destroying old drumlin forms, but not remove a previous marine deposit over a wide area along the axis of its movement is not easy to perceive. Yet the sug-

gestion of a readvance seems the most likely to account for the irregular nature of the clay. Perhaps frequent calving of the ice at the centre of its front preserved much of the clay.

Conclusion

The following pattern of events may be recognised in this area.

1. At some time during the Würm glaciation, ice moved eastwards across the whole area, producing a landscape of drumlinoid forms and till plains.
2. After the retreat of this ice, a readvance occurred. If the brown clay deposit predates this event, then the retreat of the ice before the readvance was probably considerable, in view of the considerable thickness and fine nature of the deposit. The limits of the readvance are well defined, corresponding to the limit of chaotic mounds in the area. It is believed that this readvance is the Perth Readvance of Simpson and Sissons but its maximum limit was further east than Sissons supposed. It may correlate with the ice limit east of Dollar described in the previous chapter. Sea level at the maximum of the readvance was relatively low, but there is no indication of its level.
3. The ice retreated and many fluvioglacial forms were produced. These were abandoned and sea level rose so that a marked shoreline was formed. The ice front was probably stable at this time, and was probably a contemporary of that against which the Tillicoultry ridge was formed. This line corresponds to that drawn by Sissons for the limit of the Perth Readvance in the area.

4. The ice retreated further, and sea level fell, so that the major shoreline was not developed west of Kincardine.
5. No evidence allows of an estimation of the age of the lower terraces, except that they are more recent forms.

THE AREA BETWEEN CULROSS AND ROSYTH (see Fig. 29)

The Bluther Burn Valley

The valley of the Bluther Burn is a wide depression running for some four miles in a south-easterly direction across the grain of the landscape, represented here by drumlins and till ridges aligned west-east. For the most part, the valley is floored by extensive but irregular terraces, composed of sand, gravel, and silt north-west of Blairhall, but also of clay south-east of that place.

A graph of terrace heights appears in Figure 30, in which the reference letters correspond to those in Figure 29.

Dinham and Haldane (1932) have suggested that an arm of a late-glacial sea extended up the valley to a height of "about 130 feet" and that in this sea glacial outwash was deposited, giving rise to the development of "The 100-foot Raised Beach" here. They do not claim to have measured the terraces, and by their short account of the deposits imply that the picture might well be more complex.

The head of the valley lies within the belt of chaotic mounds described earlier, and is continued westwards by the two large proglacial meltwater channels at Starton Wood and Maggie Duncan's Hill. In this area, the mounds are partly buried in a deposit of alluvium, which forms the valley

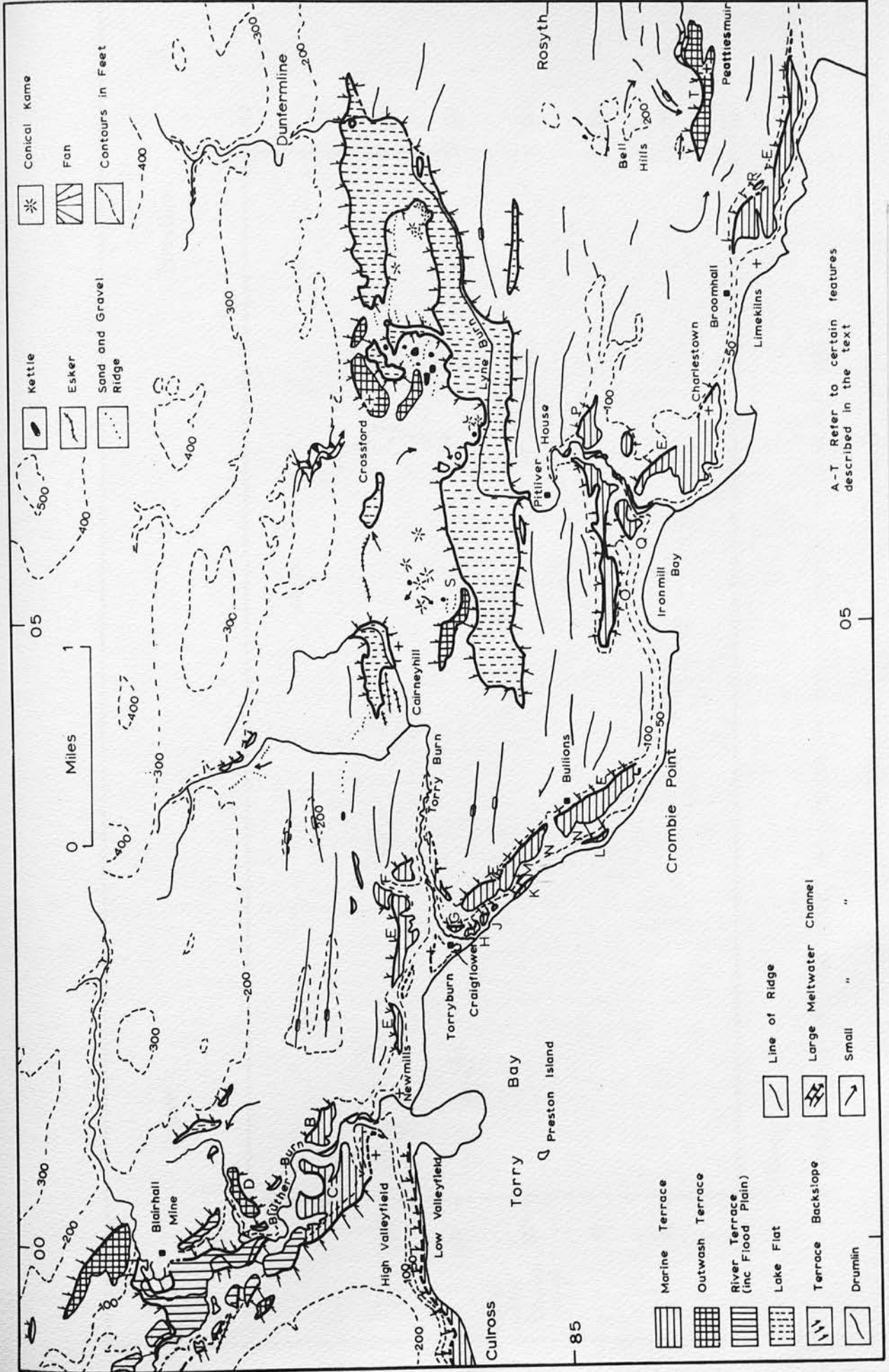


FIGURE 29 The principal glacial and post-glacial features in the area between Culross and Rosyth.

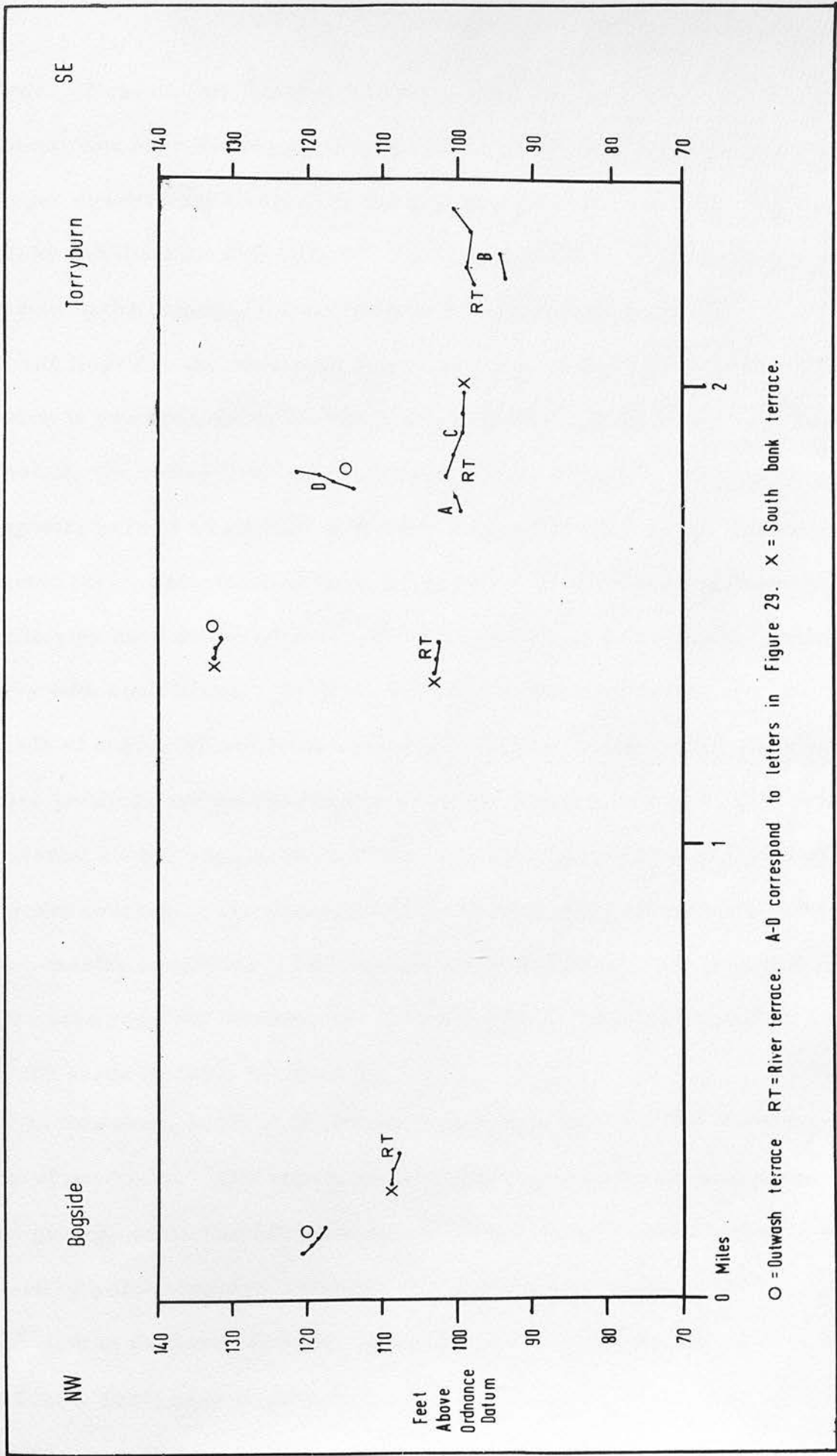


FIGURE 30 Slope of the terraces in the Bluther Burn valley.

floor. Beneath this deposit, however, sand may be observed at several points, and near Horsehead large cobbles. The surface of the alluvium slopes downstream from circa 150 feet **OD**, at the head to circa 130 feet **OD**, by Devilla Forestry village. At the latter place, a kame is partly buried in the deposit, and sections in this show contortions.

At Bogside, the sand and gravel has emerged from beneath the alluvium, which is now confined to narrow terraces bordering the burn. By West Grange, the valley widens to accommodate more extensive sand and gravel deposits here at an altitude of 120.2 to 117.9 (**S** 1369 - 1372), declining eastwards. Unfortunately here the workings of Blairhall and Bogside collieries have produced severe subsidence effects and covered much of the area with spoil heaps. Sections in the terraces show poorly sorted materials, bands of coarse gravel lying above silt. In addition, there are unconformities, false bedding, and depressions in one layer filled in with quite different material above, suggesting dead ice melting out or abandoned ephemeral stream courses. The character of the deposit suggests outwash rather than marine conditions. Measurement of a second terrace fragment (**D**) here also suggests outwash, for it slopes downstream from 121.4 to 113.7 in 300 yards (**S** 1203, **S** 1206 - 8).

In this area, south of Blairhall, however, it appears that the terraces are of two kinds. The upper, more fragmentary ones, are composed of sand and gravel, while beneath these lies a more extensive lower terrace, composed of a fine chocolate coloured clay well exposed at Shires Mill. The elevation of the lower terrace, measured in three areas, was 95.7 to 99.6 (**S** 1220 - 1224) near Bogside Mine, 99.2 to 100.1 (**S** 1204 - 1205) at A, and

93.5 to 100.5 (S 855-860) at B, though this last terrace fragment may be a double feature, one level at 93.5 to 94.3 and a second at 97.9 to 100.5. At a fourth locality, near Valleyfield, a fragment three-quarters of a mile long (C) showed first a decline downstream from 104.0 to 101.9 (S 1212-1215), then a levelling out, giving 99.0 to 100.1 (S 1216 - 1219). The homogeneous composition of this terrace and the generally uniform height suggest a marine origin. The fine character of the deposit suggests quiet-estuarine conditions; the upward trend in the fourth terrace, which lies furthest inland, probably indicates that it merges with a stream terrace.

It would appear, therefore, that both marine and outwash terraces exist in the valley of the Bluther Burn.

The coast, Culross to Crombie Point

Terrace features are well developed in this area, but again one feature (E) stands out. Except for a gap of three quarters of a mile behind Culross, where the coastline is very steep, and gaps of a quarter of a mile each at Newmills and Torryburn, it is morphologically continuous. At the western end, at Torryburn, the terrace achieves 90.7 to 97.9 (S 846-855), while between Torryburn and Crombie point it is 86.9 to 92.7 (S 792-807). A definite declination towards the east is thus present. The Torryburn - Crombie Point terrace lies by a farm called Bullions (see Fig. 29). Donner (1963) describes measuring a terrace by this farm, and he gives its height as 37 metres (120.2 feet) above the barnacle line. Since Donner avers the barnacle line to be at about high water mark, this measurement approximates to 125-130 feet O.D. Donner's grid reference (NT035851) suggests that he has measured a portion of the Torryburn-Crombie Point

terrace, and indeed it must be so, since no other terrace exists above 40 feet O.D. in this area. 4 measurements on the terrace in the locality of Donners' grid reference gave 88.6 to 90.4 (S804-807). The traverse closing error was +0.01 feet. Donner's measurement is therefore inaccurate, and in consequence no significance whatsoever can be attached to his conclusions about "The 100-foot Raised Beach" in this area.

Above the main terrace at Torryburn, lies a small feature which yielded heights of 101.8 to 103.5 (S840-845) (F). This feature is situated in the valley of the Black Burn. It could therefore be a contemporary of the large terrace, deriving its greater altitude from estuarine conditions. A section in it shows fine chocolate coloured clay. Below the main terrace several other features occur.

Culross and Low Valleyfield lie on what appear to have been a low terrace bordering the shore, now much altered by building. Road construction sections reveal pebbles and shells; while the Statistical Account (1794) speaks of the land at Culross rising steeply from the shore, "which is a dead flat". At Torryburn, more tangible evidence exists. By Craigflower, features exist at 31.1 to 33.0 (S879-882) (G), 12.8 to 13.6 (S 883-885, S 889) (H), and possibly at 16.5 to 21.5 (S 886-888) (J). These seem to be at least partly rock platforms. At Crombie Point, there are terraces at 14.3 to 15.7 (S 808-810) (K), 15.0 to 15.1 (S 826-827) (L), and a poor feature at 22.0 to 24.7 (S 824-825) (M). In the same locality, these lower terraces are separated from the major 86-92 foot terrace by a steeply sloping sandy area and a rock cliff. Where the sand is banked against the cliff (N) measurements gave 33.4 to 42.9 (S 828-839). Donner has measured

a "terrace" in this area at 26 ft. above the barnacle line, probably 30-35 ft. above O.D.. It is presumed that he measured the angle between the sandy area and the cliff.

The coast, Crombie Point to Rosyth

Clear terraces also characterise the coastline in this locality. Again, one level stands out by its width and continuity (E). At Charlestown it forms a broad expanse east of the mouth of the Lyne Burn, where measurements gave 85.6 to 90.7 (S 896-903). Here, the feature has been worked for clay. At Limekilns, a mile further east, a similarly broad terrace was measured at 76.1 to 85.6 (F 131-133, 281-283, 286-295). By Rosyth, the ground has been extensively altered, but at Orchardhead a terrace is present, though poorly developed, and this gave 80.3 to 85.3 (F 296-298) (see Fig. 33).

Other levels are present. At the mouth of the Lyne Burn, an inter drumlin depression harbours a flattish area of 91.6 to 100.5 (S 904-920 (O), rising gently inland. This may be a contemporary of the main level. Two terraces by the stream gave 94.9 to 95.1 (S 922-925) (Q) and 98.4 to 101.0 (S 890-895) (P). These again might represent the estuarine facies of the main shoreline in this area. The second terrace has been worked for brick clay in the past. Other terraces are very poorly developed or obscured by building. A small flattish feature was measured at 97.8 to 98.4 (F 284-285), but may well be purely structural. A low terrace probably margins the shore of Iremill Bay, but this locality is a Naval Armaments Dépôt, and access was not possible.

Inland, Cairneyhill to Dunfermline and Rosyth

The main relief features away from the coast in this area are drumlins, pointing due east. These are occasionally interrupted by lake flats and fluvioglacial deposits.

Between the villages of Cairneyhill and Crossford lies an extensive belt of fluvioglacial deposits. At the former place, in the west, there occurs an area of small esker ridges. These give way in the east to a kame and kettle topography. Further east some of the kames become flat-topped, and the village of Crossford stands on an outwash slope, punctuated by deep dead-ice hollows, and declining eastwards from circa 148 feet O.D. to circa 139 feet O.D. (Ordnance Survey spot heights only). A sinuous melt-water channel 40 feet deep leads in to this terrace from the north-west. To the south of the terrace, the country is again one of kames and kettles, with occasional ice contact slopes, but within half a mile gives way to the prevailing drumlinoid landforms.

These fluvioglacial features lie in a wide depression, at the eastern end of which stands Dunfermline. They were responsible for two lakes which have since silted up. One, by the village of Cairneyhill, was half a mile in length and dammed up by esker ridges at its western end. Sections show lake marls overlying sand and gravel. The present outlet of the lake site is at Conscience Bridge, to the west. The second lake is more extensive, being fully three miles long, though only half a mile wide. It extends from Dunfermline almost to Torryburn, and a section by Coal Bridge along the Lyne Burn shows:

5	Slumped and overgrown	5'
4	Mottled brown-grey clay	2' 3"
3	Mottled brown-grey clay with vegetation	10"
2	Fine grey sand	$\frac{1}{2}$ "
1	Stratified Gravel	6"

Its former outlet probably lay at Cairneyhill, where there is now kame and kettle topography and a small outwash terrace (S). At present its outlet lies at Pitliver House, where the Lyne Burn escapes through a rocky defile to the Forth at Charlestown. Both lake flats lie at an altitude of circa 120-130 feet O.D.

South-east of this area, behind Limekilns, the symmetry of the landscape is again broken by a large number of chaotic mounds, the "Bell Hills". Unlike the area further west, however, these are mainly solid, with a veneer of sand and gravel, and their origin may be purely structural. But south of this a marked terrace of sand and gravel (T) beginning near Broomhall, and providing the level area on which the village of Peattiesmuir stands, declines from circa 120 feet O.D. to circa 100 feet O.D. (Ordnance Survey spot heights only),/ ^{suggesting} that it is outwash. A section in its eastern end shows bedded sands and gravels, partly contorted. Here, it is dissected by sinuous dry valleys, considered to be proglacial stream channels. Near Rosyth, a terrace fragment occurs at 88.1 to 89.7 (F 299-300).

Offshore borehole evidence

Rockhead lies as much as 570 feet below O.D. (Cadell, 1913) and 675 feet below O.D. (Macgregor, 1940) in the centre of the Forth in this area, while a bore in Torry Bay has shown solid rock to be 276 feet beneath "the

surface of the ground" between Preston Island and the shore near Culross (Cadell, 1913). In 1913, Cadell suggested that two ancient river channels lay buried beneath the Forth deposits, one passing through Torry Bay. Recent boreholes made for the South of Scotland Electricity Board in the Torry Bay area (see Fig. 31) suggest that no buried river channel exists, at least where Cadell supposed it to be, and it would seem that the depth of 276 feet is a very localised depression. The rock surface, as revealed by the boreholes in Torry Bay, is very irregular, a condition which is probably due to glacial erosion. This same explanation may hold true for the unusual depths in the centre of the estuary. Certainly there is insufficient evidence for the suggestion of a buried river channel.

The superficial deposits revealed in the boreholes are similar to those described by Cadell (1913):

- 5 Mud and carse clay .
- 4 Sand and gravel
- 3 Boulder bed
- 2 Red Clay
- 1 Till

In this area, the position occupied by Cadell's "Red Clay" is more usually occupied by "Soft Brown Clay". Comparison of neighbouring boreholes shows that this latter deposit is often confused with till in the borehole logs.

Conclusion

The glacial and marine landforms in this area suggest the following succession of events:

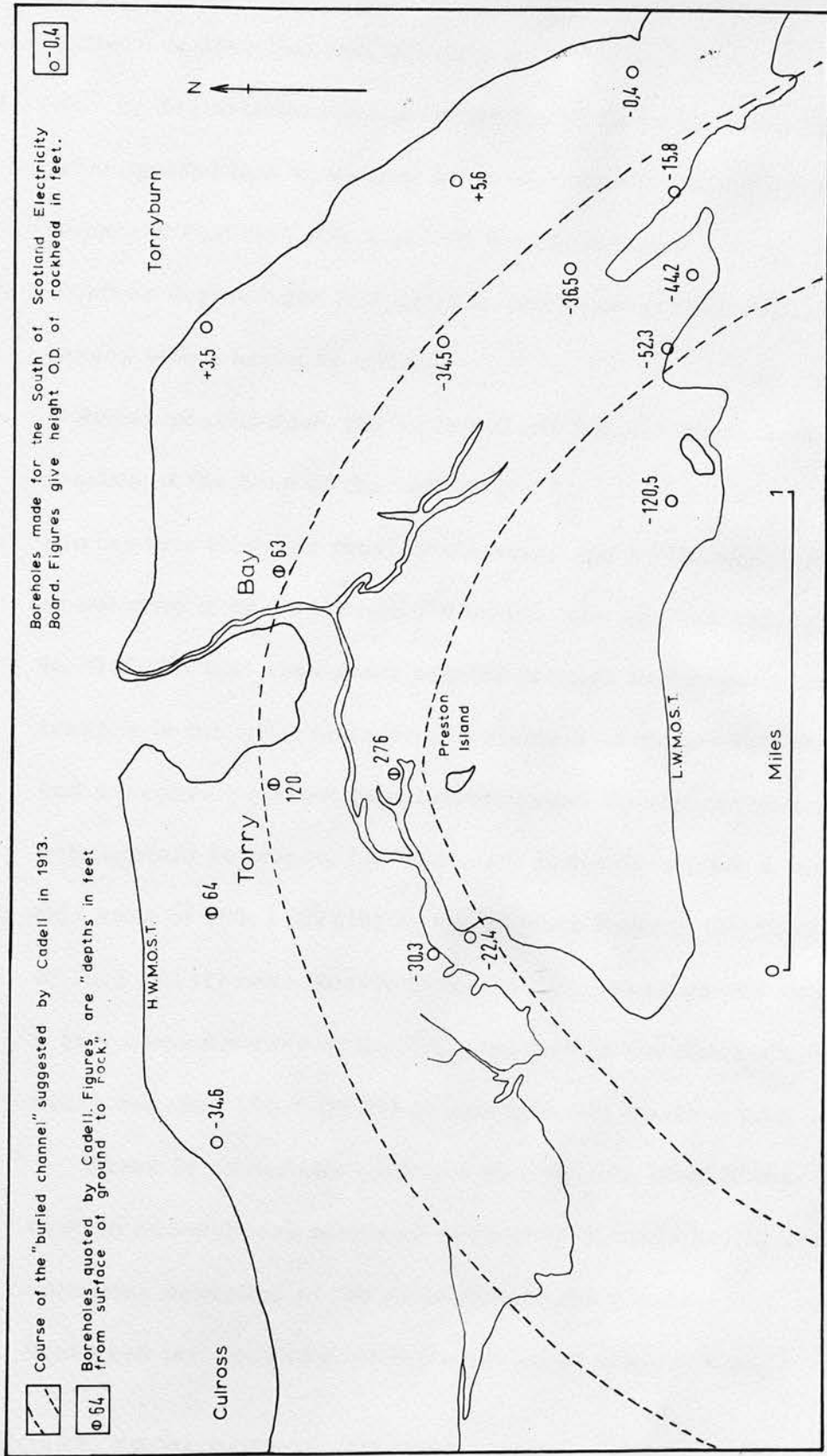


FIGURE 31 Cadell's "buried river channel" in Torry Bay, viewed in the light of recent borehole information.

1. Ice moving eastwards once covered the whole area, creating a pattern of drumlins and till ridges.
2. During deglaciation, ice margins lay at Crossford and Limekilns. It is suggested that these may have been contemporary, but it is not supposed that this was a halt of long duration.
3. Further deglaciation left an ill drained topography with two notable lakes, which began to silt up.
4. Outwash poured down the valley of the Bluther Burn from an ice margin located at the head of the valley.
5. During this time sea level was rising, and by the time outwash ceased to build up in the Bluther Burn valley, the sea had achieved 95 to 100 ft. O.D. in that area and a notable terrace had been formed. This terrace is the most conspicuous element of the present day coastline, and except for narrow gaps is continuous throughout this area. It is not constant in height, however, for it declines from a maximum in this area of 100.1 (S1216) by the Bluther Burn in the west, to a minimum of 76.1 (F131) near Rosyth in the east. There seems little doubt that it is a contemporary of the main terrace in the Alloa-Culross area, which reaches 108.5 (S687) at Kilbagie, its western end.

There is no definite evidence of a marine level higher than this, and certain non-outwash terraces slightly above this height are probably estuarine deposits of the main raised shoreline.

6. Scattered terraces of a younger age exist beneath this.

THE COAST FROM ROSYTH TO KIRKCALDY (see Fig. 32)The Inverkeithing Depression

Immediately north of Inverkeithing lies a long east-west depression in the landscape, surrounded by the drumlinoid topography characteristic of this area. The floor of the depression descends to 35 feet O.D., while the rim is at about 130 feet O.D., beached only by a narrow gap (A, Fig. 32) through which flows the Keithing Burn.

It might seem that this area should form a favourable region for accumulation of glacial or marine deposits, yet, although the towns of Inverkeithing and Rosyth prohibit a full understanding of the landforms, it seems that terrace features are poorly developed. Nevertheless, Allan and Knox (1934) claimed that two former sea levels are represented here by "a well-defined feature, cut mainly in the boulder clay, between 120 and 130 feet above present sea level" and "a notch, which occurs at a level of about 75 feet".

The outwash feature by Broomhall, described in the previous section, leads into this depression, but as already noted, is lost in the town of Rosyth. North of the town, a poorly developed terrace (B) lies astride the Dunfermline road, and may extend east as far as Middlebank. Over a short distance its height was 106.8 to 109.5 (F 732-736). A deep section in the eastern end of this feature showed:

3. Fine brown-grey sand, stratified in layers 1 - 2 inches thick alternating with layers of coal fragments, 0.5 inch thick. 30 - 40 feet.

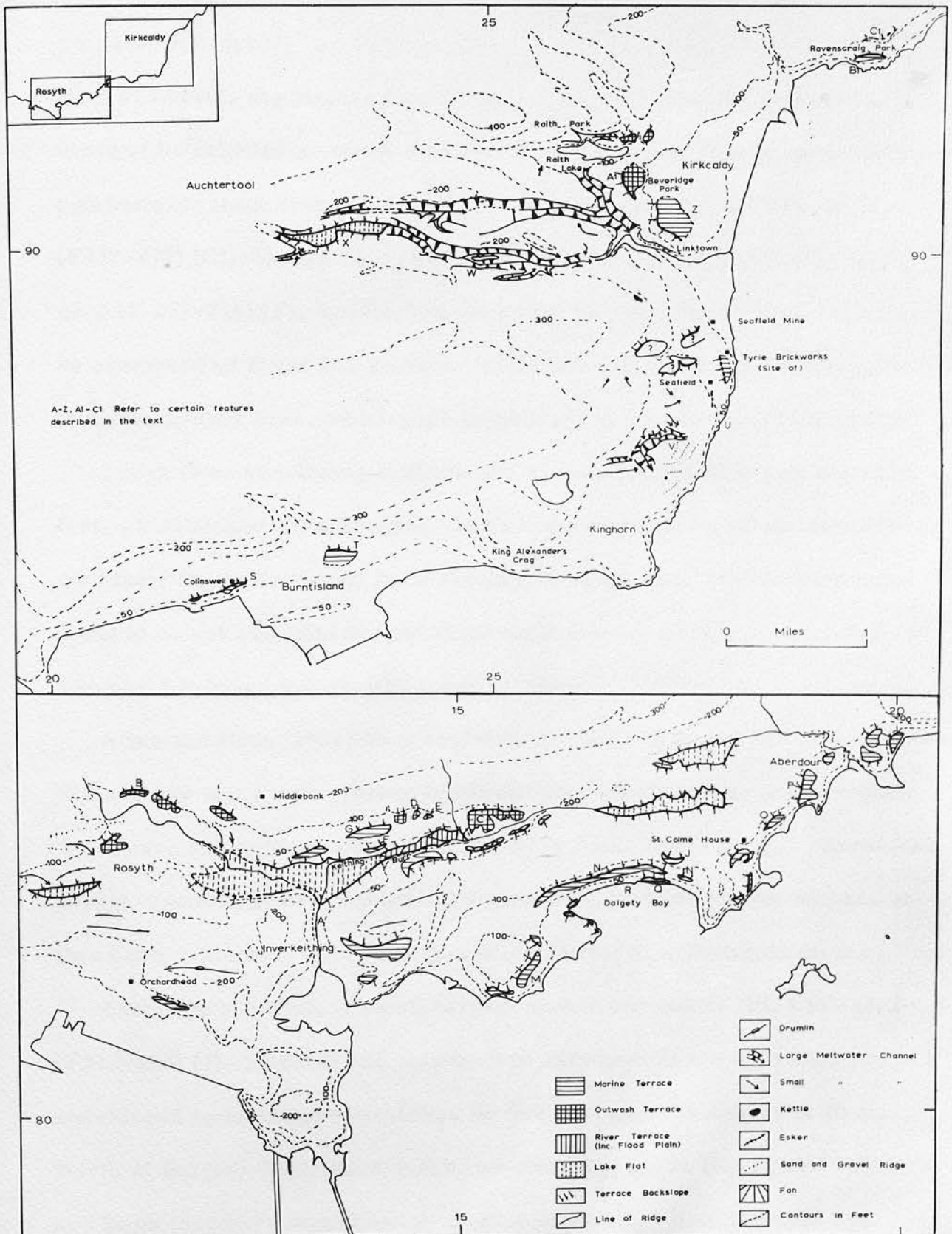


FIGURE 32 The principal glacial and post-glacial features on the coast between Rosyth and Kirkcaldy.

2. Stony blue-grey till . 10 feet .

1. Bedrock .

East of Rosyth, the picture is clearer. The northern side of the depression, north of Inverkeithing, is the more gently sloping side, and it possesses a number of terrace fragments. These were measured at 93.2 to 94.5 (F272-273) (C), 95.9 to 96.1 (F274-275) (D), 109.1 (F276) (E), 60.7 to 62.2 (F 277-278) (F), and 68.8 to 74.9 (F 279-280) (G). All appear to be composed of sands and gravels. The floor of the Inverkeithing depression is a flat, clayey area, which gave heights of 30.5 to 33.2 (F724-731) (H).

There is no convincing evidence for marine influence up to 120 to 130 feet, as Allan and Knox propose, and the terrace heights do not correspond with their figures - though their datum is a vague one. No terrace was found to be cut into till, despite their claim.

The coast between Inverkeithing and Kinghorn

Allan and Knox (1934) have said that the "well-defined feature....between 120 and 130 feet above present sea level" occurs between Inverkeithing and Aberdour, and between Colinswell and King Alexander's Crag. One would expect, from their description, to encounter a marked marine terrace in these two regions. Both were therefore examined with this in mind.

Above Dalgety Bay, a small terrace was measured at 107.4 to 112.2 (F517-522) (J). This is the only feature anywhere in the area that can be considered marine and approaches the height quoted by Allan and Knox. North of Dalgety Bay, there occur two other flat areas (K, L) that Allan and Knox may have mistaken for marine features. Both features are totally enclosed except for very narrow outlets. One (K) lies either side

of the railway from Inverkeithing to Aberdour, and was recognised by Wilson in 1893. He noted sections showing fine laminated clay, and the writer has seen quantities of a fine grey laminated silt overlying gravel. The flat is at a height of circa 110 feet O. D. The morphology of the feature suggests that it is a lake flat. A like origin is suggested for similar reasons for the second feature (L), which lies north-west of St. Colme House at an altitude of circa 116 feet O. D. .

Between Colinswell and King Alexander's Crag no terrace at all exists above 70 feet O. D.

Below 120 to 130 feet "above present sea level", according to Allan and Knox there occurs "a notch, which marks the upper limit of an intermediate beach". This is supposed to be at 75 feet "above present sea level". One gains the impression from their account that this is not a very extensive feature. However between Inverkeithing and Aberdour, the writer has mapped and heighted clear terraces at about that level. From west to east, the heights obtained were: 73.8 to 77.6 (F530-534) (M), 69.2 to 75.1 (F486-498) (N), 66.9 to 74.1 (F523-529) (O) and 69.1 to 69.9 (F301-302, F304-305) (P). These features are separated by breaks no more than a third of a mile long, all of which can be ascribed to steep rocky headlands, and it is concluded that they probably belong to one level. The widespread nature of this level suggests that it is marine. It is interesting to note that the feature declines in height towards the east.

Lower features exist between Inverkeithing and Aberdour, but are very poor. The most marked feature attains 20.9 to 22.5 (F513-516) (Q) in Dalgety Bay, and seems to be cut in rock. Wilson (1893) described a "raised beach" by the

pier at Aberdour. According to him it lay at 40 feet above high water mark and contained marine shells of species found in the Forth today. This feature is probably now obscured by building.

Some evidence exists in this area for sea level having once been lower than it is at present. In Dalgety Bay, tree stools standing in their position of growth are buried in the sand and shingle at 4.7 feet O.D. (F507) (R).

East of Aberdour, the 250 foot contour approaches the shore, and few terraces exist. About Burntisland, however, features at 66.2 to 68.1 (F52-55) (S) and 59.9 to 62.8 (F49-51) (T) occur. Burntisland appears to cover further terraces, whose altitude cannot now be determined. Allan and Knox (1934) note the belief that grassy links along the shore here once extended half a mile out to sea before the seventeenth century.

Along the coastline between Inverkeithing and Kinghorn there is thus considerable evidence for a marine level having attained circa 70 to 75 feet O.D. Little evidence exists for marine levels above this, while below this height there are occasional terraces, which may be marine.

The coast between Kinghorn and Kirkcaldy

At Kinghorn, the coastline turns abruptly northwards and is steep and rocky, with only a few vague terraces, all of which except one can be interpreted in terms of structure or soil creep. The exception is a terrace of sand and gravel at around 60 feet O.D., which is unfortunately partly buried by spoil heaps from Seafield Colliery. Just south of this terrace is a long cave (U) by the present shore at no more than 15 feet above high water mark. It was remarked upon by the writer of the Statistical Account for Kinghorn in 1794, who justifiably observed that it had been "excavated

by the sea, which has since retired".

Inland, between Kinghorn and Seafield, there occurs a multitude of glacial meltwater channels, the lowest member of which does not descend below circa 120 feet O.D. The lower channels clearly post-date some esker ridges in the area, through which they cut (V).

West of Kirkcaldy there are a number of long ridges of rock trending west-east with deep asymmetric valleys between, the southern sides of which are far steeper than the northern. This pattern has been accentuated by a system of meltwater channels. The channels are presumed to be of subglacial origin because of their sinuosity, irregular gradients and disregard for the regional ground slope. They enter the large asymmetric valleys as if the latter were an integral part of a subglacial meltwater channel system. Some of the valleys exceed 100 feet in depth, and one possesses a rock island in the centre (W). East of the village of Auchtertool the floor of a wide valley is filled with lake sediments (X), a section in which revealed:

4.	Mottled brown-grey clay	2'	3"
3.	Grey clay, with some vegetation		4"
2.	Vegetation layer, compressed		4"
1.	Blue-grey silt, some vegetation in the upper part	1'	9"

In 1896, Bennie described a similar section from lake deposits west of Auchtertool. His section showed:

5.	Soil	1'
4.	Brown earthy silt with	

	<u>Lepidurus (Apus) glacialis,</u> <u>Salix herbacea</u> and <u>Betula nana</u>	3'	
3	Marsh with <u>Lymnea,</u> <u>Pisidium</u>	1'	5"
2	Running sand or mud		4 - 5"
1	Boulder Clay		

The fauna and flora were that of an arctic climate, though Mitten (1896) in the same journal preferred sub-arctic. Duncan described a similar section by Loch Leven in 1925. The section described by Bennie is very similar to that described above, east of Auchtertool.

The valleys and channels lead eastwards to the site of Kirkcaldy, where it is likely that they distributed outwash material. In Abbots Hall park, by Raith Lake, one valley ends in a flattish area of sands and gravels (Y) lying at 117.8 to 121.2 (F61-64), declining away from the valley eastwards.

Kirkcaldy itself stands upon a number of terraces which were described by Chambers in 1848 before the town had spread so much as it has now. He recognised terraces at 25 feet "above sea level", in the centre of the town, 56 feet "above sea level" at Seafield in the south, and a "plain" 64 to 85 feet "above sea level" "behind the main street". There are several accounts of clay, probably marine, beneath the town. In 1858, a clay was worked for bricks at Tyrie (now covered by the spoil heaps of Seafield Colliery). Here, part of a seal skeleton was found 18 to 19 feet below the surface and 30 feet "above high water mark" according to Allman (1858). Later, a duck cranium was found at the same site. Walker (1863) believed this to have been of a species intermediate between Oidema fusca and Somateria mollissima. No suggestion has been made as to the climatic conditions

these fauna indicate. Allan and Knox (1934) refer to a fine clay near this district at least 20 feet thick, and similar deposits further north in the Linktown district.

The present investigation was naturally restricted by building. Road works in the town revealed considerable exposures of sand, while a deep section at one point showed upwards of 10 feet of stratified sand lying on top of blue-grey till. Recognition of terraces was confined to public parks. In Beveridge Park, a good terrace exists at 94.1 to 94.4 (F40-43) (Z). A slight step above it gave 102.6 to 113.6 (F44-48) (A), rising consistently towards the mouth of a valley. It is likely that this latter terrace is an outwash terrace. A section in the front of the lower terrace showed 10 feet of fine sand. In Ravenscraig Park, a terrace exists at 60.2 to 68.8 (F34-39) (B). Donner has measured this at 60.1 feet above the barnacle line, probably 65 to 70 feet above O.D. He has recognised a second terrace in this park, and measured it at 92.5 feet above the barnacle line. This terrace (C) is small and was considerably affected by constructional work when the writer visited it; it was not therefore measured.

The coast between Kinghorn and Kirkcaldy thus shows little evidence of sea level change compared with other areas of this study. However, since the lowest meltwater channel descends to about 120 feet O.D., this gives a maximum possible height for the sea at that locality after the retreat of the ice. Fragmentary features at circa 95 feet O.D. and 60 to 70 feet O.D. may have a marine origin.

Conclusion

From Inverkeithing to Kirkcaldy the landscape offers less opportunity

to decipher the late and post-glacial record. It is significant, however, that through a considerable part of the area one terrace stands out, as in the previous area. This time, however, it is lower, although its upper end (the western) accords in height with the lower end (the eastern) of the major terrace in the previous area.

General Conclusion

The sequence of events indicated by the glacial and marine forms of the area studied between Alloa and Kirkcaldy is as follows:

1. A large ice sheet moved eastwards across the whole area, forming widespread ice-moulded features.
2. The decay of this ice-sheet brought about the formation of large melt-water channels in the eastern part of the area, which finally operated as proglacial channels distributing outwash sands and gravels on the site of Kirkcaldy.
3. Continuing retreat westwards led to the formation of ice-marginal features at Crossford, near Dunfermline, and Broomhall, near Rosyth.
4. After further retreat, the ice readvanced about as far as the site of Kincardine.
5. During the ensuing retreat, a marked marine terrace was formed outside the ice front.
6. After the formation of this marine terrace, sea level fell as the ice retreated further.
7. During post-glacial time there may have been more than one sea level higher than now.

CHAPTER VII

THE COAST BETWEEN KIRKCALDY AND FIFE NESS

From Kirkcaldy to Fife Ness there is a greater variety and complexity of landforms than exist elsewhere on the northern side of the Forth. The Kirkcaldy-Fife Ness area has, however, received scant attention in the literature.

For the purposes of this account, the area is divided into three parts: the area between Kirkcaldy and Methil, including the lower Ore valley (shown in Figure 33); the Leven valley below Markinch and the coast of Largo Bay (Figure 34); and the coast from Drumeldie to Fife Ness (Figure 36).

THE AREA BETWEEN KIRKCALDY AND METHIL,
INCLUDING THE LOWER ORE VALLEY. (See Fig. 33)

This area is the least interesting of the three parts, for mining and urban development have considerably altered and obscured the ground surface. Moreover, along the coastal margin the longshore drift of waste material from St. Michael Colliery at East Wemyss has considerably prograded the shore and modified the present natural shore line.

1. Glacial Features

Inland in this area, results of mining subsidence are widespread, and in places the landscape takes on a most irregular form. Certain salient natural features may be recognised, however, and a sequence of glacial features interpreted.

The retreat of an ice sheet which once covered the whole area was marked by the development of glacial meltwater channels. These occur singly, are only rarely branched, and are aligned parallel to one another cutting across the lower, eastern ends of broad west-east ridges in the

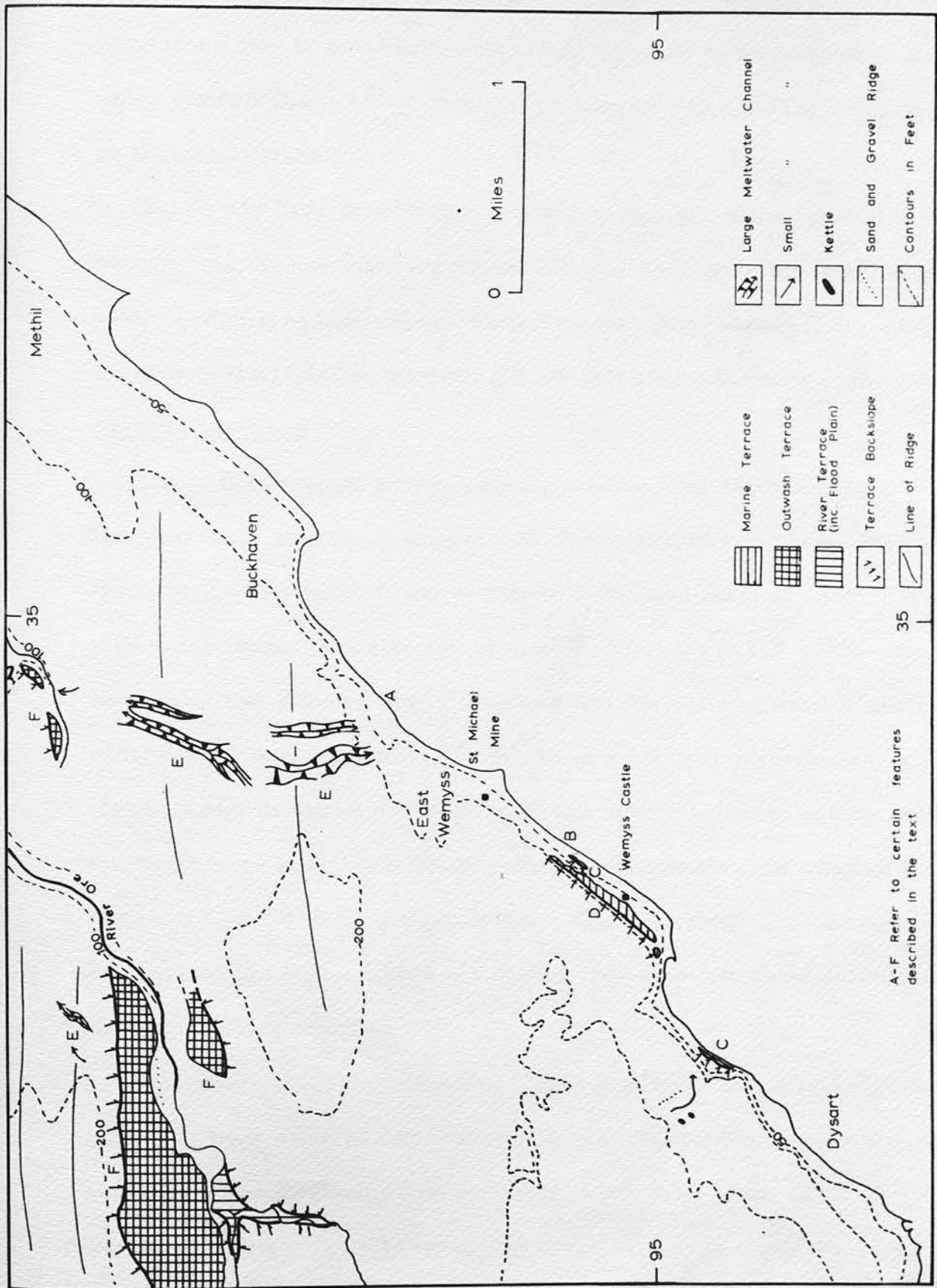


FIGURE 33 The principal glacial and post-glacial features on the coast between Kirkcaldy and Methil.

landscape north of East Wemyss (E). A satisfactory explanation for the phenomena may be found in the theory put forward by Price (1960), in which similar channels are formed by the superimposition of supraglacial or englacial streams.

There was little depositional activity on the part of sub-glacial meltwaters, and the subsequent withdrawal of the ice westwards left a generally featureless landscape. Near the river Ore, however, irregular spreads of fluvioglacial material (F) are probably glacial outwash.

2. Raised Shorelines

The best known and perhaps the most interesting feature of this area lies near East Wemyss. Here a sandstone sea cliff lying some distance back from the present reach of the waves, with its base about 15 to 20 feet above high water mark, is penetrated by a series of caves (A) (Fig. 33). In the New Statistical Account it was observed that the walls of some of the caves contained strange markings. These were more fully investigated by Simpson (1865), Edwards (1933) and Ritchie (1933), who were of the opinion that the markings were probably made by a Bronze Age people. Maclagan (1876) however, noticed Christian markings. Whatever their age, the caves show evidence of continuous human occupation over a considerable period, ending in the eighteenth century.

Else where along the coast line, other features suggest that high water mark was once some 20 feet higher. By Wemyss castle, a sea stack (B) now stands about 20 feet above the reach of the tide, while north of
 near
 Dysart and/Wemyss Castle small flat areas composed of rolled stones (C) lie just above high water mark. The impression gained from the stack, cliffs, and caves is that the sea remained at the higher level for a con-

siderable period of time.

Above these lower features there remains very little other evidence of changes in the level of land or sea, except possibly by Wemyss Castle. Here, a feature cut partly in rock (D), achieves a height of 79.6-82.9 (F56-F60). The feature, though conspicuous, is poor for measurement, since it is nowhere level, but has a considerable slope seaward from the inner margin.

THE LEVEN VALLEY BELOW MARKINCH AND
THE COAST OF LARGO BAY (see Fig. 34)

At the river Leven a remarkable change takes place in both the human and the physical landscape of Fife. The transition from the industrial complex of East Wemyss, Buckhaven, and Methil, to the more salubrious market town of Leven is no less abrupt than the change from the gently rolling landscape north of Kirkcaldy to the varied belt of fluvio-glacial forms stretching eastwards from Windygates round Largo Bay under the shadow of Largo Law. The wastage of a great ice sheet; the subsequent development of river terraces; and the relative movements of base level may all be examined here in intimate detail.

1. General description

Charlesworth (1926) said that the glacial forms of this area mark^{ed} the northern margin of a retreating lobe of ice occupying the Forth, while Allan and Knox (1934) suggested that a readvance of the ice occurred in the Leven valley depositing moraine upon "raised beach" deposits near Leven. In general terms the higher ground (in the context of this work, 150-300 feet O.D.) is furrowed by a series of meltwater channels running

eastwards and declining in that direction. Below these a complex mass of fluvioglacial deposits occurs, and still lower a number of terraces which may be marine in origin. In addition, the river Leven and its proglacial equivalent have formed a series of well defined terraces, mostly confined to the northern side of the present river. An important feature of the area is the relative absence of fluvioglacial features (except outwash terraces by the river) in the area west of Windy gates.

2. The Evolution of the glacial features

With the exception of some low kame ridges (A, Fig. 34) above 200 feet O. D. near Hatton and north of Durie House, cut through by meltwater channels, the earliest fluvioglacial features to form were the meltwater channels of the area east of Kennoway. None of the features contains a stream even remotely capable of having formed it, while most contain no running water at all. In addition, they pay no regard to the regional slope of the landscape, and their gradients are often reversed over short distances.

Certain features are characteristic of all the channels in this area, with the exception of the smaller chutes and tributaries and two channels at Windy gates. They all lead east or north east. Sinuosity is not an important feature, instead they are nearly straight. They appear mostly as single units, and are not united in complex systems. They are aligned parallel to one another down the slope. Any deviation from the main direction is followed by a rapid shallowing.

Examination of the individual characteristics emphasises further

similarities. The big channels on the slopes of Largo Law (B, C) cut across spurs and through rock. They begin as abruptly as they end, and C is in line with a smaller channel to the west (D). Their characteristics are those of channels formed by the superimposition of meltwater streams flowing upon or within an ice mass, let down by the downwasting of the ice, as envisaged by Price (1960). Near Blacketyside there exists a typical "in-and-out channel" (E); a curved up-and down- channel carved out of the hill slope. It is joined discordantly by two small channels on the northern side. Common (1957) and Sissons (1961) have suggested that channels of this nature were formed by meandering supraglacial or englacial streams cutting through the ice into the surface beneath. The suggestion accords very well with the evidence here. The channel at Cotton of Durie (F) and the big channel from Kennoway to Durie House (G) both begin in the west with tributary channels starting in large amphitheatres, probably formed by supraglacial or englacial streams descending in plunge pools through the ice on to the ground beneath. The Kennoway to Durie House channel possesses small sub-glacial chutes in the upper parts of its walls - small, streamless gullies descending obliquely to the contours. The smaller channel at Durie House is in part one-sided suggesting that part of it was once a truly marginal feature. The largest channel of the series (J) lies at Bankhead, and it attains nearly 100 feet in depth. Probably partly formed by^a superimposed supraglacial or englacial stream, it is followed in part by the Hatton Burn. In its lower end, a borehole put down for the Scottish Geological Survey revealed 26 feet of sands and gravels.

It is important to note that all the channels described may be satisfactorily explained in terms of supraglacial or englacial streams. In the east, on the slopes of Largo Law, superimposition was an important factor. In the west, near Kennoway, plunge-pool streams which ^{later} flowed subglacially were characteristic. This area, ~~however~~, shows none of the complex systems of channels described in certain other areas by Sissons (1958), ^{and} Price (1964).

When this latter fact is considered, together with the facts of alignment, parallelism, and relative straightness of the channels, it appears that there could have been some factor within the ice controlling the flow of meltwaters. It would seem that whatever factor has operated, it controlled the lowest level to which meltwaters could erode. This declined as the ice sheet melted, and meltwaters, working downwards, probably concentrated at the lowest possible level. Once a channel had been cut, it remained in use until the lower limit of meltwater flow had been so far lowered that the meltwaters passing along the channel were forced to seek a new route.

In this interpretation, the upper channels were thus formed first, and the lower ones later, in succession. The sub-glacial chutes along the sides of the Kennoway to Durie House channel suggest that after it had been mainly abandoned by meltwaters it was still covered by ice. Thus although it is possible that the channels were formed at no great distance from the ice margin, they were in no sense marginal. This scheme is not likely to hold for the channels on Largo Law, where superimpositions did not permit the migration downward, and underlying topography was a controlling factor.

It remains to suggest a cause for the restriction on the meltwaters. Clapperton (personal communication) has observed a similar pattern of meltwater channels in the Cheviot Hills; his explanation envisages a basal zone of tougher ice within the ice mass into which meltwaters could not penetrate, and that the shrinkage of this zone permitted this characteristic deployment of channels. This may well have been operative in the Forth area, but here it is also possible that sea level exerted a considerable influence on the water table within the ice, and that the height of the lowest channel in this area indicates a maximum for the sea level during its formation or since. The lowest channel is the one at Hatton, and it descends to 118.2 (F106), though several other channels reach almost as low as this.

As the ice retreated, extensive fluvioglacial deposits were laid down within and outside the ice. The deposition of these overlapped the time of formation of the channels, since some are related to the formation of upper channels and predate the lower channels in the series. At Drum-^reldie, 4 outwash terraces may be observed. The highest (K) lies between the two channels D and C and was probably formed by a marginal stream connecting the channels. The second (L) descends eastwards from 165.3 to 160.5 (F157-159) in 200 yards. The third (M) from 117.7 to 111.1 (F186-192) in 440 yards, and the fourth (N) from 93.1 to 88.3 (F211-217) in the same distance. All slope regularly. The last figure provides a maximum height for the sea level since the formation of the terrace, for it is difficult to see how a sea above this figure would not destroy the feature or bury it beneath deposits with a more uniform level.

"The 100-foot Raised Beach" cannot therefore exist here.

At Kirkton of Largo 4 (possibly 5) marginal outwash terraces exist, the uppermost (O) in association with channel B. A shallow extension of the channel cuts through the terrace at about 220 feet O.D., showing that there was still some meltwater flowing through the channel at this time. Below this terrace is one at 180 feet O.D. (P), on to which the channel leads. Below this are two fragments (Q) at 160-170 feet O.D. (163-163.4, F92-93). Lower still is a slight break in the landscape at circa 120 feet O.D. (R). Measurement was not carried out on all these features; the presence of ice in close proximity is attested to by sharp crested esker ridges (S) and two channels (T) directly below them at Lundin Mill. In addition, as already observed, the Hatton channel nearby descends to 118.2 feet O.D.

Within 2 miles to the east, extensive fluvioglacial deposits will be described later 70 feet below the level of the lowest terrace of this sequence.

Knox (1962) has suggested that "channels at Largo" were formed by water flowing alongside the ice, and that "associated flats" are evidence of sea levels at 140 and 190 feet O.D. It is supposed that he is referring to the sequence of forms at Kirkton of Largo and Drumeldie. His suggestion as to the origin of the channels has no support in the field. There are no ice-contact features on the lower sides of the channels. The channel at Kirkton of Largo (B) cuts across a spur leading from Largo Law in such a manner as to require the ice edge to rise up on top of the spur to maintain the channel in its position. This is not in conformity with observed positions of the ice margins in retreating large contemporary glaciers, where in general they follow the contours of the valley side.

Knox's suggestion that the terraces offer evidence of sea levels at 140 and 190 feet O.D. is similarly unsupported by evidence in the field. Channels (described above) and esker ridges lie below the terrace levels, and show that ice lay below the terraces. If, as seems likely, the terraces were formed at an ice margin, it is, in the opinion of the writer, more likely that they were formed by fluvial than by marine processes.

Near the mouth of the Hatton channel occur three well marked terraces. One (U), lying between 150 and 200 feet O.D. leads into a system of esker ridges below its level, and must therefore be considered to be ice marginal, very probably a kame terrace. A second (V), leading directly away from the channel, declines regularly from 144.3 to 141.0 (F101-105) in 100 yards. The short distance is limited by the extent of the terrace; it is believed that the association with a meltwater channel and the uniform slope are indicative of a small outwash feature. The third terrace (W) is most irregular and deeply kettled. A range in height from 136.6 to 133.0 (F107-111) was obtained, and it did not slope in a particular direction. However, a sharp-centred esker ridge (X) becomes flat and leads directly into the terrace from the west, while below the terrace several low esker ridges were mapped. It was thus certainly formed while ice lay about, and again a marine origin is not acceptable.

The retreat of the ice thus far was not marked by important proglacial activity on the part of the channels. Their inclination, generally parallel to the contours, would lead to abandonment by the ice along their length at a similar time. (This does not appear to have been the case with the channels west of Leven, however).

The largest channel in the area (G) is directly connected with a series of outwash deposits separated by deep dead ice hollows (Y) east of Coldstream. The various fragments decline in unison away from the mouth of the channel, where they achieve 132.0, to a level of 123.3 in the east. (F462-485). A steep ice-contact slope, and kettle holes in the terraces show that ice was about, and two eskers with sharp crests lie amongst the deposits, below their height. A peculiarity of this outwash is that it appears to flatten towards the east; the most easterly fragment (A1), gave most consistent heights at 123.0 to 123.5 over 200 yards (F474-480). It may be that this level was controlled by the sea level outside the ice edge, but with a lack of corroborative evidence in the area this can only remain a tentative suggestion.

Further retreat of the ice led to the abandonment of the large channel and the development of other channels lower and parallel. Eventually the channel at Cotton of Durie (F) functioned in part proglacially, and a limited spread of outwash gravels (B1) was formed at its mouth. This terrace feature attains a maximum height of 126.3 in the mouth of the channel, declining to 123.3 200 yards away (F124-129). This slope is not impressive, but the feature is limited in extent. Kettle holes and low esker ridges lie below this level both east and south of the feature, and establish that it was formed while ice lay around in quantity.

The Cotton of Durie channel was the last one of the series to operate, and after it had been abandoned, depositional activity took on a different form. The ice was now probably stagnant, and east of Windygates was broken up in large masses. Meltwaters in the area were no longer impeded

by a zone within the ice, and were governed only by gravity and the underlying ground surface.

Kennoway Den is a deep valley, running from Denhead, near Kennoway, south to Windygates. It is occupied by a small burn, the Kennoway Burn. From Denhead to north of Kennoway Burns it attains a depth of 75 feet and is markedly sinuous in plan. In cross section it is U-shaped through most of this part, and the present stream is too small to have eroded the valley with the present volume. When these facts are considered, and the observation that near Kennoway Burns two small sub-glacial meltwater channels lead into it is added, it seems highly likely that at least from Denhead to Kennoway Burns it functioned as an important sub-glacial meltwater channel. At Kennoway Burns, Duniface Hill, a long, narrow, steep-sided ridge of sands and gravels, slightly sinuous in plan, extends for half a mile with a short break as far as the banks of the river Leven. It would appear that this ridge is an esker, built by material passing along the meltwater channel. Along the western flank of the ridge the steep valley continues, accentuating the steepness of the ridge. Probably after the formation of the ridge, meltwaters continued to pass along this route.

A second ridge and channel to the west have an even more clear sub-glacial origin. At Lint Holes, two dry valleys originate in an impressive amphitheatre. One leads northwards, but is soon terminated by a later valley containing the Markinch Burn. The second leads southwards and has an irregular long profile. These thus appear to be meltwater channels formed by a supraglacial or englacial stream plunging down on to the ground beneath the ice. At Fernhill, the southern channel leads to a sharp

crested beaded ridge of sands and gravels (C1) ending at the river Leven. A kettle hole exists in its eastern flank. This ridge is probably an esker, fed by material passing along the channel. Subsequent to the formation of the esker, meltwaters carved a more shallow channel along its western flank, accentuating it. This channel is also dry.

After the formation of the first ridge, and probably the second one too, the previous drainage pattern was reasserted. Meltwaters issuing along the line of the present river Leven, along the northern channel at Lint Holes, and probably along the Denhead channel, poured eastwards, building out extensive outwash plains amongst the stagnant ice lying east of Duniface Hill. These meltwaters no doubt destroyed part of this esker, but left the centre portion intact. The northern outwash plain (D1) declines eastward from 135.8 to 123.5 (F375-384) in $\frac{1}{3}$ of a mile, ending in a mass of dead-ice topography, but probably continued by a small terrace (E1) near Banbeath, which declines from 120.0 to 114.2 (F. 329-320, F. 322) in 300 yards. The southern outwash plain (F1) declines eastward from 128.8 to 86.2 (F. 130, F. 119-121, F. 394-414) in 1 mile. Between these two features lies a mass of dead ice topography, with very extensive dead-ice hollows, ice contact slopes, conical kames, short esker ridges, and flat topped kames, the tops of the latter lying between 129.0 and 104.6 (F. 381-388).

After the formation of the southern outwash, a stream of meltwater flowing through the Kennoway Burns channel passed round the northern end of Duniface Hill and proceeding across or through a mass of dead ice immediately east of the hill, discharged across the southern outwash

plain. The evidence for this consists of a short dry channel round the northern end of the ridge, (G1), a deep dead ice hollow south of this, and further south a very fine sinuous dry valley (H1) cutting through the outwash to end in a terrace on the bank of the river Leven. At its terminal point the bottom of the channel is 89.8 (F.121). The terrace which it leads on to (J1) declines eastward from 90.6 to 89.1 (F.392-393) in 80 yards. The lowest point of the channel, 89.8 feet O.D., provides a maximum for the sea level both at the time it was formed and since.

Thus far the retreat of the ice sheet is well documented by the field evidence. Features are sharp and clear and a succession of events has been interpreted. The retreat has been followed in detail until the ice front lay at about Windygates, and streams of meltwater were pouring south along its face to join the major stream, the future river Leven, which was flowing eastward.

The ensuing retreat was of a different character. This was probably due to the ground surface. Between Windygates and Markinch the valley is divided into two troughs separated by a rock ridge. The southern trough contains the river Leven and its terraces, but the northern trough is almost completely enclosed, and is more like a huge elongate basin. This area is called "The Mires", for it is ill-drained, and has only a narrow (yet deep) outlet to the east.

Within this latter trough, fluvioglacial material occurs extensively, varying in component size from fine sand to cobbles, yet there are only a few features, and all of these are subdued in form and diminutive in size. A number of narrow terraces of sand and gravel, a few low esker ridges, some

kettle holes (none deep), and a short meltwater channel, were recognised. The most notable feature of this trough is a lake flat, lying in the centre at approximately 170 feet O. D., and only very slightly dissected. A section in this showed:

4	Soil	1' 7"
3	Grey clay with reed stems, some sand	1' 8"
2	Peat and clay, remains of birch	0' 7"
1	Fine grey sand	0' 2"

- a succession remarkably similar to that described earlier for the lake deposits west of Kirkcaldy and south-west of Dunfermline, and similar to that described by Bennie (1896) at Auchtertool in which he found arctic plant remains. The outlet to the lake lay in the east along the narrow valley described above.

After the ice front had retreated from Windygates, and the Lint Holes channel was abandoned, a large mass of ice lay in this depression. It is a matter of conjecture why no well formed glacial deposits were laid down in this area. It may be that much is concealed beneath the lake deposits. In any event, meltwaters from this ice were active in altering the topography to the east. The northern branch of the Lint Holes channel was destroyed, and Kennoway Den was either formed or merely deepened south of Kennoway Burns. A considerable volume of meltwater escaped south to join the central stream.

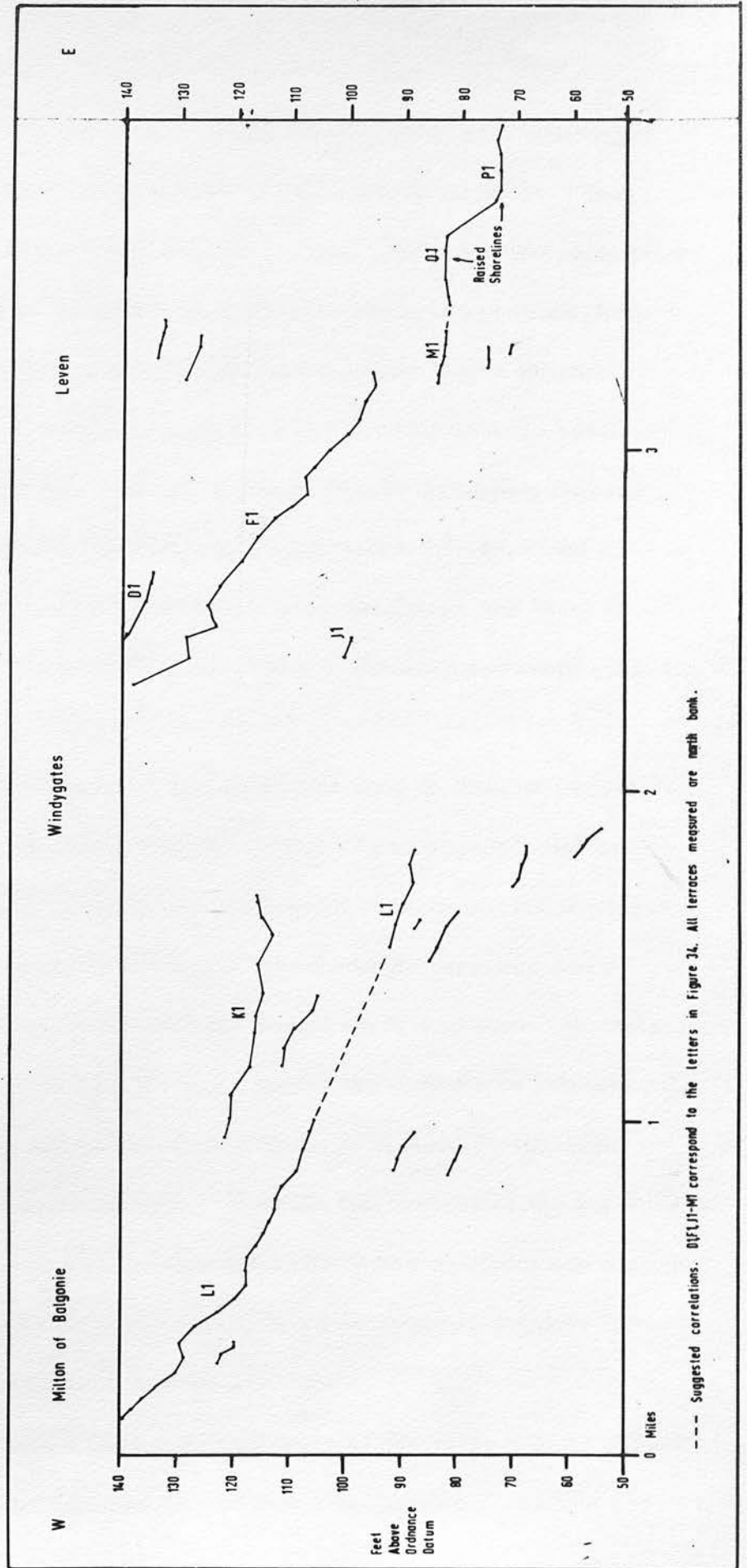
No vestige remains of retreat forms other than outwash in the Leven valley itself. A considerable volume of meltwater must have flowed through the narrow valley, carrying all before it. There is, however, a fine suite of

terraces, mostly confined to the north bank. A graph of the levelled heights of the terraces appears in Figure 35. Five terraces may be recognised, including the present flood plain, and the presence of other small fragments of terraces indicates that there have been more. The uppermost terrace at Windygates (K1) is probably an outwash feature. Its inclination is more gentle than the other terraces, descending eastward from 121.9 to 113.5 (F. 252-262) then rising slightly to 116.4 (F. 249), and this suggests that its origin is more complex. In fact, it ends in the east on the edge of the Lint Holes meltwater channel, and rises slightly towards this. This indicates that it was supplied in part along this channel. Probably the channel was functioning as a proglacial channel, carrying meltwater and materials / from "The Mires".

This cannot have been any more than a very ephemeral function, however, in view of the shallow nature of the channel at this point. It does suggest, though, that the terrace was formed while ice lay about.

The most extensive terrace of all is the highest one at Milton of Balgonie (L1), and it may be traced into the one at Greig Park, Windygates. This terrace is furrowed by a dry valley at Milton of Balgonie, and though its relationship with the end of the Lint Holes channel by Windygates is partially obscured, it may be that water was flowing in that channel during formation of the terrace. It is likely, but by no means proven, that this terrace was formed while ice lay around, and it is equally likely that it may be an outwash feature. The other terraces of the Leven in the section between Markinch and Windygates are more fragmentary but they do serve to indicate a falling base level, which must relate in some degree to a

FIGURE 35 Slope of the glacial outwash and river terraces in the Leven valley.



changing sea level.

East of Windygates terraces are poorly developed or else concealed in part beneath buildings. The terrace at 90.6 feet O. D. to 89.1 feet O. D. at the end of a channel has been described. This may be connected with a terrace at 74.6 to 70.6 (F 415-420) (M1) which is cut through by a small meltwater channel, now completely dry, near Haugh House. These fragments may in turn be linked with the outwash feature north of Windygates, (see Fig. 35). Each section in this series has a feature which suggests the presence of ice. Terraces at 65.6 to 65.2 and 61.6 to 61.1/feet O. D. near Haugh House may be tentatively correlated with the largest terrace and one other respectively, as shown in the accompanying diagram (Fig. 35).

The retreat of the ice sheet in this area was thus at first an orderly process. Meltwater channels, usually originating in supraglacial or englacial streams, were carved into the ground beneath the ice during the earliest recorded phase of retreat. Later, kame terraces were formed along the ice edge as the retreat progressed, and some channels operated proglacially. During the final stages the order was interrupted, and as the ice lay stagnant and separated in large masses, meltwaters created a different pattern of forms. Beneath the surface of the ice during all these periods secondary meltwater activity was creating a topography of smaller constructional forms. There is no evidence to support Knox's suggestion of a readvance near Leven.

The identification of the features and stages of the retreat has enabled certain figures to be obtained for the maximum height of the ensuing sea

level. At Drumeldie, 88.3 feet O.D. was obtained; at Hatton, 118.2 feet O.D.; at Duniface, 89.8 feet O.D. Other evidence will now be considered.

3. Raised Shorelines

North-west of Leven the largest dead-ice hollow in the area (N1) is bordered at its eastern end by a terrace of sand and gravel cut through by a dry channel (O1). Consistent heights were obtained throughout the length of this terrace, between 73.6 and 72.6 (F. 313-317). An outwash origin is therefore unlikely, and a main^re origin is possible. The terrace is succeeded by a lower one (P1) between 64.2 and 63.2 (F. 117-118; F. 306-309), but this feature has been modified in part by construction (R1) of playing fields and the heights may be too low. Both these features correspond well with the lower ends of Leven river terraces at 74.6-70.6 feet O.D. and 65.6-65.2 feet O.D. Further east, north-east of Leven, terraces occur at 66.3 to 67.1 (F. 434-5, F. 438-441) (Q1) and 69.7 to 73.7 (F. 436-437, F. 442-F. 444, F. 446-448, F. 452) (R1). The second terrace is associated with the presence of ice, a large dead-ice hollow occurring at the back of the terrace. It seems probable that these two latter terraces correlate with the ones at circa 73 feet O.D. and circa 64 feet O.D. above.

Just above the higher terrace in the last locality, a break occurs at 76.6 (F. 451), and east of the terrace, a most marked feature (S1) appears at 77.4 to 81.8 (F. 112-114; 455-461), or 77.4 to 75.3 if the last two readings which are of doubtful significance discounted. A third of a mile further east, at Lundin Mill, three flat areas occur around

75 feet O. D. (S1). The best feature of this series has a marked break of slope, and this was measured at 76.4 to 79.7 (F 96-100). It may correspond to the other feature described in this paragraph.

East of Lower Largo a marked feature (T1) stands out at 71.7 to 84.7 (F 667-673). This feature is composed of finer material than the others, and a section shows fine sand overlying blue clay. Near its western end an esker ridge (S) occurs, and this is composed of material far coarser than seen elsewhere in this area. It could be that this level was contemporary with an ice margin at this point, and its absence from areas further west could be explained by a fall in sea level during the further retreat of the ice.

At Drumeldie, below the lowest outwash, a level at 72.5 to 78.8 (F 224-227) (U1 Fig. 34, S2 Fig. 36) occurs, achieving 74.0 to 78.8 (F 215-221) in an almost enclosed embayment (T2, Fig. 36). Below this level, a marked terrace stands out at 48.5 to 51.9 (F 324-328) (V1, Fig. 34). The irregular surface of these features betrayed by the figures, is due to an uneven covering of blown sand. Its presence must throw some doubt on the height obtained for the features.

The most extensive terrace around the coast in this locality is the lowest one (W1). This is unfortunately covered entirely in blown sand, which does not, however, conceal its form. Measurements were very consistent, giving 28.8 to 30.5 (F 329-336), but sections showed a cover of about 3 feet of blown sand. Extensive sand dunes occur around the shores of Largo Bay, and all features some distance behind them are covered to some degree in blown sand.

4. Conclusion

Study of the fluvioglacial forms in the area of the Leven valley below Markinch and around the coast of Largo Bay has enabled the process of deglaciation to be followed in detail. Relative movements of sea level during and after deglaciation are not so well documented, however, and the heights obtained on the terraces that do exist show no correspondence outside limited areas.

THE COAST BETWEEN DRUMELDRIE AND FIFE NESS (See Fig. 36)

East of Drumeldrie the coastline swings southward as far as Elie before pursuing a north-eastward line to Fife Ness. At the same time the high ground recedes to the north. The broad expanse of land below 100 feet O. D. between Colinsburgh and Elie accommodates a continuation of the belt of fluvioglacial forms described in the previous section. Towards the east these forms gradually become more subdued until by Anstruther the landscape is one of gentle gradients and almost monotonous uniformity. Throughout this eastern area, from Anstruther to Fife Ness, the 250-foot contour lies three miles from the coastline, yet at the coastline the cliffs regularly attain 50 to 75 feet in height.

1. General Description

A considerable amount of detailed work was carried out by Brown, Bell, Bennie, and Etheridge during the nineteenth century on the marine fossiliferous clays at Elie. Otherwise little interest has been focussed on this area, though Charlesworth (1926) remarked that, as with the previous section, the proliferation of fluvioglacial forms marked the northern margin of a retreating glacier, adding that at St. Monance they merged with 'raised

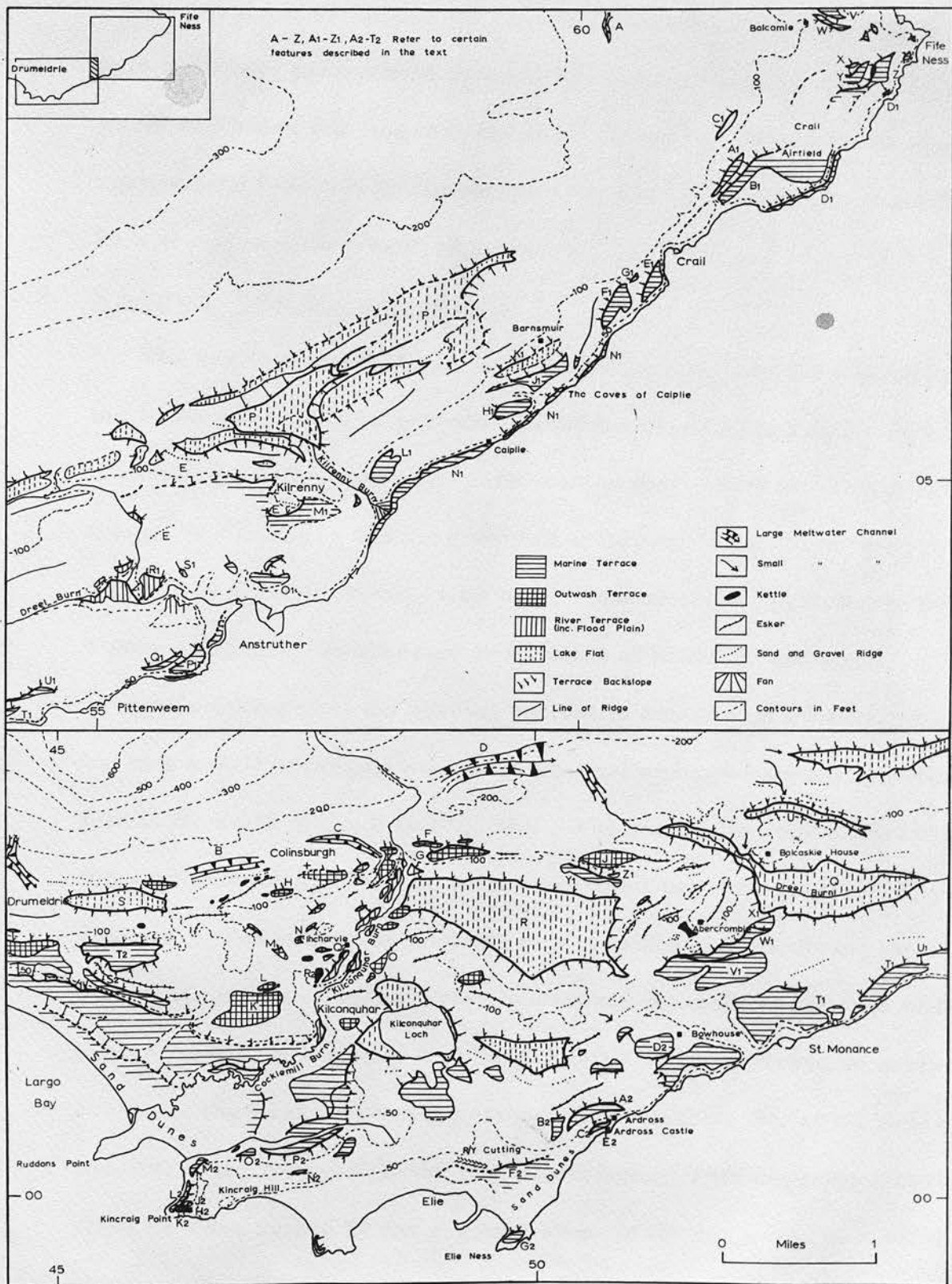


FIGURE 36 The principal glacial and post-glacial features on the coast between Drumeldrie and Fife Ness.

beaches," although he did not consider the area in any detail.

The grain of the landscape lies along a south-west to north-east axis. This is exemplified by many till and fluvioglacial ridges in the west, and broad till ridges in the east. Between these lie a number of ancient lake flats. Throughout the area the coastal margin is marked by a series of well developed terraces.

2. Evolution of the Glacial Features

The earliest traceable event is the movement of an ice sheet across the whole area. No longer confined by the steep slopes of Largo Law it radiated out eastwards and north-eastwards. This movement can be traced by till ridges and crag and tail features. The till of this ice sheet is of a brown colour, with many country rocks, principally limestone, and it may be observed in sections at Kilrenny and Crail.

Little evidence of the ensuing retreat is extant east of Anstruther, barring a well developed meltwater channel ending at approximately 150 feet O.D. north of Crail (A, Fig. 36). The picture is very different in the area west of Anstruther, where a distinct pattern of retreat may be deduced. The activity of meltwaters as erosional agents during the earlier stages of retreat is well attested by several channels at the edge of the higher ground, around 200 feet O.D. (B-D). These pursue an easterly course in the west, becoming north-easterly in the east, at all times parallel to the contours of the ground surface. This suggests that their streams were guided by the regional slope of the ice surface. All the channels are straight, beginning and ending abruptly, and they are not branched. These characteristics suggest superimposition from supra-

glacial or englacial streams, and hint at a similar control on the movement of meltwater within the ice as has been postulated for the previous area. Slight differences in the channels of the two areas have been observed. Those in the present area are generally less well formed, and two have short sections at their eastern ends leading down-slope in the manner of subglacial chutes. These differences do not affect the theory of origin.

The lowest channel (C) descends to circa 120 feet O.D. At this level the consistent southerly slope of the ground gives way to an undulating terrain. As the limit of meltwaters became lower, subglacial meltwater activity became more constructional, and numerous eskers and kames were formed. The eastward limit of these forms lies between St. Monance and Pittenweem; east of this occur only a few vague kames (E), at Kilrenny. In view of the fact that there is no change in the form of the ground, such as might explain the absence of fluvioglacial features, it is hard to avoid the conclusion that a retreat pause of some duration occurred in this neighbourhood.

Continuing retreat was marked by the development of successively lower kame terraces along the inland edge of the ice, particularly at Colinsburgh (F: 125.8-122.2 (F 688-691); G: 114.2-112.2 (F 692-695), H: 105.7-105.0 (F. 674-676)). Eventually the ice became disrupted, when large crevasses were filled up with fluvioglacial material. Near Balkaskie House a large flat-topped kame (J) has a height of 103.4-102.2 (F. 699-701), and is continued in the east by a sinuous esker ridge. Between Kilconquhar and Colinsburgh several similar features

occur, at noticeably accordant heights, declining in unison towards the east (K-O). The most westerly fragment (K) lies at 80.2-86.2 (F. 682-686), and the most easterly (O) lies at 73.1-79.6 (F. 720-723). The possible relationship of these features to sea levels outside the ice will be considered at length later.

As the ice withdrew, drainage had to begin anew the work of adjustment. In this part of Fife the retreat forms were very often created across or at an angle to the west-south-west to east-north-east pattern of advance. Consequently large bodies of water were held up by the deposits. Particularly extensive lakes were formed at Kilrenny (P), Pittenweem (Q), and near Colinsburgh (R); and lower ones near Drumeldie (S), east of Kilconquhar (T), and Balkaskie House (U). It is not known when the silting up process was completed, but it may have been at very different times depending upon the height of the outlet and the volume of the stream. Sections in the lake deposits show them to be composed of a blue clay, irrespective of the height. In the Pittenweem lake/^{deposit} a fortuitous section showed:

4. Clayey soil	1' 1"
3. Fine pure blue clay-silt	1' 7"
2. Hard red-brown layer	1' 2"
1. Grey sand with lenses of fine blue-green clay	1' 8"
Total seen	5' 6"

Layer 2 may be a hard pan, and is continuous throughout a/^{horizontal} distance of at least 300 yards. It is possible that it represents a time when there was no water over the deposit.

Measurements were carried out on several of the lake floors. The Kilrenny lake/^{floor}is much more dissected than the others, and is probably composed of several levels. Measurement of its shoreline gave heights of from 98.9 - 100.2 (F 17-21) in one place to 120.7 - 121.9 (F 22-26) at another locality. At Clephanton, the lake clays were once used for brick-making, and near here measurement gave 108.7 - 114.6 (F 27 - 33). The Pittenweem lake flat was measured at 65.1 - 55.4 (F 637 - 647). Here there is a consistent slope eastwards towards the outlet (see Fig. 37). This is probably due to a combination of silting up where the Dreel Burn enters the lake flat, and continuous downcutting where the burn leaves it. Thus the lake was never filled up to a common level.

3. Raised Shorelines

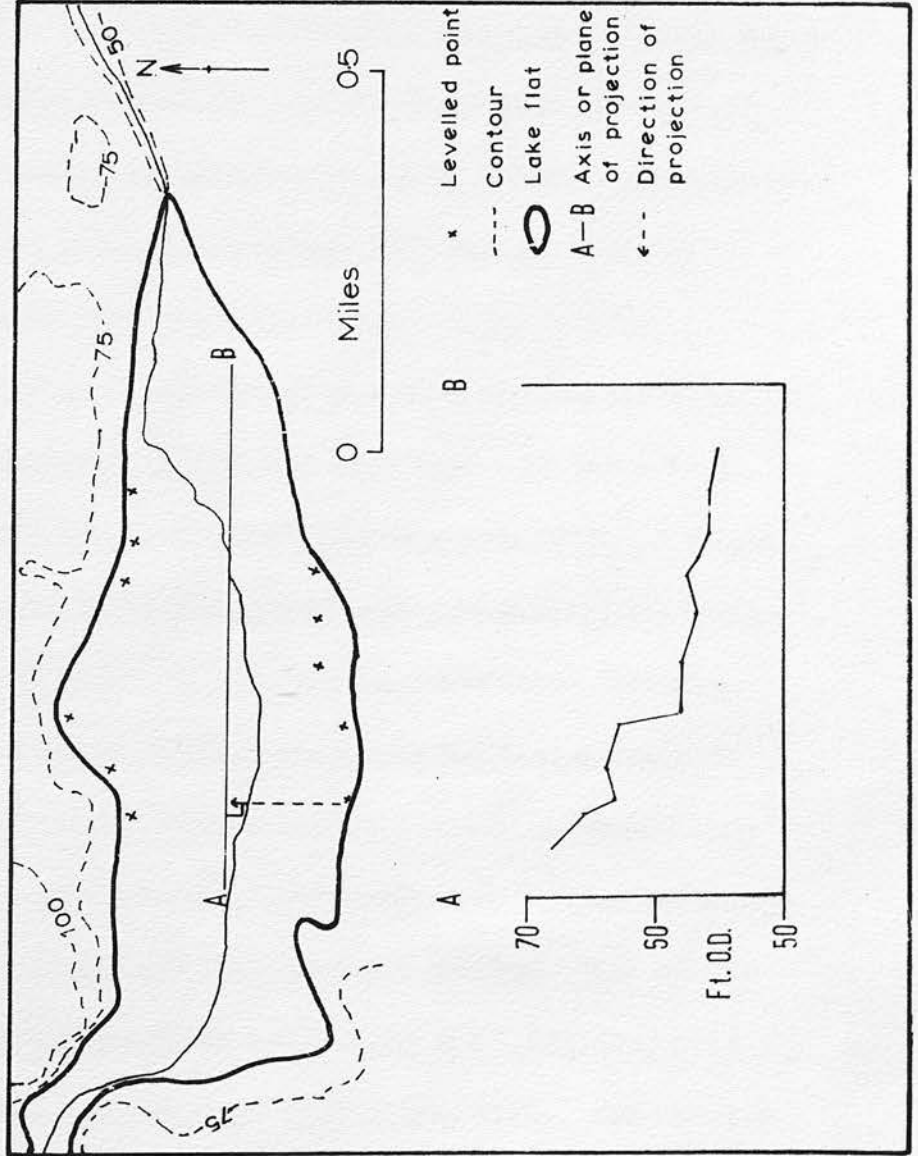
Numerous terrace features exist along the coastline of this area. Unless the contrary is specified, they are composed of sand and gravel.

(i) Fife Ness - Crail

The East Neuk of Fife is particularly rich in terraces. East of Balcomie, two terraces occur on the margin of the mapped area, at 53.5 - 56.2 (F 738 - 742) (V) and 58.9 - 61.9 (F 743 - 747) (W). South of Balcomie, three terraces are deployed in a "staircase" at 82.6 - 84.7 (F 537-539) (X), 75.7 - 77.8 (F 540 - 541, F 547) (Y), and 64.6 - 69.3 (F 542-546) (Z).

Crail airfield obscures a considerable portion of the landscape, but south of it two terraces occur near Crail, at 81.2 - 81.7 (F 193-196) (A1) and 72.8-73.4 (F 197-199) (B1). These

FIGURE 37 The inclination of a lake flat by Pittenweem.



are of a similar height to the upper two of the three south of Balcomie. Further inland, a feature at 111.8-113.6 (F 1-5) (C1) is noticeable.

Several instances (D1) of a terrace near present sea-level occur in this area, and numerous abandoned sea stacks stand along the coast, their bases at about 20 feet O.D. Though there is definite evidence here of a negative movement of sea level, measurements were not made since all the terraces were covered by landslips and slumping from the cliffs behind.

(ii) Crail - Anstruther

Immediately south of Crail, two well developed terraces fringe the coastline. One lies at 69.8 - 72.4 (F 548 - 552) (E1) and the other at 81.1 - 82.8 (F 554 - 559) (F1). A slight break occurs above the latter at 85.4 (F 560 - 561) (G1). South-east of these features, near Barnsmuir, are three terraces, one above the other. The middle one is the best developed. The lowest (H1) lies at 72.8 - 74.7 (F 572 - 576), though only F 572, 74.7, represents a true break-of-slope height, the others being taken on the terrace flat, to avoid gullies. The middle terrace was measured at 82.4 - 84.6 (F 562 - 571) (J1) over 500 yards. The upper feature (K1) is less clear, and the top-soil suggest a clay composition. It lies at 94.1 - 97.0 (F 578 - 587). Throughout the length of this feature there is a consistent drop to the east, of 4 feet or in 440 yards, or 16 feet in a mile. This is similar to the slope of the Pittenweem lake flat (Fig. 37).

It may be that it is a remnant of a marginal glacial lake.

East of Kilrenny there occurs a marked feature at 90.4-92.2 (F 202 - 207) (L1). West of the village there is a conspicuous break of slope at 89.1-94.3 (F 588 - 591) (M1). Although the figures given do not convey the impression of a consistent feature, the notch is such a marked feature as to convey an impression of importance. It continues past Anstruther to be lost in low kame-like mounds (composed of fluvioglacial material) north-west of the town.

The seaward margin of all these features is a steep cliff, only a little lower than the height of the lowest terrace. At its foot is a much lower terrace (N1), dramatically stressed by the cliff behind. Throughout its length occur sea stacks now removed from the sea, and at one place, Caplie, a natural arch with caves behind. Although, like the terrace east of Crail, there is little opportunity for accurate measurement since there is no clear break of slope on the terrace, levelling was carried out to see what kind of results could be obtained.

The Coves of Caipie (see Plate V) are a wellknown feature of the Fife coast. They consist of a limestone headland projecting from the main cliff line across the terrace which lies at its foot. There is an arch at the end of the headland and caves where it joins the main cliff line. It was described in both Statistical Accounts. Maclagan (1875) observed that the cave contained^{ed} similar carvings to those at Wemyss, so it appears that a similar people inhabited it.

Levelling showed the entrance to the cave to lie at 28.1 (F 134), and points at the base of the arch to be 20.4 - 21.3 (F 135 - 136, F 138). More relevant than these heights which are probably dependent upon rock structure, were two small terrace features, entirely constructional, south of the coves. The upper one gave 24.9-25.4 (F 139 - 140), and the lower 17.4-20.0 (F 144-147).

More important than Caipie Coves is the long stretch of raised shoreline near the mouth of Kilrenny Burn. Measurements here upon a terrace composed of 4 to 5 feet of sand underlain by limestone gave 15.0-16.9 (F 10-16). More weight is attached to these measurements than to those at Caipie, but caution is necessary since blown sand is present in places.

(iii) Anstruther - Elie

Much of Anstruther stands upon a well-marked terrace, somewhat modified by building and levelling for playing fields. Heights taken on this feature (O1) were necessarily affected by this, and gave a large range, of 54.6-58.4 (F 620-622). South of the town, a similar terrace on the golf course (P1) gave 55.4 - 56.1 (F 616-619). Above this lies a less well marked feature, at 71.3 - 74.3 (F 611-615). North of these, the valley of the Dreel Burn contains some poor terraces the best of which gave 50.0 - 53.5 (F 592 - 598) (R1) and 59.5 (F 599) (S1). Whether the last relates to the terrace of a similar height in Anstruther must remain a matter of conjecture in the absence

of further evidence.

South-east of Pittenweem, two terraces occur at 66.3-68.2 (F 600 - 603) (T1) and 81.2-82.5 (F 604 - 609) (U1). The first terrace is however somewhat affected by mining subsidence. It continues through St. Monance but then becomes too affected by subsidence for measurement to be of value.

Inland from St. Monance, near Abercrombie, there are two terraces, the lower one composed of clay and almost merging with the upper. They lie at 72.8-84.0 (F 623 - 626) (V1) and 76.8-79.8 (F 627 - 632) (W1). A smaller feature above the second lies at 81.8-84.5 (F 634 - 636) (X1). Further inland still, the Colinsburgh lake flat has a conspicuous break above it around its northern margin. This was measured at 75.2-76.9 (F 702 - 707) (Y1), with a slight break above at 88.7 (F 708) (Z1).

From St. Monance to Elie terrace features are almost continuous, but a marked break of slope occurs only at Ardross where three features were measured, one above the other. The middle feature (A2) is the best, at 64.4-69.8 (F 177 - 183), or 66.8-69.8 if one is omitted. Above this two points on a small terrace (B2) gave 75.9-78.5 (F 184 - 185), while below it a feature which may have been formed by human agency (C2) lies at 43.6-45.7 (F 167 - 170), near Ardross Castle. Measurements on a flat topped feature by Bowhouse (D2) gave 59.7-62.8 (F 648-651).

Below these forms lies a feature remarked upon by Wood in

1863. This is a small terrace (E2) composed of layers of beach sand and shells covered by 5 feet of blown sand. The surface of the blown sand lies at 26.4-27.5 (F 175 - 176), but the top of the beach sand and shell layers, measured in a section at the front of the terrace is 21.0 (F 173). The latter measurement probably relates more accurately to the former sea level.

(iv) Elie - Drumeldie

In terms of possible raised shoreline features, this part of the coastline is at the same time the most interesting and the most complex. Although the widespread presence of blown sand presents a real difficulty in recognition and relevant measurement, certain salient points appear.

On the eastern periphery of Elie, a clear break of slope (F2) runs parallel to the road over a distance of a third of a mile. For part of its length blown sand is evident on the surface, but for some distance this is not the case. Here, measurement gave 30.3-33.8 (F 654-659). South of this point, on Elie Ness, a break similarly distorted by blown sand (G2) gave 36.1-38.6 (F 151 - 155). At one point, a rock platform protrudes from beneath this; it was measured at 33.8 (F 156) at its inner margin.

West of Elie, blown sand is very much in evidence, yet on Kincaraig Hill occur several features not affected by it (see Plate VI). These benches on Kincaraig Point are among the best-known features in Scotland, and have long figured in the literature. Wood described them in 1887, identifying three levels and assigning them

to heights of 25 foot, 75 foot and 100 foot. Geikie acknowledged them in 1902, preferring "25-foot", "50-foot" and "100-foot" "raised beaches".

All recognisable features were levelled. Prior examination showed them to be primarily rock-cut features, veneered with beach sand. The lowest is covered in an assortment of sand and broken shells. The three steps of the popular conception are in reality four. Their heights are as follows: 80.2-80.5 (F 70-71) (H2), 71.9 (F 68-69) (J2), 36.9-38.1 (F 72-75) (K2), and 12.0-13.2 (F 76-80) (L2). These heights show that no validity can be attached to such terms as "25-foot", "50-foot", "75-foot" or "100-foot". The term "raised beach" is seen at its most inappropriate in these essentially rock-cut features.

Far better developed features are seen at other points on Kincaig Hill. The most outstanding example (M2) lies immediately north-east of the features just described. Here a terrace (see Plate VII) was measured at 34.6-34.9 (F 82-86) - a range of 0.3 of a foot in five readings over 200 yards. Further east lie two less marked terraces, at 81.5-84.3 (F 65-67) (N2) and 36.5-38.9 (F 87-89) (O2), but below these is a remarkably consistent feature (P2) at 20.4-22.25 (F 160-166). The last two readings (F 165, 166) are probably influenced by stream deposits; if they are omitted the result is 20.4-20.9. Westward of these features, blown sand and dunes cover the coastal margin.

The area shows an interesting relationship between ice and possible raised shorelines. At Incharvie, near Kilconquhar, lie a number of kettle holes. Attention was focussed on the two lowest ones, since, as Bremner has said (1925), the height of the lowest kettle hole in a coastal area fixes an upper limit for any high sea level after the ice has melted. Both the kettles are bordered on one side by a terrace of the Kilconquhar Burn. The lip of one (Q2) lies at 56.6 (F 711), and the other (R2) is at 55.3 (F 717). The centre of the second descends to 46.8 (F 719). It would thus appear that any raised shoreline in the area above 55.3 feet O.D. must have been formed while ice still lay here.

Kilconquhar Loch might itself be a kettle hole of considerable proportions, but evidence for this is wanting. It is probably more likely that the loch was formed by an accumulation of blown sand across its western end. Tradition supports this. The Statistical Account recalls the belief that the loch was formed in 1624 or 1625, when the drain to a patch of low-lying land was filled in by sand driven by "a violent gust of wind from the sea", so forming the loch. The loch is shallow and its water level lies at 55 feet O.D.

An examination of investigations carried out during the nineteenth century in this area indicates the succession of formation of some of the terraces, and in particular the climate during the formation of one.

In 1830, Fleming described a "submarine forest" in Largo Bay. Underneath the beach sand, and lying rooted in a bed of

clay, lay tree stools and other vegetation. In 1835, Hamilton observed layers of marine shells 5 to 14 feet above high water mark on Ruddons Point, west of Kincaig Point.

Subsequent investigations revealed the relationship between these deposits. In 1867, Brown observed that sections at Elie and along the Cocklemill Burn showed

- 4 Blown Sand
- 3 Sand, shingle, and shells
- 2 Peat
- 1 Clay with shells, no signs of disturbance.

(Though layers 3 and 4 were not always distinct, and layer 2 was missing in one locality). The basal clay contained arctic shells, but above the peat the shells were all of temperate species. In the basal clay, Brown recognised:

<u>Natica groenlandica</u>	<u>Astarte compressa</u>
<u>Turritella erosa (polaris)</u>	<u>Nucula inflata</u>
<u>Pecten groenlandicus</u>	<u>Thracia sp.</u>
<u>Crenella decussata</u>	<u>Saxicava rugosa</u>
<u>Crenella nigra</u>	<u>Fusus sp.</u>
<u>Leda (Yoldia) truncata</u>	<u>Pleurotoma sp.</u>
<u>Leda (Yoldia) minuta</u>	<u>Tellina proxima</u>
<u>Yoldia sp</u>	

- all diagnostic of an arctic habitat according to Brown. Later investigations by Etheridge (1881), Bell (1890, 1891), Bennie and Scott (1893) confirmed these observations. The sections

thus represent the following succession of events:

1. An arctic sea, with an abundant fauna.
2. A positive movement of base-level, elevating the arctic clays and shells.
3. Growth of vegetation upon the land surface.
4. A negative movement of base-level and subsequent deposition of shallow marine deposits with a fauna similar to the present day.
5. A second positive movement of base-level, elevating the deposits to their present altitude.

Thus a similar succession of events to that in the upper Forth valley is recorded here.

None of the observers attempted to record or correlate the altitude of the deposits, and as the sections are now no longer available it is only possible to make a general estimation. It is likely that none of the sections lay above 50 feet O.D. The highest one was that revealed in the railway cutting behind Elie, (see Fig. 36), probably just below 50 feet O.D. The lowest one lay on the banks of the Cocklemill Burn, its top at about 25 feet O.D. No more positive statement may be made. It is possible, however, that the arctic clay could be a deposit of the same level which formed the 35-40 feet O.D. feature so marked in this area for the following reasons:

1. The height of this terrace is about the maximum height of the arctic marine clay, and where the clay reaches this

height it is not covered by layer 3.

2. The clay possesses an abundant fauna. It is therefore unlikely to have been laid down in the immediate vicinity of ice. The next terrace above the 35-40 foot one is at area 70 feet O.D., and it, together with all other high terraces, was formed while ice lay in the area between Kilconquhar and Colinsburgh (vide the kettle holes).

3. The terraces below the 35-40 foot terrace all lie well below the limit of the arctic clay; the highest does not exceed 22.5 feet O.D.

4. Conclusion

In the area west of Anstruther, deglaciation followed a similar pattern to that in the previous area. East of Anstruther, however, there is little evidence of deglaciation, and because of this it has been suggested that a retreat pause of some duration occurred near the site of Anstruther.

As the ice retreated the sea invaded the land below 75-90 feet O.D., and marine features were formed, at first while ice still lay around. Base level fell, and by the time ice had melted out from a kettle hole at Incharvie, was not higher than 55.3 feet O.D. in that area. Eventually base level was stabilised and a well marked feature was formed around 35-40 feet O.D. in the neighbourhood of Elie. Previous investigations show that subsequently base level fell further, then rose again to form a terrace at circa 20 feet O.D., which was revealed during a following regression of the sea.

GENERAL CONCLUSION

Retreat phases of the last ice sheet to cover this area have been described. Charlesworth's conception of a retreating ice lobe giving rise to multifarious fluvio-glacial forms within its northern margin is upheld, but attention has been drawn to the striking absence of these forms east of Anstruther and west of Windygates. In the latter place this may be explained by topography, but in the absence of a similar condition obtaining in the former area, a prolonged halt of the ice there is suggested.

All along the coastline as far west as Leven many non-fluvial and non-fluvio-glacial terraces occur, but a correspondence in height can only be achieved within limited areas. The presence of low kettle holes in the Kilconquhar area indicates that if the terraces are marine, those above 55.3 feet O.D. in that area must have been formed in the presence of ice. The fine development of terraces along the coast from Elie to Fife Ness has been described.



PLATE V

The Coves of Caplie, seen from
the west.



PLATE VI Kincaig Point, from the south-west.



FIGURE VII The inner margin of the Kincaig Point 35 floor terrace, showing the point of measurement.

CHAPTER VIII

CONCLUSION TO PART I

In the preceding regional accounts, evidence has been accumulated which supports in general the pattern of glacial retreat stages in the Forth area established by Charlesworth (1926, 1955), Simpson (1933) and Sissons (1963a, 1964): the retreat of the ice sheet which once covered the whole area was interrupted by two important readvances, which extended to the sites of Kin-cardine and the Lake of Menteith respectively.

In addition, the character of the retreat and the readvances has been described, while numerous marine terraces, remnants of raised shorelines, have been investigated. The general points to emerge from this regional investigation are as follows:

1. Aberfoyle - Stirling

West of Stirling the forms of glacial retreat are particularly well preserved in the Teith valley, where a complex of outwash deposits has been described. Near the head of the Forth valley, the deposits of the second major readvance, the Loch Lomond Readvance, occur. The assemblage of deposits in this latter area is however more complex than previous observers had indicated, and it seems that the second readvance intruded amongst deposits left during the retreat of the first.

Sea level change in the Aberfoyle-Stirling area appears to have been less radical than elsewhere, for the highest possible marine terraces occur at 65-70 feet O. D. in scattered localities along the fringe of the carse. These were probably associated with the retreat of the Perth Readvance. Investigations have shown that during the Loch Lomond Readvance, sea

level was low, but that a transgression occurred either towards the end of the readvance or during the early post-glacial period. This transgression left a deposit of fine grey sand, which occurs widely beneath the carse.

The pattern of more recent sea level change in the Aberfoyle-Stirling area as revealed by this investigation closely follows that shown by Jamieson in 1865. The sea of the transgression receded, and peat grew upon the surface of the deposits revealed. Later the sea rose and deposited the carse-lands, on the surface of which great peat mosses grew when the sea receded again. Levelling suggests in addition that the carse in this area slopes up towards the west, and may, like that east of Stirling, have been the product of more than one sea level.

2. Stirling - Alloa

In the Devon valley two notable ice limits have been described and correlated with the readvance at Kincardine. The second limit is associated with a pro-glacial lake which lasted for at least 52 years. As the ice retreated back from the second limit, extensive outwash deposits were formed at Airthrey, near Stirling. From Stirling to Alloa the carse-lands are extensive, and levelling has shown that they are the product of more than one sea level. A buried marine surface has been identified beneath the higher carse level.

3. Alloa - Kirkcaldy

Between Alloa and Kirkcaldy the area contains less evidence of glacial retreat, but strong suggestions of glacial readvance. A major resurgence of the ice sheet probably took place, reaching a limit fractionally east of

Kincardine. This is correlated with the Perth Readvance. It was associated with a transgression which formed a marked shoreline.

4. Kirkcaldy - Fife Ness

The retreat of the last ice sheet to cover the Kirkcaldy-Fife Ness area left many traces between Leven and Anstruther, where a detailed story may be interpreted. The absence of retreat forms east of Anstruther, despite a basically similar pre-retreat landscape, is interpreted as evidence of a prolonged halt of the ice near the site of that town.

As the ice retreated the sea invaded the land up to about 70-90 feet O.D. and numerous marine terraces were deposited, many in association with bodies of dead ice. Away from the coastal margin, bodies of water, impounded by the irregular landscape of glacial forms, gradually silted up.

In addition to discovering certain features of the late-and post-glacial history of the area, and clarifying others, the results of this regional investigation permit certain observations to be made on the results of previous investigations. In essence, the writer has been unable to identify the patterns of raised shorelines or "raised beaches" usually quoted for the area. In fact, evidence has been produced questioning the origin and development of many of the principal features formerly quoted in support of the established schemes of raised shorelines in the area:

1. In 1902, Geikie described the marine benches on Kinraig Point as being three in number, evidence of "The 25-foot Raised Beach", "The 50-foot Raised Beach" and "The 100-foot Raised Beach". Observation made by the writer have shown that the features are not "beaches", but are rock-cut, and that there are four, not three. Moreover their heights are not 25, 50, and 100-foot, but 12-13 feet

O. D., 37-38 feet O. D., 72 feet O. D., and 80-81 feet O. D.

2. The writer has studied Peach's (1914) map of the upper Forth area. On it large areas of "The 100-foot Raised Beach" are marked at the western end of the Lake of Menteith and near Blairdrummond. These features have been shown by the writer to be glacial outwash. Dinham and Haldane (1932) state that the information gained by Peach was used in part in their memoir. How far Peach's erroneous observations have contributed to the recognition in the memoir of "The 100-foot Raised Beach" in the area is not known.
3. In 1927, Dinham stated that the highest area of "The 100-foot Raised Beach" lay at Airthrey, where its height was 145 feet O. D. This investigation has shown that the feature in question is an outwash plain, and that Dinham's figure bears no definite relationship to any former sea level.
4. Dinham and Haldane (1932) described the well known red or brown clay found east of Stirling as a deposit of "The 100-foot Raised Beach". They also described the fans on the southern edge of the Ochils as deposits of "The 100-foot Raised Beach". Borings have shown that the two deposits are not contemporaneous, and that the fans succeed the red or brown clay.
5. In accordance with the general opinion that "The 100-foot Raised Beach" was well developed, but that "The 75-foot Raised Beach" was less clear, Allan and Knox (1934) described the terraces near these heights at Inverkeithing and Aberdour in similar terms. Observations made by the writer show that in fact the "75 foot" feature is the best developed.
6. Movius (1942) and Lacaille (1950) believed the terrace at Doune to be

the highest point of "a 100-foot raised beach" in Scotland. This investigation has shown that the terrace in question is an outwash terrace.

7. Earp, Francis, and Read (1962) have described the carse surface as flat, showing no change in height along a west-east line. Levelling has shown it to be sloping up towards the west.
8. A measurement used by Donner (1963) in calculating isobases for "The 100-foot Raised Beach" in the Forth area has been shown by levelling to have been more than 30 feet in error.

In Chapter III, the accuracy of the methods of previous investigations was criticised. It is felt that such inaccuracies as are quoted here substantiate that criticism. It follows that the schemes of three or four horizontal or tilted raised shorelines throughout the Forth area can only have any truth by coincidence.

Yet it is certain that a considerable displacement of shorelines has occurred in the Forth area during late- and post-glacial time.