DOCTOR OF PHILOSOPHY

Raised shorelines and the ice limits in the inner Moray Firth and Loch Ness areas, Scotland

Firth, C.R.

Award date:
1984

Awarding institution:
Coventry University

RAISED SHORELINES AND ICE LIMITS IN THE INNER MORAY FIRTH AND LOCH NESS AREAS, SCOTLAND

by

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A thesis submitted to the C.N.A.A. in partial fulfilment

of the requirements for the degree of Ph.D.

Coventry (Lanchester) Polytechnic, Department of Geography

October 1984

ABSTRACT

RAISED SHORELINES AND ICE LIMITS IN THE INNER MORAY FIRTH AND LOCH NESS AREAS, SCOTLAND

C.R. FIRTH Ph.D. THESIS

This thesis provides an assessment of the changes in relative sea level during the Lateglacial and Flandrian in the inner Moray Firth and Loch Ness areas.

All identifiable marine, fluvial and glacial features and deposits below 100m O.D. were examined by detailed morphological mapping; and all terrace fragments were accurately levelled. Local sequences of relative sea level movements and deglaciation events are outlined. Correlation of shoreline fragments is aided by height-distance diagrams.

In the inner Moray Firth area 10 raised marine shorelines related to the deglaciation of the Late Devensian ice sheet are recognised. Each shoreline declines in altitude towards N25 E. The sequence of shorelines indicates that during deglaciation relative sea level fell. Deglaciation occurred rapidly in the deep water channels of the Moray, Inverness, Beauly and Cromarty Firths, whilst in the narrow valleys (Ness, Conon, Orrin, Glass) limited ice wastage was associated with substantial falls in relative sea level of at least 19m at Inverness, 13m at Balblair and 6m at Muir of Ord.

During the Loch Lomond Stadial relative sea level remained stable in the area and extensive marine erosion formed the Main Lateglacial Shoreline. Advance of ice during this period initiated a lacustrine transgression in Loch Ness. Subsequently, during ice decay, the drainage of the ice-dammed lake in Glens Spean and Roy temporarily raised the level of Loch Ness by circa 4m.

During the Flandrian, an initial fall in relative sea level was replaced by a rise which culminated in the formation of the highest Flandrian shoreline at 9m O.D. Subsequently relative sea level fell towards present level forming 5 successively lower shorelines.

Correlation of Lateglacial and Flandrian shoreline sequences with those in other areas of Scotland is attempted. The implications of the shoreline sequence to glacio-isostatic movements is also evaluated.

DECLARATION

This thesis is the result of my own work. Data from other authors which are referred to in the text are acknowledged at the appropriate point in the text.

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ACKNOWLEDGEMENTS

Firstly, I would like to acknowledge the receipt of the 3 year research grant from the National Environment Research Council.

I wish to express my sincere thanks to Dr. D.E. Smith and Dr. A.G. Dawson, my joint supervisors, for all the advice and criticism they have given to me in all aspects of this work and also for their patience during the preparation of this thesis. Thanks are also given to the other members of the Geography Department for their encouragement and interesting discussions. I am also grateful to Mrs.J. Summers and Mrs.J. James for taking such care with the typing.

I would also like to acknowledge the assistance in the field and express my sincere thanks to Mr. I.R. Firth, Mr. L. Firth, Mr. G. Elliot, Miss F. Little, Miss G. Miles, Mr. T. Skippins and Mr. J. Westlake. I also acknowledge the numerous landowners who granted access to their land.

Finally, I would like to thank Rick, Dawn, Ash and Jane for their continued support and encouragement.

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CHAPTER ONE

INTRODUCTION

It has long been noted that Scotland has experienced widespread changes in relative sea level (eg. Sibbald, 1707; Nimmo, 1777; Blackadder, 1824) but it was Jamieson (1865) who first proposed that many if not all of these changes resulted from glacio-isostasy (although he never used the term in his publications). Since that time isostatic movements in Scotland have become a major focus of interest. Despite the implications of Jamieson's work, however, most studies of raised shorelines in Scotland continued to propose a series of raised horizontal levels, usually at 25 ft (7.6 m), 50 ft (15.2 m) and 100 ft (30.5 m), even up to the early 1960's.

The revolution in Scottish shoreline studies occurred when Sissons (1962, 1963a) demonstrated that horizontal levels are unlikely to exist in an isostatically affected area, and many studies followed which substantiated his views. The detailed research carried out by Sissons and his co-workers in different areas of Scotland has demonstrated the complexity of the shoreline sequence, notably where shorelines occur in association with ice decay. As local studies have been completed so correlation has become possible between different areas of Scotland (eg. Cullingford and Smith, 1980; Sutherland, 1981b) and it has sometimes been possible to set deglacial events into a regional context (Dawson, 1982). However most studies have been in south east and western Scotland, and few detailed studies are available for other areas.

2. The Study Area

The Inner Moray Firth is one area where detailed information on relative sea level change is lacking. Although several authors have remarked upon the clarity of the shoreline evidence (eg. Horne and

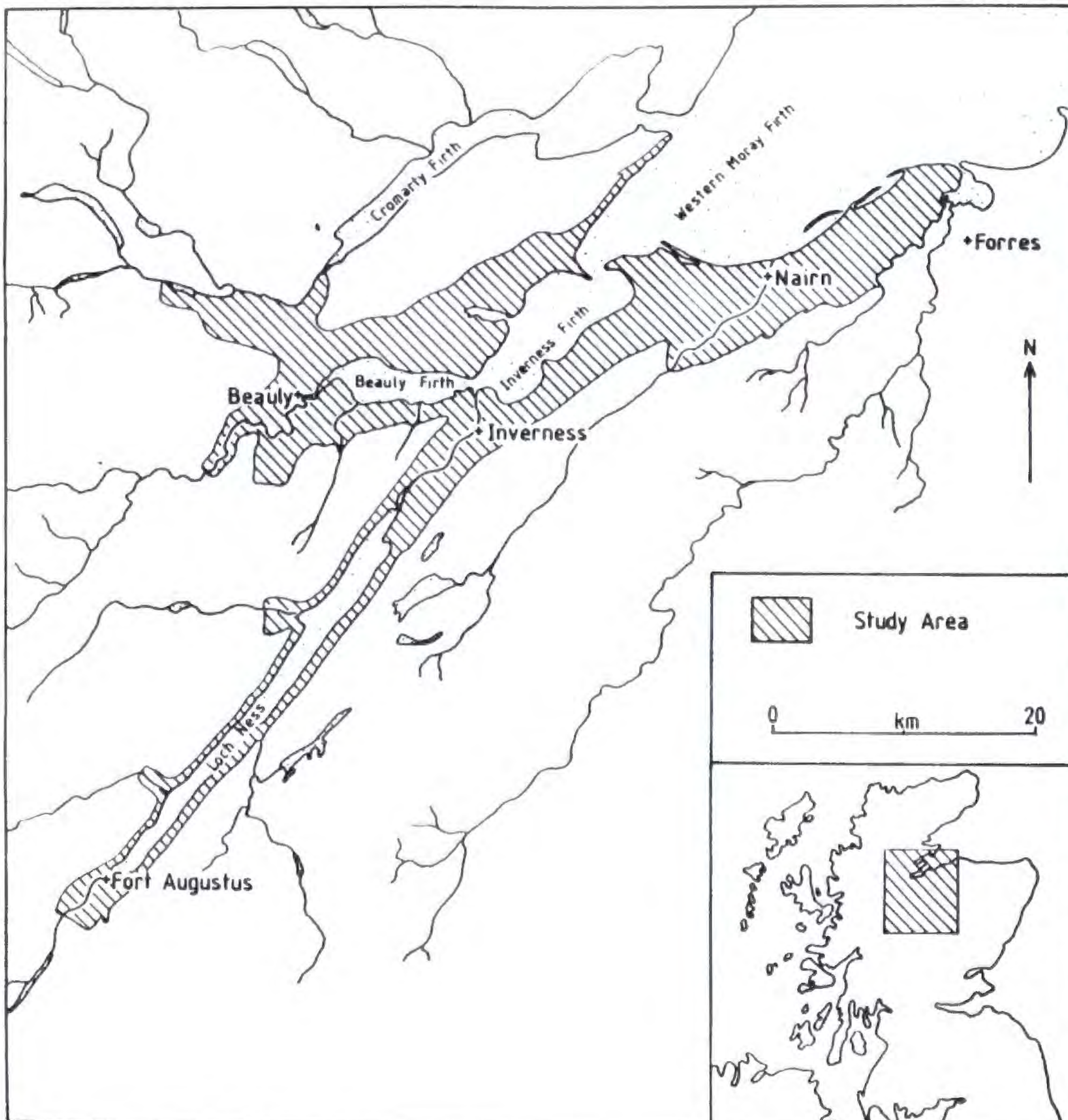


FIGURE 1 The study area.

Hinxman, 1914; Ogilvie, 1923), and a number of local studies have been undertaken (eg. Synge, 1977a; Sissons, 1981b; Haggart, 1982) no detailed study of the area as a whole has been undertaken. This account attempts to remedy these deficiencies. The area of study comprises the Inner Moray Firth (Beauly, Inverness and Western Moray Firths and the lower Conon valley) and Loch Ness (Figs. 1 and 3). In the east the limit of the area is defined by Muckle Burn and in the west by the valleys of Strath Conon and Strath Glass. In the north the boundary of the study area is defined as the river Conon whilst in the south it is located just south of Fort Augustus.

3. Objectives

This research attempts to identify the sequence of relative sea level movements during the Lateglacial and Flandrian for the study area. The objectives are:-

i) to identify and map all raised marine features and related fluvial and fluvio-glacial deposits.

ii) to determine the altitude of all raised marine features in relation to the national datum level.

iii) to analyse the altitude data in the terms of the errors involved, to determine to what degree one shoreline fragment can be distinguished from another on the basis of altitude.

iv) to relate former relative sea levels to glacial events.

v) to correlate raised marine features across the study area and in turn correlate glacial events.

vi) to deduce a chronology of relative sea level movements and glacial events for the whole study area.

vii) to attempt to correlate relative sea level movements in the present study area with those in other areas of Scotland.

4. Structure of the Thesis

This thesis is divided into three sections. In the first section a general background to the work is presented, in the second the detailed results of the field work are outlined and in the final section the results are analysed.

The first section, the general background section, comprises Chapters 2 to 4. In Chapter 2 the pre-Quaternary geological history of the study area is outlined together with brief introduction to the present coastline. In addition a review of glacio-isostatic theory is also outlined with emphasis placed upon the pattern and nature of glacio-isostatic rebound. Chapter 3 comprises a review of literature relating to the Late Devensian ice sheet. This review considers in detail relative sea level movements outlined for other areas of Scotland and then discusses the Late Devensian events currently proposed for the Inner Moray Firth area. In Chapter 4 the methodology is outlined. Considerable emphasis is placed on the analysis of altitude data and a discussion is presented on the errors involved in the collection of such data.

Chapters 5-8 present the field data. In Chapters 5, 6 and 8 the field data relating to the Open Coastline, Inverness Firth and Beauly Firth are described by locality. In contrast, Chapter 7 considers the Late Devensian and Flandrian events in the Ness valley and Loch Ness areas as a whole.

Chapters 9-11 present the results of the field study. In Chapter 9 the mode and time of formation of the main marine erosion features of the study area are discussed. Chapter 10 considers the construction of shorelines associated with ice sheet decay and in this way derives a regional deglaciation chronology as well as outlining changes in relative sea level. In Chapter 11, shorelines and events relating to the Loch Lomond Stadial and Flandrian Interglacial are presented.

In Chapter 12 a summary of the main findings relating to relative sea level changes, glacio-isostatic movements and deglaciation chronology are presented. This chapter also outlines the areas where future research would be beneficial. In the appendices all the altitudinal and stratigraphical data derived by the author is presented, and this includes over 6 000 altitudes and the records from nearly 200 boreholes. This is supplemented by commercial borehole records which are referred to in the text.

5. Definition of Terms

i) Late Devensian:- this is defined by Mitchell *et al*. (1973) as the glacial stadial between 26 000 yrs. B.P. and 10 000 yrs. B.P. and is considered equivalent to Oxygen Isotope Stage 2 in core V28-238 (Shackleton and Opdyke, 1973) which has been dated to 32 000-13 000 yrs. B.P. Due to the inconsistencies in the dates it is proposed here that the term Late Devensian embraces the period 30 000-10 000 yrs. B.P.

ii) Lateglacial:- Gray and Lowe (1977) and Lowe and Gray (1980) suggested that the term "Lateglacial" should refer to "...the period between the thermal improvement that led to the final widespread decay of the Late Devensian ice sheet and the thermal improvement that resulted in the final disappearence of ice from Scotland following the Loch Lomond Readvance." (1980, p.176). This is equivalent to the Lateglacial Interstadial (dated at *circa* 13 000-11 000 yrs. B.P.) and the Loch Lomond Stadial (dated at *circa* 11 000-10 000 yrs. B.P.). This is at variance with the usage of the term "Lateglacial" in relation to Scottish raised shoreline studies. In such studies Lateglacial is often used to refer to shorelines which may have been formed at an early stage of deglaciation of the Late Devensian ice sheet, and according to this usage the term "Lateglacial" refers to a much longer time interval, perhaps 18 000-10 000 yrs. B.P. In accordance with the shoreline usage the term "Lateglacial" is used here to refer to the period of time from the commencement of the deglaciation of the Late Devensian ice sheet to the conclusion of the Loch Lomond Stadial.

iii) Flandrian:- this term has been used as a formal stage name for the present interglacial stage in place of the equivocal term "Postglacial". The use of the term Flandrian has been recommended by the Quaternary Era Sub-Committee (Mitchell *et al.* 1973) and its lower limit is defined as 10 000 yrs. B.P. This terminology is adopted here.

iv) Altitude:- this term is used specifically to denote the altitude in relation to Ordnance Datum (Newlyn). Ordnance Datum (O.D.) (Newlyn) is defined as the Mean Sea Level at Newlyn between 1915 and 1921. All altitudes derived by the author and referred to in the text relate to O.D. (Newlyn) and are quoted in metres.

v) Radiocarbon Ages (^{14}C):- the radiocarbon ages are all based on a ^{14}C half life of 5 570 yrs. and are uncorrected. The errors quoted for ^{14}C dates are one standard deviation about the mean.

vi) Raised Beach:- this term has often been used in the literature to refer to a variety of relict marine forms. In this study the term is avoided and the specific generic terms used for the relict marine features (eg. raised marine terrace, raised shingle beach, raised shingle ridge).

vii) Shoreline:- this term represents a synchronous marine or lacustrine water level and as such is not represented by a morphological feature. In this study the term shoreline is used in accordance with the convention presently adopted in Scotland, namely that a raised shoreline refers to a comparable level identified on similar relict marine or lacustrine features. Shoreline fragment refers to a short stretch of shoreline inferred from a relict marine or lacustrine feature of limited extent.

viii) Sea Level:- the term sea level is used here to refer to shoreline altitudes at a specific site and does not relate to a specific water level (eg. MHWST, MLWST).

ix) Terrace/Terrace Fragment:- a terrace is a surface of marine, fluvial or fluvio-glacial deposition or erosion which is often dissected into individual fragments. Where the terrace is marine in origin it is referred to as a marine terrace and is characterised by a surface of marine erosion or deposition and a steeper non-marine backslope. Where fluvio-glacial and fluvial terraces are identified individual features are termed terrace fragments whilst a collection of terrace fragments which were formed at the same time are called a terrace surface.

x) Delta:- deltas have been identified throughout the study area. They may be of fluvial or fluvio-glacial origin and relate to marine or lacustrine surfaces. Where levels have been identified from them the evidence usually consists of level areas defined by breaks of slope. Such areas may reflect the grading of the delta or its erosion in relation to a specific level.

CHAPTER TWO

BACKGROUND

1. Pre Quaternary Geology

The Pre-Quaternary geology of the Inner Moray Firth is dominated by extensive areas of Moinian basement rocks and Devonian Old Red Sandstone (Fig. 2). The geological structure of the area was influenced by Caledonian earth movements, and the Great Glen Fault may have originated at this time. D.I. Smith (1977) notes that this fault is still active, with more than 60 earthquakes having been recorded since 1768 (Ahmad, 1967; Lilwall, 1967;Browitt, Burton and Lidster, 1976). Subsidence in the North Sea basin has been a major feature of the geological events of the area since the Carboniferous. (Bacon and Chesher, 1975).

The chief lithological units of the Moinian Assemblage are psammitic granulites, pelitic schists and semi-pelitic granulites or schists (Johnstone, 1966). These rocks outcrop on both sides of the Great Glen and form the interior land to the west and south of the study area (Fig. 2). Locally the Moine rocks outcrop at lower altitudes, notably as fault-bounded blocks north of Rosemarkie and along part of the southern shore of the Beauly Firth. Phemister (1960) suggested that the Moines represent sedimentary rocks of estuarine or lagoonal facies which underwent regional metamorphism during the Caledonian Orogeny. Anderton et al. (1979) and Owen (1976) suggested that the Moinian sediments accumulated in a trough on the 'northern' side of an expanding "Iapetus Ocean" during Pre-Cambrian time. Late in the Cambrian the "Iapetus Ocean" began to close and continued to do so throughout the Ordovician and Silurian. During this closure a series of orogenic phases resulted in major folding of the Moinian Series along NE-SW axes. Regional metamorphism also took place at this time. During the Lower

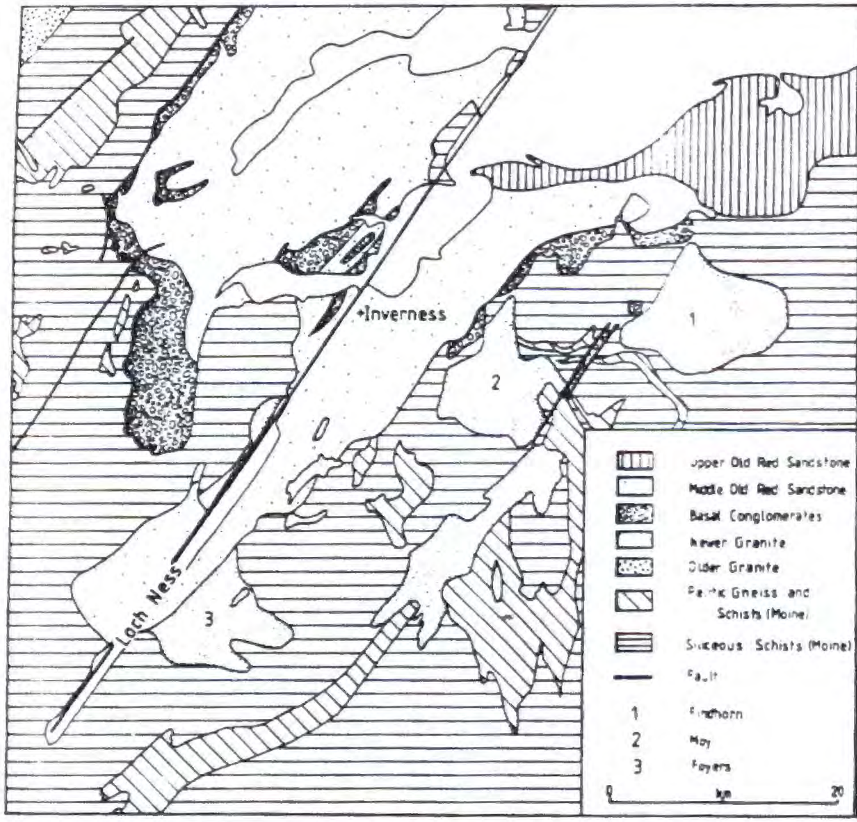


FIGURE 2 Pre-Quaternary geology of the inner Moray Firth Area.

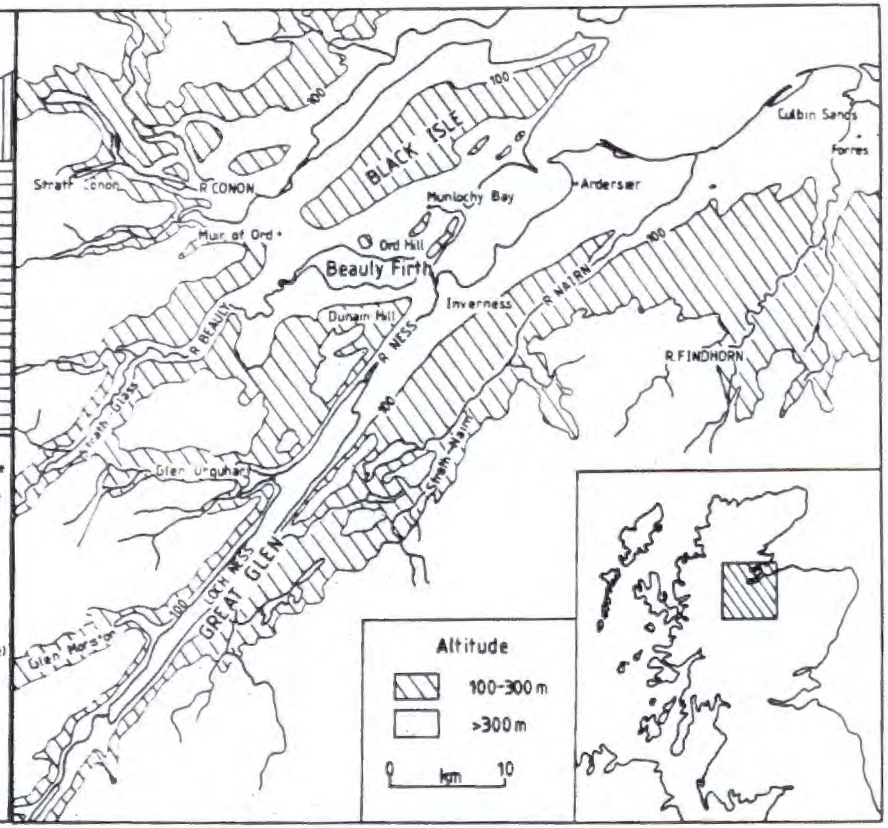


FIGURE 3 Topography of the inner Moray Firth area.

Ordovician, Northern Scotland became the edge of a highland mass and uplift and erosion continued together with major tectonic movements (eg. along the Moine Thrust). These processes resulted in the Moine rocks being brought to the surface. Phillips et al. (1976) have proposed that during this phase the convergence of subducted slabs resulted in the formation of the Great Glen Fault. The final closure of the "Iapetus Ocean" during the Silurian and early Devonian resulted in the intrusion of a number of Caledonian granites, include the Foyers, Moy and Findhorn Granites (Owen, 1976)(Fig. 2).

At the begining of the Devonian much of Scotland was occupied by a mountain range. Within this region, structurally controlled basins of subsidence were present and one of these (the Orcadian Cuvette) occupied the Moray Firth area. Sediments from the Moine Mountains were deposited in the irregularly floored Orcadian Cuvette to form the Middle and Upper Old Red Sandstone sequences (Murchison, 1839; Millar, 1841; Mykura, 1983). The Orcadian Cuvette has been interpreted as an enclosed subsiding basin in which formed a sequence of lacustrine sediments (Mykura, 1975). In the Inner Moray Firth the Moinian basement rocks are overlain by a sequence of basal conglomerates and sandstones which show great lateral variation. The conglomerates outcrop in the area around Kiltarlity and the Kilmorack Gorge (Fig. 2), in the south-eastern area of the Black Isle and as a southern rim to the Devonian deposits east of Inverness. Overlying these beds with conformity are a series of sandstones with occasional shale beds (Horne, 1923). In the Nairn-Forres area Upper Old Red Sandstone beds rest unconformably on Middle Old Red Sandstones (Westoll, 1951; Tarlo, 1961). The Upper Old Red Sandstone Beds consist of sandstones with seams of clay and occasional flags and shales.

Major movements along the Great Glen Fault have been proposed for the Devonian (Owen, 1976; D.I. Smith, 1977). The fault comprises a central zone of crushed and comminuted rock up to 4 km wide. North of the Great Glen, the fault follows the coastline of the Black Isle and Caithness (Chesher and Bacon, 1975). Horne and Hinxman (1914) suggested that it was a normal fault with a downthrow to the east of some 1800 m. However Kennedy (1946) proposed that it was a transcurrent fault with a sinistral movement of 65 km. Holgate (1969) proposed that the evidence indicated two periods of transcurrent movement; a sinistral shift of 133 km in the Devonian and a dextral shift of 29 km in the Eocene. In contrast Garson and Plant (1972) proposed a dextral movement of 120 km in the Lower Devonian and a second dextral movement of 32 km in the Upper Cretaceous. More recent work by Bacon and Chesher (1975) suggested that during the Mesozoic the fault moved in a normal sense. Movements along the fault are controversial and D.I. Smith (1977) concluded that numerous movements have occurred along the Great Glen since its formation. The presence of faults along the axis of the Beauly Firth (Armstrong, 1975 in Peacock, 1977), Cromarty Firth and Rosemarkie Gorge (Horne and Hinxman, 1914) have been suggested, but these are largely unknown.

There is no evidence of Carboniferous deposits in northern Scotland, so the area is considered to have been an upland massif at the time (Owen, 1976). Subsequently either before or during the Variscan Orogeny, minor folding of the Old Red Sandstone beds occurred to produce the synclinal structure in the Black Isle.

Since the Variscan Orogeny the Inner Moray Firth has been marginal to the large Mesozoic sedimentary basin beneath the Moray Firth and North Sea. Subsidence of this basin is closely linked with the opening of the Atlantic, and Bott (1971, 1975) suggested that the subsidence resulted from isostatic response to crustal thinning. The thinning has been explained by the transformation of basult to eclogite in the lower part of the crust as a result of loading (Collette, 1968, 1971). Ziegler and Louwerens (1979) proposed that the main features of Mesozoic rifting and later events resulted from the emplacement of a rift cushion at the crust-mantle interface. The subsidence of this cushion caused the development of a single broad saucer-shaped North Sea Basin. In the Inner Moray Firth area this basin is bounded by the Great Glen Fault and the Lossiemouth Fault. Subsidence by normal movements along these fault planes has been suggested (Bacon and Chesher, 1975). During the Cenozoic, North Sea subsidence was accompanied by uplift in the Scottish Highlands, although the magnitude of the movements are unknown.

2. Topography

The topography of the Inner Moray Firth is largely controlled by lithology and structure. Major lines of weakness such as the Great Glen and Strath Glass Faults have been exploited by glacial erosion to form deep, steeply-sided troughs. In contrast the resistant rocks of the Moines and basal Conglomerates (Old Red Sandstone) have undergone reduced erosion when compared with the sandstones and shales of the Old Red Sandstones. The former produce upstanding blocks (eg. Ord Hill, Drumdefelt Hill and Dunain Hill)(Fig. 3), while the latter are characterised by areas of subdued relief. The distribution of the lithologies enables division of the area into two distinct topographic areas; east and west of the Great Glen (Ogilvie, 1923).

West of the Great Glen lie the broad glacially deepened valleys of Strath Connon, Strath Glass and the Beauly Firth, each being bounded by steep sides. Only in the areas NE of the Muir of Ord and south of Kiltarlity does the ground rise more gently. The steep sides of the major valleys result in a narrow coastal zone, and only where extensive glacial or marine deposition has taken place does this zone widen to any great extent. The western side of the Great Glen forms a very steep slope which is continued north along the eastern shore of the Black Isle by outcrops of conglomerate. This steep slope is interrupted by the valleys of Glen Moriston and Glen Urquhart and the embayments of Munlochy Bay and Rosemarkie. These valleys may follow fault lines but Ogilvie (1923) suggested that those on the Black Isle probably represent lines of former glacial meltwater flow. The impressive gorge at Kilmorack probably has a similar meltwater origin but the exact date of formation is unknown. Farther inland on the Black Isle, the NE-SW strike of the rocks is represented by several consequent streams. Here the conglomerates and sandstone have been differentially eroded to produce scarp and vale topography. In this way the land gradually rises to the main drainage divide in the peninsula.

On the eastern side of the Great Glen the land rises more gently. North of Dores the sides of the Glen rise gradually across Middle Old Red Sandstone rocks before rising abruptly on the Moines. Between Inverness and Forres, the Middle and Upper Old Red Sandstone rocks form a wide lowland coastal zone, into which the wide glacial trough of Strath Nairn leads. This low lying area is dominated by glacial, fluvio-glacial and raised marine features. Much of the coastal lowlands between Ardersier and the River Findhorn have become covered by extensive deposits of windblown sand, notably the Culbin Sands (Steers, 1937). Farther inland glacial deposits mantle much of the surface. In contrast where the Moines outcrop in the Great Glen, steep slopes are common but unlike the western flank, this side of the valley has no major tributary valleys.

In the Glen itself, Loch Ness occupies the glacially eroded Great Glen Fault. The deepest part of this basin occurs at 200 m

FIGURE 4a The tidal ports in NE Scotland.

FIGURE 4b Tidal range around Scotland.

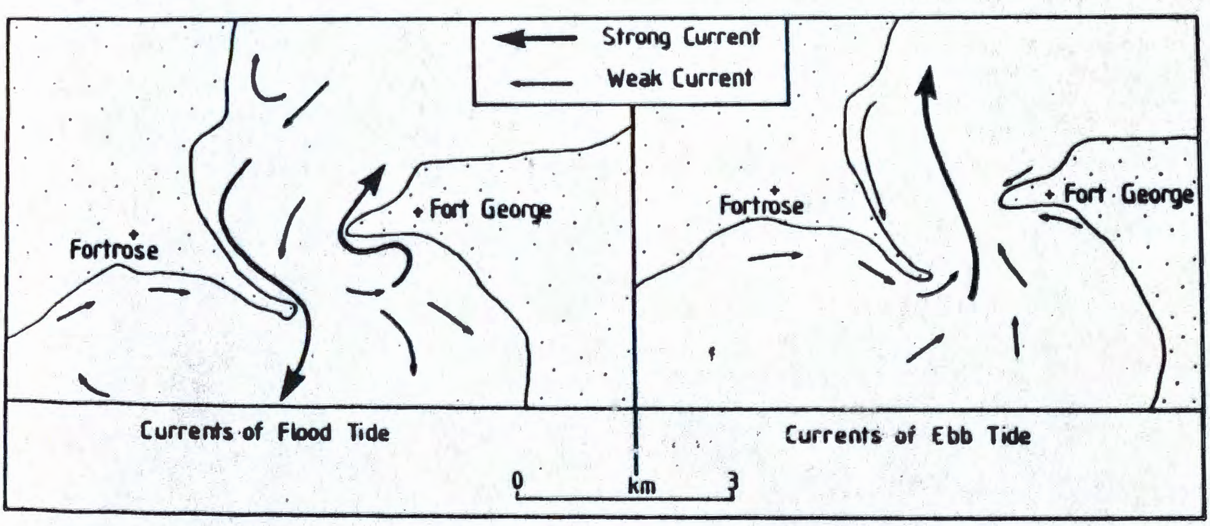


FIGURE 5 Tidal currents at Fortrose (after Ogilvie, 1923).

below mean sea level and by volume Loch Ness is the largest fresh water lake in Britain. The subsurface topography of the lake is largely unknown, the only survey having been carried out by Murray and Pullar (1910).

3. The Present Coastline

a) Introduction

The coastline of the Inner Moray Firth may be divided into 3 areas. The innermost area (Fig. 3) is the Beauly Firth, lying between Lovat Bridge (NH 515 449) and the Kessock Narrows. Beyond this the Inverness Firth (Ogilvie, 1923) (Fig. 3) extends from the Kessock narrows to the promontories of Chanonry Point and Fort George. The outer most area, here termed the open coastlands, consists of the western end of the Moray Firth. Each area is characterized by different landform assemblages, and the differences result from variations in the principal coastal parameters (tides, waves, subsurface gradient, coastal configuration and sediment supply).

b) Tidal Regime and Tidal Currents

Table 1 summarizes tidal data for the 20 secondary ports around the Moray Firth (Fig. 4a). This data indicates an increase in the altitude of each water surface (MHWS, MHWN, MTL, MLWN, MLWS) towards the Inner Moray Firth. Similarly tidal range increases in amplitude towards the inner Firths (Fig. 4b). Data from the Beauly Firth is lacking, although the single measurement of MHWS at Lovat Bridge of 2.58 m (Highland Regional Council, 1974) is in accord with the rise of this water surface. Trend surface analysis of the tidal data relating to MHWS level (Table 1) indicates that this surface is represented by a linear surface rising towards S 47° W at a rate of 0.0065 m/km.

Study of the tidal circulation in the Inner Moray Firth area

Tidal Port	No Fig. 4a	MHWS	MHWN	MTL	MLWN	MLWS
Aberdeen	1	2.05	1.15	0.225	-0.65	-1.65
Peterhead	2	1.60	0.90	0.025	-0.70	-1.70
Fraserburgh	3	1.70	0.90	0.075	-0.70	-1.60
Banff	4	1.30	0.60	-0.250	-1.10	-1.80
Whitehills	5	1.90	1.10	0.350	-0.30	-1.30
Buckie	6	2.00	1.10	0.300	-0.50	-1.40
Lossiemouth	7	2.00	1.10	0.300	-0.50	-1.50
Burghead	8	2.00	1.10	0.300	-0.50	-1.50
Nairn	9	2.20	1.20	0.375	-0.50	-1.50
McDermott	10	2.10	1.20	0.425	-0.40	-1.20
Fortrose		2.05	1.15	+	+	+
Inverness	11	2.55	1.45	0.500	-0.45	-1.55
Cromarty	12	2.20	1.30	0.450	-0.40	-1.30
Invergprdon	13	2.30	1.40	0.475	-0.40	-1.40
Dingwall		2.30	1.50	+	+	+
Portmahomack	14	2.00	1.20	0.350	-0.40	-1.40
Meikle Ferry	15	2.30	1.30	0.375	-0.60	-1.50
Golspie	16	1.95	1.05	0.250	-0.55	-1.45
Wick	17	1.69	0.99	0.290	-0.31	-1.21
Duncansby Head		1.39	0.69	+	+	+
	+ = data not available					

TABLE 1 Tidal Data for the Moray Firth area. (m O.D.)

has been restricted to the narrows at Kessock (Craig and Adams, 1969) and Chanonry Point (Ogilvie, 1914). Craig and Adams (1969) have suggested that the tidal movements in the Kessock narrows are complex. The Inverness and western Beauly Firths have normal estuarine circulation, characterised by seaward movement of upper water and landward flow of deep water. The outer part of the Beauly Firth is dominated by reverse estuarine circulation, the upper water having a net movement westward and the deeper water moving slowly eastward. They suggested that this reversal is related to the outflow of the River Ness. Surface tidal movements reach velocities of at least 4 knots, whilst the significant movements at depth help to maintain the deep channel. Craig and Adams (1969) also suggested that the tide race extracts the wave energy from the waters, thus protecting those areas to the leeward of it from wave activity.

Ogilvie (1914) conducted limited observations on the currents associated with Spring tides in the Chanonry narrows (Fig. 5). He suggested that during the flood tide the main movement is along the north shore of Chanonry Ness at velocities of 2 knots or more. Strong eddy currents occur south of Chanonry Ness and Fort George. During the ebb the main current is located in the centre of the narrows. Ogilvie (1914) considered that the deep channels of the narrowsand south of Chanonry Ness are a result of these tidal currents. He also suggested that sediment accumulation occurs at Fort George and Chanonry Points because tidal currents move towards these areas during ebb and flood tides.

c) Wave Action

Wave activity is generally dependant upon the direction of prevailing winds, fetch, coastal configuration and nearshore topography (Zenkovich, 1967). Data from Inverness (Small and Smith, 1971) indicates that the dominant wind direction is from the SW. This direction, although normal for the British Isles, is accentuated in this area by air flows being channelled along the Great Glen. The Beauly and Cromarty Firths also funnel air flow and as a result local air movements in the area are complex.

In the enclosed basins of the Beauly and Inverness Firths the fetch is limited, varying between 4-15 km. Both Firths also have shallow nearshore gradients, and these factors result in reduced wave activity.

On the Open Coastline fetch is markedly greater particularly when associated with easterly winds. The northern coastline (along the Black Isle) has a steep nearshore gradient and no embayments and therefore is characterised by higher wave energy. The effects of wave action are reduced to some extent by the directions of maximum fetch (to the NE) lying sub-parallel to the coastline. In contrast the southern coastline lies oblique to the direction of maximum fetch, yet is characterised by a shallow nearshore gradient and wide embayments which help to dissipate wave energy. In this area the importance of easterly winds is reflected in the dominant westerly movement of sediment (Steers, 1973).

d) Sediment Supply

Four large rivers drain into the Inner Moray Firth; the Findhorn, Nairn, Beauly and Ness (Fig. 3). Each of these rivers flows through areas of extensive fluvio-glacial deposits and thus sediment input into the coastal zone should have been large near the outlets of these rivers. Elsewhere however, the streams reaching the coast are small. Sediment input is therefore very variable.

e) Coastal Landforms

i) Beauly Firth

This area is characterised by extensive saltmarshes especially in the west, fringed by mud and sand flats. To the east of the area the saltmarshes and mud/sand flats are narrower and locally strewn with large subrounded boulders. Locally (eg. between Clachncharry and Bunchrew) the saltmarsh is replaced by a steep shingle beach. Around much of the Beauly Firth saltmarshes have been reclaimed.

ii) Inverness Firth

This basin is more open than the Beauly Firth and as a consequence experiences waves with greater energy. The resultant landforms are steep shingle storm beaches beyond which extend sand and mud flats (Plate 1) especially on the southern coast. In the sheltered embayments of Castle Stuart and Munlochy Bay (Fig. 3) saltmarshes occur. On the northern coastline intertidal rock platforms occur locally and are backed by a steep and locally degraded cliffline. Chanonry Ness and Fort George represent major depositional features built mainly during higher relative sea levels (Ogilvie, 1914). Ogilvie (1914) suggested that modern sediment accumulation is only occurring at the distal end of the features and erosion is dominant at the proximal ends.

iii) The Open Coastline

This area may be divided into the southern and northern coastlines. The northern coastline is marked by a narrow intertidal rock platform which is locally overlain by modern and raised sand and shingle coastal deposits. The southern coastline is characterized by wide sandy beaches backed by shingle storm beaches, sand and shingle ridges and locally by extensive sand dunes (eg. Culbin Sands). In certain localities large sand and shingle bars have built

PLATE 1. A modern shingle beach in the Inverness Firth (NH 755 523)

up (eg. The Bar and Carse of Delnies spit) (Fig. 3). Steers (1937, 1973) suggested that these large features were produced during the last 300 years. He also proposed that each feature is moving westward by erosion in its proximal end and deposition at its distal end. Landward of each major accumulation there are sandy saltmarshes.

iv) Relationship of Landforms to Tidal Level

A limited number of altitude measurements were undertaken on modern coastal landforms (Appendix I). Saltmarsh surfaces were measured at several localities (Table 2). The results indicate that the upper surface of the saltmarshes lies close to MHWS. Measurements on shingle beaches indicated great lateral variations in altitude within short distances that can not be related to a modern water level. As a result these beaches were considered to result from storm action. The distribution of sand and shingle ridges is limited to the Open Coastline area. As a result it was considered inappropriate to measure the altitude of these features.

4. Glacio-Isostasy

a) Introduction

The theory of glacio-isostasy was first proposed by Jamieson (1865) who suggested a relationship between relative sea level and ice cover. Jamieson (1882, 1887) later elaborated his hypothesis to suggest that the amount of uplift was proportional to the original thickness of the ice mass. The development of these ideas has resulted in a glacio-isostatic theory that is in accord with the field evidence. Although the basic theory is generally accepted, more recent studies (eg. Mörner, 1980) have suggested that isostatic movements are more complex than originally proposed.

Location	No. of Altitudes	Mean Grid Ref.	Mean Altitude (m O.D.)
Spital Shore	15	NH 5625 4905	2.48
Tarradale	6	NH 5551 4869	2.23
Lentran	5	NH 5929 4590	2.81
Munlochy Bay	15	NH 6555 5328	2.19
Castle Stuart	11	NH 7365 4973	2.27

TABLE 2 Location and altitude of Saltmarsh deposits in the Inner Moray Firth Area.

Readvance	Location	Proponents	Modern Equivalent
Lammermuir-Stranraer	Central Valley	Charlesworth (1926)	None
Aberdeen	NE Scotland	Synge (1956)	None
Dinnet	Grampians	Synge (1956)	None
Aberdeen-Lammermuir	Eastern Scotland	Sissons (1967)	None
Perth	Eastern Scotland	Simpson (1933)	Stillstand or Minor Readvance
Oban Ford	Oban Ford Area	Synge (1966)	None
Loch Lomond	Widespread	Numerous see Sissons (1967)	Accepted
Wester Ross	Wester Ross	Robinson and Ballantyne (1979)	Accepted
Otter Ferry	Cowal Peninsula	Sutherland (1981b)	Accepted
Achnasheen	Achnasheen	Sissons (1982a)	Accepted

TABLE 3 Major Readvances Proposed for Scotland

b) Theory

The premise behind glacio-isostatic theory is that changes in surface load on the earth's crust caused by the accumulation or melting of ice masses result in vertical crustal movements (Walcott, 1980). These vertical crustal movements are achieved by flowage within the earth, denser materials being moved at depth to compensate for loading or unloading at the surface (Andrews,1970). The nature of the flow is very complex due to lateral variations in the flowage of material within the earth, possible changes from laminar to non-laminar flow and variations in flow patterns taking place through time (Walcott, 1980). Several authors (Broecker, 1966; McConnell, 1968; Walcott, 1970, 1980; Peltier and Andrews, 1983) have attempted to model flowage resulting from glacio-isostasy. Several models have been produced, ranging from models which envisage flowage in a relatively thin layer (thin channel models) to those which envisage flowage through much of the mantle (linear viscoelastic models).

Von Bemmelan and Berlage (1935) proposed the thin channel model. In this model all the isostatic flowage occurs within a thin zone or channel between the rigid lithosphere and mesosphere. Values obtained by Minester et al. (1974) suggest flowage could be confined to a layer 350 km thick associated with viscosity values of 2×10^{21} poise. Some current concepts of plate movement support this theory (Harper, 1978).

The linear viscoelastic model (Haskell, 1935) supposes that flowage occurs throughout much of the mantle. This model has been applied to postglacial uplift data in Canada (Peltier, 1976; Peltier and Andrews, 1976) and has produced a good fit when a realistic deglaciation chronology is considered (Bryson, et al. 1969). A variation of this model assumes layers of different viscosity within the earths crust, but flowage throughout the crust still occurs (Peltier and Andrews, 1983).

c) Disposition of Displaced Materials

Displacement of material due to glacio-isostasy presents the problem of where the sub-crustal material is moved to or from and how this effects the altitude of the crust. Daly (1934) suggested that slow relaxation times (the times taken to displace/recover 1/e of the displacement) and high viscosities within the earth's crust would result in an uplift bulge in peripheral areas (Fig. 6). The rigidity of the earth's crust would mean that this peripheral bulge would extend many kilometers beyond the ice margin (Daly, 1934; Walcott, 1970). Initially, evidence for peripheral bulges was lacking so ideas of flowage from beneath ice sheets to below the oceans crust were proposed (eg. Bloom, 1967). The wide displacement of material to beneath the ocean floor requires lower viscosities than are currently proposed (eg. Walcott, 1970, 1980; Peltier, 1976). More recently evidence has been presented for areas marginal to the Late Devensian ice sheets which suggests forebulge or peripheral bulge subsidence (Kaye and Barghoon, 1964; Mörner, 1969; Walcott, 1972; Cathles, 1975). It has also been suggested that the peripheral bulge migrates towards the centre of isostatic uplift during ice sheet decay (Brøgger, 1901; Newman et al., 1980).

d) The Patterns and Nature of Isostatic Rebound

Following the work of Jamieson (1865) glacio-isostatic movements were recognized in Scandinavia (De Geer, 1888, cf. Mörner, 1979) North America (Whittlesey, 1868; Shaler, 1874) and other areas. In Scandinavia, North America and Scotland sequences of tilted shorelines have been subsequently identified as having resulted from differential

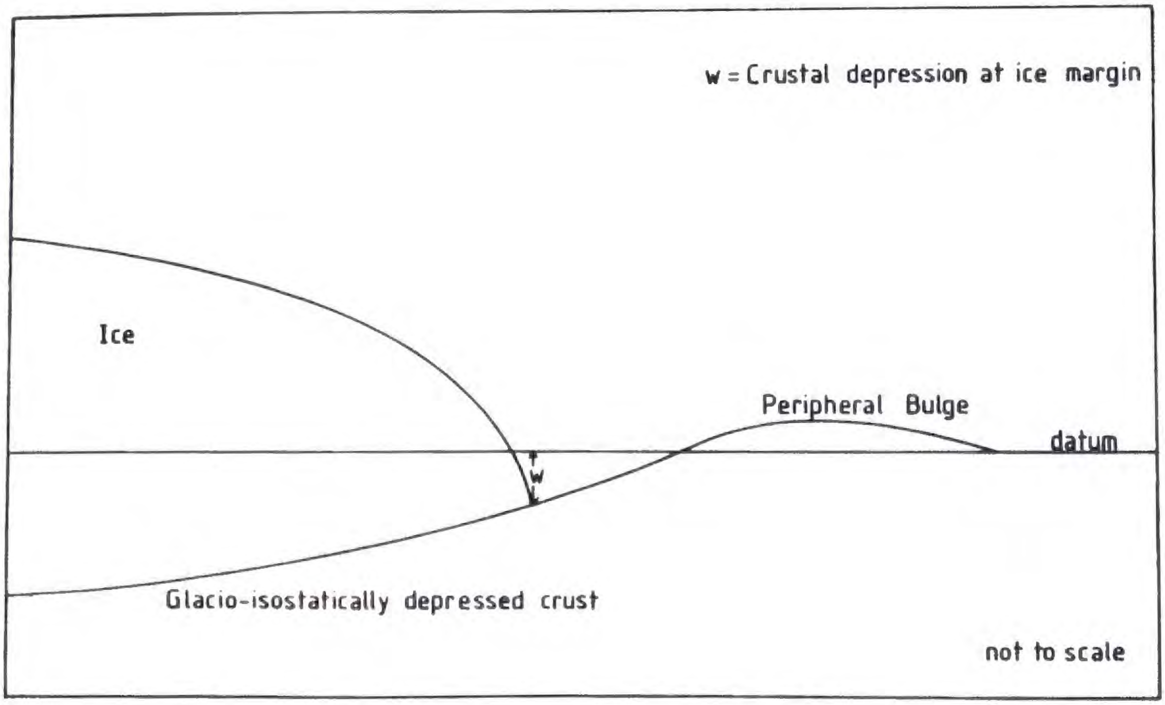


FIGURE 6 The location and form of a peripheral bulge (after Daly, 1934)

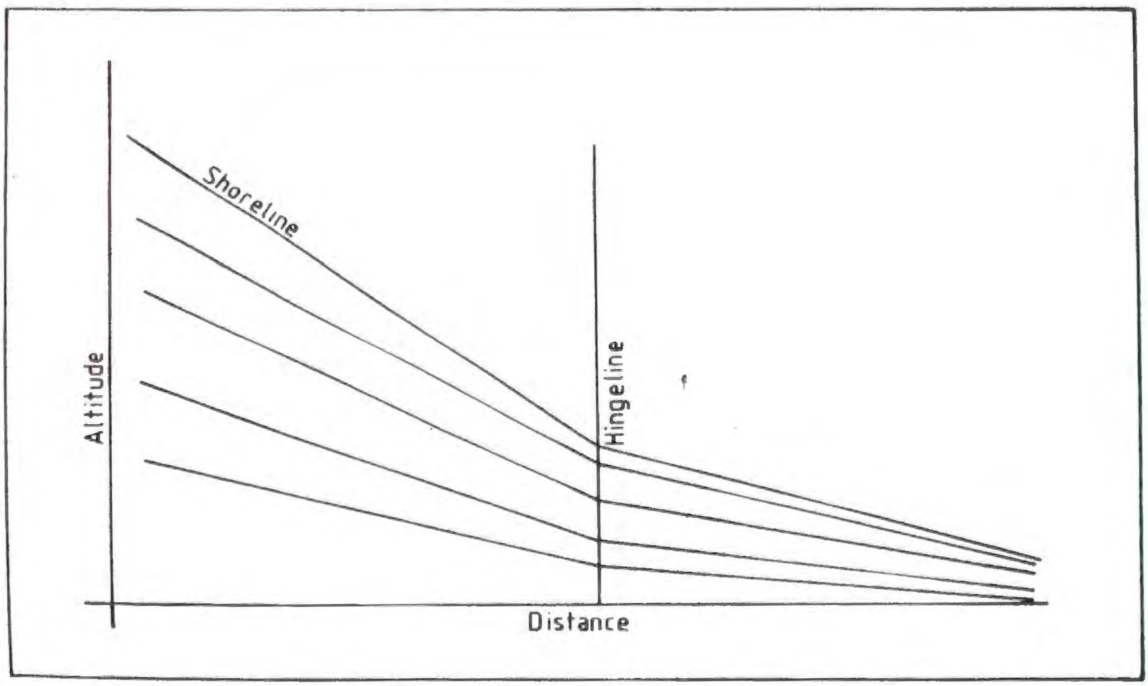


FIGURE 7 The effect of a hingeline on shoreline gradient

isostatic movements (eg. Sissons, Smith and Cullingford, 1966; Mörner, 1969; Andrews, 1970). In each area it is accepted that the shoreline sequence only indicates part of the uplift, since an unknown portion of the uplift occurred as the ice sheet thinned while the area remained ice covered.

The pattern of uplift was originally proposed to be regular (eg. Wright, 1914), in that the amount of uplift at any site was directly proportional to ice thickness. Sauramo (1939, 1955) proposed more irregular patterns of uplift when he introduced the concept of hinge lines. A hinge line represents a boundary across which rates of uplift markedly change and it is normally represented by a marked change in the gradients of individual shorelines (Fig. 7). Mörner (1969, 1972) also identified a series of hinge lines in Scandinavia.

In Scotland, Sissons, (1972) suggested that uplift may vary locally, for specific blocks in the Forth Valley indicated separate uplift histories, with some shorelines being dislocated across block boundaries.

The nature of uplift has often been illustrated by uplift curves (eg. Andrews, 1970). Uplift curves produced from dated sea level indicators nearly all have an inverted exponential form, with rates of uplift decreasing with time (eg. Wahsburn and Stuiver, 1962; Broecker, 1966; Sissons and Brooks, 1971; Mörner, 1970; Grant, 1980). These uplift curves assume that irregularities are the result of variations in the eustatic curve. Sissons (1967) and Gemmell (1975) suggested that uplift may be complicated by readvances redepressing the crust. More recently it has been suggested that uplift may have been a discontinuous process (Sissons,1972; Mörner, 1980; Grant, 1980). In the Forth Valley, Sissons (1972) identified an area in which there had been no differential uplift between the formation of two shorelines; outside of this area differential uplift between the two shorelines was recognized. Sissons and Cornish (1982) identified dislocated shorelines and suggested that the dislocations occurred over a short time period. Similar features have been noted by Mörner (1980) who suggested that much of the faulting resulted from high stress and strain rates during periods of rapid uplift. Grant (1980) provided further evidence of irregular isostatic uplift and he suggested that this may result from discontinuous isostatic readjustment (accelerating and decelerating rates). Isostatic uplift thus appears to be a complex process.

e) Summary

Isostatic theory is accepted in simple form but has many problems associated with its detail. Several models have been proposed and as of yet can not be resolved. The material displaced by ice accumulation is suggested to form a peripheral bulge which migrates towards the centre of ice accumulation during ice sheet decay. The nature of isostatic uplift may generally be represented by exponential curves showing decreasing uplift rates. More recent study has indicated that the uplift was probably complex and irregular.

CHAPTER THREE

THE LATE DEVENSIAN IN SCOTLAND

1. Introduction

The Devensian stage in Britain has been defined as the glacial stage between 116-10 ka. B.P. (Bowen, 1978). This stage has been divided into 3; the Early (pre 50 000 B.P.), the Middle (50 000-26 000 B.P.) and the Late (26 000-10 000 B.P.) Devensian (Mitchell *et al*., 1973). The dates outlined are based on stratigraphical evidence from the British Isles and are not in accord with those determined from the oceanic sedimentary record (the Late Devensian equivalent is stage 2 dated at 32 000-13 000 B.P. in core V28-238) (Shackleton and Opdyke, 1973). In consequence the Late Devensian is dated to *circa* 30 000-10 000 B.P.

The growth, limits, age and decay of the Late Devensian Scottish ice sheet have been subjects of considerable debate. The 'traditional' viewpoint is that the ice sheet covered the mainland of Scotland and was confluent with Scandinavian ice. In recent years Sutherland (1981a) and Sissons (1981a, 1983a) have suggested a smaller ice sheet, which originally built up in the Early Devensian. During the deglaciation of the Late Devensian ice sheet several major readvances have been proposed (Table 3). The validity of these events has been questioned, some have been disregarded, and some redefined as stillstands (Table 3). The final decay of the Scottish ice sheet is also in dispute (eg. Peacock, 1970; Sissons, 1976b). Before the events in the Inner Moray Firth area can be considered it is necessary to review those currently proposed for the rest of Scotland.

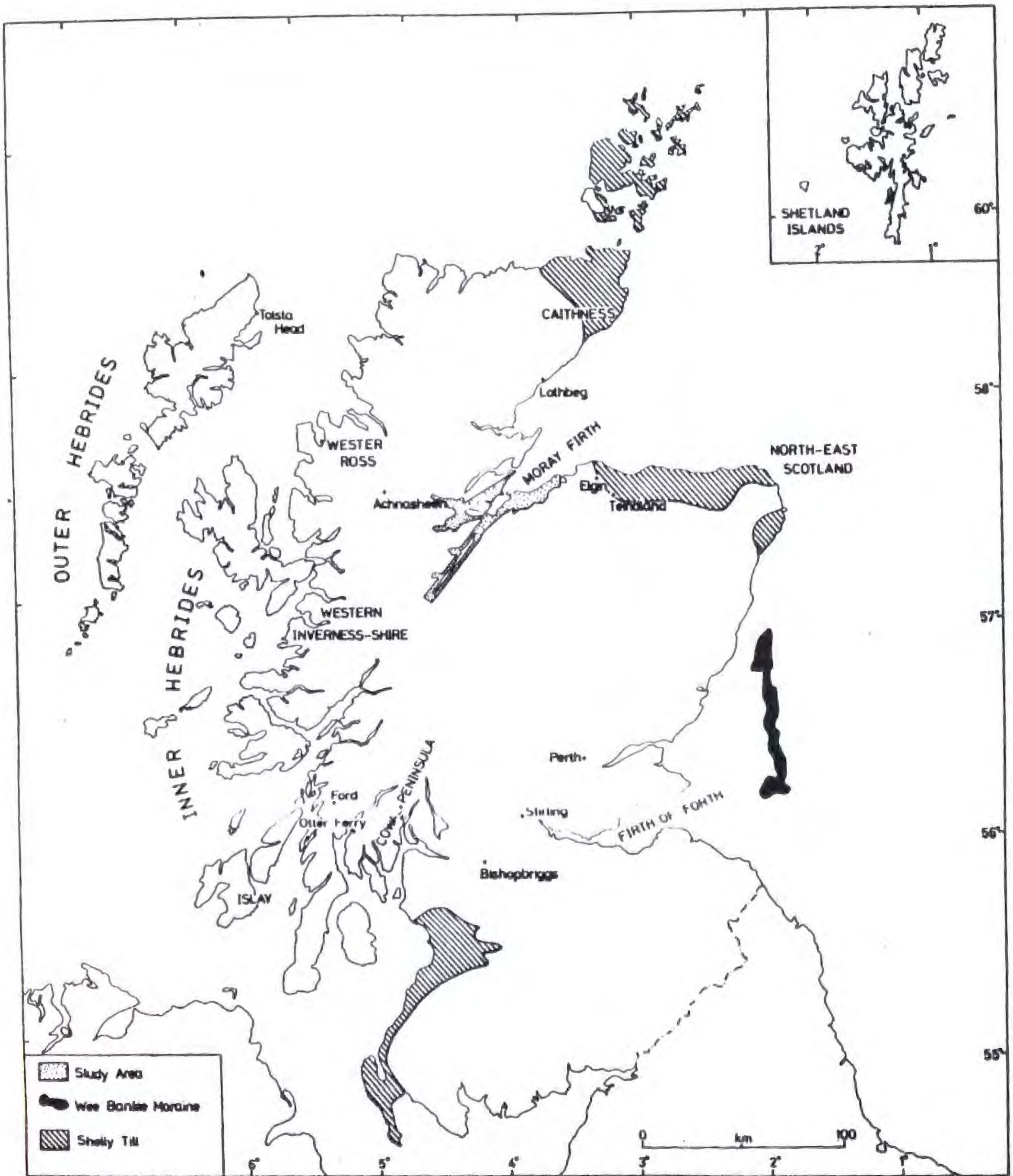


FIGURE 8 Scottish locations referred to in the text and the distribution of shelly till in Scotland.

2. The Growth and Extent of the Late Devensian Scottish Ice-Sheet

a) Traditional Viewpoint

The growth of the Late Devensian ice sheet in Scotland has traditionally been placed after 30 000 B.P. (Sissons, 1967, 1976b; Price, 1983). This date is based on a ^{14}C date of 28 100^{+480}_{-450} yrs. B.P. from a buried soil at Teindland (Fig. 8)(Fitzpatrick, 1965; Edwards, Caseldine and Chester, 1978); a woolly rhinoceros bone beneath till at Bishopbriggs dated at 27 550^{+1370}_{-1680} yrs. B.P. (Rolfe, 1966)(Fig. 8) and peat beneath till at Tolsta Head dated at 27 333 $^{+240}_{-240}$ yrs. B.P. (von Weymarn and Edwards, 1973). These dates were interpreted to suggest that much if not all of Scotland was ice free prior to 30 000 B.P. (Sissons, 1967). The Scottish ice sheet later reached its maximum extent circa 18 000 B.P., this date being based on the evidence from ocean sediments (Shackelton and Opdyke, 1973) and ^{14}C dates from England (eg. Straw and Clayton, 1979).

The maximum limit of the Late Devensian ice sheet is largely unknown in Scotland. On the west coast many authors (eg. Boulton et al. 1977; Synge, 1977b, 1980; Denton and Hughes, 1981) have suggested a limit on the Atlantic continental shelf. The limit is placed east of St. Kilda because this island was not covered by Scottish mainland ice (Wager, 1953; Sutherland, Ballantyne and Walker, 1982). The rest of the Outer Hebrides are considered to have been covered by ice (eg. Boulton et al. 1977).

In eastern Scotland the inferred pattern of former ice sheet flow (Fig. 9) based on the distribution of erratics and shelly till (Fig. 8), was interpreted as having resulted from the confluenceof the Scottish and Scandinavian ice sheets (Charlesworth, 1955; Synge, 1956). Interpretation of Quaternary North Sea sediments (eg. Holmes, 1977; Thomson and Eden, 1977; Eden, Holmes and Fannin, 1978)

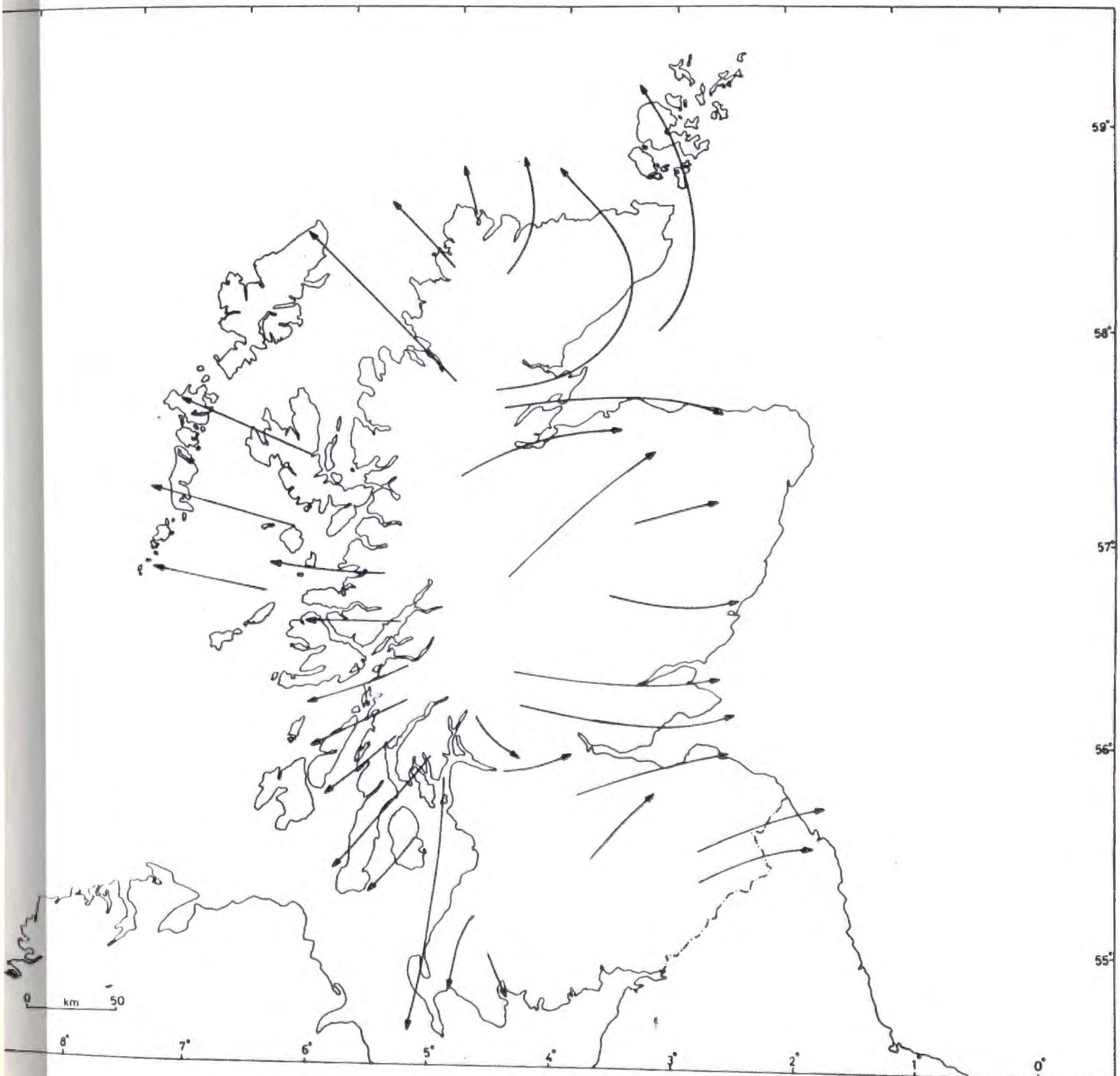


FIGURE 9 The major directions of ice-sheet flow in Scotland (Sissons, 1976b).

has provided a similar conclusion. Charlesworth (1955) and Synge (1956) also suggested that the Scottish ice sheet did not cover part of North East Scotland (Fig. 10). This concept of "moraineless Buchan" (Synge, 1956 p.132) was based on a distinction between 'fresh' and 'modified' morainic forms and was later criticized by Clapperton and Sugden (1977). Clapperton and Sugden (1972, 1975, 1977) suggested that the area contained a fluvio-glacial channel network associated with the deglaciation of an ice sheet and they inferred that all of North East Scotland was glaciated during the Late Devensian.

b) 'New' Viewpoint

Sutherland (1981a) and Sissons (1981a, 1982b, 1983a) have suggested that the growth of the last ice sheet commenced prior to 30 000 B.P. Sutherland (1981a) proposed that ice first accumulated in the Early Devensian and that an ice sheet remained in Scotland throughout the Mid Devensian. This ice sheet formed the basis of the Late Devensian ice mass.

Sissons (1981a,c,1982b, 1983a), suggested that the Late Devensian ice sheet in Scotland was smaller than traditionally proposed. On the west coast evidence from the Outer Hebrides (von Weymarn, 1974; Coward, 1977; Peacock and Ross, 1978; Flinn, 1978a) indicates that the area nourished a local Late Devensian ice cap. Peacock and Ross (1978) and Flinn (1978a) suggested that this ice cap developed <u>in situ</u>. In contrast Sissons (1980, 1981a,c,1982b, 1983a), suggested that initially the Scottish mainland ice covered much of the island chain. Subsequently calving in the deep waters around the islands resulted in a large mass of ice on and west of the Outer Hebrides. He proposed (1983a) that the Late Devensian ice sheet would normally have stabilized amidst the Inner Hebrides but no exact limits were given.

In eastern Scotland several limits of the Late Devensian ice sheet have been proposed. Synge (1977a), J.S. Smith (1977) and Synge and Smith (1980) suggested that parts of Caithness and North East Scotland were unglaciated during the Late Devensian (Fig. 10). Large drift accumulations at Lothbeg and Elgin (Fig. 8) were reported to represent the limits of an ice sheet that was not confluent with the Scandinavian ice mass. Evidence from Shetland (Hoppe, 1970, 1974; Flinn, 1978b, c) suggests that this area nourished a local ice cap and was not covered by Scandinavian ice (eg. Boulton, 1977). Sissons (1981a) re-interpreted this evidence and that from the North Sea (eg. Thomson and Eden, 1977) and suggested that the Late Devensian Scottish ice margin lay along or near to the Wee Bankie Moraine (Fig. 10) and was not confluent with Scandinavian ice. The proposed eastern limit in north east Scotland is similar to the limit of the Aberdeen-Lammermuir Re-advance (Fig. 10) which Sissons (1967 p. 145) noted as the "... possible maximal extent of this ice sheet...".

3. Initial Deglaciation of the Late Devensian Scottish Ice Sheet

From the study of oceanic sediments Ruddiman and McIntyre (1981) suggested that the decay of the Late Devensian European ice sheets resulted from snow starvation due to southerly positions of the polar oceanic and atmospheric fronts. Sissons (1981a) suggested that such a process could have resulted in the maximum limits of the British ice-sheet being non-synchronous. He suggested that while the more southerly parts of the ice sheet were advancing the more northerly ice margins may even have been retreating. This may be interpreted to suggest early deglaciation of the northern

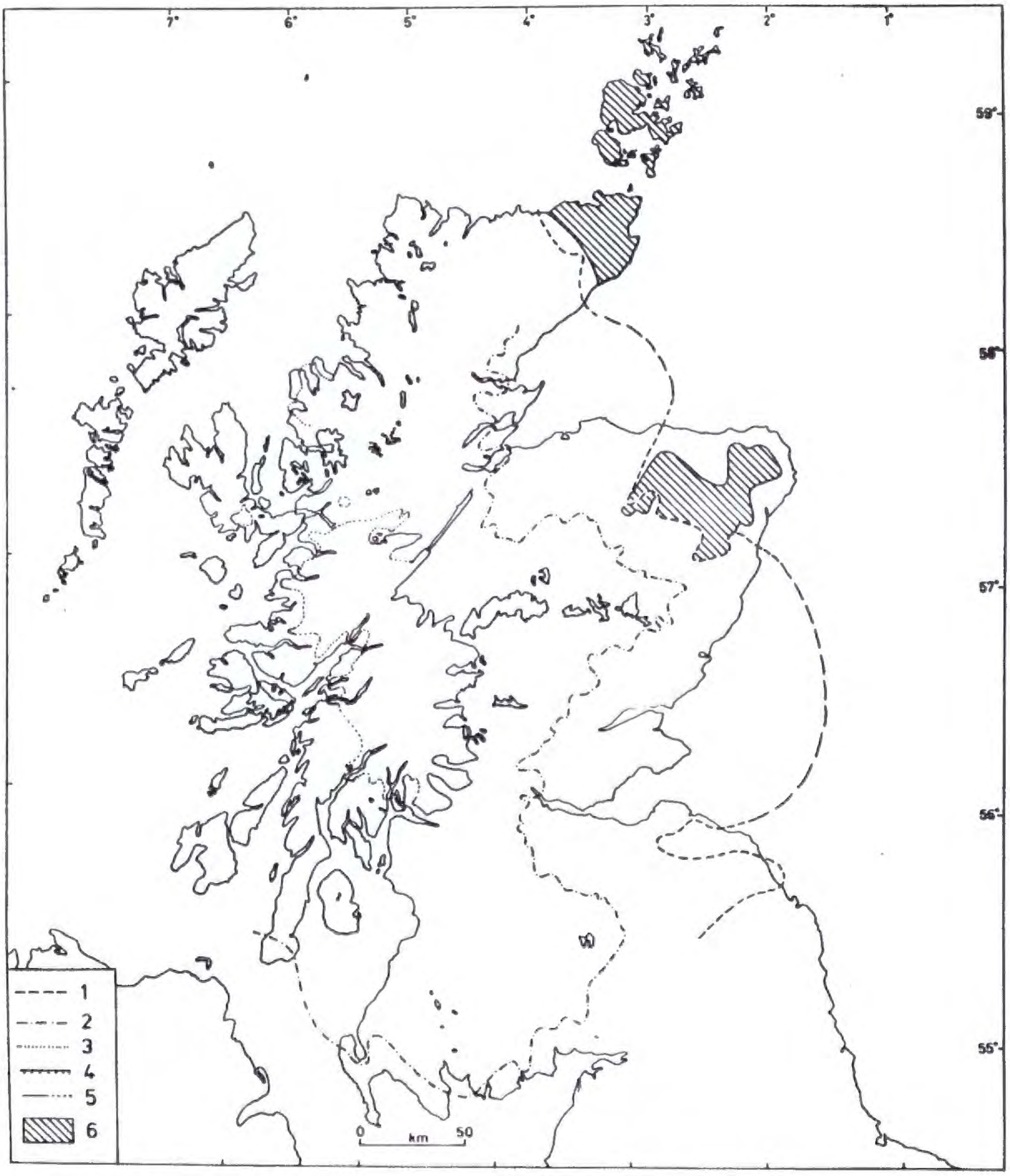


FIGURE 10 The Late Devensian ice limits which have been proposed for Scotland. 1. Aberdeen-Lammermuir Readvance (Sissons, 1967). 2. Perth Readvance (Sissons, 1967). 3. Wester Ross Readvance (Robinson and Ballantyne, 1979). 4. Achnasheen Readvance (Sissons, 1982a). 5. Loch Lomond Readvance (numerous sources). 6. The unglaciated area in North East Scotland (Charlesworth, 1955; Synge, 1956).

parts of the Scottish ice mass.

Ruddiman and McIntyre (1981) also suggested that circa 50% of the ice in the European ice sheets was removed by downdraw caused by calving. During this period of active downwasting the polar fronts remained south of the ice sheets. To what extent this process is applicable to the Scottish ice sheet is unknown, but it suggests that if the ice sheet terminated in the sea it probably remained active during the initial decay of the ice sheet. In contrast Price (1983) proposed that much of the ice mass became stagnant in the relatively early stages of deglaciation. He suggested that ice sheet decay resulted from progressive downwasting in situ.

a) Stillstands and Readvances: Eastern Scotland

Outside the Moray Firth (see below) only two interruptions in the decay of the Late Devensian ice sheet are currently proposed for eastern Scotland, the Perth Stage and Achnasheen Readvance (Fig. 10)(for the purpose of this thesis Eastern Scotland is defined as those areas east of the main drainage divide).

The Perth Stage was initially identified as a major readvance by Simpson (1933). At a site northwest of Perth, Simpson identified rhythmically laminated sediments overlain by kettled outwash. He interpreted the laminated deposit as varves, and estimated that they took 640 years to accumulate. The kettled outwash was interpreted as evidence of a subsequent major ice readvance across the varves. Sissons (1963b, 1964) mapped the limits of this readvance in central and eastern Scotland. In the Forth, Earn and Tay valleys distinct shorelines (Sissons and Smith, 1965a; Sissons et al., 1966, Cullingford, 1972, 1977) were associated with the Perth limits proposed by Sissons (Fig. 10). At Stirling (Fig. 8) Sissons and Smith (1965a) identified a fall in relative sea level of 25 m during which the ice retreated only a short distance from the maximum Perth extent. A similar major drop in the marine limit was also suggested in the Earn and Tay valleys (Sissons et al., 1966; Cullingford, 1972, 1977).

Paterson (1974) disputed the evidence of the Perth Readvance. He suggested the rhythmites identifed by Simpson were not annual deposits but successive discharges of sediment down the front of an advancing delta. On these grounds the marine sequence could have accumulated in a short time and a readvance or major still stand did not have to occur. Sissons (1976b) suggested that the major drop in the marine limit associated with the event was evidence of a halt in ice retreat or possible minor readvance. This major drop in the marine limit has been disputed (Armstrong, Paterson and Browne,1975; Browne, 1980; Browne et al., 1981a) on the basis of high level marine clays lying within the suggested ice limits. Smith and Cullingford (1981) have contested the evidence of the high level marine clays but this matter remains unresolved.

In the Achnasheen (Fig. 8) area Sissons (1982a) identified a series of moraines produced during an ice sheet readvance. He proposed that a glacial readvance occurred in this area and resulted in the formation of an ice-dammed lake. Sissons (1982a) suggested that the readvance may be correlated with the Wester Ross Readvance but admits that such a correlation has associated problems. As a result he concluded that the relation of the Achnasheen Readvance to other glacial events in Scotland is unknown.

b) Stillstands and Readvances: Western Scotland

An early stage of deglaciation in the South Western Inner Hebrides was identified on Islay (Dawson, 1982, 1983)(Fig. 8). In central Islay a moraine associated with a distinct Lateglacial shoreline is thought to have been produced at one of the several margins of the Late Devensian ice sheet. The extensive nature of the deposits and the drop of the marine limit across the moraine has been interpreted to represent a major halt in ice sheet decay (Dawson, 1982, 1983a) On the basis of location and shoreline gradient Dawson (1982, 1983a) considers this to be one of the earliest known recessional limits of the Scottish ice sheet.

In SW Argyll Sutherland (1981b) proposed that a readvance or stillstand (the Otter Ferry Stage) occurred circa 12 900 yrs B.P. in the Cowal Peninsula (Fig. 8). The ice limit is associated with a well developed raised shoreline. Sutherland (1981b) suggested that the ice margin remained stable for 200-400 years while relative sea-level fell 20-25 m. Sutherland (1981b) also proposed that the readvance was caused by an increase in precipitation which resulted from the northward passage of the polar oceanic and atmospheric fronts around 13 000 B.P. as proposed by Ruddiman and McIntyre (1981). Sutherland (1981b p. 251) tentatively correlated the Otter Ferry Stage with the Perth Stage, on the basis of similar marked drops in the marine limit and similar shoreline gradients.

Farther north Synge (1966) and Synge and Stephens (1966) proposed a stage in ice sheet retreat which was represented by the Oban Ford Moraine (Fig. 8). It was suggested (Synge and Stephens, 1966) that the moraines were associated with a high sea level at 130-140 feet (40-43 m) and represent a synchronous major readvance. Gray and Sutherland (1977) suggested that the ice limits do not mark a readvance or significant, synchronous, recessional stage but more probably brief, diachronous halts in the general recession. In the case of the ice limit near Ford at the south end of Loch Awe, Sutherland (1981b) suggested that it may be correlated with the Otter Ferry Stage on the basis of a fall in the marine limit of at least 11 m.

In western Inverness-shire (Fig. 8) Peacock (1970) noted that high raised beaches terminate at the mouths of sea lochs or slightly within them. Farther inland lower Lateglacial shoreline fragments were identified. Peacock (1970) tentatively suggested that the termination of the high raised shoreline fragments may be related to a readvance or stillstand during the recession of the Scottish ice sheet.

In Wester Ross (Fig. 8), Robinson and Ballantyne (1979) identified an end moraine which they traced intermittently over 30 km (Fig. 10). They suggested that the moraine was formed during a readvance. Price (1983) disagrees with this view and considered that a stillstand during the ice sheet recession could have produced the same feature. Sissons and Dawson (1981) later showed that the Wester Ross Readvance is associated with a gradual drop in relative sea-level as the ice retreated. As no major local fall in the marine limit occurs, correlation with the Perth and Otter Ferry Stages could not be made.

4. Final Deglaciation and the Loch Lomond Readvance

Sissons (1976b) and Price (1983) suggested that the Late Devensian ice sheet had disappeared by circa 12 500 B.P. Sissons suggested that as the downwasting proceeded, mountains and hills gradually appeared above the ice surface, the ice becoming increasingly restricted to valley floors and basins. This interpretation of total ice sheet decay is supported by biostratigraphical evidence. Studies of coleoptera (Coope and Brophy, 1972; Bishop and Coope, 1977) and marine shells (Peacock, 1975, 1980) indicate that large parts of Scotland were ice free by 13 000 B.P. and that the climate was as warm as present (Bishop and Coope, 1977). Study of over 60 pollen sites indicates vegetation growth during the Lateglacial Interstadial (Sissons, 1976b). The oldest ^{14}C dates from basal organic deposits vary between 12 750^{+120}_{-120} B.P. (Lowe, in Sissons, 1976b) and 13 151^{+390}_{-390} B.P. (Sissons and Walker, 1974). In addition Ruddiman and McIntyre (1981) suggested that at circa 13 000 B.P. polar waters withdrew from the Scottish coastline and were replaced by warmer waters.

The biostratigraphical evidence is in contrast with the ideas proposed by Sutherland (1981b). He suggested that an ice advance occurred at Otter Ferry at circa 12 900 B.P. and that ice remained in the are for 200-400 years. Sutherland (1980, 1981b) suggested that the pollen evidence may have been misinterpreted since the basal ^{14}C dates may be too old as a result of contamination. He also suggested (1981b) that no tangible evidence of total ice sheet decay exists, so that ice may have remained in Scotland during the whole of the Lateglacial Interstadial. This idea was earlier proposed by Peacock (1970) and Sugden (1970) the former having suggested that the volume of ice involved in the Loch Lomond Readvance could not have accumulated in the time available.

Studies of coleoptera (Bishop and Coope, 1977) indicate that after 12 000 B.P. the climate deteriorated and by circa 11 000 B.P. Scotland was subject to severe periglacial conditions. This deterioration coincided with the passage of the polar oceanic and atmospheric fronts southward (Ruddiman and McIntyre, 1981). This cold period has been termed the Loch Lomond Stadial (Sissons, 1967, 1974a, 1976b, 1979d) and is associated with an advance or readvance of valley glaciers and the development of an ice cap in the Western Highlands (Fig. 10). During this period extensive periglacial erosion has been suggested in coastal areas (Sissons, 1974b, 1976a, 1979; Gray, 1978; Dawson, 1980b). Detailed former environmental conditions have been proposed on the basis of former glacier limits (Sissons and Sutherland, 1976; Sissons, 1980). The stadial ended at circa 10 300 B.P. (Gray and Lowe, 1980) with rapid climatic amelioration, as the polar fronts moved poleward to locate north of the British Isles (Ruddiman and McIntyre, 1981).

5. Late Devensian Events in the Inner Moray Firth

Since 1900 a number of authors (eg. Horne and Hinxman, 1914; Ogilvie, 1923, J.S. Smith, 1968; Synge, 1977a) have investigated the deglaciation of the Inner Moray Firth area. The early studies (Horne and Hinxman, 1914; Ogilvie, 1914, 1923) outlined a series of events associated with the deglaciation of the Late Devensian ice sheet. Interpretation of some of the features has been questioned (Synge, 1977a) and the underlying hypothesis relating to horizontal shorelines has been discounted (Sissons, 1962). Recent investigations have related raised shorelines to former ice limits (Synge, 1977a; J.S. Smith, 1977). The sequence of events proposed in these recent studies has rarely been questioned but they have proved difficult to reconcile with events in other areas of Scotland. (cf. Sutherland, 1981b).

a) The Early Studies

The officers of the Geological Survey (cf. Horne and Hinxman, 1914; Horne, 1923) described evidence relating to the maximum glaciation of the area. They identified, from studies of erratics and striae, two separate directions of ice sheet movement in the study area (Fig. 11). Horne (1923) noted that the ice which flowed across the lowland belt south of the Moray Firth was deflected by ice radiating from Ross-shire. At higher elevations more northerly ice movements are indicated but the relationship of these to lower striations are unknown (Horne, 1923). The last ice sheet glaciation

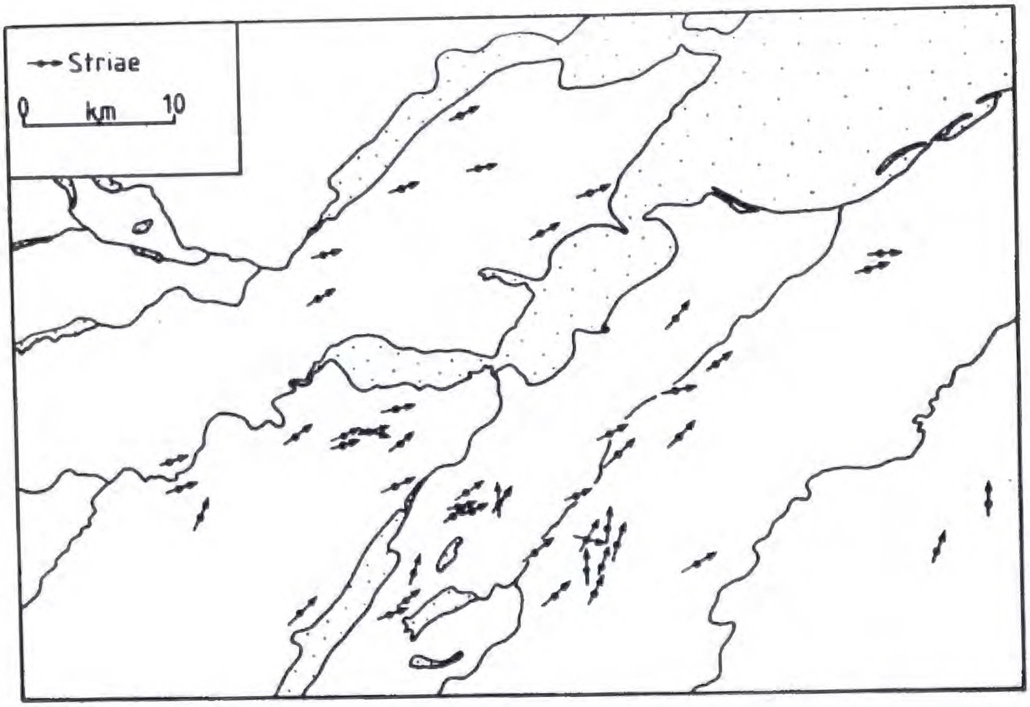


FIGURE 11 Striae in the inner Moray Firth area (after Horne and Hinxman, 1914; Horne, 1923).

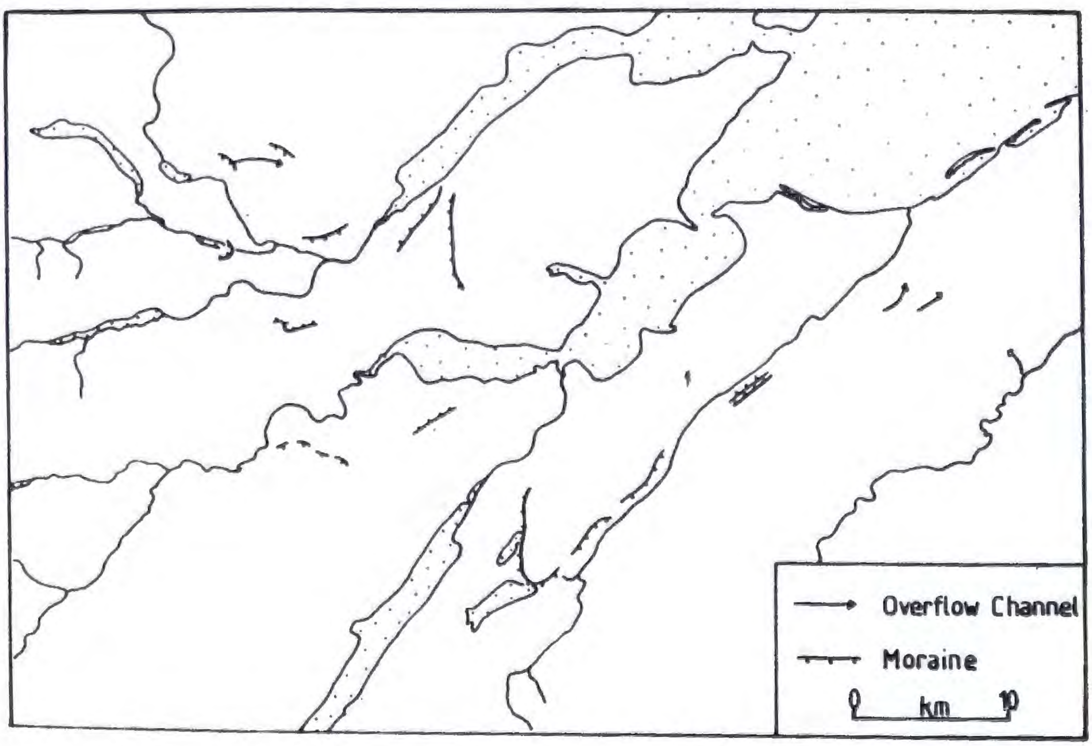


FIGURE 12 Ice marginal features in the inner Moray Firth area as identified by Horne and Hinxman (1914) and Horne (1923).

was considered to have been followed by a period of valley glacier development. Ice marginal features were noted at several locations (Fig. 12) and terminal moraines were described south of Kiltarlity and west of Muirton Maines (Horne and Hinxman, 1914). At Muirton Mains Horne and Hinxman (1914) suggested that the terminal moraine rests upon the 100 foot beach. This same water level was associated with an ice margin at Muir of Ord, so this sea-level was attained during the retreat of the ice mass. Subsequently the ice readvanced to form the moraine at Muirton Mains.

Ogilvie, (1914, 1923) considered that 4 raised shoreline levels are represented in the Inner Moray Firth area at altitudes of 90, 50, 25 and 15 feet, although he noted that raised marine features also occur at other altitudes. In the Strath Conon and Muir of Ord areas Ogilvie (1923) suggested that ice contact features are contemporaneous with a "90 foot" beach. He also suggested that lower beaches may have been over-ridden by readvancing ice, or have large kettleholes associated with them. Ogilvie did not present a detailed discussion of deglaciation events in the study area.

b) More Recent Studies

More recently J.S. Smith, (1968) and Synge (1977a) have suggested a pattern of deglaciation for the Inner Moray Firth area. The first stage of deglaciation was described as a general down-wasting and retreat of the ice mass (J.S. Smith, 1968, 1977), which resulted in a series of fluvio-glacial deposits in the area between Inverness and Forres (Fig. 13). Synge (1977a) and Synge and Smith (1980) suggested that the ice initially retreated as far as Inverness, because the highest shoreline described by them is found at this locality (Fig. 13).

A subsequent readvance of ice to the Ardersier-Chanonry

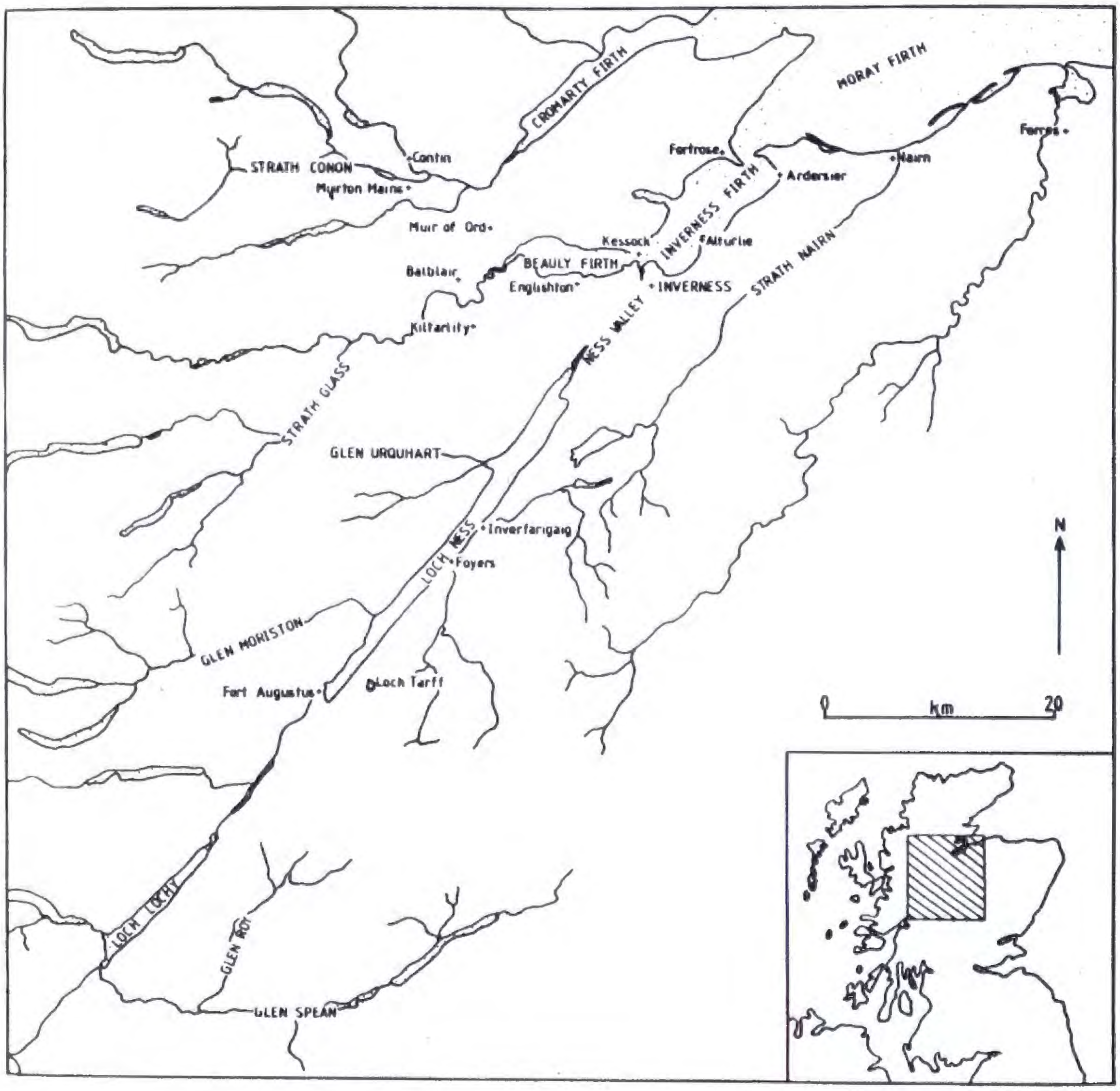


FIGURE 13 Locations in the inner Moray Firth and Loch Ness areas referred to in the text.

Ness Points has been advocated by several authors (Kirk, Rice and Synge, 1966; J.S. Smith, 1968; 1977; Synge, 1977a). This event is reported to be represented by a large morainic ridge west of Inverness airport, which extends as far as Ardersier village.

The Ardersier Readvance is reported to have been followed by ice retreat to Alturlie (Fig. 13) where a large morainic feature pitted by kettleholes is said to mark a halt of the retreating ice margin in the firth (Synge and Smith, 1980). J.S. Smith (1968) and Synge (1977a) suggested that this retreat stage is associated with the esker system at Torvaine in the Ness Valley (Fig. 13). Synge (1977a) also suggested that the above features are of the same age as a lateral moraine on the eastern slopes above Loch Ness. The ice continued to retreat from this limit until ice streams in the Beauly Firth and in the Great Glen became separated. The termini of these ice streams are claimed to be marked by extensive outwash deltas at Kessock and Inverness (Fig. 13). Synge (1977a) suggested that these deltas were produced when relative sea-level was at 33-34 m. J.S. Smith (1977) suggested that this ice limit was associated with an esker which he traced for nearly a mile along the slope south of Lentran (Fig. 13).

Synge (1977a) and Synge and Smith (1980) proposed that the ice then retreated westward along the Beauly Firth as far as Englishton, while in the Great Glen the contemporary ice margin was located in Glen Urquhart and at Inverfarigaig (Fig. 13). In the Great Glen this ice limit was associated with a high lake level, while in the Beauly Firth an outwash fan at Englishton was suggested to have been produced while sea-level remained at 34 m. Synge (1977a) suggested that sea level later fell to a low level close to

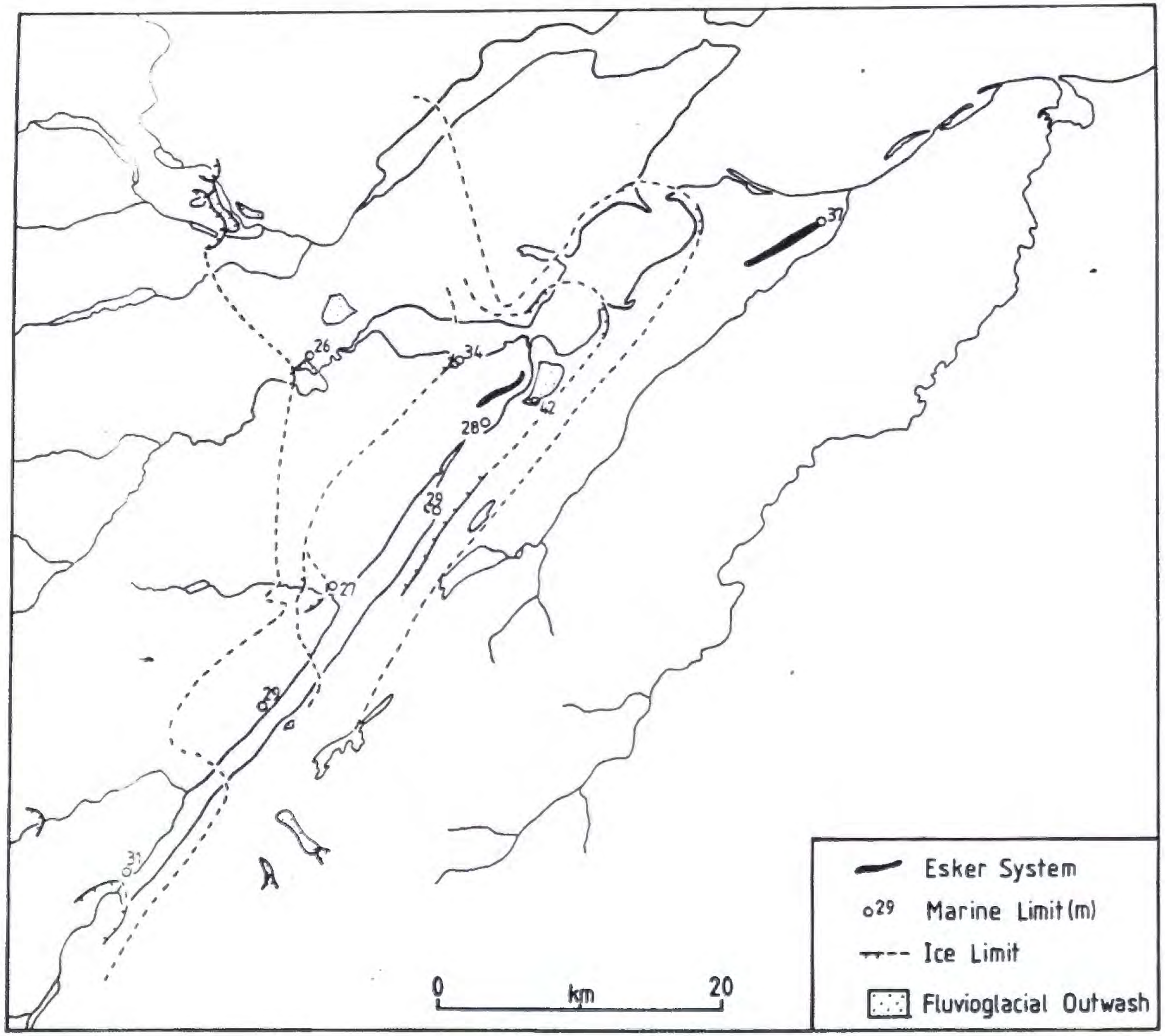


FIGURE 14 Late Devensian ice limits in the inner Moray Firth area as proposed by Synge (1977a) and Synge and Smith (1980).

present to form a large fan at Bunchrew. However this view has been challenged by Haggart (1982).

The next recessional stage is said to be marked by outwash deposition at the Muir of Ord (Fig. 13). Synge and Smith (1980) suggested that during this period of deposition ice occupied the Conon Valley. However, J.S. Smith (1968) suggested that the outwash fan had been deposited during a marine regression, the sea initially penetrated as far inland as Muirton Mains. Such an interpretation is not in accord with the ice contact topography described by Ogilvie (1923) in the Muir of Ord area.

It was also proposed that relative sea-level rose while meltwaters formed outwash spreads at Contin and Balblair (Kirk et al., 1966; Synge, 1977a; Synge and Smith, 1980). These outwash spreads are said to be associated with a prominent "sea-level notch" around much of the coastline and within Loch Ness. Synge and Smith (1980) suggested that this shoreline is associated with a moraine near Glendoe Lodge (Fig. 14) although they do not present evidence to support this correlation.

The events described are considered by Synge (1977a) to have been followed by a period of ice decay. Palynological investigations at Loch Tarff (Pennington et al., 1972) indicate that the ice retreat was followed by the milder climatic conditions of the Lateglacial Interstadial. The pollen diagram also indicates a later climatic deterioration during the Loch Lomond Stadial. During this period ice is considered to have advanced northwards along the Great Glen and terminated at the southern end of Loch Ness (Synge, 1977a; Sissons, 1979c). A separate glacier advanced to 10 km west of Loch Ness in Glen Moriston (Sissons, 1977). Synge (1977a) suggested that this ice advance was not related to a former lake level in Loch Ness. In contrast Sissons (1979a) suggested that the altitude of Loch Ness was at 22.5 m at its southern end during this period. Sissons (1979a, b, c, 1981b) suggested that the large ice-dammed lakes in the vicinity of Glen Spean and Glen Roy drained catastrophically to form large outwash spreads at Fort Augustus (Fig. 13). The volume of water involved temporarily raised the level of Loch Ness by 8.5 m. This high lake overspilled at the northern end to drain, via the gorge it cut, into the Beauly Firth. Relative sea-level at this time (the end of the Loch Lomond Stadial) was suggested to be at circa 2m (Sissons, 1981b). Sissons (1981b) also suggested that during the Loch Lomond Stadial extensive marine erosion occurred in the Beauly Firth. He also disputed the evidence presented by Synge (1977a) which indicated that the sea entered Loch Ness during the Lateglacial.

The age of the reported retreat and readvance stages are unknown except for those associated with the Loch Lomond Stadial. Synge (1977a) suggested that the prominent shoreline around Loch Ness was produced circa 12 600 B.P. when the ice was located at Balblair and Contin. A similar pattern of deglaciation was proposed for the Cromarty Firth (Peacock, 1974, 1981). Study of the marine deposits in the Cromarty Firth (Peacock, 1974; Peacock, Graham and Gregory, 1980) has indicated that the deepest marine deposit may be correlated with the Clyde beds of the Forth and Clyde estuaries Radiocarbon dates from Central Scotland suggest that such deposits formed between 13 500 and 10 000 B.P. Peacock (1974, 1981) suggested that the lack of earlier Errol and St. Abbs Bed deposits may indicate the area was covered by ice prior to 13 500 B.P.

In contrast to the late deglaciation dates proposed above the ^{14}C date from the basal organic material from Loch Droma of 12 810 $^{+155}_{-155}$ B.P. (Kirk and Godwin, 1963) has been interpreted to indicate early deglaciation of the area (J.S. Smith, 1968) and Scotland as a whole (Sissons, 1984a, 1976b). Recent studies of Sutherland (1980, 1981a) have suggested that the date may be too old due to contamination.

The suggested events for the Inner Moray Firth are problematical For example the Ardersier Readvance proposed by Kirk et al. (1966) is not linked anywhere to a specific sea-level. The Lateglacial relative sea-level movements are far more complex than any other area of Scotland, and in some cases shoreline fragments lie within ice limits which they predate. As a consequence it is felt that no logical sequence of ice sheet deglaciation has been demonstrated in the Inner Moray Firth area.

6. Late Devensian Events Peripheral to the Inner Moray Firth

Beyond the inner Moray Firth deposits and landforms relating to the Late Devensian have been identified (eg. Peacock et al., 1968; Smith, 1968). To the north of the Beauly Firth in the Cromarty and Dornoch Firths raised shoreline fragments of Lateglacial age have been identified at several levels (Ogilvie, 1926, J.S. Smith, 1968), however no attempt has been made to relate these directly to stages in the retreat of the last ice sheet. Ogilvie (1926) did remark upon the western termination of high shoreline fragments in the Dornoch Firth and this was interpreted by Sissons (1967) as a possible location for a drop in the marine limit associated with an ice margin. However, the only detailed research carried out in this area was by Peacock (1974) and Peacock et al. (1980) who suggested that the Cromarty Firth may not have been deglaciated until sometime after 13 500 B.P.

To the east of the study area more detailed studies are available. It has long been recognised (Jamieson, 1865; Bremner, 1934) that more than one till is present east of Elgin. Bremner (1934) suggested that the ice which finally advanced across the Elgin area came from the North-west; and both Synge (1956) and Peacock et al. (1968) have proposed that this ice movement was a readvance of the last ice sheet (the limits of this readvance lying from Buckie to Whitechurch, Peacock et al., 1968). More recently it has been proposed that the limit of the Late Devensian ice sheet may have possibly lain in this general area (Synge and Smith, 1980; Sutherland, 1984). As the ice withdrew so marine features were formed and these have been reported by Ogilvie (1926) and Peacock et al. (1968). Peacock et al. suggested that shorelines were present which declined in altitude towards the east, but no mention was made of associated ice limits or major drops in the marine limit. However, Peacock et al. (1968) do draw attention to considerable deposits of glacio-lacustrine silty-clays which occur just east of the present study area near Forres. These silty-clays range in altitude from circa 50ft (15.2m) to 100ft (30.5m), whilst the highest marine feature in the area is reported at 50ft (15.2m) (Peacock et al., 1968) near Grange Hall (NJ 064 606). The considerable extent of the glacio-lacustrine deposits suggests the presence of a former ice dammed lake at the mouth of the river Forres. Shoreline fragments associated with such a lake may therefore be present in the eastern section of the present study area.

Farther east near Loch Spynie glacio-marine deposits have been identified (Buchan, 1935). Buchan (1935) noted that the glacio-marine deposits contain numerous drop stones and a fauna which included the arctic species Portlandia arctica (Gray) and Ophiolepis gracilis (Allman). Buchan suggested that the deposit could be correlated with the Clyde Beds, but Peacock (pers. comm.) suggested that the arctic fauna indicated correlation with the Errol Beds to be more likely. There is therefore evidence to suggest that initial deglaciation in the Moray Firth occurred whilst actic waters were still present. To what extent these arctic waters remained during initial deglaciation is unknown, but Peacock (1974) and Peacock et al. (1968) have suggested that a climatic amelioration had occurred by the time the Cromarty Firth was deglaciated.

7. Summary

Late Devensian glacial events in Scotland remain largely speculative even though considerable research has been undertaken (cf. Sissons, 1981a). The development and limits of the Late Devensian ice sheet are still largely unknown, although ideas of a smaller ice sheet are becoming more popular. The pattern of deglaciation is largely unknown, although stillstands and/or readvances have been proposed. Problems still exist over the final decay of the ice sheet and the possibility exists that ice may have remained in the Highlands during the Lateglacial Interstadial. The limits of the Loch Lomond glaciers and the associated environment are well known for large areas of Scotland. In the Inner Moray Firth area the proposed pattern of deglaciation is not entirely logical.

CHAPTER FOUR

FIELD METHODS AND DATA ANALYSIS

1. Introduction

Sissons (1962, 1963a) outlined a series of problems associated with previous Scottish raised shoreline studies. He suggested the use of a detailed unselective methodology (eg. Sissons and Smith, 1965a) to solve some of these problems. This methodology has been reviewed (Gemmell, 1975; Gray, 1975, 1983; Rose, 1981) and debated on several occasions (Sissons, 1967; Synge and Stephens, 1967), but remains the basis for many Scottish shoreline studies (Fig. 15). In order to allow comparisons with other research, the present study adheres to the suggested methodology, but where applicable modifications have been made. The methodology consists of field methods (morphological mapping, stratigraphical studies, altitudinal determination) and data analysis.

2. Field Methods

a) Morphological Mapping

All marine, glacial and fluvial features below 100 m O.D. were mapped unselectively at a scale of 1:10 000. The maps portray specific landforms by symbols modified from Sissons and Smith (1965a) and Gray (1975) (Fig. 16). The mapping allowed the relationships between specific features to be determined and an assessment for later altitude determination to be made (cf. Cullingford, 1972). In the Ness Valley area (Fig. 46) the mapping was initially undertaken from aerial photographs and later modified in the field.

b) Stratigraphical Studies

The sedimentary composition of depositional features and of erosional forms was determined by the use of a soil auger. Further

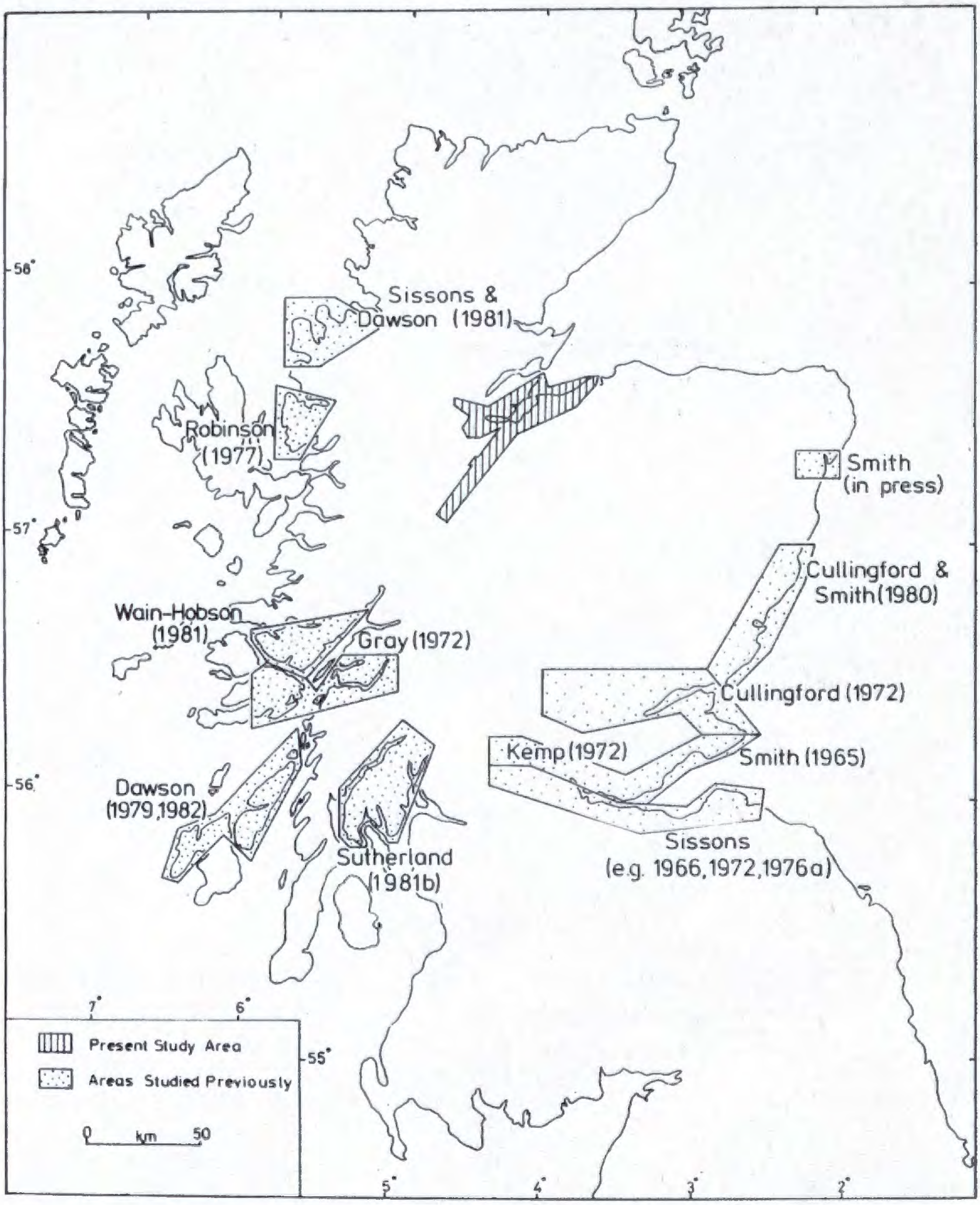


FIGURE 15 Location of areas where detailed, systematic studies of relict shoreline altitudes have been completed in Scotland (modified from Gray, 1983).

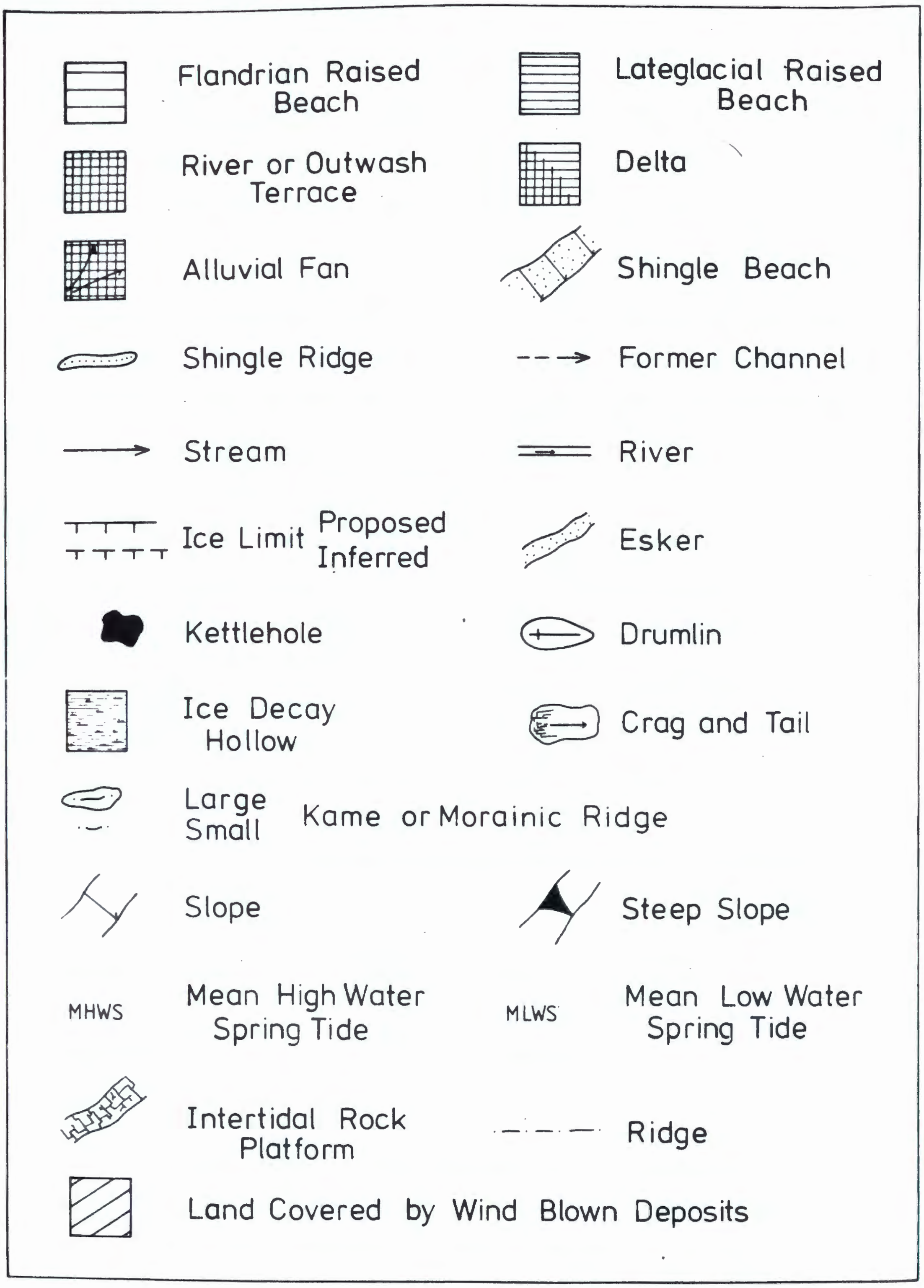


FIGURE 16 The morphological map symbols used in the thesis.

work was conducted using a Hiller peat borer with auger attachment in order to identify the general stratigraphy in areas of 'carse' deposits. Haggart (1982) outlined a detailed Flandrian stratigraphy for specific sites in the study area. As a result the present study was confined to the identification of specific horizons, (ie. the 'buried gravel layer' Sissons 1981b). The methodology adopted was that used by Sissons (1981b), the boreholes being located at 20 m intervals from the landward limit of 'carse' deposits. Once consistency was obtained in the borehole stratigraphy the coring locations were spaced at 50 m intervals. Each borehole surface altitude was determined by instrumental levelling from Ordnance Survey Bench Marks (Newlyn Datum). The tilt of each auger hole from vertical was measured using a clinometer and corrections were applied to the depth measurements. In practice the tilt ranged from 2° to 7°. By using such techniques 196 augerholes were recorded. This information was supplemented by detailed observations of sediment stratigraphy in natural sections and by the study of commercial borehole records.

c) Altitude Determination

The altitudes of all well-developed raised shoreline fragments, fluvio-glacial and fluvial terrace fragments were determined at 50 pace (approx 50 m) intervals. This procedure permitted the gradients of specific features to be determined and in this way, where other evidence was not forthcoming, relict outwash features were distinguished from marine terraces; the former having considerably steeper gradients (Sissons and Smith, 1965a). In addition the altitudes of specific features, such as the lowest points on the rims of kettleholes, were also determined. All altitudes were obtained by instrumental levelling from Ordnance Survey Bench Marks (Newlyn Datum), using

Zeiss and Wild automatic levels reading to 0.01 m. The level was checked for collimation errors and adjusted as necessary every two weeks during fieldwork. Any traverse with a closing error greater than 0.10 m was repeated.

Various staff positions were adopted depending upon the type of feature being surveyed. On terrace fragments the altitude was determined 3-5 m away from the break of slope at the rear of the feature. The measured point thus avoided areas covered by colluvium, yet the altitudinal difference between this point and the buried break of slope was minimized (Fig. 17). This is thought to be important on steeply sloping beach fragments (Gemmell, 1975) which are common in the study area. On shingle ridges the staff was positioned at the crest of the feature. The altitudes determined for the various features were subjectively classed as being of good, moderate or poor quality.

d) Errors Associated with the Field Methods

The correlation of shoreline fragments on the basis of altitude requires a knowledge of the precision of the field data. Within the data set there are three possible types of error: observational error, instrumental error and inherent landform error.

i) Observational Error

In any study gross observational errors, such as misreading a staff, can occur. By using the field methods outlined above such errors are minimised since each feature was mapped and levelled on separate occasions, and each altitude was viewed in the context of those around it.

Certain observational errors are dependent on the operator. In this study the positioning of the staff during altitude determination was the most subjective operator-controlled element. In order

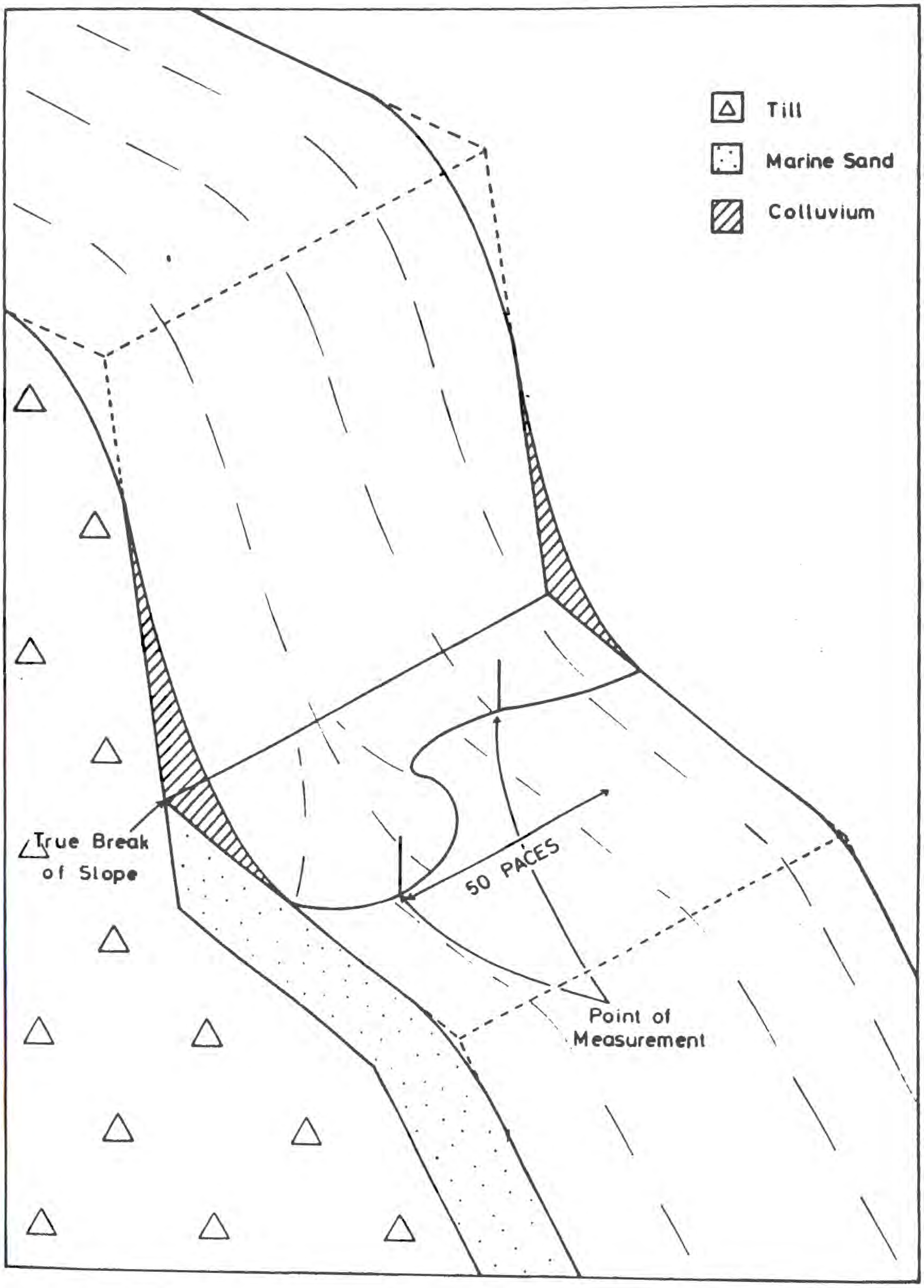


FIGURE 17 The location of the break of slope of a terrace fragment and its relation to the actual point of measurement.

to produce consistent results the author always positioned the staff. A measure of the possible altitude variation caused by selecting the staff position was made by remeasuring three fragments of various quality. After 6 or more months a site was remeasured, the altitude being determined at the same point initially marked on the map (Table 4). The results suggest that the staff holder could vary the altitude of a measured point by as much as 0.29 m on a 'poor' feature, but most altitudes had a possible variation between 0.05 m and 0.15 m.

ii) Instrumental Error

Instrumental errors consist of datum errors within the Ordnance Survey Bench Marks System and errors caused during the traverse by slight misalignment of the instrument. The datum errors in the Bench Mark network are dependent upon the type of bench mark in use (Geodetic, Secondary or Tertiary) and the distance between Bench Marks (Seymour, 1980) (Table 5). As the area has a high density of Bench Marks it is reasonable to suggest that all the Bench Marks altitudes are regionally correct to 0.02 m. Large errors in the datum altitudes were avoided by checking the altitude of one Bench Mark against another when there was possibility of movement (for example, in the case of Bench Marks situated on milestones), but at no time was this found to have occurred. Errors caused by misalignment of the level are in part indicated by the closure error of the traverse and could reach a maximum of 0.10 m but rarely exceeded 0.05 m. Sutherland (1981b) suggested that such errors could be distributed throughout the traverse but as the closure error did not entirely consist of collimation errors this process was not undertaken.

Quality of Fragment	Location	Original Altitude	Resurveyed Altitude	Difference
Poor	Avoch (NH 6983 5379)	12.42m	12.56m	0.14m
		12.82m	12.53m	0.29m
		13.06m	12.90m	0.16m
		13.32m	13.25m	0.07m
			Mean difference	0.184m
	Estimate of inherent uncertainty		0.354m	
Moderate	Munlochy (NH 6359 5238)	29.61m	29.64m	0.03m
		29.37m	29.28m	0.09m
		29.74m	29.28m	0.11m
		29.01m	29.05m	0.04m
		29.58m	29.51m	0.07m
			Mean difference	0.068m
	Estimate of inherent uncertainty		0.242m	
Good	Wester Lovat (NH 5415 4611)	6.61m	6.65m	0.04m
		6.77m	6.74m	0.03m
		6.77m	6.79m	0.02m
		6.70m	6.68m	0.02m
		6.60m	6.69m	0.09m
			Mean difference	0.040m
	Estimate of inherent uncertainty		0.064m	

TABLE 4 Comparison of initial and secondary survey altitudes on certain shoreline fragments.

Order of Bench Mark Network	Inherent Error	
Geodetic	± 2F mm	
Secondary	± 5F mm	F= distance between bench marks (km)
Tertiary	± 12F mm	

TABLE 5 Errors associated with the Ordnance Survey bench mark networks (Seymour, 1980).

Physiographic Constraint	Definition
Staircase	Raised beaches that occur one above the other cannot be contemporaneos with each other.
Continuity	Raised beach fragments which are connected by an unmeasured section must be contemporaneous with each other.
Ice-margin	Shoreline fragments which are correlated with an ice margin cannot be correlated with raised beaches which lie within the said ice margin

TABLE 6 Physiographic constraints used in the analysis of shoreline altitude data. (Cullingford, 1972).

iii) Inherent Landform Error

As the point of measurement is affected by the extent of colluvium some variability will occur in the altitude of the point of measurement along a fragment (Fig. 17). A measure of this variability was calculated by Sutherland (1981b, p. 73) which he called an "estimate of inherent uncertainty of the landforms". Using Sutherland's (1981b) equation 'estimates of inherent uncertainty' were calculated for the remeasured fragments and were found to range from 0.35 m for 'poor' terrace fragments to 0.06 m for 'good' features (Table 4).

When all these errors are combined it is suggested that the magnitudes of the altitude error associated with specific landforms are 0.55 m for 'poor' features, 0.32 m for 'moderate' features and 0.16 m for 'good' features (Table 4). Such errors are only applicable to the present study. The magnitude of the errors signifies that shorelines separated vertically by more than 1.20 m should form discrete populations. If only 'good' and 'moderate' altitudes are used, then shorelines as close as 0.70 m should be separable. In practical terms the errors indicate that separate shorelines can be identified if they have an altitude separation of 1 m or more.

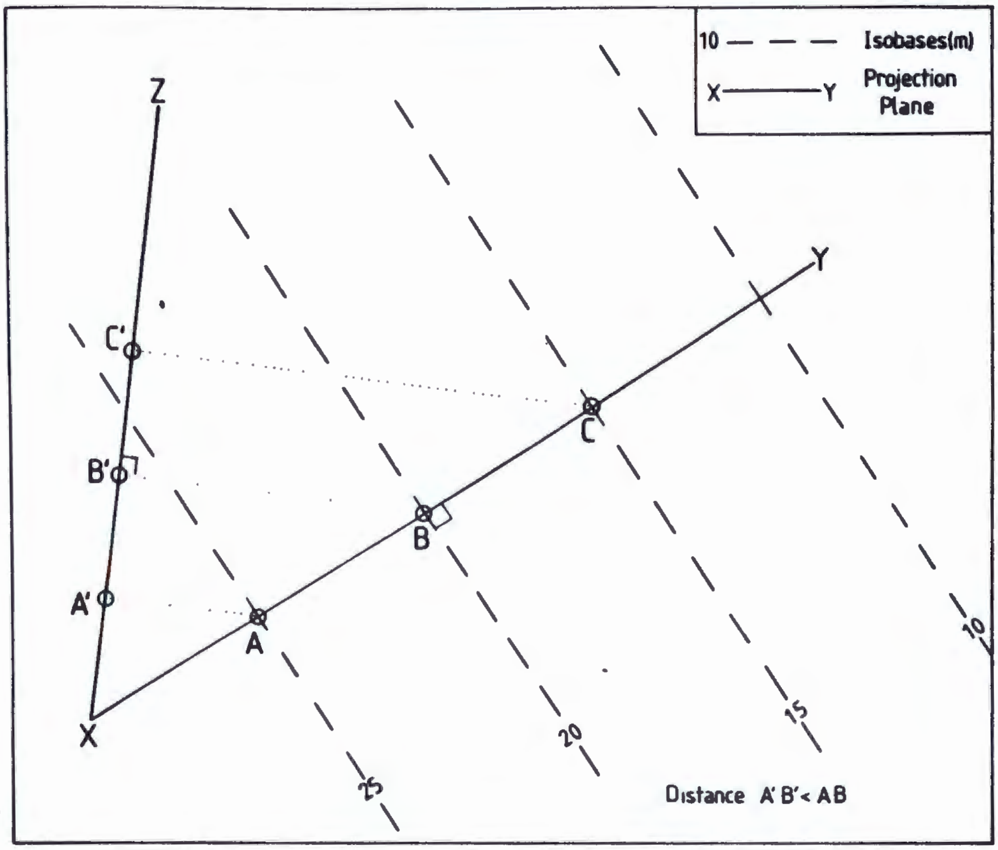
3. Data Analysis

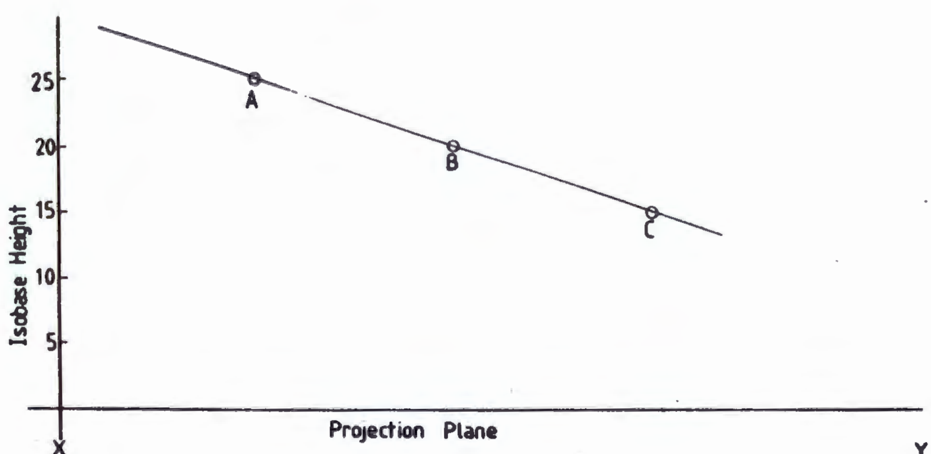
The data analysis involved an as objective study as possible of the altitudinal information within the constraints of morphological analysis. One of the prerequisites of such a study is an understanding of the relationship between the altitudes of raised shoreline fragments and former water levels. Kidson (1982, p. 135) suggested that "... marine deposits cover such a wide range of heights from the seaward margin of the near shore to the crests of storm beaches, that they must be interpreted with great care". Storm beaches, shingle ridges, marine terraces, estuarine deposits and erosional marine terraces may all form at separate altitudes in relation to the same mean tidal level. It is often claimed that such differences can be corrected by the measurement of similar modern coastal features (eg. Smith, 1966; Dawson, 1979; Synge and Smith, 1980), but environmental changes (eg. variations in fetch, storm and tidal conditions) may invalidate such a process (Kidson, 1982). The only way to produce meaningful correlations between raised shoreline fragments is to compare similar features. Shingle ridges are features which bear little relation to mean tidal level (Kidson, 1982) and as a result are not used in the determination of former shorelines. In contrast measurement of modern coastal features in the study area (see Chapter 2) suggests that the break of slope associated with marine terraces is equivalent to Mean High Water Ordinary Spring Tide. Although such a relationship may be valid for Flandrian deposits (which formed in a similar sedimentary environment to modern terrace features) it may not be applicable for Lateglacial marine features.

The analysis of the altitudinal data was based on the equidistant shoreline diagram (Gray, 1975). Sutherland (1981b, p. 75) stated that such diagrams are "... graphical representations of landform altitudes in which the height of a particular feature (y-axis) is plotted with respect to the distance of the feature from a common origin, projected at right angles into a vertical plane running through the origin". The ideal plane of projection is normal to the isobases, but since the isobases are unknown for the area, a series of projection planes were produced at 15° intervals from a W-E aligned plane to one aligned SE-NW. The origin of the projection planes was the arbitarily chosen point on the National Grid NH 000 000. The altitude data was plotted on these planes and correlation of shoreline fragments made on the basis of marked alignments of points under morphological constraints (Table 6). Specific shorelines were only identified by using terrace fragments associated with altitude determinations considered as 'good' and 'moderate'.

It is critical that a projection plane normal to the isobases should be chosen, since Cullingford (1977, p. 16) stated that any "... deviations from this alignment cause distortions that may lead to miscorrelations, especially where vertical separation of successive shorelines is small". Within the literature (eg. Sissons et al., 1966; Cullingford, 1977; Sutherland, 1981b) conflicting opinions exist on how to determine the projection plane normal to the isobases. The earlier shoreline studies (eg. Sissons and Smith, 1965a; Cullingford and Smith, 1966; Sissons et al., 1966) selected the plane "... as being the one most nearly at right angles to the isobases so far as they are known at present" (Sissons et al., 1966, p. 10). In the study area only isobases for the Main Postglacial Shoreline have been suggested (Sissons, 1967; Jardine, 1982) but due to possible differences in the isobase patterns for separate shorelines (Gray, 1983) this pattern cannot be used for the study of Lateglacial shorelines. Sutherland (1981b) and Gray (1983) have suggested that the projection plane that produces the minimum gradient for a shoreline with the maximum correlation coefficient will be the one normal to the isobases. This statement is illustrated in Fig. 18 where points A, B and C are considered to lie on the isobases shown. By projecting the points onto a series of planes (eg. XY, XZ) it is evident that the line producing the minimum gradient is also that normal to the isobases. This hypothesis is based on a single line of data and as a result alterations in the relative positions of the points cannot be produced by altering the plane of projection.

FIGURE 18 The hypothetical diagram proposed by Sutherland (1981b) as evidence that the projection plane with the minimum gradient is normal to the isobases.


10 Isobases(m)
X Y Projection Plane
Z
Y
C'
B'
A'
A
B
C
X
25
20
15
10
Distance A'B'< AB


Isobase Height
25
20
15
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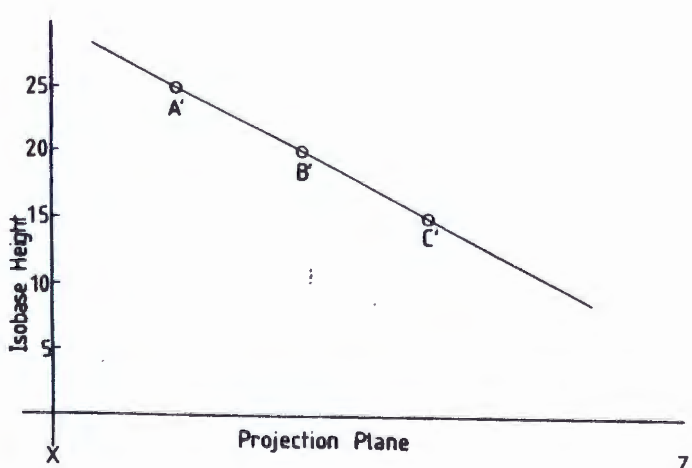
5
A
B
C
Projection Plane
X
Y

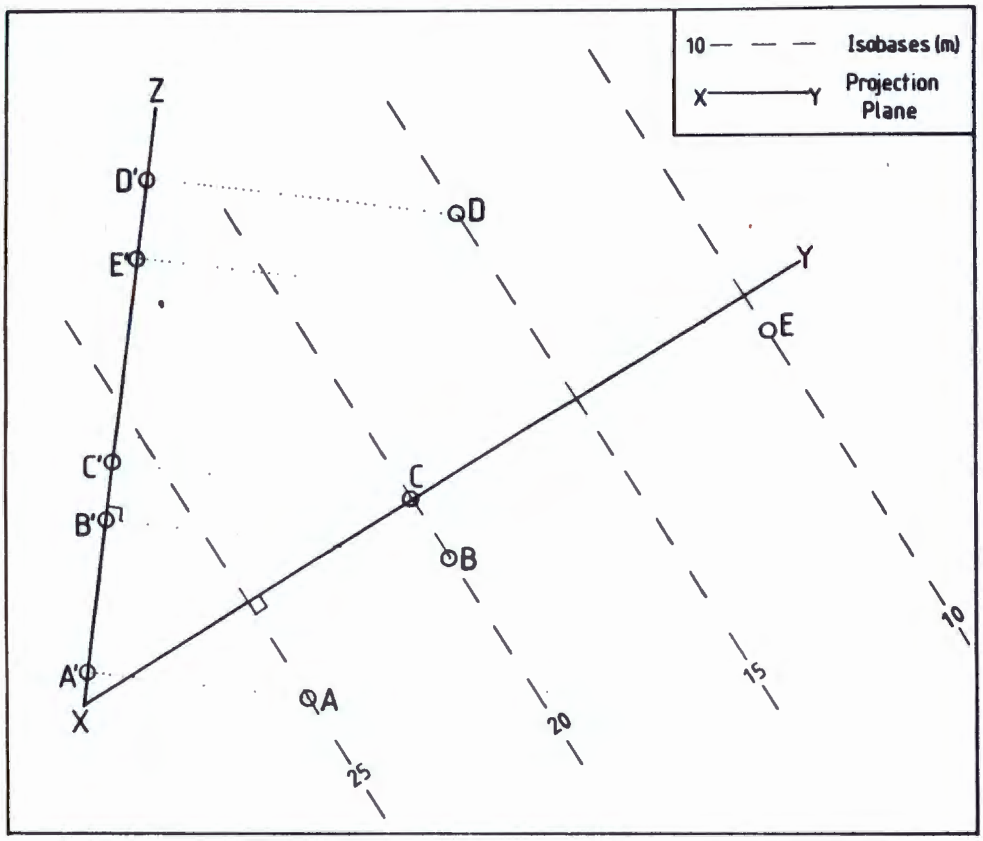

Isobase Height
25
20
15
10
5
A'
B'
C'
Projection Plane
X
Z

Shoreline fragments occur in a spatial distribution (Fig. 19) and as a result variations in the plane of projection can alter the locations of the fragments relative to each other. Cullingford (1972, 1977) suggested that the projection plane that maximises the correlation coefficient for a shoreline and maintains consistent decreases in the gradient of successive shorelines is the one that is approximately normal to the isobases. This relies on an a priori argument for the pattern of isostatic uplift which may not be valid.

In order to solve the above contradictions, two data sets were formulated for a hypothetical coast similar in general dimensions to the present study area. One set of data was produced for isobases which sloped at a gradient of 1.08 m/km in a direction N30°E while the second has the same slope and data points but is associated with isobases that slope in a direction N60°E. The points were projected onto a series of planes aligned from S-N to W-E and the gradients and correlation coefficients were calculated (Table 7). The results indicate that the correlation coefficient is the only reliable indicator of the plane lying normal to the isobases, since it maximises at this point. The gradient is thus dependent upon the relationship of the isobases to the spatial distribution of the data points.

Gray (1975) noted that shorelines associated with strong isobase curvature produce greater errors in the projection of points in relation to each other on an equidistant diagram. According to Sutherland (1981b) such shorelines are more likely to be associated with Lateglacial events. Therefore in this study the location of shoreline fragments was always considered when correlations were proposed. Marked isobase curvature may be associated with a wide spread of points and thus a reduced correlation coefficient for a specific shoreline in the equidistant diagram. In such cases data from localised areas was analysed separately in order to see if significant improvements

FIGURE 19 A hypothetical diagram which illustrates the fact that different projection planes can alter the relative position of data points to each other and thus invalidate the findings outlined by Sutherland (1981b).


10 — — — Isobases (m)
X——Y Projection Plane
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D'
E'
C'
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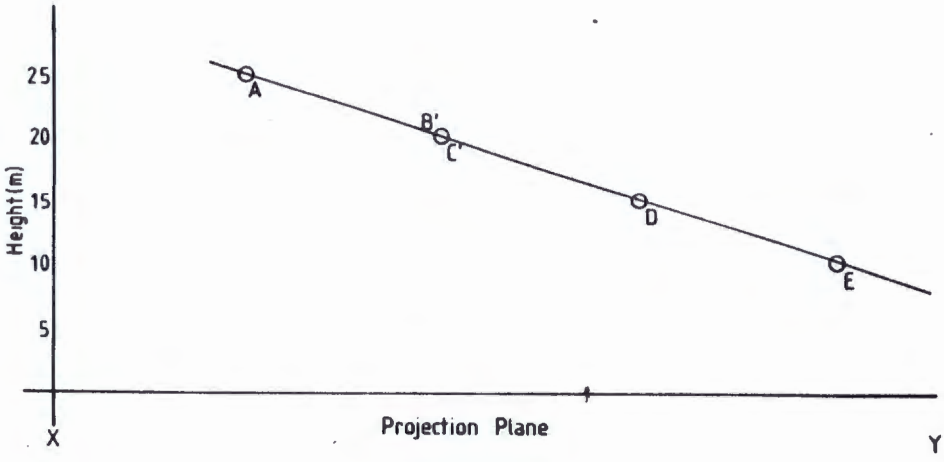
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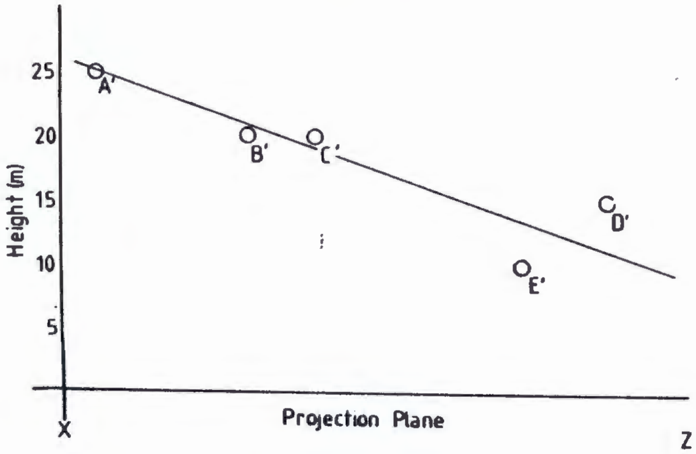
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Projection Plane
Z

Projection Plane	Gradient (m/km)	Correlation Coefficient
N-S	1.395	0.330
N15° E-S15° W	2.394	0.857
N30° E-S30° W	1.818	0.968
N45° E-S45° W	1.435	0.993
N60° E-S60° W	1.226	0.999
N75° E-S75° W	1.123	0.996
E-W	1.094	0.989

TABLE 7a Gradient and correlation coefficients produced from a data set associated with isobases declining in altitude towards N60° E with a gradient of 1.08 m/km.

Projection Plane	Gradient (m/km)	Correlation Coefficient
N-S	1.018	0.646
N15° E-S15° W	1.304	0.958
N30° E-S30° W	1.045	0.996
N45° E-S45° W	0.802	0.952
N60° E-S60° W	0.646	0.893
N75° E-S75° W	0.552	0.832
E-W	0.495	0.767

TABLE 7b Gradients and correlation coefficients produced form a data set associated with isobases declining in altitude towards N30° E with a gradient of 1.08 m/km.

in the fit of the data were achieved. If the data sets indicated differing isobase patterns then marked isobase curvature was accepted (similar patterns indicated either separate shorelines or poorly developed shorelines). If no improvement in the correlation coefficient was produced, the data was considered as a poor representation of a single shoreline or insufficient to distinguish shorelines where vertical separation is small.

The gradients of specific shorelines were determined by using minimum least squares linear regression analysis. The data produced by altitudinal determination of shoreline fragments is not wholly in accord with the prerequisites of such a statistical technique due to auto-correlation of altitudes from individual terrace fragments (Gray, 1975), and the non-independence of individual shoreline fragments (Tarrant, 1970; Gemmell, 1975). Since the correlation coefficient has been used as a criterion to define the projection plane normal to the isobases, it was important to minimise the first of these problems. Consequently the arithmetic mean of individual shoreline fragments was used (Gray, 1974a, 1983). Cullingford (1977 p. 17) noted that this technique is "... probably to be preferred in areas where the shoreline remnants are highly fragmented", as is the case in the present study area. Data grouping introduces three problems:-

i) how the mean position of the fragment is determined

ii) whether this position should lie on the original fragment

iii) loss of detail due to short fragments having an equal significance to longer fragments

The position of the fragment mean may be derived either from a projection plane, by identifying the mid-point; by obtaining the mean of the grid referenced points; or by identifying the centre point of the fragment (Sutherland, 1981b). Tests indicate that the position of the mean point varies by a few metres depending on the method being used and this has no effect on the final equidistant diagram. As a result shoreline fragment means were determined using the arithmetic mean of the grid referenced points.

Cullingford (1977) proposed that in order to avoid over emphasis of the short fragments, the longer fragments should be divided into two or more 'sub-fragments'. He noted that this technique involves problems in the choice of suitable 'sub-fragments' lengths. If the errors involved in altitude determination are known as well as the shoreline gradient, then lengths of the 'sub-fragments' can be calculated and this is illustrated in Fig. 20. For example a terrace fragment associated with a shoreline with a gradient of 0.5 m/km and a potential measurement error of 0.40 m would have to be traced over 800 m before one point could be distinguished from another. As the gradients could not be calculated until the 'sub-fragments' were derived a standard practice was used. Shoreline fragments were subdivided into 'sub-fragments' up to 500 m in length. Tests on specific shorelines (Table 8) indicated that this subdivision did not significantly affect shoreline identification nor did it alter shoreline gradients.

Sissons (1972) suggested that shorelines are better represented as zones of altitudinal data which are bounded by standard error bars. It must be remembered that some regional variation in the altitudinal data is due to variations in fetch and tidal regime. Standard error bars thus produce a shoreline zone in excess of that resulting from errors associated with altitude determination. Therefore, in this study the shorelines are represented as single lines. Shoreline residuals were also plotted on separate height distance diagrams and inspected to see if any patterns were evident. These were compared with possible

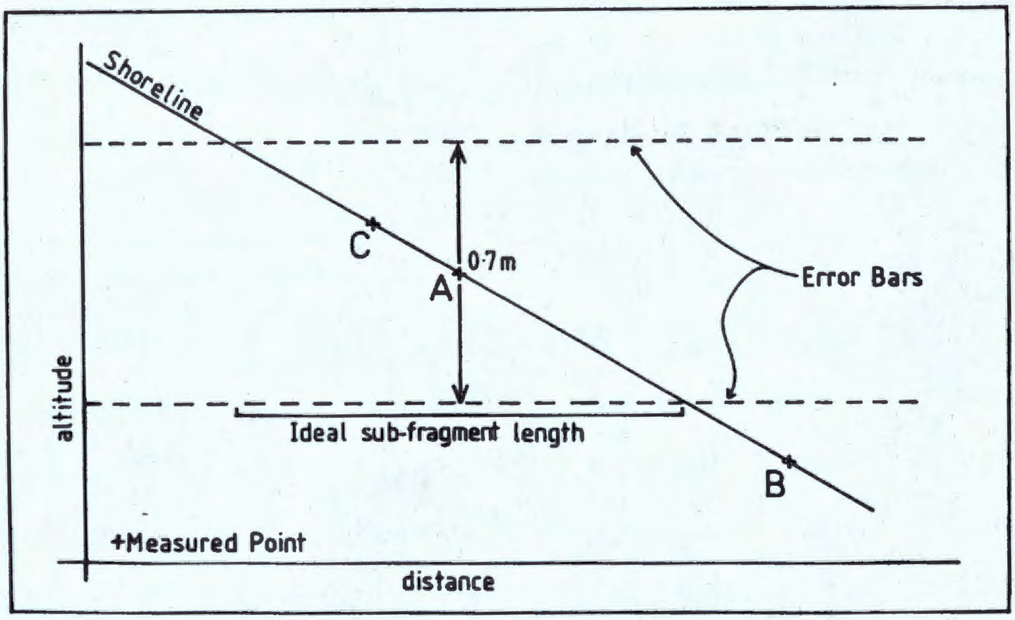


FIGURE 20 Diagrammatic representation of the ideal sub-fragment length. The error bar reffers to the altitude measurement error for a particular shoreline fragment. It can be seen that point C can easily be confussed with point A on the basis of the errors involved. For this reason it would be inappropriate to place these altitude measurements in different sub-fragments. In contrast point B is less likely to be confussed with point A so it could be placed in a separate sub-fragment. The length of the subfragment is therefore dependent upon the gradient of the shoreline.

Plane of projection (degrees E of N)	Gradient (m/km) With subfragments	Without subfragments
0	0.4077	0.2845
10	0.3177	0.3036
15	0.2724	0.2722
20	0.2373	0.2406
25	0.2099	0.2134
30	0.1886	0.1911
35	0.1719	0.1731
45	0.1482	0.1468
60	0.1280	0.1235
75	0.1190	0.1118
90	0.1180	0.1077

TABLE 8 Comparison of the gradients obtained from on Lateglacial shoreline (ILG_{8B}) when fragments longer than 500m were
a) divided into subfragments (with subfrags.)
b) used as single fragments (without subfrags.)

external factors.

As shorelines in areas affected by glacio-isostasy are displaced in two dimensions, it is possible to define the spatial displacement patterns by trend surface analysis (Smith, Sissons and Cullingford, 1969; Gray, 1974a, 1978; Cullingford and Smith, 1980). Gray, (1972a, 1975, 1978) noted that the shoreline data collected in Scotland was not entirely suitable for trend surface analysis due to clustering, non-independence and auto-correlation, but he claimed that such problems could be overcome by using arithmetic means for shoreline fragments. This claim was disputed by Doornkamp (1972) who suggested that the use of means is not valid since it reduces the variability of the data. However, Robinson (1972) and Gray (1972b) have demonstrated that the use of shoreline fragment means does not produce significantly different results from surfaces produced using all the data points. Tarrant (1970) and Gemmell (1975) suggested that shoreline fragments relate to a single surface whereas trend surface analysis attempts to fit a surface to a population with an expected normal distribution. The 'true shoreline' as represented by the buried break of slope (Fig. 17) will not produce a series of points with a normal distribution. The point of measurement on the shoreline fragment is influenced by the thickness of colluvium at the break of slope and the population derived from these points is likely to have a normal distribution. As a result the use of trend surface analysis is valid but individual shoreline surfaces are located below the 'true shorelines', which are buried beneath colluvium.

The spatial distribution of shoreline data tends to produce empty areas where boundary effects become important. Such effects become more pronounced as the trend surfaces reach higher orders. For this reason trend surface maps were only produced for the best developed shorelines to the cubic level using grouped data with an adapted programme (Whitten, 1964). The F-test was applied to decide if quadratic and cubic surfaces gave a greater understanding of the data distribution (Chayes, 1970). The residuals from the trend surface analysis were also plotted and resulting patterns compared to external factors.

4. Summary

Field techniques derived by Sissons and his co-workers were applied to the study area. The resulting data was analysed within the constraints of the errors associated with it in an as objective manner as possible. Where possible the original data was modified to be compatible with the statistical tests used. In this way a series of distinct raised shorelines was identified.

The Field Evidence

An Introduction to Chapters 5, 6, 7 and 8

The study area (Fig. 1) has been divided into four regions:

a) the Open Coastlands

b) the Inverness Firth

c) the Great Glen

d) the Beauly Firth

The field evidence relating to former sea levels and ice-sheet recession is presented for each of these regions in the next four chapters. For each region a map is presented to show the location of the major glacial features (including proposed ice-limits) and the location of the detailed morphological maps referred to in the text. In addition to table giving the mean altitude and location of all the raised marine and lacustrine features (which are divided into subfragments where appropriate) is also presented for each region. For each region specific localities are decribed in detail, with both the previous and present interpretations of the features and deposits being outlined and discussed. For each locality a local sequence of events is proposed. Detailed morphological maps (at 1:10 000) for areas not described in the text are available from the author.

In the study area extensive fluvio-glacial and glacial deposits occur which have an irregular hummocky morphology, and throughout the text these are referred to as kames (fluvio-glacial) or morainic ridges (glacial). Sections in these deposits are rare and often only reveal the upper 1-2 m of sediment. The sections which are available usually occur in gravel pits (eg. Dochgarroch Saw Mill, NH 6226 4118; Laggan Gravel Pit, NH 6295 3938; Moray Hill Sand Pit, NH 5732 4942; Mid Coul Gravel Pit NH 7756 5045) and usually display sand and/or gravel deposits which have been lain down by the action of running water. Peacock et al. (1968) have suggested that similar features and deposits to the east of Forres formed during in situ ice decay. However they noted that the deposits may have been lain down either supra-glacially or sub-glacially (cf. Gjessing, 1960). Since the actual mode of formation is uncertain and many of the sections reveal little evidence relating to ice retreat or relative sea level change they are not discussed within the thesis. Detailed accounts of the location and description of the sections are however available from the author. The hummocky deposits are therefore interpreted as having been overlain or underlain by ice when they were formed. In contrast terrace fragments and outwash deltas which have a regular undisturbed surface are considered not to have been underlain by ice when they were formed.

Throughout the study ice limits are placed along the margins of undisturbed fluvio-glacial deposits which lie adjacent to hummocky terrain or along terminal/lateral moraines. In the former case the ice lying adjacent to the ice margin may have been at the surface or buried and it may have been either 'active' or 'dead'. Where a moraine is present active ice is assumed to have been present. Ice margins associated with fluvio-glacial deposits must not therefore be interpreted as limits of active ice, mearly limits of ice masses.

Specific morphological features (marine/lacustrine/fluvio-glacial/ fluvial terraces and shingle ridges) are identified by a number with a prefix letter which is dependant upon the process of formation. Marine terrace and lacustrine terrace fragments are prefixed by the letter 'S', shingle rides are prefixed by the letter 'R' and fluvial and fluvio-glacial terrace fragments are prefixed by the letter 'T'. Features are referred to in the text by these identification numbers and where possible features identified in published papers are also referred to by these figures. All altitudes referred to in the text for raised marine/lacustrine terrace fragments and shingle ridges are mean altitudes for the fragment as a whole rather than individual altitude measurements (Appendix 1).

CHAPTER FIVE

THE OPEN COASTLANDS AND THE NAIRN VALLEY

1. Lochloy

a) Previous Research

The region directly east of Nairn, here termed Lochloy, stretches from Kingsteps (NH 9038 5736) to Cothill (NH 9522 5858) (Figs. 21, 22). Little detailed research has previously been carried out in the area. Horne (1923) described large areas of fluvio-glacial deposits and raised shoreline fragments. He suggested that these features are truncated by a cliffline which extends from Nairn to the river Findhorn. He associated this cliffline with sand beaches at 15-30 ft (4.6-9.1 m).

Ogilvie (1923) proposed that the only clear evidence of marine action in the area was a cliffline associated with a 25 ft (7.6 m) sea level. Similarly J.S. Smith (1977) suggested that the area is largely covered in fluvio-glacial deposits.

b) Field Evidence

The Lochloy region can be divided into three distinct areas; to the north a broad terrace area below 10 m, in the centre a narrow strip of land with marine terraces, and to the south an area of fluvio-glacial deposits and landforms. The area in the north in which the broad terrace lies is extensively wooded and covered with deposits of wind-blown sand and for these reasons no altitude determinations were attempted. The southern margin of the terrace is defined by a steep degraded cliff circa 5-10 m high.

The central area consists of a staircase of raised marine features (Figs. 22, 23, R1-R6, S8-S24). In the Maviston area

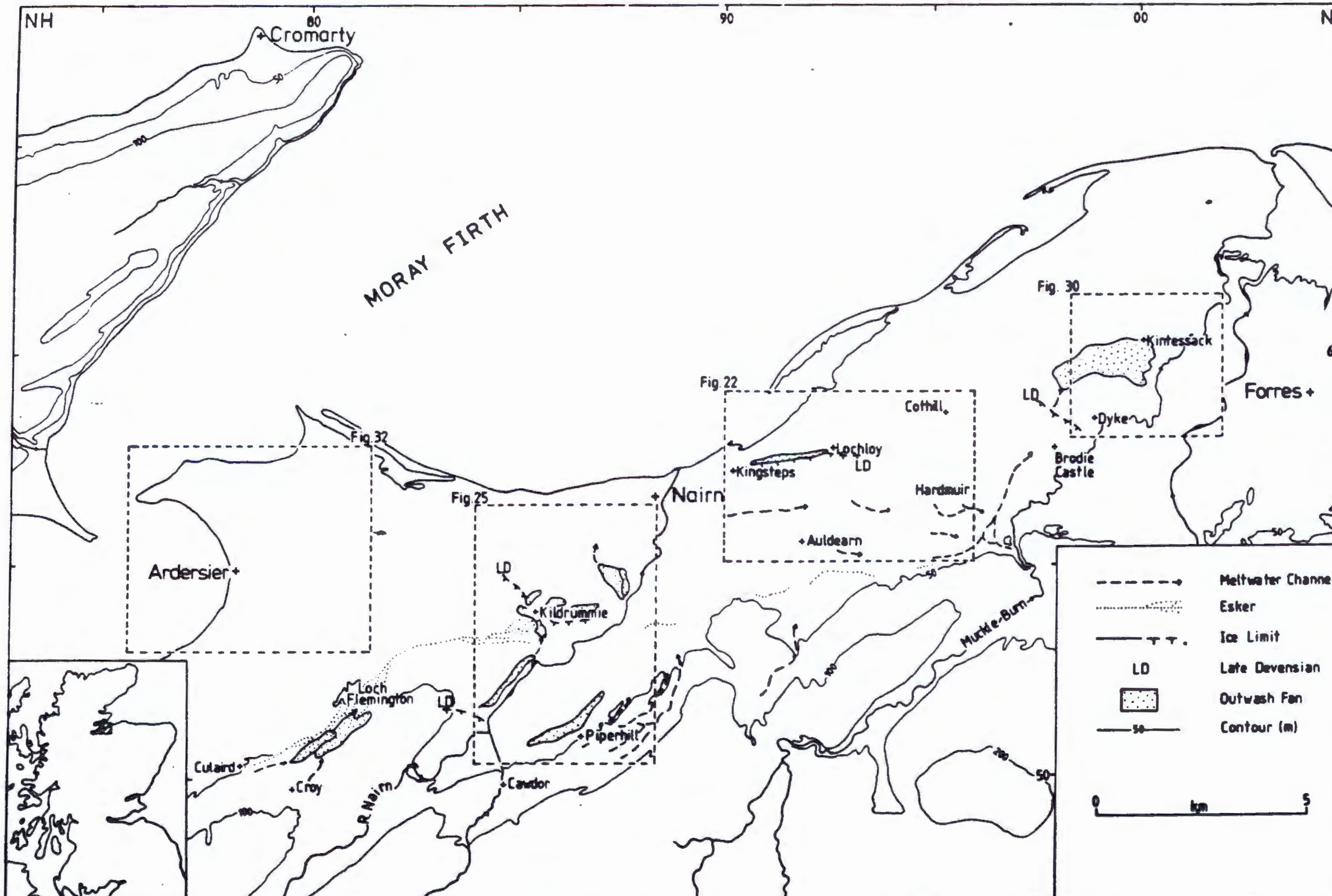


FIGURE 21 The Open Coastlands region.

Shoreline Fragment	No. of Points	Mean Grid Ref.	Mean Altitude	Quality of Measurements
S1	7	NJ 0033 6044	16.02	G
S1	7	NJ 0062 6034	15.73	G
S2	9	NJ 0061 6042	12.68	G
S3	7	NJ 0067 6070	9.42	G
S4	5	NJ 0096 6054	7.43	M
S5	5	NH 9927 5929	24.00	M
S6	6	NH 9938 5940	21.99	G
S6	6	NH 9927 5918	22.06	G
S7	8	NH 9891 5950	23.14	P
S8	6	NH 9379 5837	21.73	M
S8	6	NH 9449 5855	22.30	M
S9	4	NH 9470 5859	21.91	M
S10	9	NH 9432 5861	18.35	G
S10	6	NH 9375 5846	18.82	G
S11	7	NH 9383 5859	15.08	G
S11	7	NH 9408 5865	14.84	G
S12	7	NH 9361 5819	23.56	M
S12	6	NH 9385 5828	23.29	M
S13	6	NH 9277 5779	24.93	M
S14	7	NH 9214 5761	23.82	M
S14	7	NH 9239 5767	23.91	M
S15	9	NH 9157 5775	14.71	G
S15	8	NH 9197 5776	14.63	G
S15	8	NH 9233 5779	14.50	G
S15	8	NH 9264 5788	14.42	G
S15	8	NH 9293 5799	14.38	G
S20	7	NH 9281 5805	11.99	G
S20	7	NH 9254 5795	12.08	G
S21	9	NH 9147 5749	23.31	M
S21	8	NH 9182 5753	23.26	M

TABLE 9 Raised Shoreline Fragments in the Open Coastlands Region. P=Poor, M=Moderate, G+Good.

Shoreline Fragment	No. of Points	Mean Grid Ref.	Mean Altitude	Quality of Measurements
S22	8	NH 9114 5752	23.10	M
S22	8	NH 9082 5749	22.72	M
S23	10	NH 9165 5768	17.34	M
S23	9	NH 9124 5767	17.43	M
S24	5	NH 9080 5756	17.35	M
S25	7	NH 8764 5538	23.01	P
S26	8	NH 8318 5578	18.83	G
S26	8	NH 8355 5593	18.85	G
R1	7	NH 9483 5846	23.73	G
R1	6	NH 9508 5856	24.04	G
R2	7	NH 9430 5841	23.50	G
R2	6	NH 9455 5849	23.38	G
R3	8	NH 9430 5844	23.03	G
R3	7	NH 9461 5853	23.19	G
R3	7	NH 9487 5858	23.18	G
R4	6	NH 9439 5854	20.81	G
R5	8	NH 9423 5855	19.78	M
R5	7	NH 9449 5864	19.78	M
R5	7	NH 9374 5842	19.66	M
R6	3	NH 9239 5792	12.54	P

TABLE 9 continued

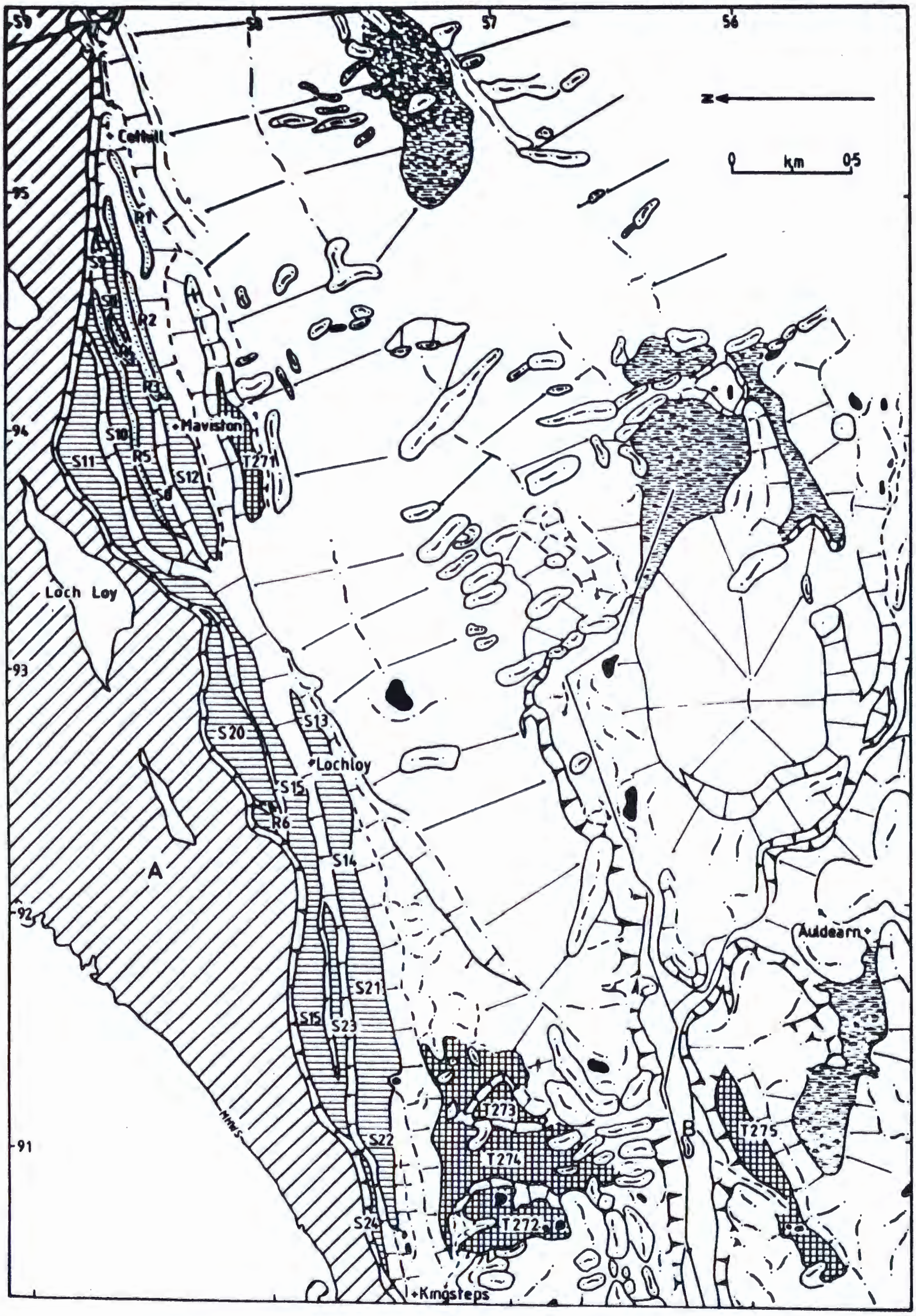


FIGURE 22 The Lochloy area.

(NH 9402 5834) raised marine features form a staircase of 5 levels. The highest level (T/S 271) forms a broad flat-topped ridge at 26.4 m. To the west and east this ridge grades into fluvio-glacial deposits so its marine origin is questionable. Below this is a flat-topped ridge (S12) at 23.4 m with a channel to the rear. Towards the east the surface of S12 is represented by 3 shingle ridges (R1-R3) at 23.9-23.1 m. Below these shingle ridges (R1-R3) there are raised marine terraces at 22.0 m (S8, S9), 18.5 m (S10) and 15.0 m (S11). Farther west terraces occur at 24.9-22.9 m (S13, S14, S21, S22), 17.4 m (S23, S24), 14.9 m (S15) and 12.0 m (S20). Many of the features are exceptionally well developed and extend over considerable distances. The higher features (S13, S14, S21, S22) form a continuous flat-topped ridge with a break of slope to its rear only at its eastern and western extremities. For the most part the ridge overlooks a semi-enclosed basin to the south in which lower kettled terraces are present (T 272-T 274). The surface of the flat-topped ridge is largely horizontal but in the east the surface slopes northward. This northward slope can in part be attributed to wind-blown sand accumulating on the southern margin of the feature and for this reason altitudes were determined along the centre of the ridge rather than at its present day crest.

In contrast, the southern area is characterized by N-S trending kames and kettleholes. Several poorly defined terraces also occur (T 272-T 275). The highest (T 275) occurs at circa 26 m while the lower (T 272-T 274) are pitted by small kettleholes. Several of the lower terraces (T 272-T 274) occur within a semi-enclosed basin. The steep sided valley of Auldearn Burn (Fig. 22, B) is located within the fluvio-glacial deposits. The present stream is a misfit and the valley was probably a subglacial meltwater channel,

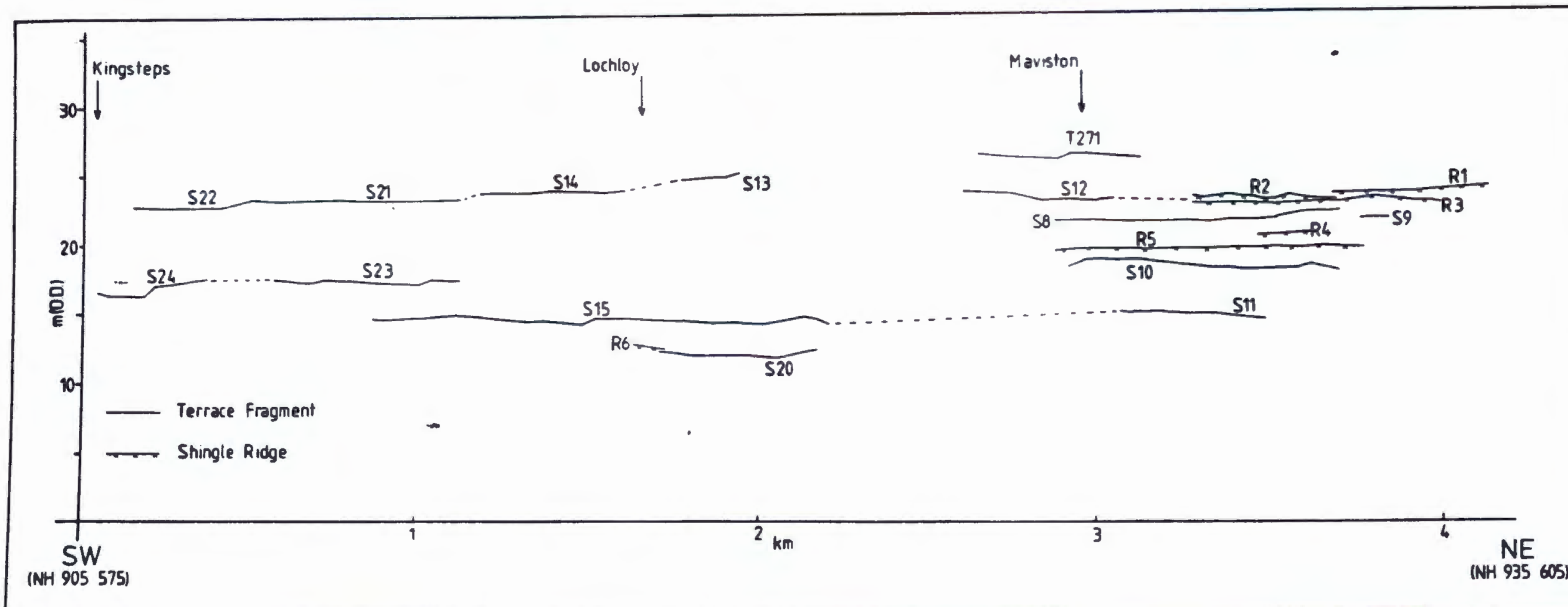


FIGURE 23 Altitude data for the Lochloy area.

related to the eastward flow of meltwaters.

c) Discussion

The raised shoreline fragments in the Lochloy area (R1-R6, S8-S24) consist of staircases of raised marine features at levels between 24.9 m (S13) and 12.0 m (S20) with a possible area of marine deposits at a lower level (Fig. 22, A). The relationship of the highest marine features (R1-R3, S12-S14, S21, S22) to the fluvio-glacial deposits to the south is problematical. It is possible that the ice may have melted from the area by the time that the highest raised shoreline features were formed. Alternatively ice may have lain directly to the south of the raised marine ridge when it was being formed. The second hypothesis is preferred for several reasons:-

i) There is evidence of ice being present to the south of the marine ridge after the highest marine features had been formed. The lower terraces to the south of the marine ridge are kettled (Fig. 24, T 272-T 274) and the slope directly south (Fig. 24, A) of the marine ridge is also kettled.

ii) To the south of the highest raised shoreline features, in the area proposed to have been covered by ice, there are few terrace fragments at circa 26 m. If the ice had not been present the sea would have flooded this area via Nairn and so numerous marine terraces would be expected.

iii) If the ice had not been present the highest marine features would have formed a barrier between water to the north and to the south. However,

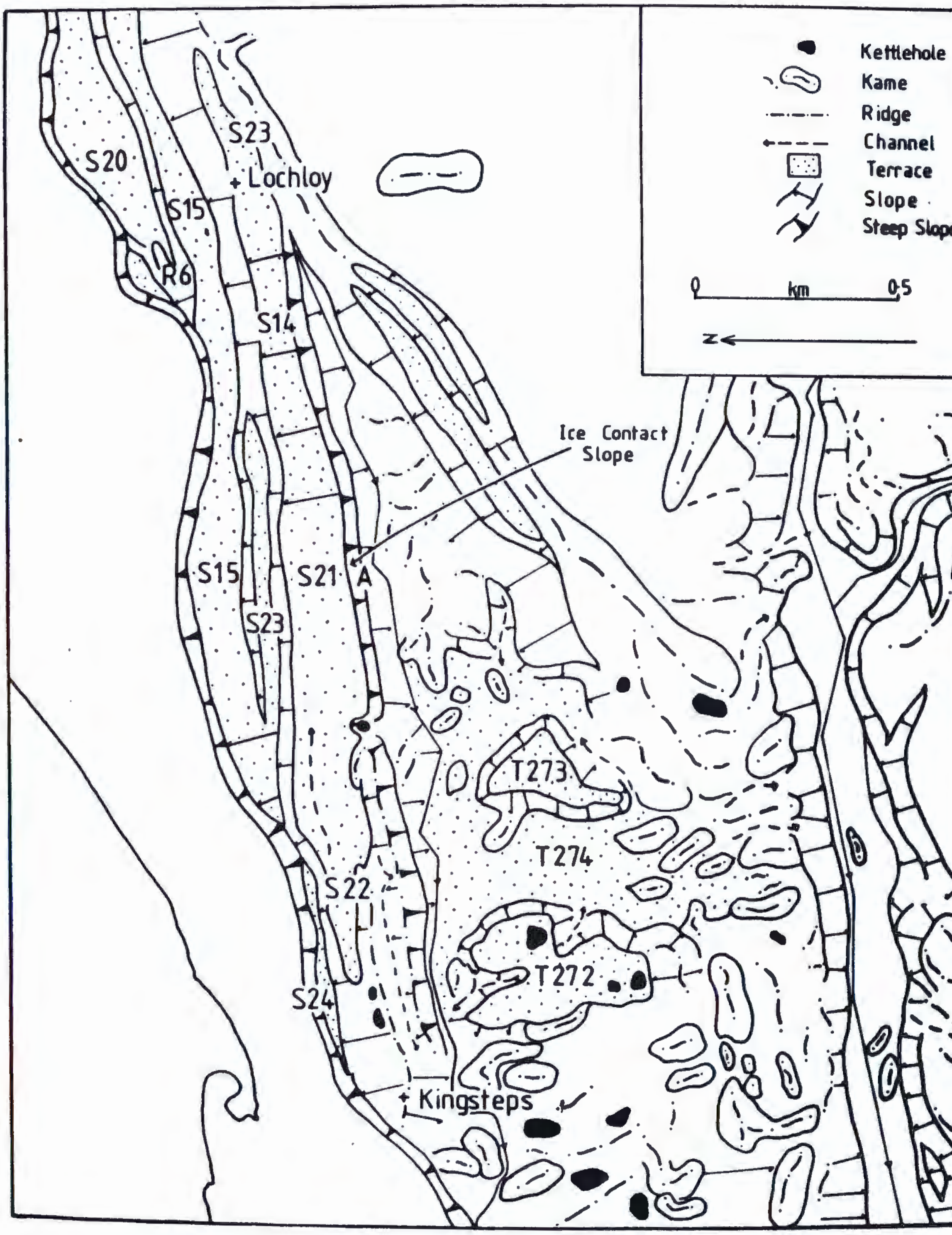


FIGURE 24 The location of the ice-contact slope in the Lochloy area.

the northward slope of the surface of the raised marine ridge (Fig. 24) suggests northward drainage of water, rather than water on either side of the feature. If ice had been present, the northward slope of the surface of the ridge can be explained as an outwash deposit.

It is therefore inferred that while the highest raised shoreline fragments were being formed ice lay directly to the south. The slope (Fig. 24, A) to the south of the raised marine ridge is interpreted as an ice contact slope and so some of the raised marine features (S14, S21, S22) lay directly against the ice margin. It is probable that the ice was stagnant for no evidence of active ice movement during the period of formation of the marine features is present. The raised marine ridge varies in altitude by 2 m along its length and this may be interpreted as the result of a falling relative sea level. Alternatively, the range in altitude may indicate that the altitudes were determined on outwash deposits rather than on raised marine features.

d) Sequence of Events

i) Ice covered the whole area and meltwaters flowed subglacially eastward along the Auldearn valley.

ii) The ice mass started to downwaste and retreat.

iii) The sea penetrated into the area from the north to form raised marine features at 24.9-22.9 m (R1-R3, S12-S14, S21, S22). At this time stagnant ice lay directly to the south. In some localities marine terraces were formed adjacent to the ice mass.

iv) Relative sea level fell to form raised marine features at 22.0 m (S8, S9), 18.8 m (R4), 17.4-18.5 m (S10, S23, S24, R5), 15.0 m (S11, S15) and 12.0 m (S20). During this period of time the mass of dead ice inland melted and terraces were developed in an enclosed basin (T 272-T 274).

v) The raised marine deposits were then cliffed along their northern margin and a lower group of raised marine terraces were formed (Fig. 22, A) at circa 6-8 m.

2. Kildrummie and the Lower Nairn Valley

a) Previous Research

Kildrummie is located 3 km SW of Nairn on the northern slopes of Strath Nairn (Figs. 21, 25). The features around Kildrummie and in lower Strath Nairn have attracted considerable discussion since 1877. In 1877 attention was drawn to the long sinuous ridge that was said to extend from Nairn to the moor of Culloden (Fig. 21). Fraser (1877) suggested that the ridge was an esker. Horne (1923) described the same feature in great detail. He suggested that it is composed of sand and gravel and forms a prominent ridge which locally divides into a series of anastomosing ridges.

Ogilvie (1923) identified the ridge as an esker, which he traced from Loch Flemington (Fig. 21) to Kildrummie where it ends in a steep slope which he identified as a sea cliff cut during the "maximum submergence" (p. 395)(circa. 30.5 m). North of the ridge he identified kames and drumlins orientated NE-SW. He suggested that these mounds are truncated by cliffs which lie adjacent to a zone of "kames for the most part smoothed by surf..." (p. 395). Ogilvie indicated that the latter features have accordant summits at about 80 ft (24.4 m). He described the 'surf-smoothed kames' as being truncated to the north

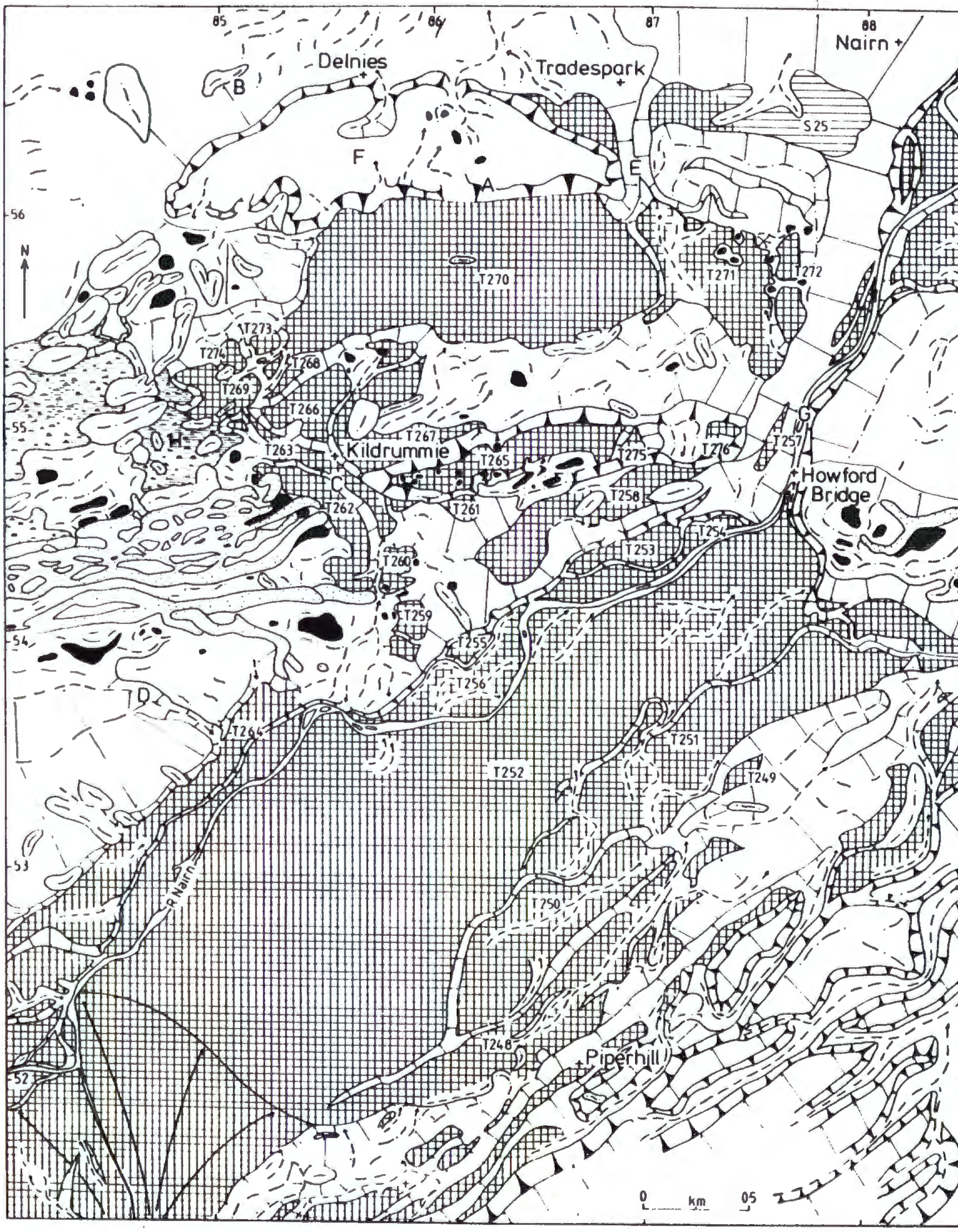


FIGURE 25 The Kildrummie area.

by a cliff related to a 25 ft (7.6 m) relative sea level.

J.S. Smith (1968) and Small and Smith (1971) identified a series of ridges extending between Culaird (Fig. 21) and Kildrummie. They suggested that these ridges could be related to subglacial meltwater channels in the Dalcross area (Fig. 21) and that the ridges are an esker complex. J.S. Smith (1968, 1977) inferred that the features indicated a continuous phase of ice downwastage with the ice surface gradient causing an easterly subglacial flow of the meltwater. He also suggested that highest raised marine feature in the area is a raised shingle ridge which occurs at 87 ft (26.5 m) (Fig. 25, B). J.S. Smith inferred that the smooth fluvio-glacial mounds which lie at a lower level than, and north of, the shingle ridge have been modified by wave action.

Synge (1977a) and Synge and Smith (1980) suggested that raised marine features occur up to 38 m in the Kildrummie area. They proposed that the esker ridge identified by earlier researchers (termed the Flemington esker by Harris and Peacock, 1969) terminates in a flat-topped ridge at 36-38 m. The surface of this flat-topped ridge was described as pitted by small kettleholes. Synge (1977a) considered that the flat surface of the feature resulted from meltwaters of a subglacial river debouching into the sea. He advocated that if the ice roof of the tunnel in which the esker was forming collapsed a crevasse would have been produced, and if the sea then flooded into the crevasse a flat-topped feature would have resulted. On the basis of the kettlehole evidence Synge proposed that relative sea level had fallen below the surface of the ridge by the time the ice melted. Synge (1977a) and Synge and Smith (1980) also suggested that a lower relative sea level at 33 m resulted in marine erosion of the eastern ends of the Flemington esker. They considered that wave action associated with this period produced small beach ridges at the eastern ends of the individual esker ridges. Farther north at Moss-side (Fig. 25, A) Synge (1977a, P. 86) described "... horizontally bedded glacial outwash gravels punctured by kettleholes filled to the brim with gravel...", and he advocated that the infilling of the kettleholes resulted from wave action. At a lower altitude Synge and Smith (1980) identified a beach ridge at Delnies (Fig. 25, B) at 29 m. They suggested that the fluvio-glacial features in the vicinity of the shingle ridge are "... marine washed ..." (p. 20).

b) Field Evidence

Lower Strath Nairn forms a broad valley between Kilravock Castle (NH 8143 4934) and Howford Bridge (Fig. 25). In this area terrace fragments are well-developed particularly on the southern slopes. Although terrace fragments occur up to an altitude of 100 m, altitude measurements were restricted to features below 40 m. Many of the higher, unmeasured features are probably kame terraces which were formed in close association with large meltwater channels east and south of Piperhill (Fig. 25). At Howford Bridge the river Nairn turns northward through a broad ridge of fluvio-glacial deposits before it enters the sea. In this area terrace fragments are only locally developed.

Below Piperhill (Fig. 25) five distinct fluvial terrace fragments were identified (T 248-T 252). Four of the terrace fragments (T 248, T 250-252) extend over considerable distances and these represent surfaces which progressively decline in altitude down valley (Fig. 26). The surfaces of the terrace fragments are frequently dissected by channels. Farther up-valley the terrace fragments merge into a single feature. On the northern side of the river Nairn low-lying terrace fragments (T 235-T 256) occur beneath a steep bluff. The features on the northern side of the river are correlated with the two

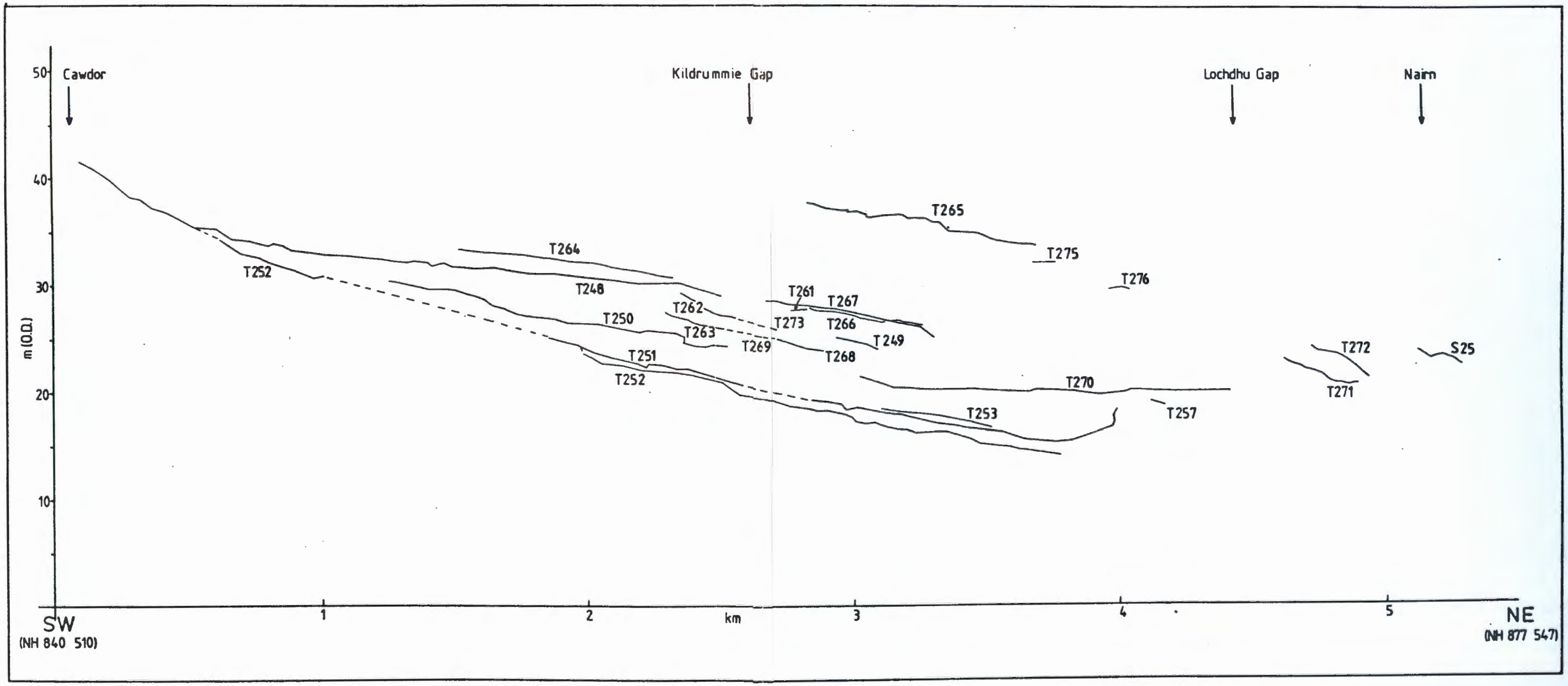


FIGURE 26 Altitude data for the Kildrummie area.

poorly-developed terrace fragments occur (T 258-T 264, Fig. 25). In the east the area is extensively channelled and pitted by small kettleholes. In the west a number of terrace fragments were identified. Terrace fragment T 264 extends into the area from the SW and in this direction it rises to circa 42 m. A number of channels produced by fluvio-glacial erosion lead onto this terrace fragment (T 264) from the north (ie. Fig. 25, D). The best developed of the terrace fragments (T 262, T 263) descends in altitude northwards through the Kildrummie Gap. The higher of these terrace fragments (T 262) lies adjacent to the kettleholes formed between the ridges of the Flemington esker complex.

North of the eastern section of the Flemington esker there is a broad lowland area. In the east this lowland area (Fig. 25, H) is occupied with kames which are surrounded by broad peat-floored dead-ice hollows. In the west a series of terrace fragments occur (Figs. 25, 26, T 266-T 270, T 273). The highest terrace fragments (T 266, T 267) rise westward to an altitude of 27.7-28.7 m. Both terrace fragments (T 266, T 267) are channelled and pitted with kettleholes and both end eastward in a steep slope at the base of which lies terrace fragment T 263. Terrace fragment T 263 extends northward and correlates with T 268, T 269 and T 273. Below terrace fragment T 268 a channel grades eastward into a large flat-bottomed depression (T 270). Borehole records indicate that T 270 is composed of circa 2 m of grey sand which is locally overlain by peat. The margin of the depression (T 270) is sharply defined and altitude measurements suggest the existence here of a former lake shoreline at 20.2 m. The outflow of the former lake, here termed Kildrummie lake is located at Lochdhu Pass (Fig. 25, E). East of the former lake are two dissected poorly-defined terrace fragments (T 271, T 272). Each terrace fragment declines in altitude northward (Fig. 26) and both are pitted by small kettleholes. It may be inferred that when these terrace fragemnts formed (T 271, T 272) water flow through the Lochdhu Pass.

The northern margin of Kildrummie lake terminates at a steep-sided bluff which rises to circa 30 m. At the top of the bluff an irregular surface (Fig. 25, F) is pitted with small kettleholes and dissected by numerous small channels. An exposure in the deposits reveals beds of sands and gravels with pockets of contorted silts and sands (Fig. 27). Detailed examination indicates that most of the deposit consists of:-

0-1.2 m	Massively bedded rounded-subrounded gravel with sand and cobbles.
> 1.2 m	Well-bedded steeply-inclined sands and gravels interbedded with finely-bedded medium-coarse sand with occasional fine gravel layers.

The steeply inclined beds may indicate foreset bedding, but in the context of this deposit it is more likely to represent current action. Within these deposits there are pockets of sand and silt up to 3.5 m thick. At depth the sands and silts are finely-bedded and often exhibit cross bedding and ripples (Fig. 27). Towards the base of the sand and silt pockets small reverse faults are also present. At the top the sands and silts are contorted. The contortions are interpreted as load structures resulting from the extrusion of water upon sediment loading. None of the sedimentary structures are unequivocally indicative of marine action.

North of the irregular surface (Fig. 25, F) there is a subdued undulating surface at circa 25 m. At certain localities kames and kettleholes occur, but at other sites poorly-defined terrace fragments are present. The highest raised marine feature

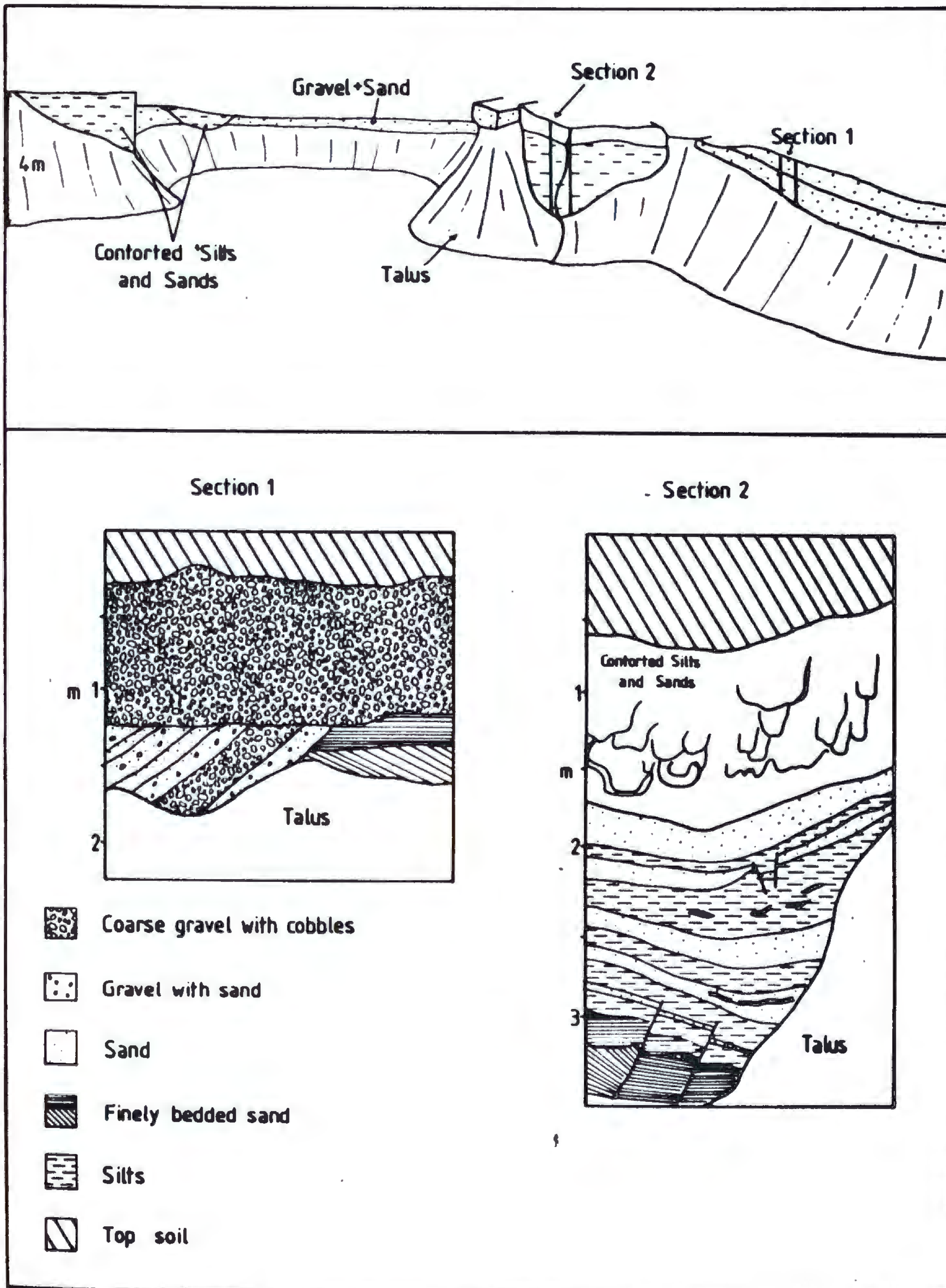


FIGURE 27 Sections in the gravel pit at Moss-side (NH 863 552) in the Kildrummie area.

identified in the area occurs just south of Nairn (S25) at 23.0 m. Laterally this feature may grade into a fan at the northern end of the Lochdhu Gap. The other raised marine terrace in the region occurs at 18.8 m (S26) and it lies directly below two kettleholes whose lowest rims occur at 23.1 m and 23.3 m.

c) Discussion

The Flemington esker forms the most distinctive feature in lower Strath Nairn. The ridges indicate a considerable flow of water eastward through subglacial channels, yet the ridges end abruptly in a flat-topped ridge (T 265). Synge (1977a) suggested that the flat-topped ridge represents a crevasse-filling graded to a former high relative sea level at 36-38 m (the crevasse having formed when the former ice roof of the esker tunnel collapsed). Alternatively the flat top may reflect a subglacial water table developed in an esker tunnel. The surface of the flat-topped ridge (T 265) declines regularly in altitude towards the east (Fig. 26) and it is not graded to a specific water level. Farther east small esker fragments are present and these may represent a continuation of the Flemington esker complex. It is thought that meltwaters initially flowed across the present course of the river Nairn at Howford Bridge, but later the waters flowed northward when the flat-topped ridge was formed. The flat-topped ridge is considered to be a crevasse filling for several reasons:-

i) Kame terrace fragments in the vicinity of Loch Flemington indicate that the ice margin lay at _circa_ 55 m, while meltwaters drained into the Flemington esker system, which is surrounded by land at _circa_ 25-40 m. On these grounds it is inferred that whilst meltwaters still flowed along the esker tunnels the ice mass was 15-20 m thick. The ice mass would probably have become thinner towards the east and the possibility that the roof of the tunnel (in which the esker formed) collapsed is likely.

ii) The eastern end of the flat-topped ridge is crossed by channels (T 275, T 276). Water flowing through these channels must have drained across an ice surface This flow is more likely to have been sub-aerial rather than subglacial.

Below the flat-topped ridge (T 265) there are several kettled terrace fragments (T 259-T 263, T 266, T 267). The higher terrace fragments (T 266, T 267) end abruptly westward in a steep slope. No terrace fragments at a similar or higher altitude were identified farther west. These features are interpreted as small outwash fans related to an ice margin located directly west of Kildrummie Gap.

Terrace fragment T 262 truncates the higher outwash fans (T 266, T 267) and is related to a northward flow of water through Kildrummie Gap. T 262 is correlated with T 259, T 260 and T 274 (Fig. 25). Small blocks of ice lay buried in these terrace fragments and between the ridges of the Flemington esker complex while these terrace fragments formed. Whether ice lay farther south in the Nairn valley is problematical, since T 248 may represent a kame terrace or an outwash fan. The water which flowed through the Kildrummie Gap would also have drained into the broad depression occupied by Kildrummie lake (T 270).

Terrace fragment T 263 also leads northward through the Kildrummie Gap and into the Kildrummie lake basin via terrace fragments T 268, T 269 and T 275. Farther south terrace fragment T 263 was traced to a series of meltwater channels and these imply either ice located to the south or the flowage of meltwater down the Nairn valley from an ice margin located in the west. Above the Kildrummie lake basin this terrace surface descends to 23.7 m, so the Kildrummie lake was at or below this level. The lowest Kildrummie lake occurs at 20.5 m and so at the time of formation sea level must have lain at or below this altitude. The poorly-developed fan at the mouth of the Lochdhu Gap may grade to a poorly-developed raised marine terrace (S25) at 23.0 m. The Kildrummie lake associated with this fan must have had a water surface at circa 26 m, and this is equivalent to the lowest portions of T 266 and T 267.

The terrace fragments developed east of Kildrummie lake are associated with water which drained from the south. These features (T 271 , T 272) are pitted by small kettleholes and must have been formed during ice wastage. It is probable that the terrace fragments (T 271, T 272) represent the former course of the river Nairn, which would have drained through the Lochdhu Gap. Whether water also flowed along the present course of the river (through the Howford Gap (Fig. 25, G) is unknown but the lack of terrace fragments at an appropriate altitude detracts from such a proposal. T 271 and T 272 may be of the same age as the outwash fans at the western end of Kildrummie lake (T 262, T 263). On this basis T 262 would be related to terrace fragment T 271 which grades to a 21.5 m lake level, while T 263 would correlate with T 272 which grades down to a lake at 21.0 m.

The ridge of high ground (Fig. 25, F) north of the former Kildrummie lake shows no evidence of being washed by the sea as proposed by Synge (1977a) and Synge and Smith (1980). The channels and kettleholes on the surface of the feature are indicative of sub-aerial deposition and the sand and gravel deposits with pockets of sand and silt are interpreted as outwash. It is thought that the pockets of sand and silt represent kettleholes which became infilled as the ice melted which is indicated by tectonic and water escape structures in these sediments. This ridge of fluvio-glacial sediments (Fig. 25, F) must have formed while ice covered the Kildrummie lake basin, and it may be the same age as the flat-topped ridge (T 265) at the eastern end of the Flemington esker.

The fluvial terraces at the eastern end of lower Strath Nairn (T 248-T 257) merge upstream. Sissons (1982a) noted that most Scottish river terraces merge downstream, rather than diverge. Many authors (King and Oakley, 1936; Bloom, 1978) have suggested that lower terraces which have steeper gradients may be attributed to dissection which resulted from a fall in base level. In contrast, Clayton (1977), Rose (1978) and Castleden (1980) have indicated that sediment characteristics and river discharge properties are the most important variables in determining the gradients of river terraces. However, Rose (1978) noted that where river terraces formed in close proximity to the sea, a fall in sea level resulted in incision and an increase in the terrace gradient. Since the fluvial terraces of lower Strath Nairn (T 248-T 257) have formed in close proximity to the coast it is possible that the steeper gradients of the lower terraces reflect a fall in base level. However, the fall in base level may only reflect part of the increase in gradient.

The two lowest terrace surfaces in Strath Nairn (T 251, T 253, T 255 and T 252, T 254, T 256) form broad continuous terraces which are related to the present outflow of the river Nairn through the Howford Gap (Fig. 25, G). The higher terrace fragments (T 248 - T 250) may be correlated in several ways:-

i) On the basis of altitude, T 248 may be correlated with T 249 (Fig. 28) since no other terrace fragment is high enough to be correlated with this feature (T 249). Such a correlation implies that the gradient of T 248 becomes steeper (Fig. 28) and this is supported by the steeper gradient at the eastern end of this terrace fragment (T 248). The downstream projection of terrace fragment T 249 may possibly suggest correlation with fragment T 257, which in turn implies the drainage of meltwater through the Howford Gap. On this basis water associated with the lower terrace fragment T 250 would also have drained through the same gap.

ii) The downstream projection of terrace fragment T 248 (ignoring the steeper eastern end of this terrace fragment) however may also indicate correlation with either fragment T 271 or T 272 at the eastern end of Kildrummie lake. The altitude of terrace fragment T 248 near Piperhill (Fig. 28) may equally suggest correlation with fragment T 262 and the flowage of water through the Kildrummie Gap. In a similar way terrace fragment T 250 may be correlated with terrace fragment T 257. Therefore the waters associated with this lower terrace surface drained through the Howford Gap. This proposal however does not explain the formation of terrace fragment T 249.

An alternative proposal is that fragment T 248 is a kame terrace. In the north the ice would have lain adjacent to the Flemington esker (T 265) and could therefore explain the poor development of a terrace fragment equivalent to

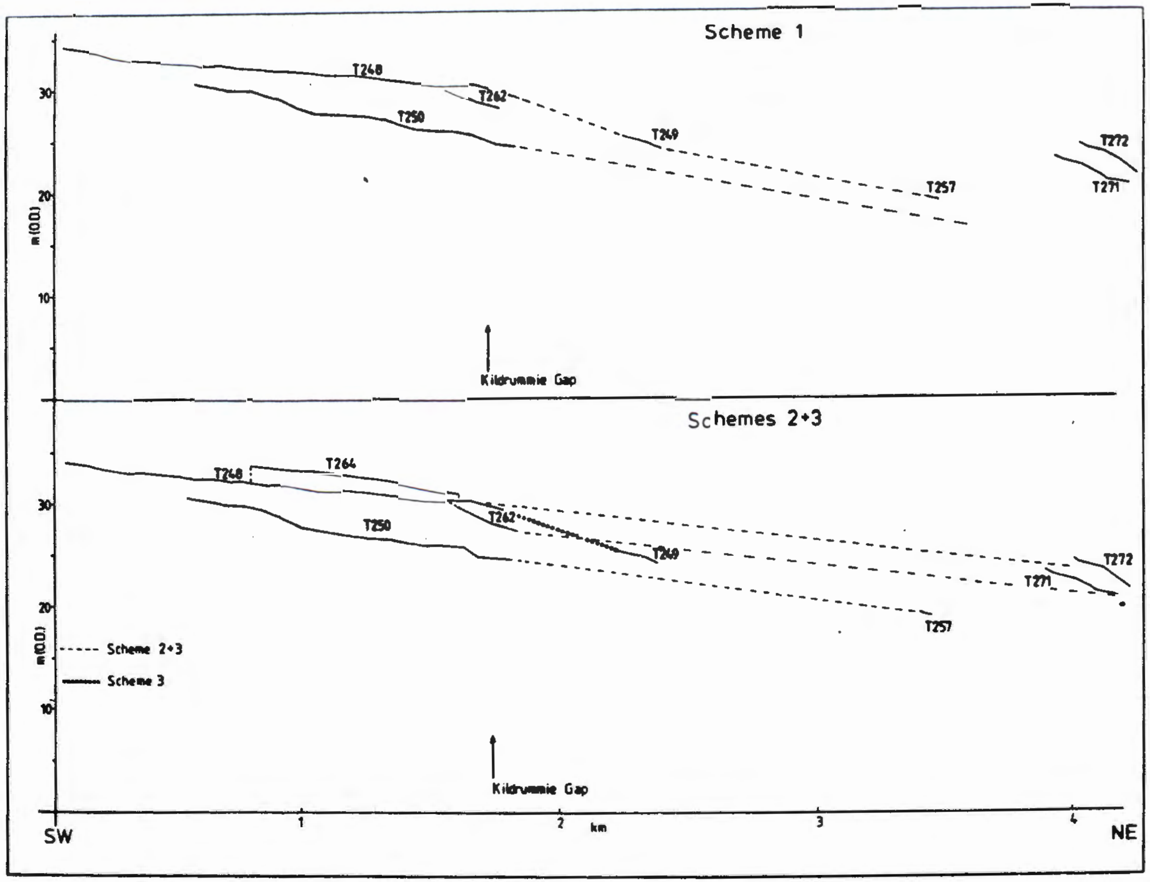


FIGURE 28 The various schemes of correlation of fluvial terrace fragments in the Kildrummie area.

T 248 in this area.

iii) The final hypothesis combines the theories presented above. It suggests that outwash related to an ice margin to the west flowed down Strath Nairn and formed terrace fragments T 248 and T 264. The Howford Gap may have been blocked at its northern end by a mass of dead ice so that the meltwaters flowed into the Kildrummie lake via the Kildrummie Gap (T 259, T 260, T 262) and around the eastern end of the Flemington esker ridge (T 272) (Fig. 29). A fall in level of Kildrummie lake resulted in the formation of a lower terrace surface (T 263, T 268, T 269, T 271, T 273) associated with the same pattern of drainage. Deglaciation thereafter resulted in the drainage of melt-water through the Howford Gap. A consequence of this change in drainage pattern is the steep gradient at the NE end of terrace fragment T 248 and the formation of T 249. Thereafter a lower base level resulted it the formation of terrace fragment T 250 and the drainage of associated meltwaters through the Howford Gap.

The second and third hypotheses are considered the more acceptable due to the coincidence of terrace levels either side of the river Nairn. In contrast the first hypothesis does not incorporate the transfer of meltwater through the Kildrummie Gap.

The evidence also indicates that marine features do not occur south of the fluvio-glacial ridge (Fig. 25, F), because in this area the rims of small kettleholes and outwash deposits occur down to altitudes of 21.0 m. Ice therefore remained in the area until relative sea level fell below 21.0 m. North of the ridge (Fig. 25, F) marine features are only locally developed. The fluvio-glacial

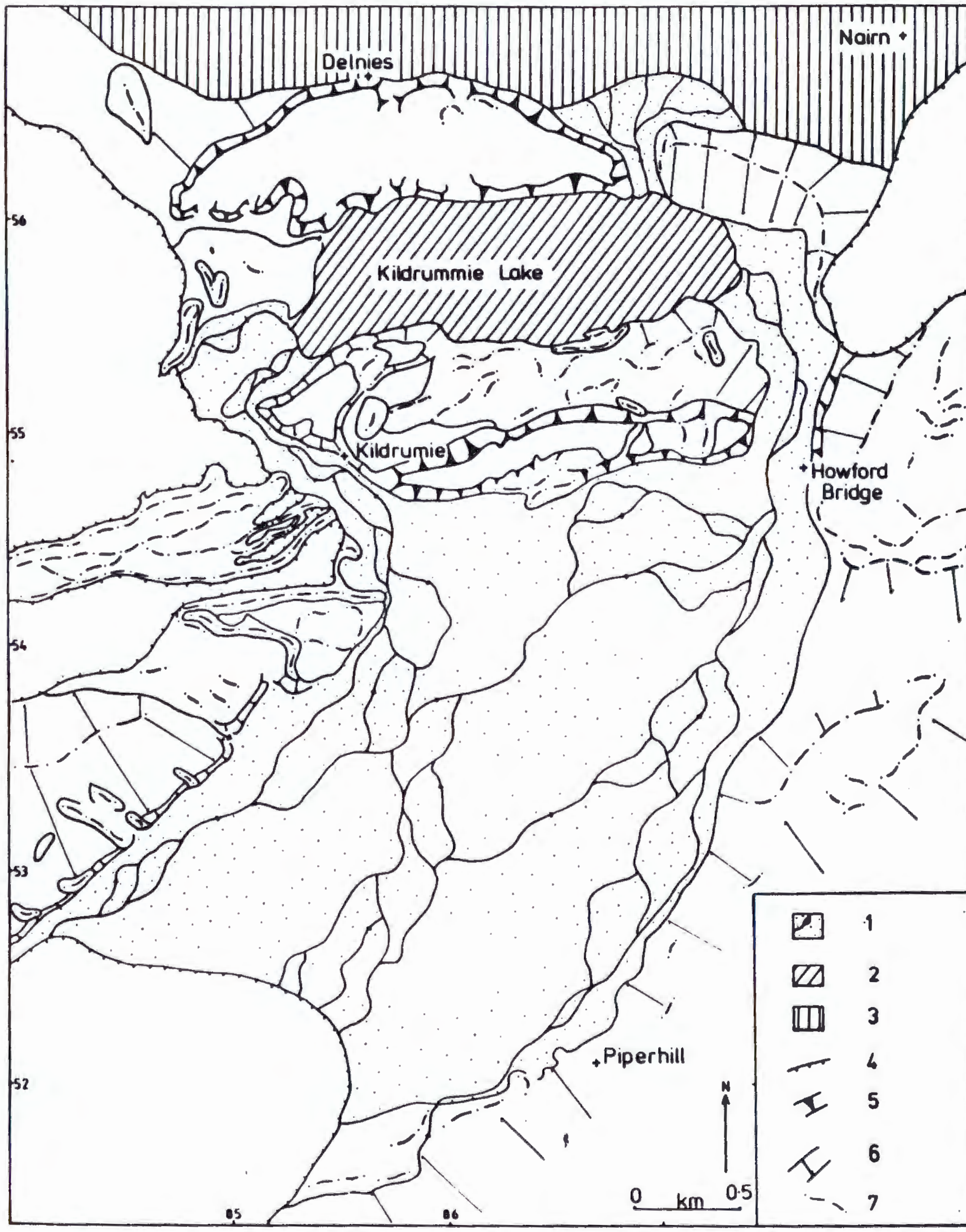


FIGURE 29 An idealised map of the Kildrummie area during the Late Devensian when outwash entered the Kildrummie lake from two directions. 1. Outwash terrace and river channels. 2.Lake. 3. The sea. 4. Ice margin. 5. Steep slope. 6. Slope. 7. Fluvio-glacial ridge or kame.

features in the area are poorly-defined as far west as Blackcastle (Fig. 21). Farther west marine features occur up to 27.4 m (R7). This implies that much of the area north of the fluvio-glacial ridge lies below the marine limit. It is therefore possible that the poorly defined fluvio-glacial features have been modified by wave action.

d) Sequence of Events

i) A series of meltwater channels and kame terraces formed in association with downwasting ice on the southern slopes of Strath Nairn between circa 40-120 m. Meltwaters in the Croy area drained underneath the ice mass to form an esker system from Culaird to Howford Bridge and possibly also farther east.

ii) The ice mass downwasted to circa 55-60 m in the Loch Flemington area and kame terraces were formed which drained into the Flemington esker system. In the east the roof of the esker tunnel collapsed and formed a crevasse in which a flat-topped ridge developed (T 265). Farther north a broad fluvio-glacial ridge was possibly formed at the same time (Fig. 25, F).

iii) The ice mass continued to downwaste and the ice margin retreated westward to the Kildrummie Gap. Outwash related to this ice margin formed outwash fans T 266 and T 267 which grade into a Kildrummie lake at circa 26 m. Water flowed out from the lake through the Lochdhu Gap and formed a fan graded to a raised shoreline fragment (S25) at 23.0 m.

iv) The main ice mass retreated westward and left large ice masses in the vicinity of the Flemington esker ridges and at the northern end of the Howford Gap. Outwash drained into the

Kildrummie lakes at 21.5 m and 21.0 m through the Kildrummie Gap and east of the flat-topped esker ridge (Fig. 29).

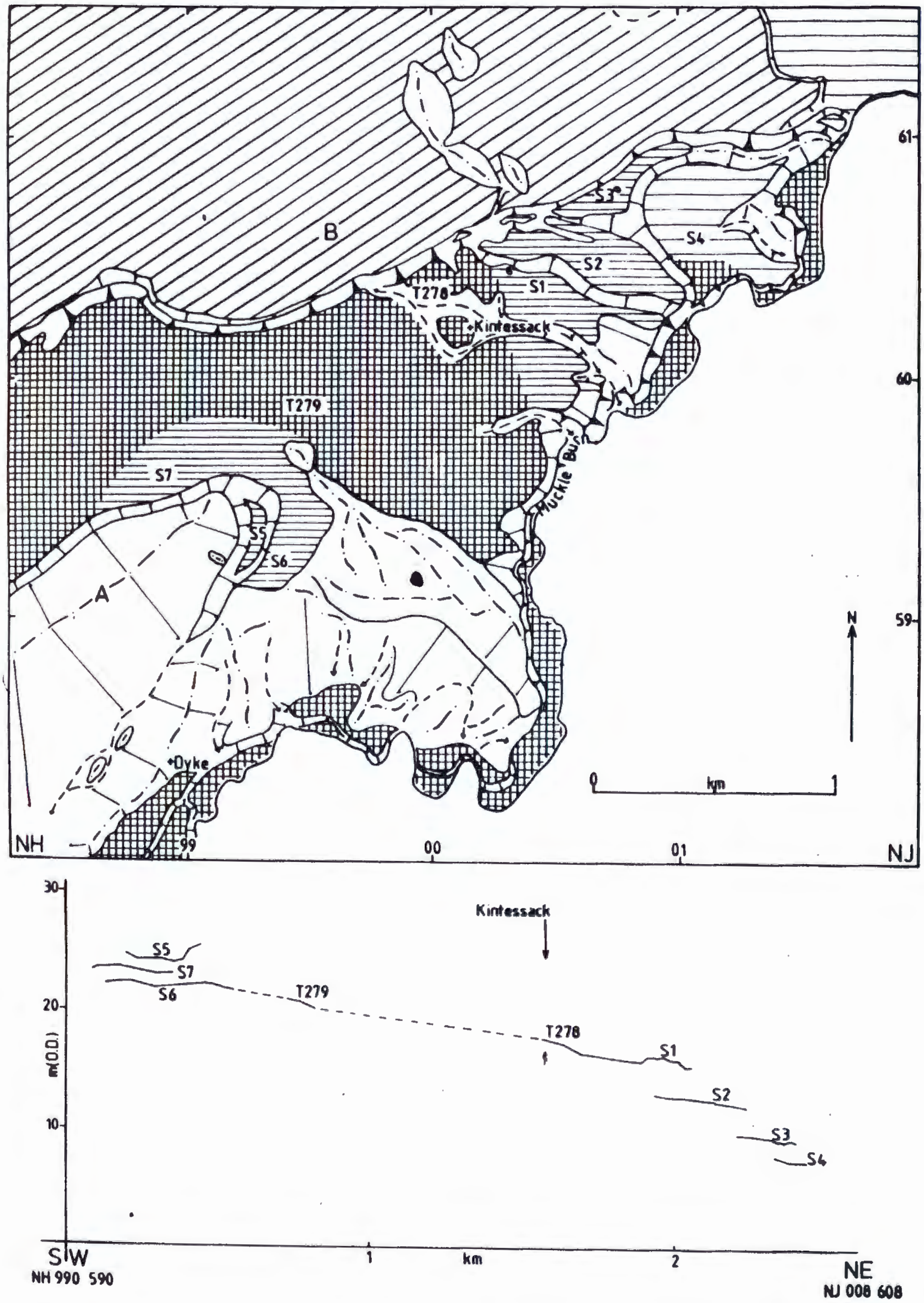
v) The Howford Gap became deglaciated and the river Nairn formed lower outwash terrace fragments (T 250, T 257). A succession of lower river terraces (T 251-T 256) were then formed. During the same time period the 20.0 m level of Kildrummie lake (T 270) was infilled with sediment.

3. Other Areas/Features of Interest

a) Dyke and Kintessack

The villages of Dyke and Kintessack lie at the eastern extremity of the study area (Figs. 21, 30). The area forms a narrow strip of land confined between the Culbin Forest to the north and Muckle Burn to the south. The only published reference to the area is by Ogilvie (1923), who identified marine features near Dyke at 90 ft (27.4 m), 80 ft (24.4 m) and 45 ft (13.7 m). He described these marine features as being cliffed to the north by a prominent feature related to a 25 ft (7.6 m) raised marine terrace (Fig. 30, B).

The highest terrace fragment in the area occurs at the eastern end of a broad morainic ridge (Fig. 30, A). The terrace fragment (Fig. 30, S5) lies at 24.0 m for much of its length but rises in altitude at its northern end. Below this is a well-developed shoreline terrace (S6) at 22.0 m which is related to terrace S7 which lies north of the morainic ridge. East of S6 there are several large elongated kame ridges and a large kettlehole. In contrast S7 forms a broad surface. A dense tree cover made it impossible to map the surface of S7 but it is thought to grade westwards into fluvio-glacial features. A large meltwater channel (Fig. 21) grades into the fluvio-glacial features which occur at the western end of S7. In the east S6 may be related to lower outwash terrace fragments T 278 and T 279. T 278 is a kettled and



<u>FIGURE 30</u> The Kintessack and Dyke areas.

dissected outwash spread which is graded to a raised shoreline fragment at 15.9 m. Below this, raised shoreline fragments occur at 12.6 m (s2) and 9.4 m (S3) the latter has a large lettlehole in its surface.

The outwash and raised marine terraces are cliffed to the north. Adjacent to the cliff is a broad terrace (Fig. 30, B) which is locally overlain by wind-blown sand. The presence of blown sand excluded altitude measurements but a raised marine terrace at 7.4 m (S4) in this area is thought to correlate with B (Fig. 30).

The features in the Dyke and Kintessack area are unusual in several respects:-

i) The highest terrace feature (S5) indicates that although water flowed from the north extensive fluvio-glacial deposits occur below it. It is therefore suggested that the horizontal part of the terrace fragment may represent an ice-dammed lake shoreline fragment. The glacio-lacustrine sediments identified by Peacock et al. (1968) to the east of Kintessock support this conclusion (see page 49b).

ii) Terraces S6 and S7 although horizontal merge to the east and the west with kettled outwash graded to the raised shoreline fragment at 15.9 m. The altitudes of S7 are of poor quality and may explain the lack of gradient of the feature. In contrast S6 forms a distinct terrace fragment at 22.0 m. As a result S6 is interpreted as an ice dammed lake shoreline fragment, with the ice lying to the south of the broad morainic ridge (Fig. 30, A) during this period.

iii) The kettlehole in shoreline fragment S3 is the lowest kettle identified in the study area, with its lip occurring at 9.0 m. However, this region is probably one of the first that would have been deglaciated as the ice retreated westward.

It is therefore suggested that ice lay to the south of the broad morainic ridge (Fig. 30, A) and produced small glacier-dammed lakes at 24.0 m (S5) and 22.0 m (S6). The latter lake drained onto an outwash surface (S7, T 278, T 279) associated with an ice margin 1.5 km to the west. This outwash surface declines eastward where it merges with a raised shoreline fragment at 15.9 m (S1). Relative sea level then fell to form marine terraces at 12.6 m (S2) and 9.4 m (S3), and during this time buried blocks of ice remained in the area. These deposits were then cliffed and a raised marine terrace was produced at 7.4 m (S4, Fig. 30, B). Relative sea level then fell to its present level and the lower marine deposits were covered by wind-blown sand deposits (Ogilvie, 1923; Steers, 1937).

b) Fluvio-glacial Features between Nairn and the River Findhorn

Inland of the narrow strip of land occupied by high raised marine features there is an extensive area of glacial and fluvio-glacial deposits. Across the higher ground several ridges are aligned N-S en echelon. No exposures are present in these ridges and thus their composition is unknown. Their alignment (transverse to the expected ice flow) and their asymmetric profile suggest that they represent glacial meltout ridges associated with sediment-rich bands of decaying ice. In contrast, in the valleys the ridges are aligned E-W and exposures indicate that they are composed of fluvio-glacial sands and gravels.

Between Grigorhill (NH 9062 5456) and Hillend Belt (NH 9375 5466) there is a single esker ridge intermittently developed (Fig. 21). This esker may represent a continuation of the Flemington esker system. Towards the east the esker feeds into a large meltwater channel which extends eastward towards Dyke. Other meltwater channels from Muckle Burn (Fig. 21) and from Hardmuir (Fig. 21) merge with the main meltwater channel. Throughout the area large kettleholes are common and locally kame terraces are present. The features together represent a downwasting ice mass with meltwater having flowed subglacially in an easterly direction.

CHAPTER SIX

THE INVERNESS FIRTH

1. Ardersier

a) Previous Research

Ardersier village lies at the eastern end of the Inverness Firth below an area of higher ground (Figs. 31, 32). The area has been of particular geomorphological interest since the last century. Jamieson (1874) described an exposure of grey clay near Ardersier at Kirkton (NH 7852 5645) from which he obtained arctic marine shells. He described the clay as being buried beneath, or enveloped within, a brown unfossiliferous mass of gravel and silt, and he claimed that the clay layer was the remnant of some bed that had been destroyed by later glacier action. Wallace (1883) referred to the same section as a deposit of blue clay which contains numerous shell fragments overlain by a mass of yellow till. He identified several marine shells (*Leda pernula* (*Nuculana pernula* (Müller)), *Tellina calcarea* (Chemnitz) (Macoma calcarea (Chemnitz)), *Astarte elliptica* (Brown)) and concluded that the clay accumulated in an arctic environment. Further study by Robertson (in Wallace, 1883) indicated that the shells were still comparatively intact and showed little sign of being water worn and some were interpreted as *in situ*. Several marine micro fossils were also identified (Table 11). Robertson noted that the micro fauna was not necessarily of Arctic origin but they indicated cooler waters than present.

Horne (1923) described the same section as a grey clay overlain by 6ft (1.8 m) of stratified sand, capped by a sandy and clayey deposit about 4 ft (1.2 m) thick containing some stones. J.S. Smith (1968) and Synge and Smith (1980) interpreted these reports of the section at Kirkton as evidence of a readvance of ice. J.S. Smith (1968, 1977) believed that sections in the bluff behind Ardersier

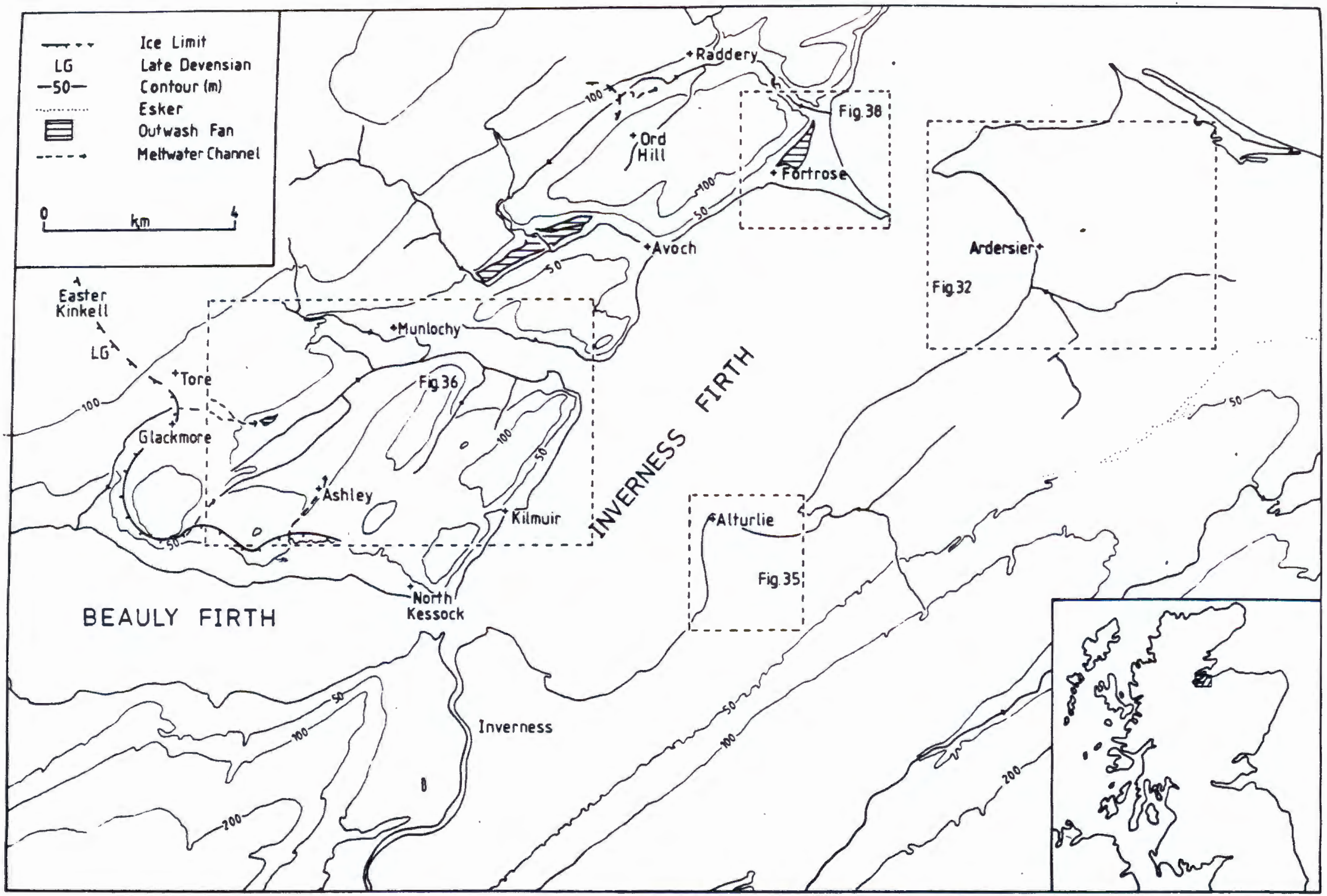


FIGURE 31 The Inverness Firth region.

Shoreline Fragment	No. of Points	Mean Grid Ref.	Mean Altitude	Quality of Measurements
S24	5	NH 9080 5756	17.35	M
S25	7	NH 8764 5538	23.01	P
S26	8	NH 8318 5578	18.83	M
S26	8	NH 8355 5593	18.85	G
S27	7	NH 8140 5552	24.22	M
S28	7	NH 8108 5492	21.96	M
S29	2	NH 8063 5497	12.80	M
S30	1	NH 8068 5505	11.75	P
S31	4	NH 8062 5505	9.83	M
S32	3	NH 7857 5506	28.50	M
S33	6	NH 7909 5608	26.97	M
S33	5	NH 7910 5586	26.23	M
S34	10	NH 7934 5534	21.20	M
S35	8	NH 7844 5640	22.51	P
S35	7	NH 7813 5634	20.51	P
S36	3	NH 7819 5658	11.04	M
S37	9	NH 7885 5481	18.50	M
S38	8	NH 7787 5627	8.75	G
S38	7	NH 7778 5656	8.86	G
S39	5	NH 7976 5614	7.21	M
S40	6	NH 7744 5316	13.50	M
S41	9	NH 7754 5350	5.68	G
S41	10	NH 7778 5377	5.36	G
S42	6	NH 7728 5324	6.84	M
S43	6	NH 7680 5294	7.94	M
S43	7	NH 7652 5278	7.43	M
S44	10	NH 7611 5256	8.46	G
S45	5	NH 7584 5241	7.57	M
S46	10	NH 7553 5222	8.43	M
S47	5	NH 7411 5834	19.74	M
S48	3	NH 7307 5711	30.25	P
S49	8	NH 7324 5689	25.16	M
S50	8	NH 7313 5654	16.60	M

TABLE 10 Raised shoreline fragments in the Inverness Firth region. P = Poor, M = Moderate, G = Good.

Shoreline Fragment	No. of Points	Mean Grid Ref.	Mean Altitude	Quality of Measurements
S51	8	NH 7353 5708	14.58	M
S51	7	NH 7344 5682	14.78	M
S52	5	NH 7358 5715	13.95	M
S53	6	NH 7350 5664	11.56	M
S53	6	NH 7354 5674	11.89	M
S54	9	NH 7412 5829	8.53	P
S55	5	NH 7368 5669	8.09	G
S56	1	NH 7444 5606	7.57	M
S57	4	NH 7411 5644	7.01	M
S58	10	NH 7486 5624	4.58	M
S58	9	NH 7422 5607	4.77	M
S59	9	NH 7425 5635	4.81	M
S60	5	NH 6983 5379	13.19	M
S61	6	NH 6933 5564	22.55	M
S62	5	NH 6856 5544	19.86	M
S63	5	NH 7356 4989	19.36	M
S64	5	NH 7348 4982	15.08	M
S65	10	NH 7385 5053	8.41	M
S66	10	NH 7366 5021	7.66	M
S69	9	NH 7345 4990	8.51	M
S70	3	NH 7349 4949	3.56	P
S71	9	NH 7417 4985	7.93	M
S72	4	NH 7390 4923	8.55	M
S73	3	NH 7383 4922	7.29	M
S74	2	NH 7407 4903	11.83	P
S75	7	NH 7373 4894	7.13	M
S76	1	NH 7335 4882	17.30	P
S77	4	NH 7320 4896	16.57	M
S78	1	NH 7265 4907	15.29	P
S79	4	NH 7283 4902	14.67	M
S80	2	NH 7225 4908	29.27	M
S81	4	NH 7233 4909	23.22	P
S82	2	NH 7256 4913	8.57	M

TABLE 10(cont.)

Shoreline Fragment	No. of Points	Mean Grid Ref.	Mean Altitude	Quality of Measurements
S83	7	NH 7190 4937	6.93	M
S83	7	NH 7217 4925	7.03	M
S84	2	NH 7139 4931	7.51	P
S85	5	NH 7136 4914	8.76	G
S86	9	NH 6823 5094	14.41	G
S87	2	NH 6820 5100	20.38	P
S88	3	NH 6735 4982	22.10	P
S89	10	NH 6763 4984	4.38	G
S90	3	NH 6829 5227	32.54	P
S91	8	NH 6786 5222	29.29	M
S92	3	NH 6835 5234	8.46	P
S93	9	NH 6800 5231	8.47	M
S94	9	NH 6724 5234	3.02	G
S94	9	NH 6762 5232	3.13	G
S95	2	NH 6604 5366	3.44	P
S96	8	NH 6530 5342	3.14	G
S96	7	NH 6553 5353	2.96	G
S96	7	NH 6583 5362	2.67	G
S97	8	NH 6549 5297	2.95	M
S98	6	NH 6493 5281	4.40	M
S98	5	NH 6512 5295	4.05	M
S99	6	NH 6757 5226	8.91	P
S100	10	NH 6403 5278	29.02	M
S101	10	NH 6359 5238	29.59	M
S101	9	NH 6324 5213	28.86	M
S102	7	NH 6285 5186	27.70	M
S103	3	NH 6252 5165	29.18	M
S104	3	NH 6258 5161	26.83	M
S105	6	NH 6296 5186	14.42	P
S106	3	NH 6408 5269	17.57	M
S107	2	NH 6447 5307	14.80	M
S108	8	NH 6424 5170	28.94	M
S109	1	NH 6415 5160	26.95	M
S110	1	NH 6418 5168	24.63	M

TABLE 10 (cont.)

Shoreline Fragment	No. of Points	Mean Grid Ref.	Mean Altitude	Quality of Measurements
S111	2	NH 6466 5234	17.90	M
S112	3	NH 6460 5231	17.82	M
S113	3	NH 6433 5209	17.58	M
S114	2	NH 6464 5242	14.50	P
S115	9	NH 6399 5172	10.93	M
S116	3	NH 6315 5094	14.02	M
S117	2	NH 6343 5173	7.98	M
S117	3	NH 6339 5193	7.87	M
S119	3	NH 6380 5196	6.69	G
S120	3	NH 6364 5196	6.81	G
S121	6	NH 6458 5246	5.28	G
S121	6	NH 6437 5232	5.46	G
S122	7	NH 6442 5284	5.29	G
S122	6	NH 6410 5255	5.39	G
R7	9	NH 8147 5547	27.35	M
R8	7	NH 8113 5494	24.86	M
R9	7	NH 7863 5521	29.63	M
R10	2	NH 7855 5511	30.55	P
R11	8	NH 7910 5539	29.04	G
R11	7	NH 7899 5579	28.33	G
R11	7	NH 7896 5606	28.70	M
R12	6	NH 7803 5302	9.38	G
R12a	6	NH 7786 5647	9.62	G
R12a	5	NH 7797 5661	9.04	G
R13	5	NH 7816 5406	8.17	G
R13	6	NH 7817 5400	8.42	G
R13a	5	NH 7783 5669	9.45	M
R14	6	NH 7334 5640	9.17	G
R15	3	NH 7379 5639	8.90	M
R16	7	NH 7365 5682	9.62	G
R16	7	NH 7370 5709	9.74	G
R17	5	NH 7375 5717	9.28	G
R18	5	NH 7383 5692	8.43	M
R19	10	NH 7407 5625	8.58	G
R20	5	NH 7382 5707	8.61	M

TABLE 10 (cont.)

Shoreline Fragments	No. of Points	Mean Grid Ref.	Mean Altitude	Quality of Measurements
R21	9	NH 7391 5682	7.76	M
R22	5	NH 6983 5407	9.64	M
R23	7	NH 7371 5009	22.74	M
R24	10	NH 7264 4904	17.32	G
R25	9	NH 7339 4998	9.78	G
R26	2	NH 7339 4972	9.99	G
R27	6	NH 7166 4942	10.43	G
R28	10	NH 7153 4825	9.90	G
R28	10	NH 7150 4780	9.94	G
R29	6	NH 7100 4766	5.50	M
R30	5	NH 6760 4993	9.21	M
R31	4	NH 6822 5235	10.51	G

TABLE 10 (ocnt.)

Ostracoda	Foraminifera
Cytheridea punctillata (Brody)	*Polymorphina lactea* (W.& T.)
Cytheridea papillosa (Bosquet)	*Polymorphina asummata* (Will.)
Cytheridea Sorbyana (Jones)	*Polystomella striato-punctata* (F. & M.)
Cytherura Sarsii (Brody)	*Polystomella Arctica* (P. G.)

TABLE 11 Microfossils identified by Roberston in the blue shelly clay deposits found near Ardersier. The names are unmodified from the original paper (Wallace, 1883)

Type of Feature	Grid Ref.	Present Study No.	Suggested Altitude m O.D.	Proponent
Erosional Notch	NH 782 557	-	32.92	J. Smith, 1968
Shingle Ridge	NH 791 556	R11	27.10	J. Smith, 1968
Marine Terrace	NH 782 565	S35	26.82	J. Smith, 1968
Erosional Notch	NH 780 560	-	32	Synge, 1977a
Erosional Notch	NH 780 560	S35	24	Synge, 1977a
Erosional Notch	NH 780 560	S38	9	Synge 1977a
Erosional Notch	NH 780 560	-	7	Synge, 1977a
Shingle Ridge	NH 790 557	R11	31	Synge, 1977a

TABLE 12 Raised marine features identified by J.S. Smith (1968) and Synge (1977a) in the Ardersier area

village (Fig. 32) show beds deformed by the same re-advance of ice. He suggested that the sand and silt beds with inliers of marine clays represent ice borne material dredged up from the Inverness Firth and pushed into a ridge form. The ridge was thought to be a readvance moraine. He initially suggested that outwash associated with his proposed moraine grades to a low relative sea level, but in 1977 he suggested in contrast that there is a significant drop in the marine limit west of the moraine.

Synge (1977a) and Synge and Smith (1980) also suggested that an arc of fluvio-glacial deposits above Ardersier village represent the frontal remnant of morainic deposits associated with a readvance Synge advocated that when this ridge formed, relative sea level was at a low level. Later sea level rose and during the subsequent regression a series of marine features were said to have been formed in the Ardersier area (Table 12).

In contrast, Ogilvie (1914) did not associate the changes in sea level with ice retreat. He identified 4 former marine levels at 100 ft (30.5 m), 50 ft (15.2 m), 25 ft (7.6 m) and 15 ft (4.6 m). He suggested that the two higher levels were partially eroded when relative sea level stood at 25 ft (7.6 m).

b) Field Evidence

The higher ground at Ardersier is cliffed along its western and northern margins, and a series of sections are exposed. The sections reveal steeply-dipping beds of sand and silt and occasional clay layers. These are truncated by horizontally bedded sands and fine gravels. The upper beds (some 2-3 m thick) locally show symmetrical ripple marks, which are indicative of current action probably produced in a marine environment (Allen, 1970). The lower beds are well expos at NH 7802 5596 (Fig. 32, B) (Plate 2). At this section beds of silty clay, silt

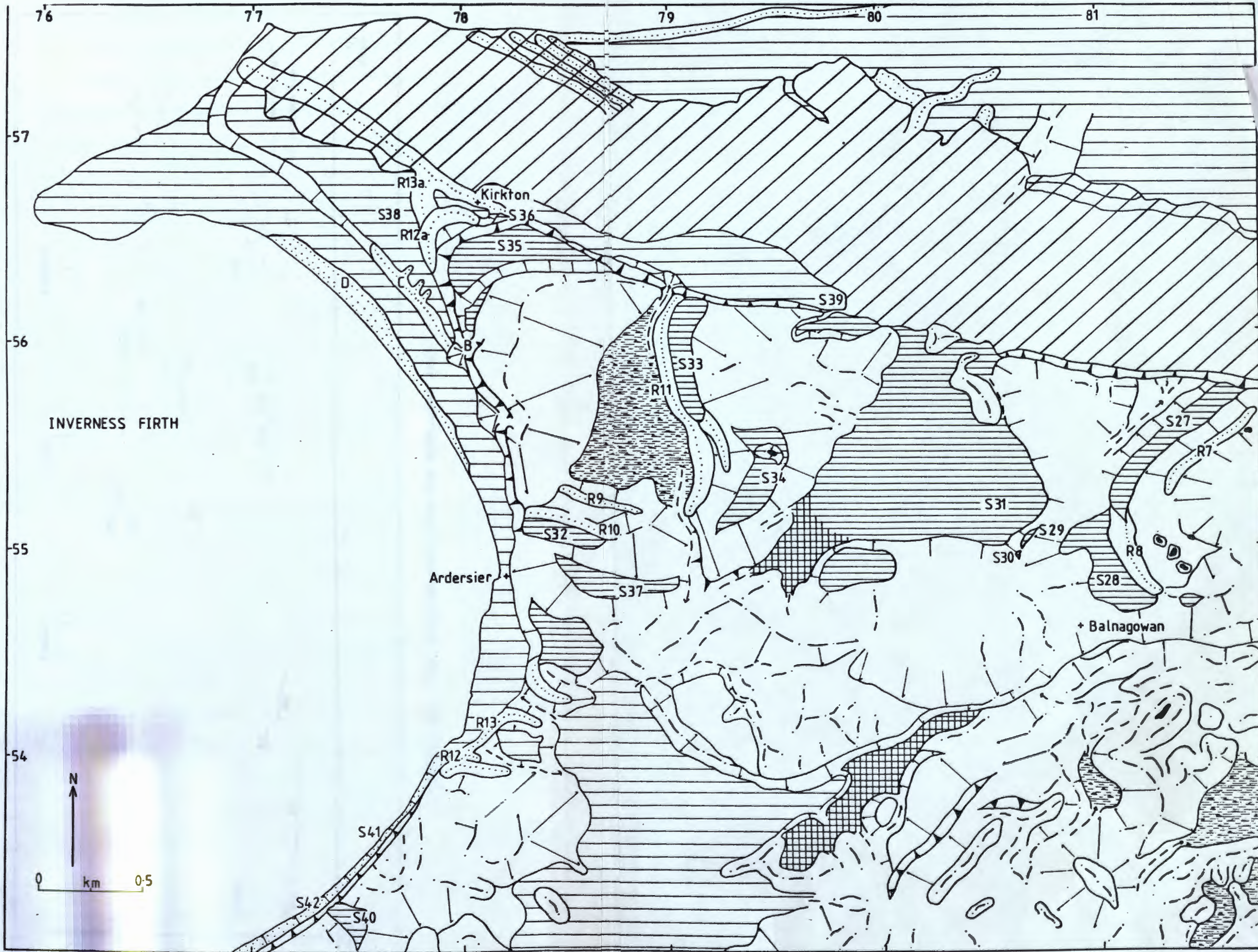


FIGURE 32 The Ardersier area.

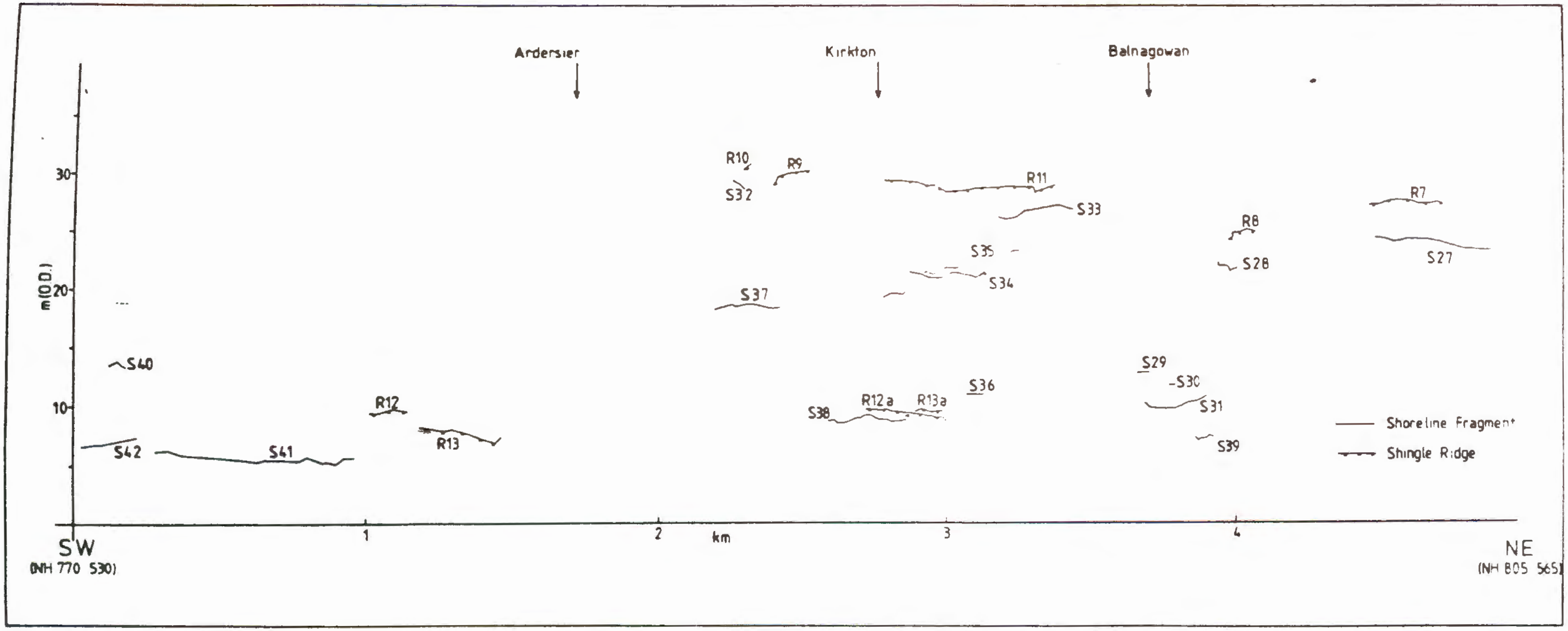


FIGURE 33 The altitude data for the Ardersier area.

and fine sand are folded. More detailed inspection revealed sand beds (0.2-0.5 m thick) interbedded with finely-bedded layers of silt, sand and clay. Within these finely-bedded layers there are a series of soft sediment deformation structures (Fig. 34, Plate 3). At certain sites well-developed load casts and water escape structures are evident. The core of one of the folds is composed of a ball of silty clay around which the other beds appear to have been draped. The well-developed load casts and water escape structures indicate that the sediments were initially deposited in water. The horizontal beds which locally truncate these deposits indicate that the deformation occurred before the upper beds were lain down. Samples of the various sediments were sieved (125 µm) but no faunal remains were identified.

The higher ground at Ardersier rises to circa 42 m and forms an undulating topography which slopes towards the east. Below the crest are a series of shingle ridges (R9-R11) and associated marine terraces (S32, S33)(Fig. 32). The highest ridge (R10) at 30.6 m extends westward from an area of higher ground to the cliffline above Ardersier village. To the north of this shingle ridge (R10) lies another ridge (R9) at 29.6 m and together these two marine ridges represent a tombolo between the higher land masses to the west and east. Farther east another ridge (R11) forms a prominent feature, the crest of which lies at 28.7 m and this is fronted by a marine terrace (S33) at 26.6 m.

Below these shingle ridges there are marine terraces at 21.2 m (S34), 21.6 m (S35), 18.5 m (S37) and 11.0 m (S36) (Figs. 32, 33). The first of these features (S34) is pitted by a large kettlehole whose rim lies at 20.8 m. Shoreline terrace fragment S35 lies between 23.9-19.2 m and it is thought that it may be a composite feature because of this large range in altitude of its break of slope.

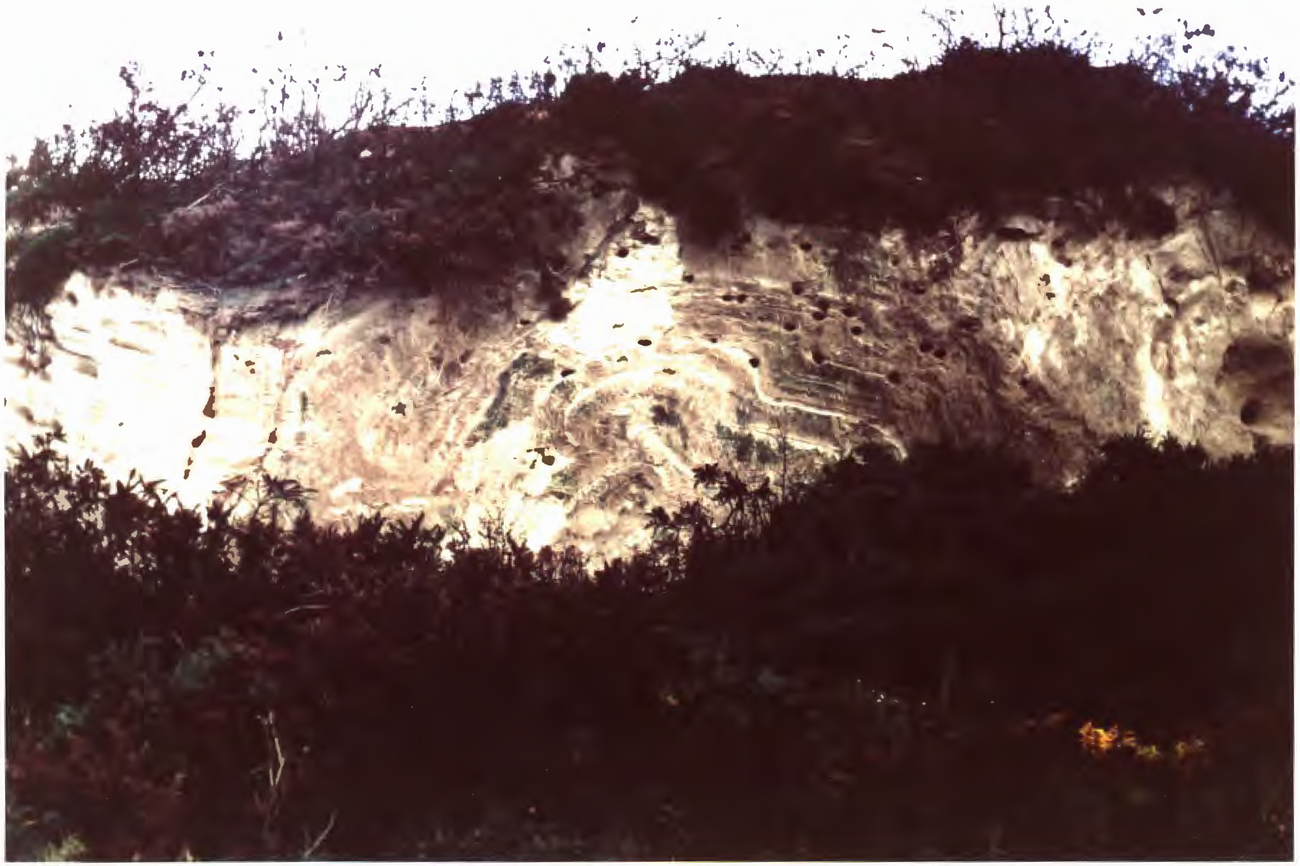


PLATE 2 The section of contorted sediments at Ardersier (NH 780 560).

PLATE 3 Load structures in the contorted sediments at Ardersier (see Figure 34).

Farther east a staircase of raised shoreline fragments is present, the highest ridge (R7) at 27.4 m encloses a small kettlehole. Below this a marine terrace at 24.2 m (S27) extends southward to grade into a shingle ridge (R8) at 24.9 m. This ridge encloses an area which is extensively kettled. Below the ridge (R8) is a staircase of raised marine terraces at 21.9 m (S28), 12.8 m (S29), 11.8 m (S30) and 9.8 m (S31). To the south there are kames and dead ice hollows, and many of these fluvio-glacial features lie below the altitude of the marine terraces described above.

The higher raised shoreline fragments are truncated by a cliff-line which extends intermittently throughout the Ardersier area. In the west this cliffline is fronted by a narrow, steeply-sloping, raised, shingle beach between 5.5 and 7.6 m (S41-S43). East of this the cliff is absent and shingle ridges are present. The crests attained altitudes of 9.4 m (R12) and 8.3 m (R13). North and east of Ardersier village the cliffline is fronted by a series of sand and shingle ridges and terrace fragments. Locally, shells are abundant in the lower marine features. The highest shingle ridges (R12a, R13a) both occur at 9.4 m and they are continued to the NW by a broad shingle spit. Below this there are marine terraces at 8.8 m (S38) and 7.2 m (S39) and a series of lower shingle ridges (eg. Fig. 32, C, D). In the north the shingle ridges have been covered by wind-blown sand and therefore altitude measurements were not attempted in this area.

c) Discussion

The contorted sediments exposed in the sections to the north of Ardersier village have been interpreted as evidence of a major readvance of ice (Smith, 1968, 1977; Synge, 1977a; Synge and Smith, 1980). There is however reason to believe that this interpretation is in error. The sediments themselves consist of well bedded sands

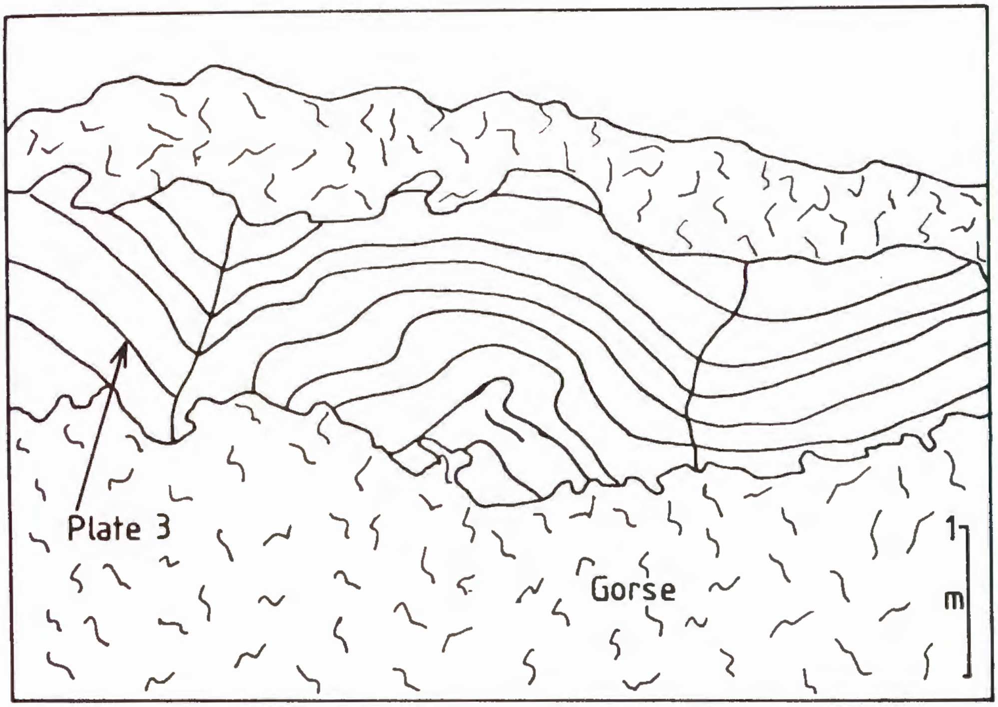


FIGURE 34 The section of contorted sediments at Ardersier (NH 780 560) showing the location of Plate 3 and providing a scale for Plate 2.

and silts with clay lenses and are indicative of deposition by running water. Further, deformation structures in glacial sediments can result from a number of processes and they are not conclusive evidence of an ice readvance. Carruthers (1947, 1948) and Sugden and John (1976) indicated that sediments folded by glacial processes are found in close association with till. At Ardersier no till was identified by the present author and the deposits interpreted as till at Kirkton by Wallace (1883) were subsequently described as fluvio-glacial sediments (Horne, 1923). The deformation structures are thus considered to have resulted from water expulsion from super saturated sediments which were initially deposited sub-aqueously. This interpretation is in accord with the views of Robertson (in Wallace, 1883) that some marine shells in the grey clay are in situ, and therefore the sediments were deposited in the sea. In order to accumulate such a large volume of material an ice margin must have lain close by. The meltwater would have flowed directly into the sea so the ice margin may have, in part, been floating. The expulsion of water from the sediments may be explained in three ways:-

i) Glacier movement deformed the soft sediments, and this movement could have been initiated by a floating ice margin becoming unstable.

ii) Sub-aqueous deposition resulted in turbidity flows or slumping which deformed the sediments.

iii) Localised sediment loading resulted in expulsion of water and the deformation of the sediments.

In each case there is no need to invoke a major readvance, particularly since till deposits are absent.

The deformed sediments at Ardersier thus indicate a high relative sea level. The uppermost horizontal beds are also marine in origin and lie at *circa* 30 m. These deposits may be related to the highest marine features of the area (R9, R10) at 30.6 m and 29.6 m. These later features, which are ridges, indicate considerable areas of open water. It is likely that the open water lay to the north and that the ridges represent successive levels during a fall in relative sea level. The lower ridge (R11) and associated marine terrace (S33) also reflect open water north of Ardersier.

The large kettlehole (whose rim lies at 20.8 m) in shoreline fragment S34 presents a problem of formation. It is possible that an ice rafted or *in situ* mass of ice was buried in the sediments which make up the high ground at Ardersier. Under this hypothesis the mass of ice would have been in place whilst the higher shingle ridges were being formed (R9-R11). The mass of ice then melted after relative sea level fell below 20.8 m. Alternatively, the shingle ridges may have formed adjacent to a mass of ice to the south. This ice withdrew and left a block of ice in the sediments which were then reworked by marine processes to form S34. Subsequently relative sea level fell below 20.8 m and the block of ice melted. The second theory is supported by the presence of extensive fluvio-glacial deposits to the south whose surface lie below the marine limit of the area, although no evidence of modification by marine processes is present. It is concluded that a large mass of ice did lie south of Ardersier while the higher raised marine features were formed. However, the extent of this ice mass is largely unknown. It is also hard to reconcile the exact origin of the kettled raised shoreline fragment (S34), for it is possible that marine features were formed in close proximity to a decaying ice mass.

After the 9.8 m (S31) raised shoreline fragment formed there was a period of extensive marine erosion. This was followed by the formation of another sequence of raised marine features (R11-R13), S38-S43) between 5.5 m and 9.4 m.

d) Sequence of Events

i) The ice sheet downwasted and retreated to the Ardersier area.

ii) While the ice lay in the Inverness Firth and south of Ardersier meltwaters deposited sands and silts sub-aqueously in a marine environment. These sediments became deformed by either glacier movement, slumping, or through sediment loading.

iii) Relative sea level fell and truncated the contorted sand and silt beds and deposited marine sands and gravels at <u>circa</u> 30 m.

iv) Relative sea level fell to form raised marine features at 28.5 m (S34, R9, R10); 26.6 m (R11, R7, S33); 24.0 m (S27, R8); 21.6-22.0 m (S28, S35); 18.5 m (S37); 12.8 m (S29); 11.8 m (S30, S36) and 9.8 m (S31). During at least the initial fall in relative sea level small masses of ice remained in the area, while farther south larger masses of dead ice may have been present.

v) During a period of marine erosion the higher raised marine features were truncated and an extensive cliff-line developed.

vi) A large spit formed adjacent to the cliff north of Ardersier (R12a) while a smaller spit (R12) sealed the depression south of the village. Marine terraces which correlate with these shingle ridges occur at 8.4-8.8 m (S41, S38).

vii) Relative sea level then fell to produce a series of raised shingle ridges and marine terraces (eg. R13, S38).

2. Alturlie

a) Previous Research

The village of Alturlie stands on a promontory on the shores of the Inverness Firth some 9 km NE of Inverness (Figs. 31, 35). The promontory has been ascribed a variety of origins. Ogilvie (1923) described it as a remnant of a fluvio-glacial apron which covered the western part of the Inverness Firth. He noted that in this area the apron is pitted with kettleholes. He also suggested that the deposits had been partially eroded by marine action when relative sea level stood at 15 ft (4.6 m), at the same time a looped bar extended the point seaward.

J.S. Smith (1968) interpreted the deposits at Alturlie as asymmetric moraine ridges which had been subsequently modified by marine processes. He suggested that the highest marine feature in the area, a shingle ridge, lay at 102 ft (31.0 m). He advocated that the morainic ridges represent an ice limit which he associated with the Tomnahurich-Torvean gravel complex in the Ness valley (Fig. 39) and kame terraces on the southern slopes of the Beauly Firth.

Synge (1977a) and Synge and Smith (1980) identified the features at Alturlie as a large morainic feature pitted by kettleholes. They suggested that features mark a halt of the retreating ice margin in the Inverness Firth. Synge (1977a) advocated that the ice limit could be traced westwards and then southwestwards by lateral moraines. He also proposed that the Tomnahurich and Torvean ridges at Inverness (Fig. 39) were deposited while ice lay at the Alturlie ice margin. Synge and Smith (1980) suggested that subsequently the Alturlie area was covered by the sea, and the highest marine feature they reported from the area was a shingle ridge at 29-30m. They also proposed that the morainic deposits were later cliffed by Postglacial seas which stood at 11.0 m and 8.0 m.

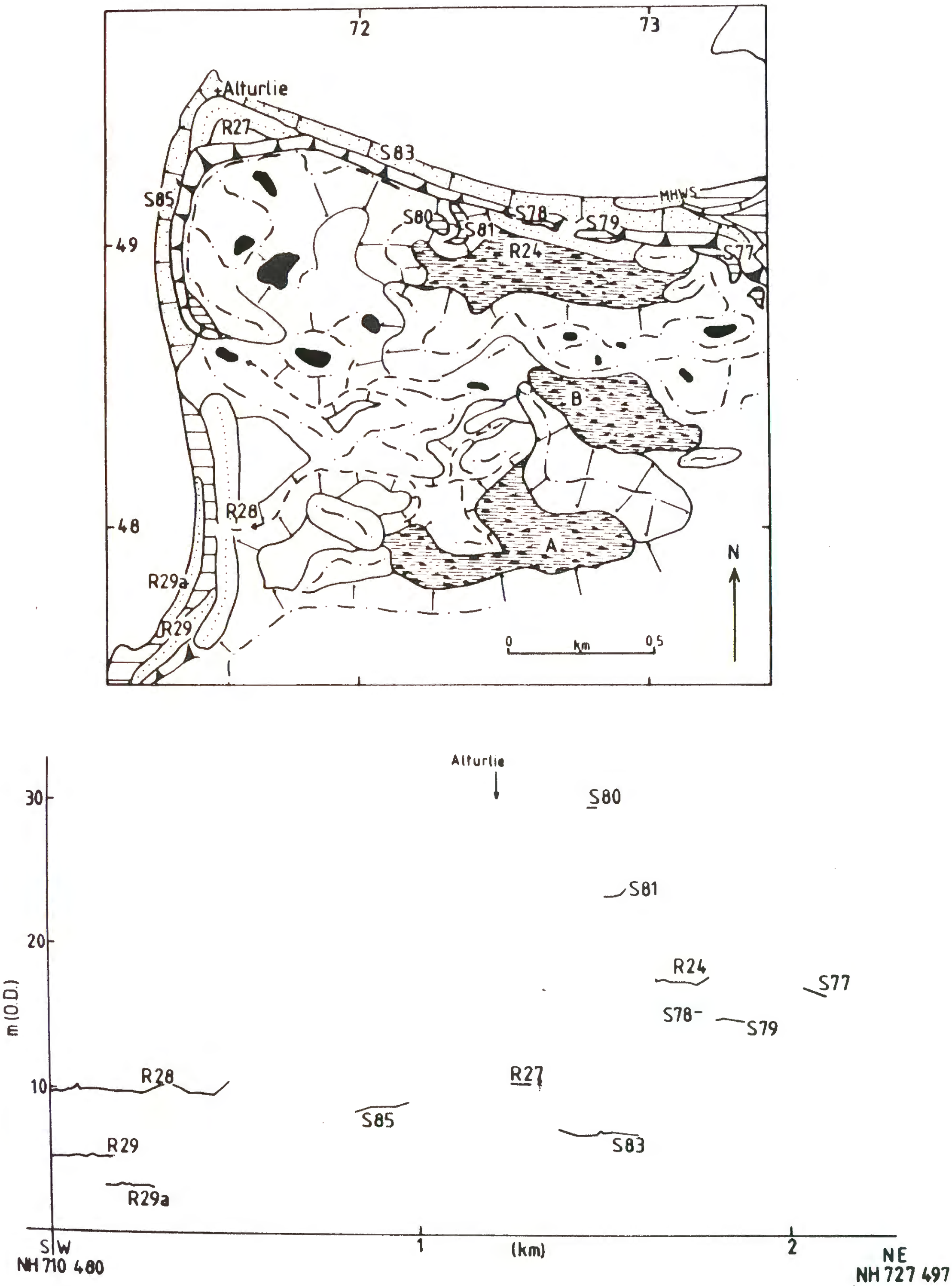


FIGURE 35 The Alturlie area.

Haggart (1982) concluded that there was no evidence of an ice limit at Alturlie. Instead he suggested that the area was made up of fluvio-glacial deposits that resulted from ice decay.

b) Field Evidence

The higher ground at Alturlie is made up of a series of ridges (Fig. 35), the highest of which reaches circa 31 m at its crest. Exposures in the ridges (NH 7150 4920, NH 7262 4818) indicate that they are composed of a series of cross-bedded sands and coarse gravels. The ridges are interpreted as fluvio-glacial deposits. Between some of the ridges there are large kettleholes, while in other localities (Fig. 35, A, B) the ridges lie adjacent to flat-bottomed semi-enclosed basins which contain laminated clays and silts. Analysis of these laminated sediments by sieving (125 µm) revelled no faunal remains.

The highest unequivocal marine feature in the area is a raised shingle ridge (R24) whose crest reaches 17.3 m. Above this there is a flat-topped hill (S80) at 29.3 m and a poorly-defined terrace fragment (S81) at 23.2 m, both of which may be of marine origin. However horizontally bedded deposits at circa 29 m are present in a gravel pit section (NH 715 493). Although the marine origin proposed by J.S. Smith (1968) is accepted the morphological feature of a shingle ridge which he and Synge (1977a) identified in association with these deposits could not be distinguished. Lower well-defined raised marine terraces are also present at 16.6 m (S77) and 14.7 m (S79).

The high ground and higher marine features (S77-S80, R24) have been cliffed. Adjacent to the cliffs are shingle beaches (S83, S85) at 8.8 m and 7.0 m and a shingle cuspate foreland (R27), the crest of which reaches 10.4 m. Farther south there is a shingle ridge (R28), the crest reaching 9.9 m (Fig. 35). Below this ridge (R28) two lower ridges (R29, R29a) are present.

c) Discussion

The fluvio-glacial ridges which make up the high ground at Alturlie can not be related to a former ice margin. The lack of alignment of these ridges suggests that ice decay was chaotic and was probably associated with stagnant ice. The origin of the laminated clays and silts within the flat-bottomed basins between the fluvio-glacial ridges is unknown. It is possible that the deposits are marine, but alternatively, they may be lacustrine.

The highest inferred marine feature in the area (S80) at 29.3 m and the marine deposits at circa 29 m indicates that much of the promontory could have been modified by marine action. However, there are few well developed marine features in the area and this may be explained as a result of ice coverage or because of the limited fetch situations between many of the ridges.

Subsequently the fluvio-glacial deposits were cliffed. Since the small cuspate foreland (R27) lies adjacent to this cliffline it must have developed at a later date. The cuspate foreland is also correlated with the raised shingle beach (S85) and the raised shingle ridge (R28) found farther to the south.

d) Sequence of Events

i) The ice sheet downwasted and formed a series of kames in the Alturlie area.

ii) The sea inundated into the area and formed raised marine features at 17.3 m (R24), 16.6 m (S77) and 14.7 (S79). Higher features at 29.3 m (S80) and 23.2 m (S81) may also be marine. As relative sea level fell large masses of ice may have remained in the area. Between some of the kames laminated deposits of marine or lacustrine origin accumulated.

iii) The fluvio-glacial and higher raised marine deposits were cliffed.

iv) Shingle ridges (R27, R28) and shingle beaches (S85) were formed adjacent to this cliffline to a maximum altitude of 10.4 m.

v) Relative sea level fell to form raised shingle ridges (R29) and lower raised shingle beaches (S83).

3. Munlochy Bay and Valley

a) Previous Research

Munlochy Bay forms an inlet aligned approximately at right angles to the main trend of the Inverness Firth (Figs. 31, 36, Plate 4). The Bay is continued inland by the steep sided valley of Munlochy which has a similar alignment as the Inverness Firth. Horne and Hinxman (1914) suggested that within this valley there are shoreline fragments at 100 ft (30.5 m) and at 50 ft (15.2 m). They reported that the highest shoreline fragment is composed mainly of sand and gravel, but with areas of stiff laminated clay. Above the main valley they described a series of fluvio-glacial gravel deposits which they associated with terminal moraines on Millbuie Moor (Fig. 31).

Ogilvie (1923) suggested that raised marine features are present in Munlochy Bay/valley at a variety of altitudes. He identified the highest marine terrace (S101) as being at 100 ft (30.5 m) and associated this with an outwash plain,(remnant of which he identified just within the entrance of Munlochy Bay).

J.S. Smith (1968) also indicated that a series of raised marine features are present in this area. He suggested that the highest marine features (S101, S108) form a distinct notch on both sides of the valley at an altitude of 89-90 ft (27.4 m), but he described none of the lower marine features.

b) Field Evidence

On the slopes of Munlochy valley and above Munlochy Bay there are a series of raised shoreline fragments (S90-S122, R31; Figs.

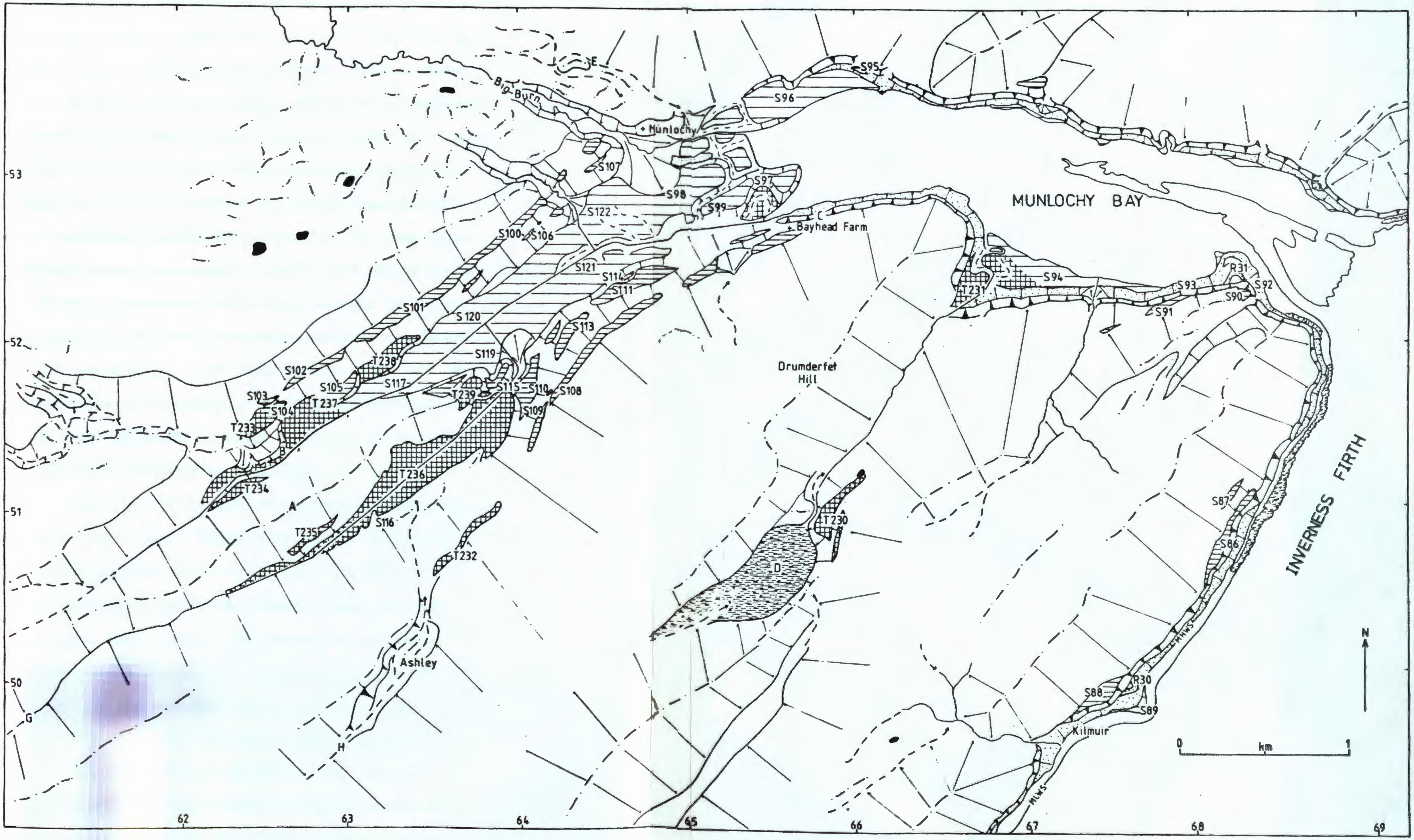


FIGURE 36 The Munlochy area.

36, 37). The highest and most distinct features form a marine terrace at 29.0-29.3 m (S91, S100, S101, S103, S108)(Plate 5). On the northern side of Munlochy valley the highest shoreline fragment (S101) appears to grade laterally into a lower marine terrace (S102) at 27.7 m. At another locality (S104, S109) a marine terrace at 27.0 m forms a separate terrace surface below the highest marine terrace. At lower altitudes there are a series of raised marine terraces which are only locally developed (S104-S107, S110-S116). Many gullies are present on the valley sides and they appear to grade to the highest raised marine terraces, but some dissect the highest marine feature and grade to lower raised marine terraces. This indicates a progressive fall in relative sea level, and precludes the possibility that the lower marine features were formed earlier than those above them. At the head of the valley (Fig. 36, B) laminated grey clays occur beneath sand and gravel deposits of an alluvial fan. The clays are probably marine deposits, but no faunal remains were obtained to substantiate this view.

The floor of Munlochy valley is composed of grey silty clays which contain shell fragments and which overlie sands and gravels. Towards the head of the valley the silty clay deposits become peaty and at certain localities islands of peat have been identified (Haggart, pers. comm.). The surface of the silty clay forms a series of horizontal sections (S117, S119-S122) linked by gently sloping ramps. In the east the lowest horizontal section (S121, S122) is separated from lower marine terraces (S95-S98) by a distinct slope.

Around the shores of Munlochy Bay there is a degraded cliffline (Plate 4). This cliffline could be traced as far inland as Bayhead Farm (Fig. 36, C). Lying adjacent to the cliffline are several shingle beaches and shingle ridges (R31, S92, S93) at 8.5-10.5 m. Below these there is a lower raised estuarine terrace

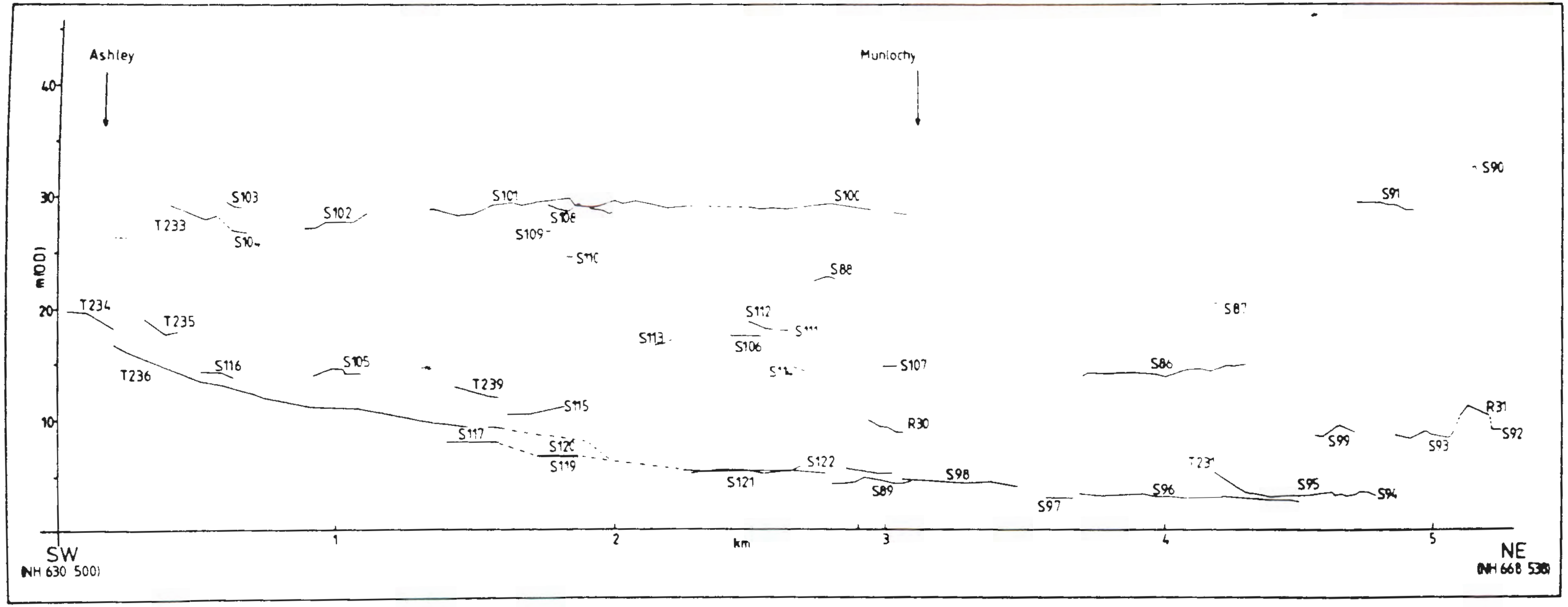


FIGURE 37 Altitude data for the Munlochy Bay and Munlochy Valley areas.

PLATE 4 Munlochy Bay at low tide (viewed from NH 6548 5388 looking towards ESE). Note the raised estuarine deposits adjacent to the present day mudflats, the steeply sloping raised shingle beaches on the opposite side of the bay and the degraded cliffline behind these shingle features.

PLATE 5 Shoreline fragment S100 in Munlochy Valley (viewed from NH 6434 5179). The lower house stands on the shoreline fragment, whilst lower Flandrian estuarine deposits occur in the bottom of the valley.

at 3.0 m (S94).

On the hillslopes above Munlochy Bay/valley there are several fluvio-glacial features. In the valley to the SE of Drumderfet Hill (Fig. 36, D) a peat filled depression lies adjacent to a poorly-defined outwash terrace fragment (T 230). This terrace fragment only extends a short distance down valley and can not be correlated with the raised marine features in the area. Directly north of Munlochy village there are several small meltwater channels (Fig. 36, E). Farther west in the vicinity of Muirton Burn (WH 628 547) there is a dissected outwash fan whose meltwaters would have passed into Munlochy valley via Big Burn (Fig. 36). West of Munlochy the higher ground is composed of kame and kettle topography, indicative of downwasting ice.

At the head of Munlochy valley a ridge (Fig. 36, A) divides the valley into two arms. Leading into the northern arm are a series of well-developed meltwater channels which extend NW to kame and kettle topography around Tore (Fig. 36) and eastwards to the Glackmore col (which divides the Munlochy basin from that of Redcastle Burn). Leading into the southern arm of the valley are meltwater channels associated with cols at Taindore (Fig. 36, G) and Ashley (Fig. 36, H). The latter forms a channel which passes near Bogalian Church (NH 6350 5050) to a poorly-defined terrace fragment (T 232) which extends down to <u>circa</u> 30 m.

c) Discussion

The fluvio-glacial deposits in the Munlochy area testify to extensive decay of a former ice mass. Many of the meltwater channels associated with these deposits ultimately lead into Munlochy valley, but the direct association of these features with the raised marine terraces is only known near Ashley. Meltwaters flowed from the Beauly

Firth across the Ashley col and probably graded to the highest marine terrace in Munlochy valley (S108). On these grounds it is probable that meltwaters flowed into the Munlochy area across the Glackmore and Taindore cols at the same time. The presence of decaying ice in the vicinity of Tore is also likely during this period. This indicates that ice remained in the Beauly Firth, on the higher parts of the Black Isle and in the southern limb of Munlochy valley, whilst the Inverness Firth and much of Munlochy valley were ice free.

The clarity of the highest raised marine terraces throughout the Munlochy area suggests either considerable stability of relative sea level or high sediment availability during their formation. The likelihood that meltwaters poured into the area while these marine features formed makes the latter explanation the more plausible. Lower marine terraces are only locally developed and this may reflect reduced sediment input when the meltwaters no longer flowed across the cols. The presence of gullies which dissect the highest raised marine terraces and which grade to lower raised shoreline fragments indicates a progressive fall in relative sea level.

The marine terraces located in the bottom of Munlochy valley (S117, S119-S122) are unlike most of the estuarine deposits in the study area, for they are not separated by distinct slopes. In the Forth valley similar silty clay deposits have produced a similar phenomenon (D.E. Smith, 1968) but on a considerably larger scale. It is possible that the horizontal sections represent the former saltmarsh areas and the sloping ramps the former mudflats. Restricted fetch in the estuary of the time resulted in no intervening slope being formed when relative sea level fell to a lower level. Located in the highest of the terraces composed of silty clay are islands of peat (Haggart pers. comm). Limited statigraphical study suggested that the peats contain layers of silty clay. It is possible that the peat mosses continued to accumulate as the silty clays were deposited, and this hypothesis was advocated by Sissons and Smith (1965b) for similar features in the Forth valley.

The abrupt end of the cliffline which is found around Munlochy Bay suggests that the marine erosion did not occur farther inland. As a small shingle cuspate foreland (R31) lies adjacent to this cliffline it is unlikely that the cliff and the foreland formed at the same time. In contrast, it is probable that the foreland (R31), shingle beaches (S92, S93, S99) and the highest estuarine deposits (S117) were formed at the same time.

d) Sequence of Events

i) The ice sheet that formally covered the Munlochy area downwasted and retreated. During this time period an outwash terrace (T 230) was formed south of Drumderfit Hill.

ii) Ice retreated from the Inverness Firth and Munlochy valley and allowed the sea to enter the area at 29.0 m. During this time meltwater flowed into Munlochy valley from ice to the north near Tore as well as from an ice mass in the Beauly Firth.

iii) Relative sea level fell to produce raised marine terraces at 27.0 m (S102, S104, S109), 24.6 m (S110), 17.5 m (S106, S111-S113) and 14.0-14.8 m (S105, S107, S114, S116).

iv) Subsequently, during a period of marine erosion a cliff was formed around Munlochy Bay.

v) At the head of Munlochy valley raised estuarine deposits accumulated as sea level rose. Peat mosses sea level. The rise culminated at 8.0 m (S117) and on the more exposed shores around Munlochy Bay shingle beaches (S92, S93, S99) and a shingle cuspate foreland (R31) formed.

vi) Relative sea level fell to form raised estuarine terraces at 6.8 m (S119, S120), 5.3 m (S121, S122), 4.2 m (S98), 3.4 m (S95) and 3.0 m (S94, S96, S97).

4. <u>Other Features/Areas of Interest</u>

a) Fortrose and Chanonry Ness

Chanonry Ness forms a promontory into the north eastern end of the Inverness Firth. The narrow triangle of land (Figs. 31, 38) separates the Inverness Firth from the Open Coastlands. Ogilvie (1914) suggested that the promontory was composed of raised marine features at 100 ft (30.5 m), 75 ft (22.8 m), 50 ft (15.2 m), 25 ft (7.6 m) and 15 ft (4.6 m). He described the lower two features as a complex breached shingle cuspate foreland.

J.S. Smith (1968) suggested that the highest marine feature identified by Ogilvie (1914) was a kame moraine truncated by marine deposits at 101 ft (30.8 m). Smith associated this moraine with the deposits at Ardersier and postulated that together the features represented an ice readvance limit. He also suggested that the beds of stratified sand and clay in the Rosemarkie Glen (Fig. 38) were deposited during the same glacial event.

The promontory of Chanonry Ness is characterised by a staircase of raised marine features. The highest marine feature (S49), (Fig. 38) forms a distinct marine terrace eroded into an alluvial fan (T 246) which rises towards the mouth of Rosemarkie Glen. The alluvial fan and raised shoreline fragment may merge at the site of Fortrose. Below this marine terrace there are three lower marine terraces

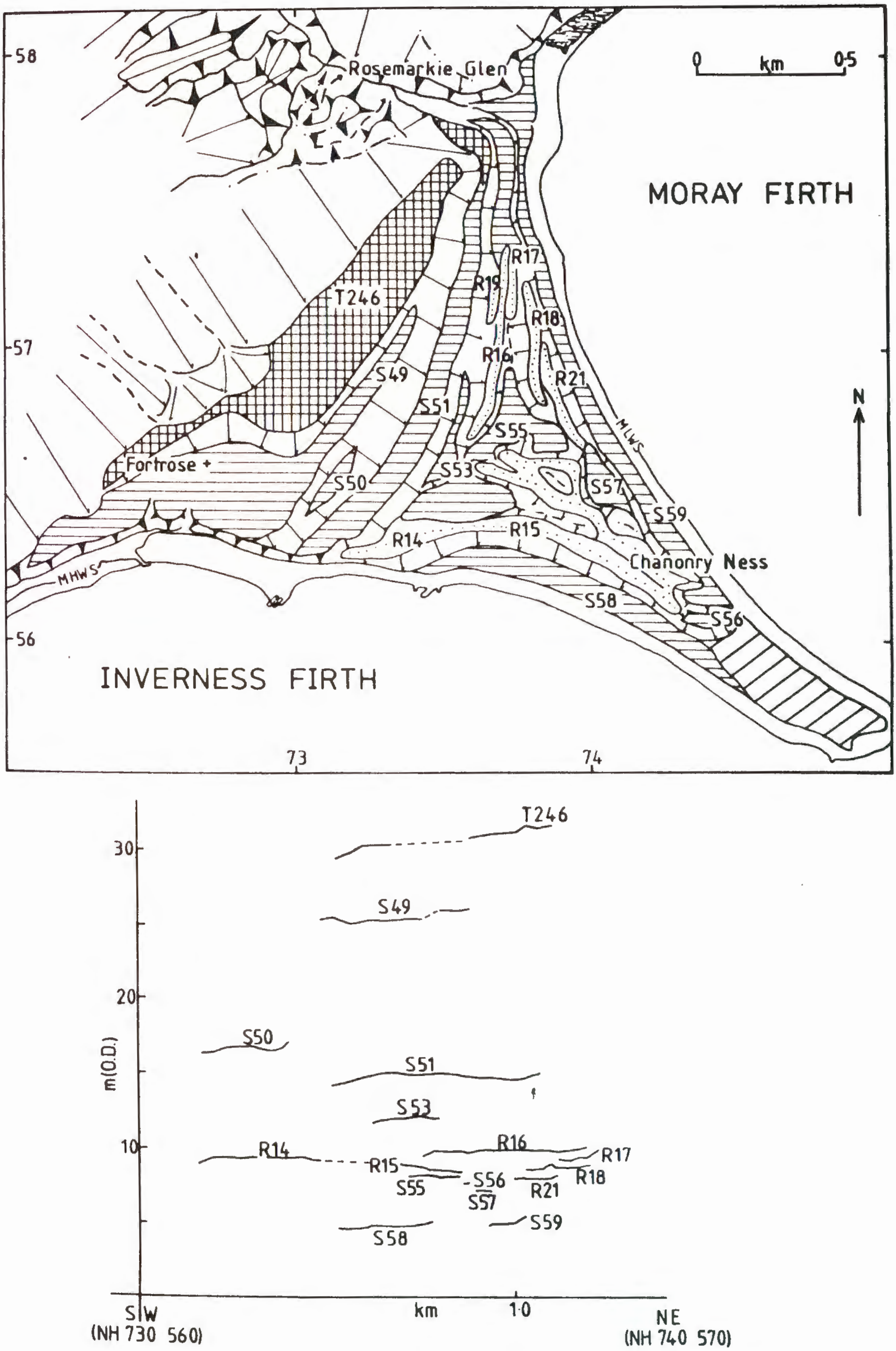


FIGURE 38 The Fortrose area.

S50 (16.6 m), S51 (14.6 m) and S53 (11.7 m). Each of these marine features is composed of coarse sand and gravel overlying coarse gravel with boulders. Lying below these terraces are a series of raised shingle ridges (R14-R20) the highest of which rises to 9.7 m at its crest. The lower of these ridges forms a raised cuspate foreland. Below these ridges raised marine deposits occur at 7.8-7.0 m (R21, S56, S57) and at 4.7 m (S58, S59). These lower marine features are composed of well-rounded fine gravel and sand with shells. Locally, especially towards the end of the promontory, the marine features are overlain by wind-blown sand.

The most likely source of sediment for the raised marine features lies to the north in Rosemarkie Glen. Here a rock gorge (as indicated by the rock quarry at NH 728 583 has been infilled with stratified deposits which have been dissected and partly removed. Sections in these deposits (eg. NH 7293 5781) indicate that these deposits rise at least 100 m. At one section (NH 7362 5784) crossbedded sands and gravels are interbedded with red clay layers and beds of silty clay with angular clasts. The surface of these deposits forms a steeply-sloping terrace. Observations of the inclination of the crossbedded sediments indicates that the deposits dip up-valley. The thickness, dip and composition of the deposits suggest that they were formed while ice lay in the Inverness Firth to an altitude of at least 110 m. The silty clay beds with angular clasts may represent glacio-lacustrine sedimentation, while the crossbedded sands and gravels are indicative of a fluvio-glacial origin. It is possible that the deposits may have accumulated subglacially or alternatively they may have formed during deglaciation. As the high level fan (T 246) is associated with water which flowed through the Rosemarkie Glen it is evident that the massive deposits in the Glen were formed before the alluvial fan.

b) Rosehaugh Valley

Rosehaugh Burn drains into the Inverness Firth at the village of Avoch (Fig. 31). The line of the valley is continued to the SW by Munlochy valley, and a col at 34 m separates the two drainage basins. A series of misfit streams (Rosekill Burn, Killien Burn) and dry meltwater channels pass into the valley from the north. Each meltwater channel extends into areas of extensive fluvio-glacial deposits.

At the mouth of Killien Burn a dissected fan (T 240) extends down valley where it grades into a raised shoreline fragment (S61) at 22.6 m. A lower fan (T 241) is graded to a marine terrace (S62) at 19.9 m. The surface of the lower raised marine terrace is pitted by a deep kettlehole which has become filled with peat. In the rest of the area there is no evidence to suggest that ice was present when the raised shoreline fragments (S61, S62) were formed. However, it may be inferred from the size of Killien valley, and the meltwater channels which grade to the surface of the highest fan (T 240) that meltwater flowed into the area when the raised marine terraces were formed. It is therefore tentatively suggested that decaying ice lay to the north of the area while the raised marine shoreline fragments (S61, S62) were produced.

c) Raddery Valley

Raddery valley (Fig. 31) trends ENE-WSW and at its eastern end it turns through a right angle to pass into Rosemarkie Glen. To the west the valley is divided into two arms by Ord Hill (Fig. 31). The northern arm forms a broad depression continued across a shallow col (circa 91 m) into the basin of Killien Burn. At the eastern end of Raddery valley there are several steeply-sloping kame terraces, the lowest of which descends to circa 75 m. Water from this kame terrace must have drained through Rosemarkie Glen. Below this terrace the flat valley bottom is characterised by extensive deposits of white sand. These deposits extend to the WSW where they pass into a narrow channel which leads to the col. The channel is eroded in outwash deposits which are bounded by ice contact slopes to the west and descend eastwards to circa 90 m. All these features are attributed to a downwasting ice mass which retreated towards the west. It is possible that the white sands represent a former lake which was dammed by higher kame terraces and the deposits which filled Rosemarkie Glen. The sediments were certainly deposited while ice lay to the SW since meltwaters must have drained through the channel at the head of the valley. The relationship of the features in Raddery valley to those at Fortrose and in the Rosehaugh valley is unknown. It is possible that ice remained in the Raddery valley while meltwaters drained through Rosemarkie Glen and Killien Burn.

d) Intertidal Rock Platform

Along the northern shore of the Inverness Firth an intertidal rock platform can occasionally be identified (especially between Kilmuir and Munlochy Bay)(Fig. 31). The platform is also present north of Fortrose and at Nairn (Fig. 21). The platform is 30-50 m wide and frequently mantled by Flandrian sand and shingle including modern deposits. At several sites it is overlain by till and fluvioglacial deposits, but many of these deposits have been displaced to their present positions by mass movement processes. No evidence of ice moulding of the platform was identified. Near Munlochy Bay the rock platform is backed by a degraded cliff 4-6 m high. The platform certainly predates Flandrian marine terraces and at no site was it found eroded into higher raised marine features. The age of the platform is therefore problematical and it may represent more than one phase of marine erosion.

CHAPTER SEVEN

INVERNESS AND THE GREAT GLEN

1. Introduction

Various interpretations have been proposed for the deposits and landforms which lie in the Great Glen (Fraser, 1876; Horne and Hinxman, 1941; Ogilvie, 1923; J.S. Smith, 1968, 1977; Peacock, 1977; Synge, 1977a; Sissons, 1979a, c, 1981b, d; Synge and Smith, 1980). The early researchers (Horne and Hinxman, 1914; Ogilvie, 1923) limited their investigations to the narrow strip of land between the northern end of Loch Ness and the sea (termed the Ness valley)(Fig. 39). Horne and Hinxman suggested that the Ness valley is occupied by numerous fluvio-glacial terraces . They also described gravel terrace fragments which border Loch Ness at 100 ft (circa 30 m) between Tor Point and Bona Ferry (Fig. 45), and they concluded that these may not be of marine origin. Ogilvie (1923) suggested that the higher part of Inverness rests on a remnant of a great fluvio-glacial apron which was deposited when relative sea level stood at 90 ft (27.4 m).

The views of the early researchers have been qualified or superceded by more recent studies. At present two contrasting interpretations exist for the deposits and landforms which lie in the Great Glen. J.S. Smith (1968, 1977) and Synge (1977a) have advocated a Lateglacial marine incursion into Loch Ness. In contrast, Sissons (1979a, 1981b, d, pers. comm.) suggested that there is no evidence for a Lateglacial marine incursion and considers that many of the landforms in the area resulted from or were modified by a jökulhlaup flood at the end of the Loch Lomond Stadial.

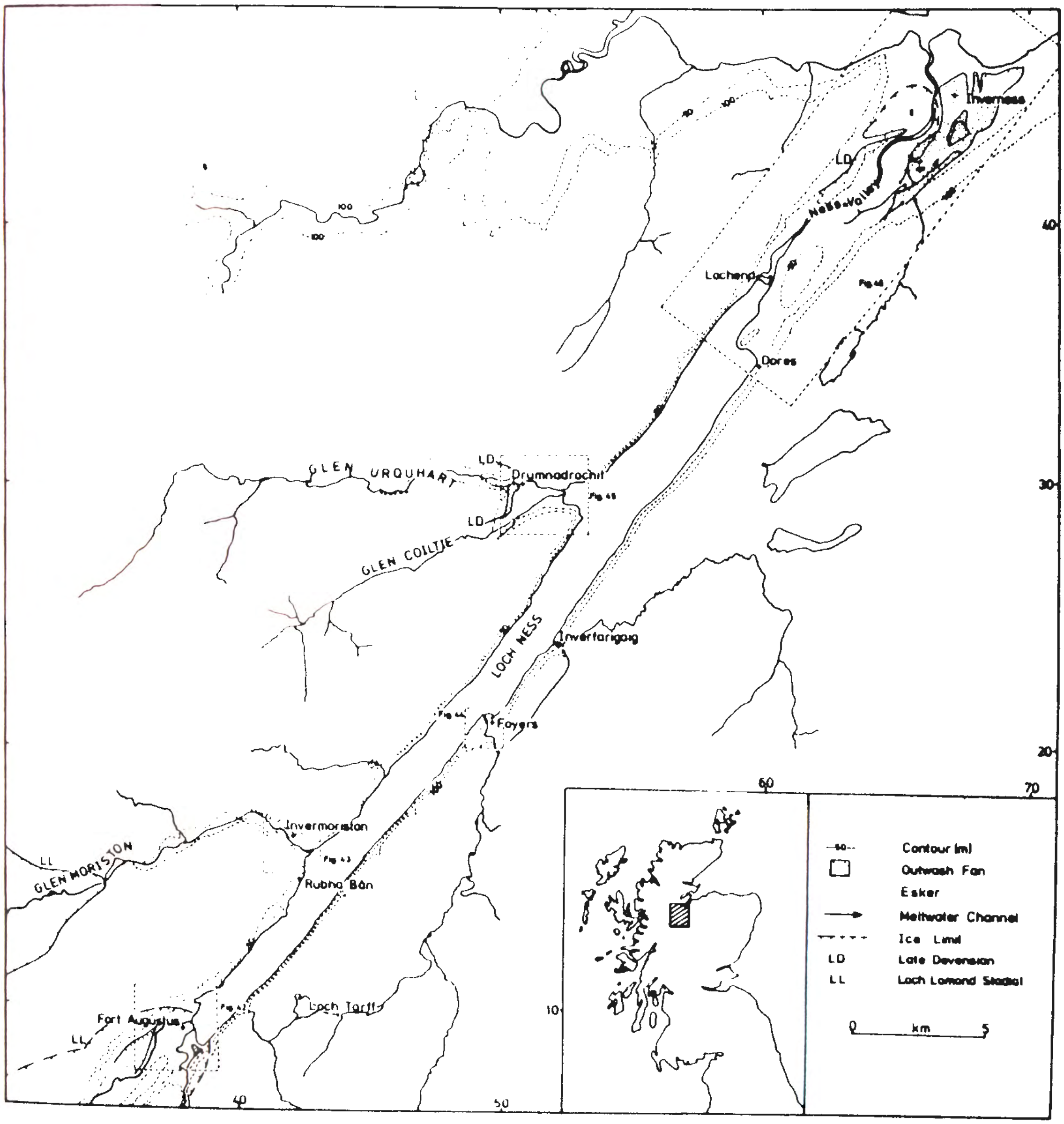


FIGURE 39 The Loch Ness and Inverness region.

Shoreline Fragment	No. of Points	Mean Grid Ref.	Mean Altitude	Quality of Measurements
S123	5	NH 6957 4513	31.01	M
S124	6	NH 6960 4513	31.23	M
S125	3	NH 7067 4546	30.64	M
S126	3	NH 7095 4586	27.31	M
S127	3	NH 7077 4571	27.67	M
S128	8	NH 7030 4556	27.30	M
S129	3	NH 6958 4531	27.80	G
S130	8	NH 6925 4497	27.60	G
S131	3	NH 6904 4529	27.13	M
S132	5	NH 6927 4578	27.18	M
S133	4	NH 6929 4561	24.83	M
S134	2	NH 6997 4591	24.61	M
S135	9	NH 7017 4609	15.78	P
S136	3	NH 7080 4648	16.25	M
S137	7	NH 6538 4363	16.62	M
S138	6	NH 6501 4423	13.73	M
S139	6	NH 6002 3838	24.33	M
S140	8	NH 6043 3791	25.78	P
S141	7	NH 6002 3826	16.65	G
S141	8	NH 5983 3805	16.44	G
S142	6	NH 6011 3784	17.26	P
S143	4	NH 6022 3782	18.10	M
S144	8	NH 6020 3586	35.27	P
S145	8	NH 6012 3570	34.60	M
S146	5	NH 5958 3546	34.83	P
S147	5	NH 5961 3537	25.48	M
S148	7	NH 5895 3348	18.82	G
S149	5	NH 5231 2911	26.98	M
S150	3	NH 5100 2993	27.09	M
S151	3	NH 3886 0858	29.53	M
S152	6	NH 4245 1613	31.68	G
S154	9	NH 4292 1631	17.19	M

TABLE 13 Raised shoreline fragments in the Inverness and Loch Ness region. P = Poor, M = Moderate, G = Good.

Shoreline Fragment	No. of Points	Mean Grid Ref.	Mean Altitude	Quality of Measurements
S155	5	NH 4242 1505	29.18	M
S156	6	NH 3980 1150	29.62	M
S157	9	NH 3882 1060	28.96	G
S157	8	NH 3855 1038	29.23	G
S158	4	NH 3908 0889	28.90	M
S159	11	NH 3662 0902	36.06	M
S160	7	NH 3840 0831	32.53	G
S161	2	NH 3813 0846	22.37	M
S285	3	NH 4923 2111	21.00	M
R32	6	NH 5985 3791	19.40	M
R32	6	NH 6006 3781	19.42	M
R33	6	NH 6003 3532	28.67	G
R33	6	NH 5984 3544	28.66	G
R34	6	NH 5985 3503	19.92	G
R34	6	NH 5965 3513	20.34	G
R35	5	NH 5859 3303	28.02	M
R36	6	NH 4950 2150	17.67	G
R37	5	NH 4913 2098	28.98	M
R38	7	NH 3846 0851	17.83	G

TABLE 13 (cont.)

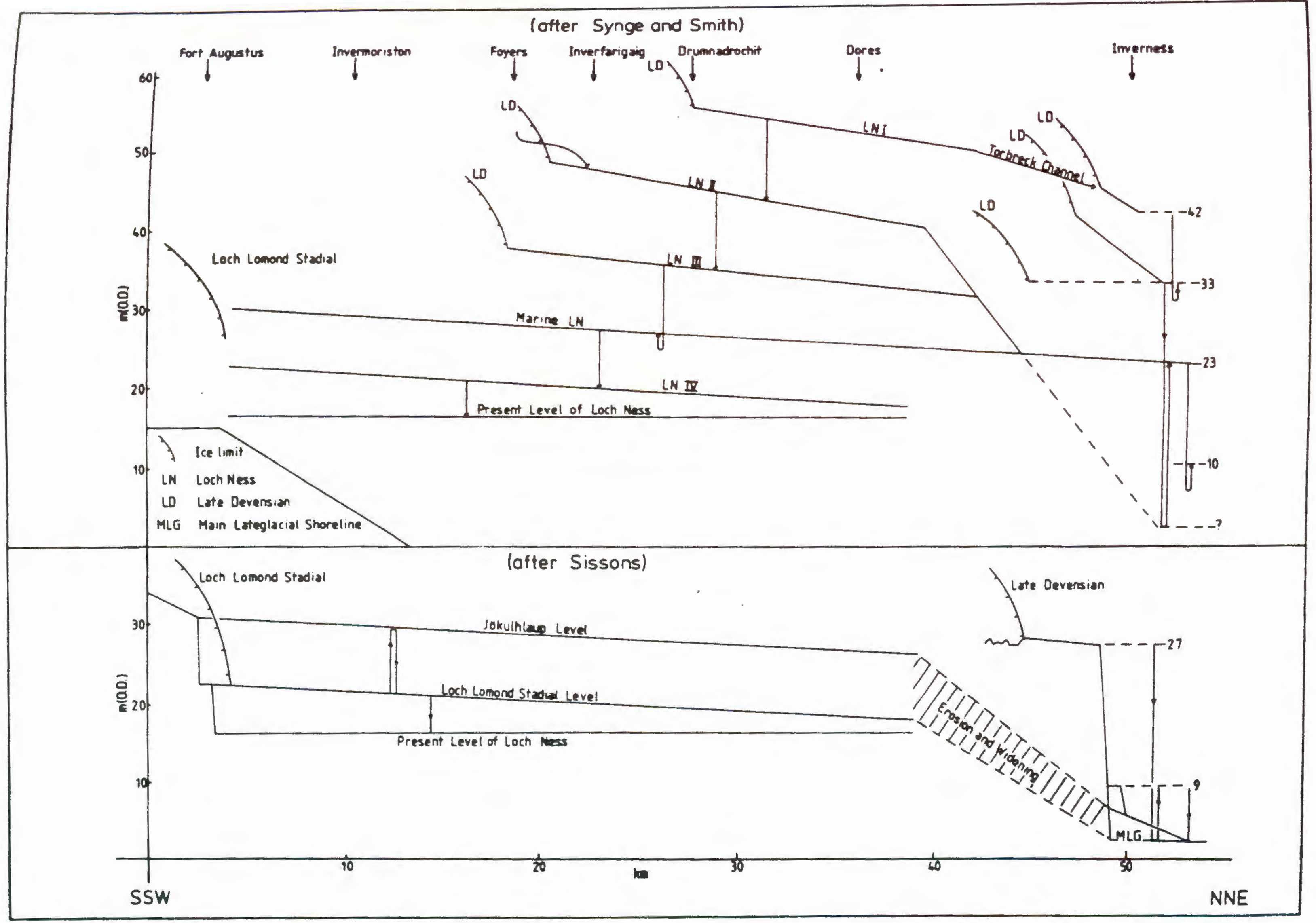
PLATE 6 The southern end of Loch Ness (viewed from NH 3947 0853, looking towards the NE.). Note the limited fetch environment across the loch and the indentation of Glen Moriston(in the centre of the plate).

a) Events Proposed by Synge and Smith

Synge (1977a) suggested that the highest marine feature in the Inverness area is a high delta surface at Lochardil (Figs. 40, 45, T142, T143). He proposed that the delta surface descends northward from an ice contact slope, declinnig from 46 m to 42 m and that relative sea level stood at circa 42-43 m at the time of its formation. He concluded that the associated ice front lay in the Inverness area. However, Synge also suggested that while the sea stood at this level water passed through the Torbreck channel (Figs. 40, 46) from a lake at 56 m in Loch Ness. He claimed that evidence for this high lake level exists in Glen Urquhart where a moraine was correlated with deltaic outwash at 56-57 m. Synge advocated that the 56 m loch level was impounded between a receding ice margin in the Great Glen and a drift plug in the Ness valley. This conflicts with the ice limit proposed by him for the Lochardil delta.

J.S. Smith (1968, 1977), Synge (1977a) and Synge and Smith (1980) suggested that whilst ice occupied the Ness valley and Beauly Firth relative sea level fell to circa 33-34 m (Fig. 40). Extensive spreads of deltaic gravel were deposited at Culcabock, Inverness (T153). Synge suggested that "... the course of the main subglacial river that fed the delta is represented by the massive esker ridge of Tomnahurich and Torvaine." (p. 87). Synge considered that the ice then retreated southward to allow the sea (still at the same relative level) to extend up the Ness valley as far as Clachnahulig (NH 6423 4275) where a raised shoreline fragment occurs at 33 m.

Further ice recession was proposed whilst relative sea level fell (Synge, 1977a). Synge suggested that the ice front lay 1 km west of Drumnadrochit in Glen Urquhart and between Inverfarigaig and



<u>FIGURE 40</u> The two contrasting sequences of events proposed for the Loch Ness region.

Foyers in the Great Glen (Figs. 39, 40). He proposed that meltwaters in Glen Urquhart formed a delta at 47 m whilst the river Foyers was diverted through Glen Liath (Fig. 39) to form a delta at Inverfarigaig at 46 m. Synge interpreted the two deltas as evidence of a 46-47 m level of Loch Ness and he suggested that water from the lake passed down the Ness valley by way of the highest fluvial terrace (T175) to a low relative sea level (below 26 m).

Synge maintained that with a further withdrawal of the ice front, meltwaters formed a delta at Foyers in a loch at 39 m. He also considered that delta flats at 37 m at Drumnadrochit accord with the same loch level.

Synge (1977a) and Synge and Smith (1980) advocated that relative sea level then rose to form a prominent Lateglacial shoreline. J.S. Smith (1968) indentified several raised shoreline fragments in the Ness valley at circa 88-90 ft (26.8-27.4 m). He suggested that the northern end of Torvean esker is notched (S137), whilst farther south the raised marine terraces are kettled (T175). J.S. Smith traced the raised marine features throughout the Ness valley and advocated a Lateglacial marine incursion into Loch Ness. A shingleridge at Dores (Fig. 45, R 33) at 96 ft (29 m) was attributed to this marine incursion, whilst Synge (1977a) also correlated deltas at Drumnadrochit (T201), Invermoriston (S152) and Foyers (T208) with this marine incursion, as well as a shore platform at 31 m between Invermoriston and Fort Augustus. In particular he drew attention to a section in the platform at Rhubha Ban (Fig. 39) which shows beach gravels overlying deltaic deposits at 30 m. Synge noted that the raised shoreline is absent at Fort Augustus and he suggested that the end moraine in this area postdates the formation of the Lateglacial shoreline. Synge also cited evidence from lake sediments cores obtained from Dores Bay to support his hypothesis of a marine incursion. Analysis of the cores by Pennington et al. (1972) indicated a salt content no higher than that obtained from lake sediment cores from the lakes of Cumbria. However, one horizon of the Dores core had a total halide count more than double that from any of the lake sediments in Cumbria and Synge considered this significant in terms of a Lateglacial marine incursion. He suggested that the general absence of salt in the lake sediments can be explained by the former presence of a high threshold in the Ness valley that acted as a barrier to incoming tidal waters.

Synge proposed that a later period of widespread ice wastage was associated with a fall in relative sea level. He indicated that a climatic deterioration during the Loch Lomond Stadial resulted in an advance of glaciers in Glen Moriston, Strath Errick and the Great Glen. He suggested that lateral moraines at Tomanhoid (Fig. 42) and Bunoich (Fig. 42) near Fort Augustus mark the limit of this ice advance. On the basis of pollen evidence from Loch Tarff and Loch Oich (Pennington et al., 1972) he correlated these moraines with the Loch Lomond Stadial and considered that during this period relative sea level was low.

Synge suggested that after the final disappearance of the ice at the beginning of the Flandrian, relative sea level rose once more. He considered that sea level attained a maximum altitude of 10-12 m in the Inverness area at circa 7 000 B.P.

b) Events Proposed by Sissons

Sissons (1979a, c, 1981b, d) suggested that many of the landforms in the Great Glen, can be attributed to a jökulhlaup that occurred at the end of the Loch Lomond Stadial. He (1979c) identified an ice limit at Fort Augustus which he correlated with Loch Lomond Stadial ice limits in Glen Spean and Glen Roy (Fig. 41). Sissons (1979a) noted that inside the ice limit a very extensive outwash terrace commences a few kilometres SW of Fort Augustus and rises from 31 m at Borlum (Fig. 42, S160) to circa 40 m SW of Fort Augustus, where it is extensively kettled. Since he placed the outwash terrace within the Loch Lomond Stadial ice limits he could not correlate it with Synge's (1977a) proposed Lateglacial marine shoreline. Sissons (1979a) also noted that the large outwash terrace is anomalous in several respects since it is extensively kettled, well within the ice limit and graded to an apparent high loch level. He (1981b, d) also proposed that at Inverness a low level alluvial fan which makes up much of lower Inverness (at Longman)(Fig. 46) is also anomalous. Peacock (1977) had suggested that this feature was deposited during the Loch Lomond Stadial as a consequence of summer meltwater floods. However, Sissons (1981b) noted that the alluvial fan is composed of gravels which lack silt and clay, and postulated that these latter sediments would be expected if the feature had accumulated from a series of snowmelt floods. He also noted that the alluvial fan extends completely across the Beauly Firth and that it infills a former channel. He suggested that an alluvial fan deposited by periodic floods would have not such a characteristic. Finally he indicated that the alluvial fan is composed of material coarser than that carried by the present river Ness. Sissons also claimed that the highest shoreline fragments around Loch Ness occur at 18.2 m at the northern end and at 22.5 m (S161) at the southern end.

Sissons (1979a, 1981b) proposed that the anomalous features at Fort Augustus and Inverness can be explained by the drainage of a former ice-dammed lake in Glen Spean and Glen Roy. He maintained

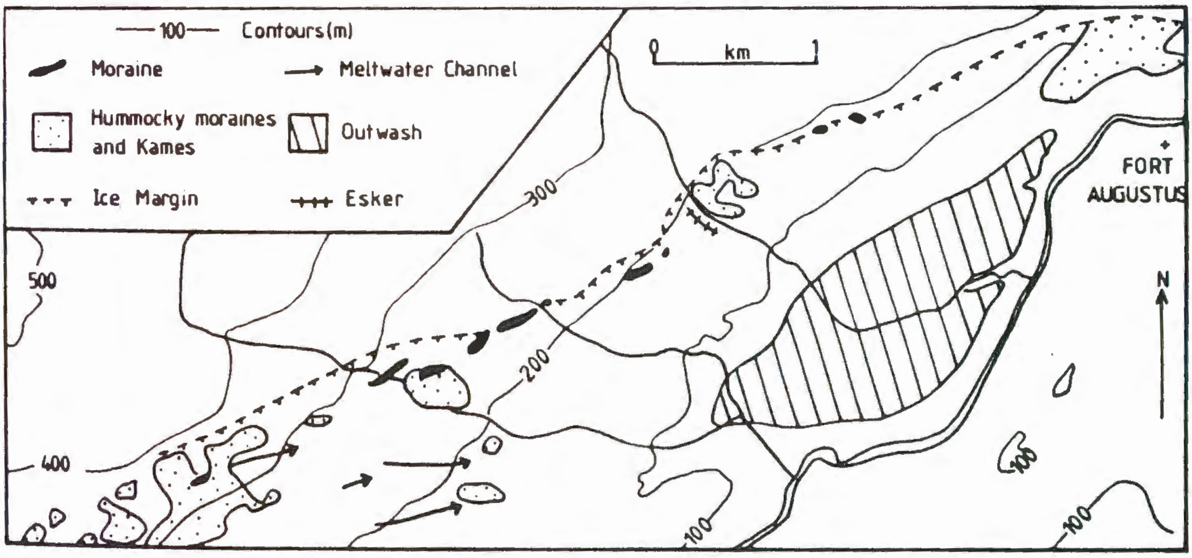


FIGURE 41 The Loch Lomond Stadial ice limit identified at Fort Augustus by Sissons (1979c).

that as glacier ice retreated after the Loch Lomond Stadial advance, an ice-dammed lake in Glen Roy merged with an ice-dammed lake in the Spean valley to form a lake at 260 m which attained a volume of 5 km^3. Sissons (1979a) suggested that this lake drained subglacially in a single catastrophic event which possibly formed the Spean gorge. He proposed that the water flowed northward subglacially with a peak discharge of <u>circa</u> 22 500 $m^3 s^{-1}$ and drained into Loch Ness which then stood at 22.5 m at its southern end. Sissons considered that the ice in Glen Spean had thinned some 200 m when the jökulhlaup occurred and that a similar thinning of ice at Fort Augustus would have placed the terminus of the glacier at the proximal end of the large outwash spread. He advocated that the large volume of water associated with the jökulhlaup formed the kettled outwash spread near Fort Augustus and proposed that the discharge of water into Loch Ness temporarily raised it by 8.5 m from 22.5 m to 31 m (Fig. 40). At the northern end of the loch, Sissons envisaged that the overflow waters drained into the Ness valley and he attributed the prominent bluff on the eastern side of the valley and the width of the valley to this drainage. Sissons (1981d) also maintained that the debris derived from the enlargement of the Ness valley was deposited as the low-level alluvial fan at Inverness. He concluded that since the alluvial fan resulted from a single flood event its anomalous features (lack of silt, filling a former channel, very coarse material) could be explained. Sissons advocated that Loch Ness then returned to its pre-jökulhlaup level (Fig. 40) although he suggested (1979a, 1981d) that later jökulhlaups may have occurred from later ice-dammed lakes in Glen Spean and Glen Roy. However, he postulated that these jökulhlaups were of a smaller magnitude and for this reason left no evidence in the Fort Augustus area.

The events outlined by Sissons suggest that the terrace fragments in the Ness valley (T175-T190) were formed during or after the main jökulhlaup event and that there is no evidence for a Lateglacial marine incursion into Loch Ness.

2. Field Evidence

a) Fort Augustus

Fort Augustus (Figs. 39, 42) (Plate 7) lies on the low ground at the southern end of Loch Ness. At this site the river Tarff enters the Great Glen from the east, while the river Oich drains northward from Loch Oich to Loch Ness.

On the eastern side of the Great Glen above Fort Augustus there is a marked drift limit (Fig. 42, a). In this area, a ridge north of Tomamhoid (NH 3862 0781) has been identified as a lateral moraine by Synge (1977a), but outcrops of bedrock in this ridge belie the proposed moraine origin. However, a drift limit occurs along the ridge. The drift limit rises from Loch Ness along the Allt an Dublair stream (Fig. 42) to an altitude of circa 107 m. Outside this ice limit a narrow rock-cut terrace (S158) at 28.9 m is present. Within the ice limit a high-level fan grades to a poorly-developed terrace fragment at 29.3 m (S151).

At a distance of circa 0.5 km inside the ice limit there is a high-level delta (S160) that is graded to a 32.0 m level of Loch Ness. The delta is composed of coarse gravel and sand and is backed by a complex of ice disintegration features. The delta extends southward into a meltwater channel (Fig. 42, D) which leads to an outwash terrace fragment (T220). It is inferred that ice lay adjacent to the outwash terrace fragment (T220) while the delta was deposited. In the north the high-level delta is truncated by a cliff against

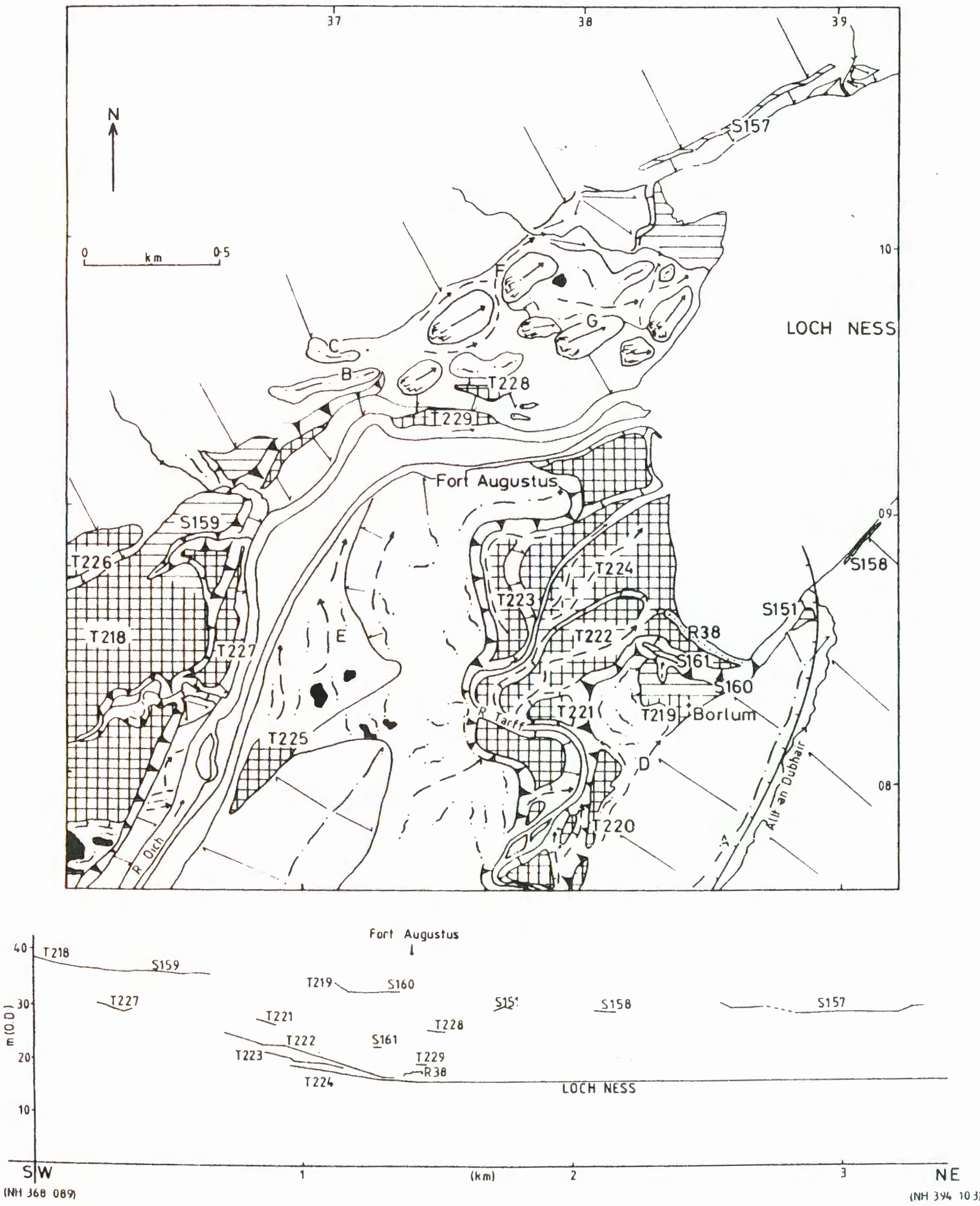


FIGURE 42 The Fort Augustus area.

which a small terrace fragment (S161) occurs. The altitude of this lower terrace (S161) was measured at 22.4 m but this value is probably too low because the break of slope is obscured by a road.

Ridge R38 (Fig. 42) lies along the edge of Loch Ness below terrace S161. The ridge attains an altitude of 18 m, circa 2 m above present loch level. The ridge may be a storm ridge, but since it is vegetated and is presently being eroded it may relate to a former loch level.

West of the high delta (S160) a series of river terrace fragments of the river Tarff (T221-T224) are present. Terrace fragment T221 may be associated with S161 (Fig. 42) and a former 22.4 m level of Loch Ness. Terrace fragments T22 and T223 are related to a loch level below 16.7 m and hence may correlate with the shingle ridge R38. The lowest river terrace fragment (T224) is graded to the present delta of the river Tarff.

Much of the southern part of Fort Augustus stands on a ridge of hummocky fluvio-glacial deposits which rise to circa 38 m. These are continued westwards by a low lying area (Fig. 42, E) which is intersected by numerous channels and extensively pitted. Farther south this area forms a distinct kettled terrace fragment (T225).

The northern part of Fort Augustus stands within an area of kames and roches moutonnées. Sissons (1979c) suggested that the eastern limit of the kames marks the limit of the Loch Lomond Stadial ice, while Synge (1977a) suggested that the large ridge near Jenkins Park (Fig. 42, B, C) is a lateral moraine. A section in the ridge reveals stratified sands and gravels and may indicate that the ridge is a kame. The two meltwater channels which lead from the kame topography (Fig. 42, F, G) may represent proglacial drainage channels.

PLATE 7 Fort Augustus (viewed from NH 3947 0853). The large wooded area in the centre of the plate is the extensively kettled outwash spread T218, also note the fluvial terrace fragments of the R. Tarff in the foreground.

About 1 km SW of Fort Augustus a large outwash spread (T218, S159)(Plate 7) is present on the western side of the Great Glen. The outwash surface merges southward with extensively kettled topography at circa 40 m, and is related to an ice margin which lay circa 4 km within the ice limits proposed at Fort Augustus. At the northern end the outwash forms a horizontal surface at circa 36 m (Fig. 42, S159) which suggests that it grades to a former 36 m level of Loch Ness. Above the outwash surface (T218) a higher outwash terrace fragment (T266) is present whilst to the east a lower terrace fragment (T227) occurs. This latter terrace fragment (Fig. 42, T227) rises southward to circa 31 m beyond which extensively channelled deposits occur. Towards the north terrace fragment T227 is correlated with terrace fragment T228 at 25.3 m and with the extensively channelled area (Fig. 42, E) on the opposite side of the river Oich.

Between Fort Augustus and Invermoriston a series of raised shoreline terraces occur on the western side of the Great Glen at circa 29-30 m (S155-S157). The shoreline terraces are rock platforms 10-20 m wide and are backed by a cliff locally eroded in bedrock. The surface of the terraces slope towards the loch and are locally mantled by large sub-rounded boulders. At Rubha Ban (Fig. 39) a terrace section shows steeply-dipping sand and fine gravel beds unconformably overlain by horizontally-bedded sands and fine gravels. This is interpreted as foreset and topset bedding of a former delta. Due to scrub and dense forest cover the rock shoreline fragments were only measured at three localities (S155-S157) which have altitudes of 29.1, 29.6, and 29.2 m. As a result a former 29.0-29.5 m level of Loch Ness is suggested.

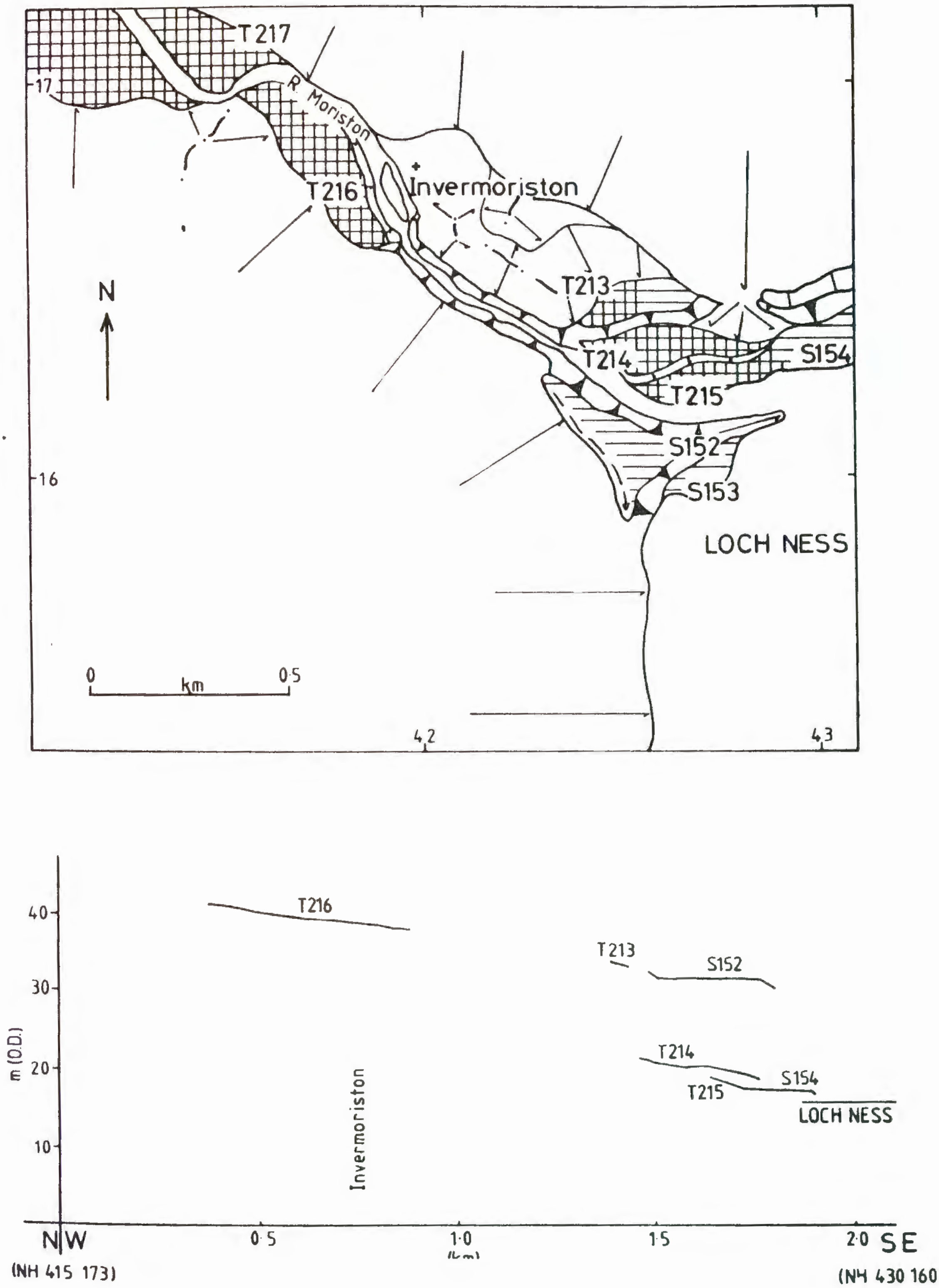


FIGURE 43 The Invermoriston area.

b) Glen Moriston

Invermoriston (Figs. 39, 43) lies at the eastern end of Glen Moriston where this valley joins the Great Glen. Sissons (1977) mapped the limits of the Loch Lomond stadial glaciers in this valley as lying some 10 km to the west of Invermoriston (Fig. 39). On the southern side of the valley at Invermoriston a high-level terrace occurs (S152) which descends from 33 m to level out at 31.7 m. This terrace is interpreted as a delta graded to a raised shoreline fragment at 31.7 m (Fig. 43). Along its southern margin a former course of the river Moriston is present. The delta is cliffed at its proximal end, and a raised shoreline terrace (S153) is present along the base of this cliff. A section at the front of the lower terrace (S153) indicates that it is in part man-made land, so no altitude measurements were taken on it.

North of the river a fluvial terrace fragment (T213) at circa 35 m is considered to be the same age as the high-level delta (S152). Below the high river terrace (T213) there are two lower river terrace fragments (Fig. 43, T214, T215), the lowest of which grades to a 17.2 m level of Loch Ness. East of the delta area (Fig. 43) there is kame and kettle topography through which the river Moriston has cut a gorge, in part reaching bedrock. East of the gorge broad river terrace fragments are present on both sides of the valley (T216, T217). The exact relationship of these river terrace fragments to former levels of Loch Ness is unknown.

c) Foyers

The village of Foyers lies on the eastern side of the Great Glen about half-way along Loch Ness (Figs. 39, 44). Here the river Foyers descends 120 m to Loch Ness via a series of waterfalls and

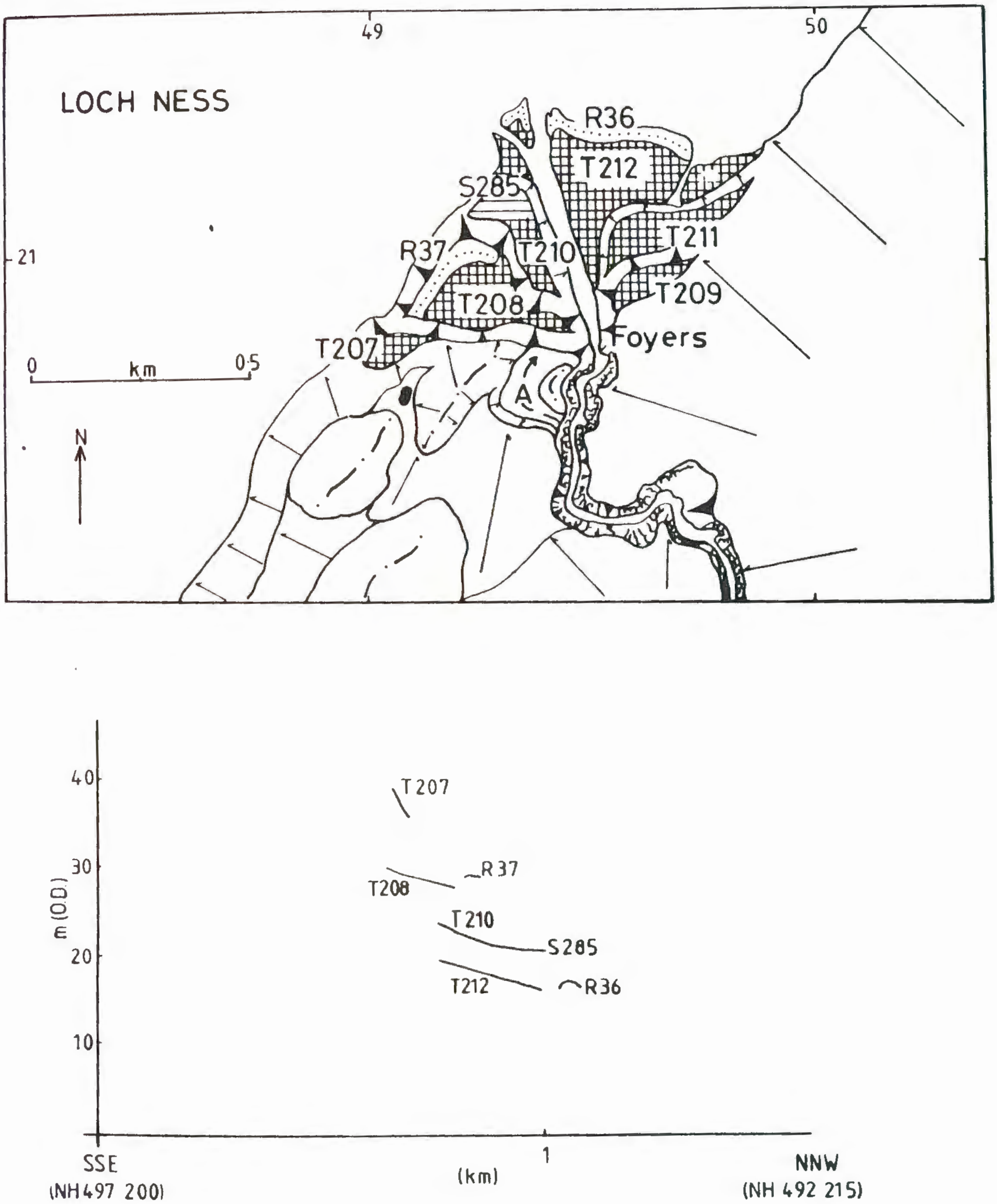
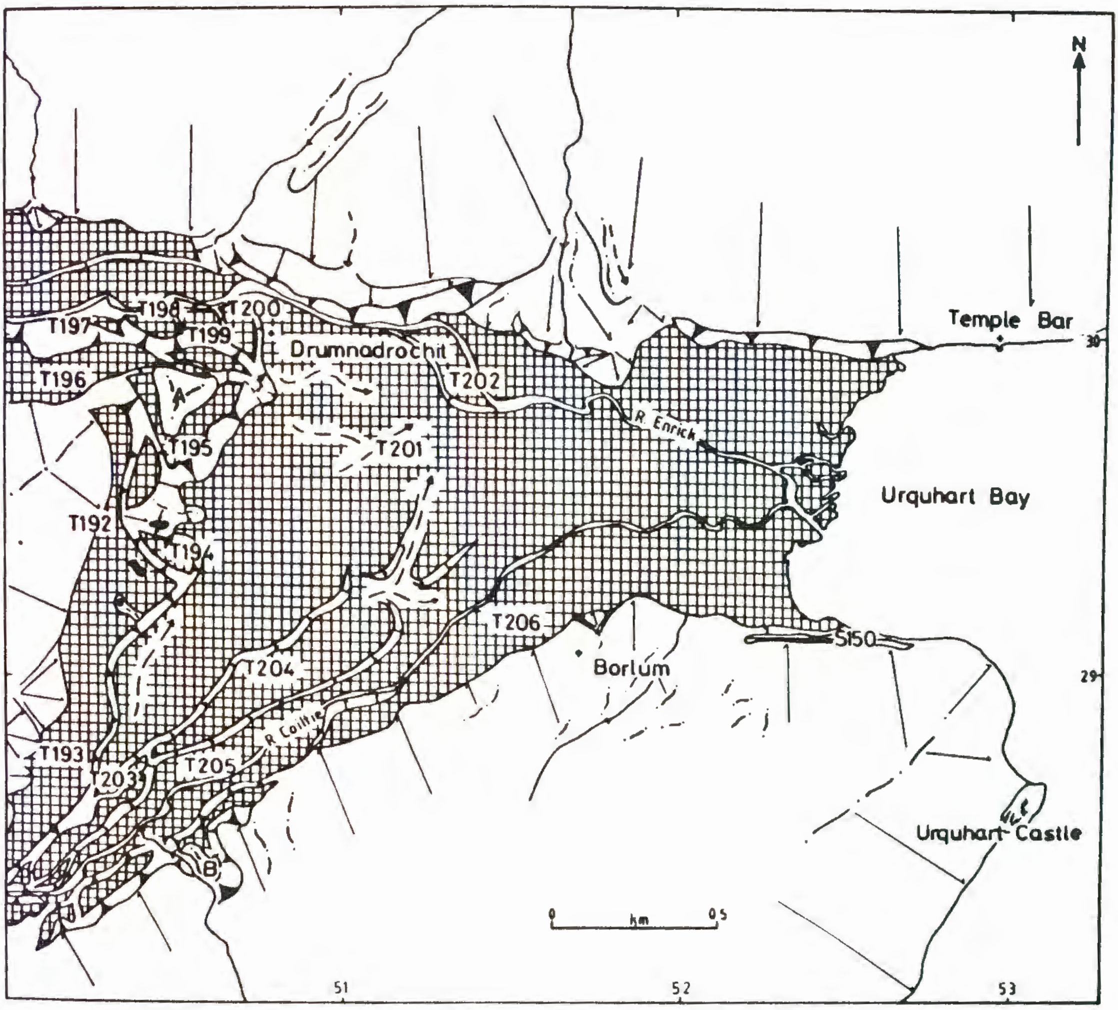


FIGURE 44 The Foyers area.

a deep rock gorge. At the mouth of the gorge there are several terrace fragments (Fig. 44, T207-T212). The highest terrace fragment (T207) is interpreted as a kame terrace since it occurs on the slopes of the Great Glen and descends towards the NE from 39 m to 36 m. This kame terrace (T207) is correlated with an abandoned channel of the river Foyers (Fig. 44, A) which descends to circa 38 m at the mouth of the gorge. The kame terrace is truncated by a lower terrace fragment (T208) which descends from 31 m at the mouth of the gorge to 28 m at its distal end. The lower terrace fragment (T208) is interpreted as a delta on which a shingle ridge (R37) occurs at 29.3 m. This delta (T208) is dissected by two lower deltas of the river Foyers. One of the lower deltas (T210, T211) is graded to a raised shoreline fragment (S285) at 21.0 m, whilst the other delta (T212) is graded to the present loch level. On the surface of the lowest delta (T212) a shingle ridge (R36) whose crest rises to 17.5 m occurs adjacent to the loch side.

d) Glen Urquhart

The eastern end of Glen Urquhart lies at the confluence of the rivers Enrick and Coiltie (Figs. 39, 45). These rivers drain into an embayment (Urquhart Bay) of Loch Ness. Directly west of Drumnadrochit (Fig. 45) a large morainic ridge (Fig. 45, A) surrounded by outwash is present. The ridge is aligned N-S and its surface is covered with large boulders. The location of the ridge at the entrance of the Enrick valley, its N-S alignment, and its close association with outwash terrace fragments suggest that it may be a terminal moraine as propos by Synge (1977a). A small morainic ridge (Fig. 45,B) in the valley of the rive Coiltie may represent the ice margin in this valley when the morainic ridge at A (Fig. 45) was formed.



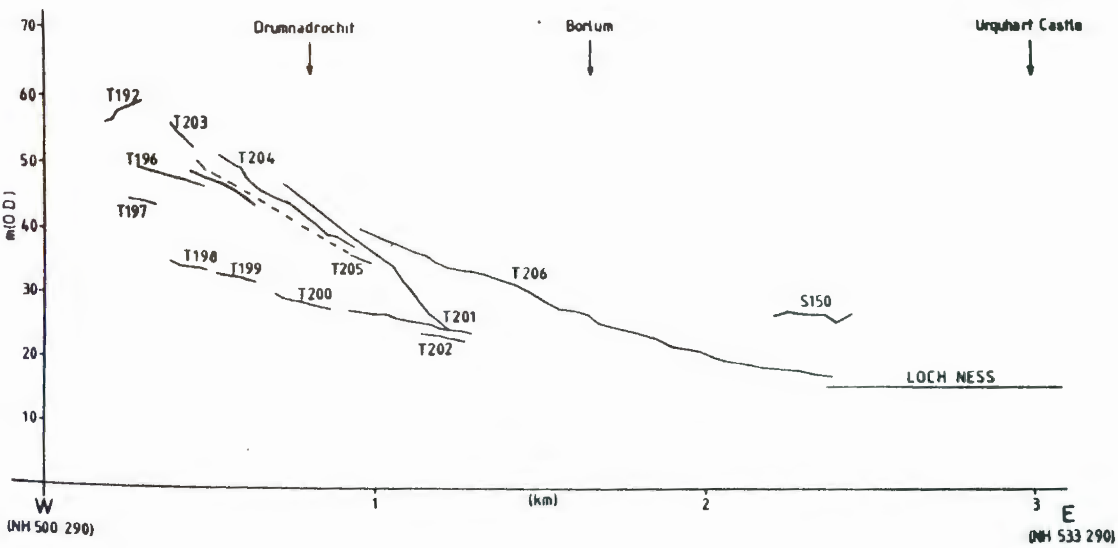


FIGURE 45 The Glen Urquhart area.

A series of outwash terrace fragments (Fig. 45, T192-T195) commence near the morainic ridge east of Drumnadrochit. The highest outwash terrace fragment (T192) descends from circa 61 m to 56 m and is pitted by small kettleholes. The outwash terrace fragment T192 merges with an alluvial fan (T193) which passes towards the SE into Glen Coiltie. Below T192 large kettleholes occur with a poorly-developed terrace fragment (T194). Between T194 and the morainic mound (Fig. 45, A) a lower terrace fragment (T195) descends in altitude from 49-45 m. Each of these terrace fragments (T192-T195) is interpreted as an outwash fan associated with a retreating ice margin. Since none of the outwash fans grade into raised shoreline fragments they cannot be related to former levels of Loch Ness as proposed by Synge (1977a). Instead, the large kettlehole below terrace fragment T192 suggests that ice may have lain to the east whilst the outwash fans were formed. The three outwash fans (T192-T195) are dissected by a series of terrace fragments (T196-T202) of the river Enrick. The highest of these terrace fragments may represent fluvio-glacial outwash terraces.

The lower ground at the eastern end of Glen Urquhart between Drumnadrochit and Urquhart Bay is a complex delta. In the north the delta (T201) descends from 29.7 m to 24 m but it has a horizontal section at 27.1 m. The lower portion of the delta is composed of sands and silts, while farther up-valley it is composed of sands and gravels. In the west the delta is dissected by lower terrace fragments (T202-T205) of the Enrick and Coiltie rivers (Fig. 45). The terrace fragments (T202-T205) merge with the delta and then with the present floodplain as they extend downstream. South of the river Coiltie a river terrace fragment (T206) also merges with the present floodplain, and this fragment also has a horizontal section at 27.5 m. The only measureable shoreline fragment in the area occurs just south of Urquhart Bay (S150) and has an altitude of 26.9 m. It is suggested that the horizontal sections of terrace fragments T201 and T206 relate to a loch level at circa 27 m. It is also suggested that when loch level fell the rivers Coiltie and Enrick modified the foreset deposits laid down during the 27 m loch level.

e) Dores and Lochend

Dores is located 2.5 km south of the outlet of Loch Ness (Figs. 39, 46). In the low ground between An Torr and Clune Farm (Fig. 46) several terrace fragments and raised shoreline features are present. Directly below Clune Farm a kame terrace is present (T191) and lower still a steeply-sloping terrace fragment (T192) occurs, which descends to a flat-topped terrace fragment at 35.3 m (S144). Several meltwater channels grade to the latter feature (S144) which also lies adjacent to a large kettlehole (Fig. 46). The steeply-sloping terrace fragment (T192) indicates that ice lay in the area while S144 was formed. A lower shoreline terrace (S145) occurs at 34.5 m and truncates shoreline terrace S144. S145 is correlated with a poorly-developed shoreline terrace (S146) at 34.8 m which overlooks Loch Ness.

Within the area of low ground are the three arcuate shingle ridges (R33, R34, R34a) which Synge (1977a) identified. The lowest (R34a) is unvegetated and occurs 3 m above present loch level. This ridge is considered to be related to present loch level. The remaining ridges occur at 20 m (R34) and at 29 m (R33) and are interpreted as shingle ridges produced during higher levels of Loch Ness. The highest ridge (R33) is continued as a poorly-developed raised shoreline terrace (S147) at 25.4 m and this is composed of shingle and sand.

FIGURE 46 The Ness Valley area.

KESSOCK NARROWS
S162
MLWS
MHWS
J
G
J
G
INVERNESS
R. Ness
T153
E
T146
F
T153
T151
Raigmore
T143
S131
S132
T144
S133
T158
T153
S130
S135
S134
S129
S123
T154
S124
S136
T157
S128
S127
S125
S126
T155
Castlehill
D

Pennington *et al*. (1972) obtained 2 Mackereth cores of sediment from Dores Bay. Analysis of these sediments only identified grey micro-laminated glacial clay and no microfossils or lake muds were found (Pennington *et al*., 1972). They attributed the lack of organic matter to strong water movements which transfers such sediment to deeper water. One core was analysed for total halide content and Pennington *et al*. concluded that "... it seems unlikely that sea water was present in the loch during the formation of the clays..." (p. 267). However, one sample from 1.33-1.35 m (taken from a stratum of grey clay with brown sand) has a halide content double that found in any other layer. Haggart (1982) sampled one core at 29 levels and prepared slides for diatom analysis. He identified diatoms in only two of the samples (at *circa* 3.5 m depth) and reported that these were of fresh water and fresh-brackish affinity.

At Lochend (Figs. 39, 46) a well-developed shoreline terrace (S139) occurs at 24.3 m (a road in part obscures the break of slope of S139 so the altitudes determined on it may be too low). On the other side of the loch a poorly-developed terrace (S140) occurs at 25.8 m and this extends as far north as Cambusloch Bay (Fig. 46), where two large depressions pit its surface.

At a lower altitude a shingle ridge (R32) at 19.4 m is continued as a shoreline terrace (S143) at 18.1 m. Another shoreline terrace (S141) occurs at 16.5 m and is only 0.5 m above the present loch level. However, the level of Loch Ness at 16 m is artificial since the outlet was raised by *circa* 1 m when the Caledonain Canal was constructed (R. Moray, pers. comm.).

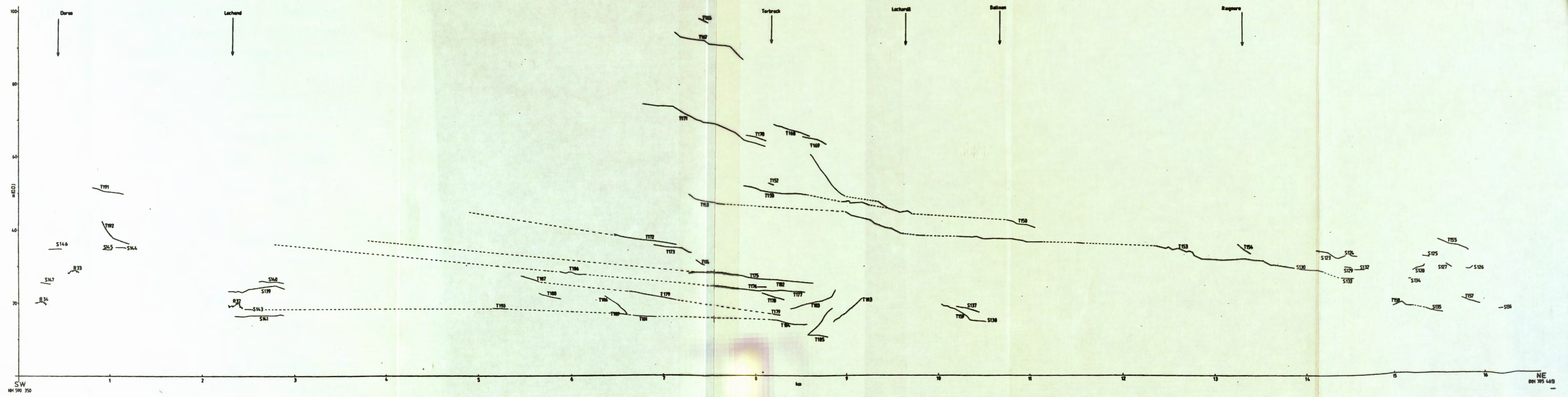


FIGURE 47 Altitude data for Inverness and the Ness Valley.

f) Inverness and the Ness valley

Inverness (Figs. 39, 46) lies at the northern end of the Great Glen at the site where the river Ness enters the sea. South of Inverness a narrow area of low ground (below 100 m) extends as far as the northern end of Loch Ness. Borehole evidence from the Inverness railway yard (NH 6710 4570) and from Craig Dunain Hospital (Fig. 46) indicate that bedrock is buried beneath at least 100 m of Quaternary sediments. The northern end of the Great Glen is therefore choked with Quaternary glacial and fluvio-glacial deposits.

The higher ground of Inverness (eg. Lochardil and Raigmore) (Fig. 46) is composed of several outwash terrace fragments (T142-T153) which merge with ice-decay topography towards the SW. The highest outwash surface (T142, T143) descends northwards from circa 45 m to circa 40 m. Synge (1977a) suggested that the slope south of terrace fragment T142 is an ice contact slope. However, the presence of a meltwater channel (Fig. 46, B) at the base of this slope suggests that Synge's inference may be incorrect. The lack of high terrace fragments farther south may indicate that the ice margin lay just south of terrace fragments T142 and T143 whilst they were being formed. Since this outwash surface (T142, T143) is built over no altitude measurements were taken on it. For this reason it is unknown if the outwash surface is graded to a raised shoreline fragment towards the south. If the outwash surface is graded to a high relative sea level then on the basis of spot heights on the 1:10,000 map this relative sea level lies below circa 40 m.

Another outwash surface is represented by terrace fragments T144-T149. The terrace fragments in the south (T148, T149) merge into kames and an esker ridge (Fig. 46, A) and it is suggested that these terrace fragments lay adjacent to the ice margin. This outwash surface (T144-T149) descends towards the north from circa 45 m

(T149) to circa 35 m (T144). Since this outwash surface is built over no altitude determinations were attempted and as a result it is unknown if the surface grades into a raised shoreline fragment towards the north.

A second lower outwash surface is made up of terrace fragments T150-T152. Fragment T152 is a flat-topped hill which overlooks extensive ice stagnation topography towards the NW. Terrace fragment T150 descends from the outlet of a marginal meltwater channel at Torbreck at 51 m NE to Ballon at 39 m (Fig. 46), in a distance of 3.5 km. A large alluvial fan grades onto terrace fragment T150 from Big Burn (Fig. 46) and this may be attributed to former meltwater flow down the valley of the Big Burn. It is suggested that terrace fragments T150 and T152 were formed while ice lay in the vicinity of Torbreck. On the basis of spot heights from the Ordnance Survey 1:10 000 map terrace fragment T150 is correlated with the housed and therefore unmeasured terrace fragment T151. Fragment (T151) descends to circa 33 m and like the higher outwash surfaces (T142, T143; T144-T149) it is uncertain if it merges into a raised marine terrace.

The higher outwash surfaces at Inverness are dissected by the fourth and most extensive outwash surface which is represented by terrace fragment T153. Towards the south terrace fragment T153 passes into large meltwater channels (Fig. 46, B, C) one of which, the Torbreck channel (Fig. 46, C), extends southwards 2.5 km to Cullaird (NH 6356 4033). At its southern end the Torbreck channel declines in altitude towards the south and it is inferred that the channel was subglacially produced in this area. The second meltwater channel (Fig. 46, B) is truncated by the steep bluff that extends along the eastern side of the Ness valley. Since the channel (Fig. 46, B) ends at circa 38 m and no terrace fragments other than kame terraces are present that can be correlated with the channel it is inferred that ice lay in the Ness valley whilst the channel was being formed. Terrace fragment T153 descends from 44 m at Torbreck and grades to several raised shoreline fragments (S130-S132) near Raigmore at 27.2 m. Shoreline fragments and small deltas also occur at a similar altitude farther east (S126-S129). The outer part of terrace fragment T153 is graded to another, lower, shoreline fragment (S133) at 24.8 m and this is correlated with the flat-topped hill (S134) at 24.6 m.

In the Raigmore area there are also several small deltas graded to raised marine terraces (Figs. 46, 47, S123-S125) at 30-31 m. One of the marine terraces (S125) is eroded into a higher outwash terrace fragment (T155) which continues into a marginal meltwater channel (Fig. 46, D). It is suggested that while the meltwater channel and terrace fragment T155 formed, ice lay in the vicinity of Castlehill (Fig. 46). However the relationship of these outwash features to the higher outwash surfaces at Inverness is unknown.

Terrace fragment T153 is dissected by streams which are locally flanked by terrace fragments. In one of the stream valleys a terrace fragment (T157) grades into a raised shoreline terrace (S136) at 16.2 m. A poorly-developed marine terrace (S135) and a small alluvial fan probably relate to the same relative sea level.

The high ground at Inverness ends northward in a degraded cliffline. In the east the cliffline is succeeded seaward by steeply-sloping raised shingle deposits and modern shingle beaches. At Inverness the cliff is fronted by two wide terraces (Fig. 46, G, J). The higher terrace (Fig. 46, G) terminates against the cliffline at circa 10 m on the eastern side of the river Ness and is more extensive to the west of the river. The western portion of terrace G (Fig. 46) descends from 13 m to 9 m where it ends in a shingle ridge.

Boreholes indicate that the terrace (Fig. 46, G) is composed of sand and gravel with some silt and clay layers, and is here interpreted as a marine deposit.

The surface of the lower terrace (Fig. 46, J) rises gradually in altitude from 2-3 m near the coast to 4-6 m inland. Boreholes (Fig. 48) indicate that the terrace is composed mainly of gravel with large cobbles and boulders and that the deposit is of a considerable thickness. Layers of silt or clay are only reported from the upper 1-2 m of the deposits. Beneath the gravel, laminated clays, silts and sands with marine shells have been interpreted as Lateglacial marine sediments (Peacock, 1977). Inspection of Fig. 48 indicates that the deposits of gravel extend across the Kessock narrows and infill a former channel in the Lateglacial marine deposits. Above the buried channel a later channel has been eroded into the gravel deposits.

North of the Kessock narrows a degraded cliffline fronted by raised marine shingle deposits is also present. This cliffline truncates a broad terrace fragment which for the most part is built over. However, in the west a raised shoreline fragment (S162) occurs at 33.4 m and it is suggested that it is graded to an outwash terrace towards the west.

West of the Caledonian Canal there are two terrace fragments (Figs. 46, 47, S137, T159). The higher terrace fragment (S137) descends in altitude from 17.8-16.0 m while the lower fragment (T159) declines from 17.0 m and is graded to a raised shoreline fragment at 13.7 m (S138). The surface of the lower terrace fragment (T159) is pitted by large kettleholes (Fig. 46). Above these terrace fragments (T159, S137) and north of the Torvean ridge terrace fragments are absent. Commercial bores show that the area north of the Torvean ridge is composed of till overlain by a thin layer of gravel,

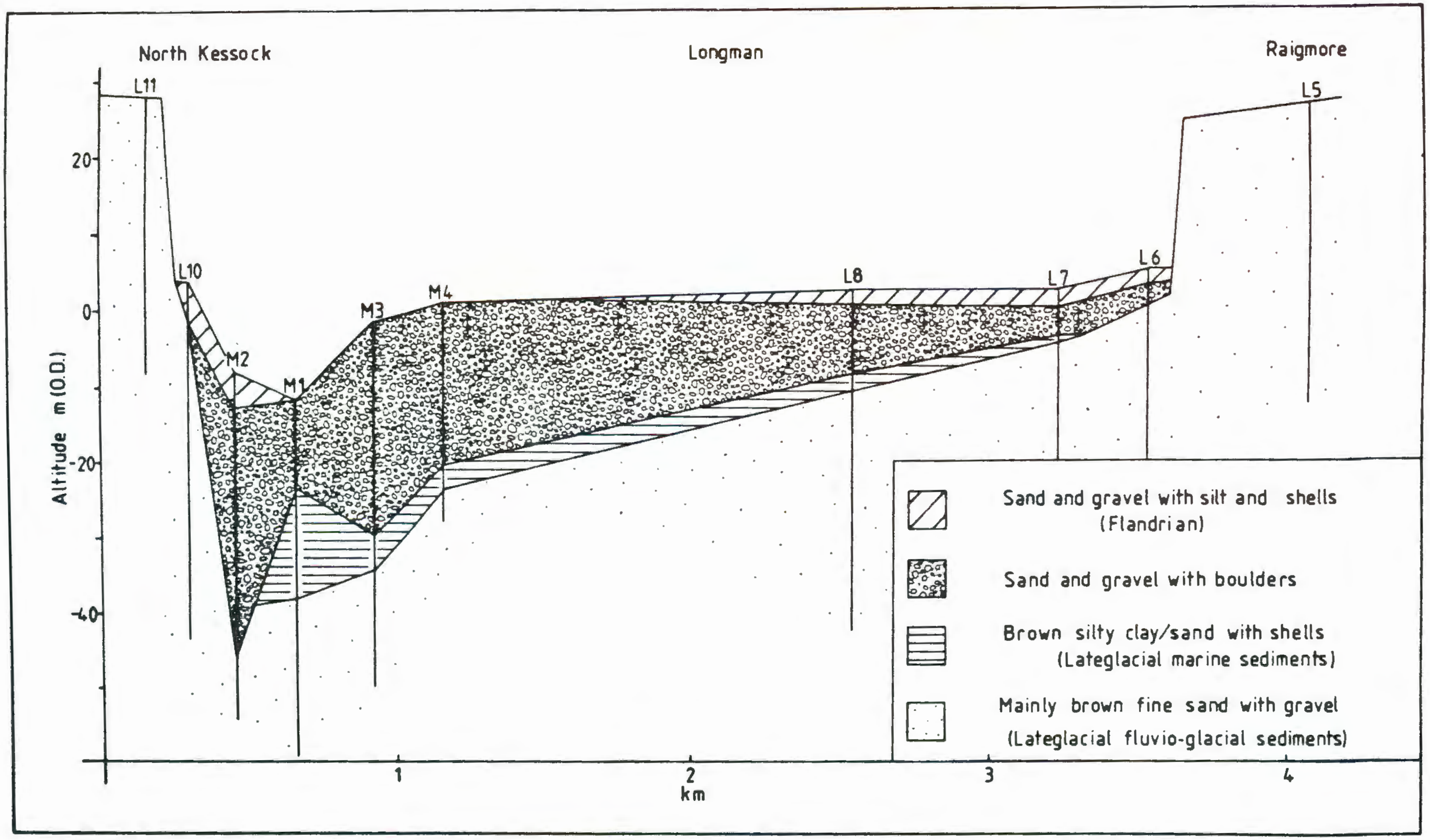


FIGURE 48 A section across the low level alluvial fan at Inverness derived from commercial borehole records (see Appendix II).

yet directly to the east the high outwash surfaces of Inverness are made up of thick accumulations of fluvio-glacial and marine deposits (Fig. 48). It is suggested that the area north of the Torvean ridge lacks fluvio-glacial deposits because the meltwaters flowed eastward along the side of the Torvean ridge towards Inverness, and because ice covered this area whilst the high outwash surfaces at Inverness were formed.

Sections in the Torvean ridge (Fig. 46, I) show that it is composed of bedded sands and gravels. Many of the sand layers exhibit cross-bedding whilst the arched nature of the beds across the feature supports the view that it is an esker. The ridge extends westward to Poll Cruaidh (Fig. 46) where it merges into a series of kame terraces, whilst to the north it is continued by the Tomnahurich ridge (Fig. 46, H). The top of the esker ridge rises from circa 65 m at Tomnahurich to circa 100 m at Poll Cruaidh.

To the south of Inverness on the western side of the Great Glen, 11 kame terraces (Figs. 46, 47, T161-T171) are present. The highest kame terrace (T161) passes into the Torvean esker at circa 100 m. The 10 kame terraces below T161 descend in altitude down-valley (Fig. 47) and the lowest declines to 62 m. The lowest kame terrace is the most extensive and is pitted by large kettleholes. This kame terrace (T171) merges into a series of esker ridges along its southern margin and at its northern end it grades into an esker whose crest descends to circa 40 m at Clachnahulig (Fig. 46, K). Below the lowest kame terrace (T171) a wide area of kame and kettle topography, crossed by esker ridges occurs. This area of fluvio-glacial ice stagnation topography extends SW to Loch Darroch.

East of the river Ness an extensive area of fluvio-glacial deposits extends from Torbreck (Fig. 46) SW to Loch Ness. Kame terraces are rare and poorly-developed, while eskers are small and

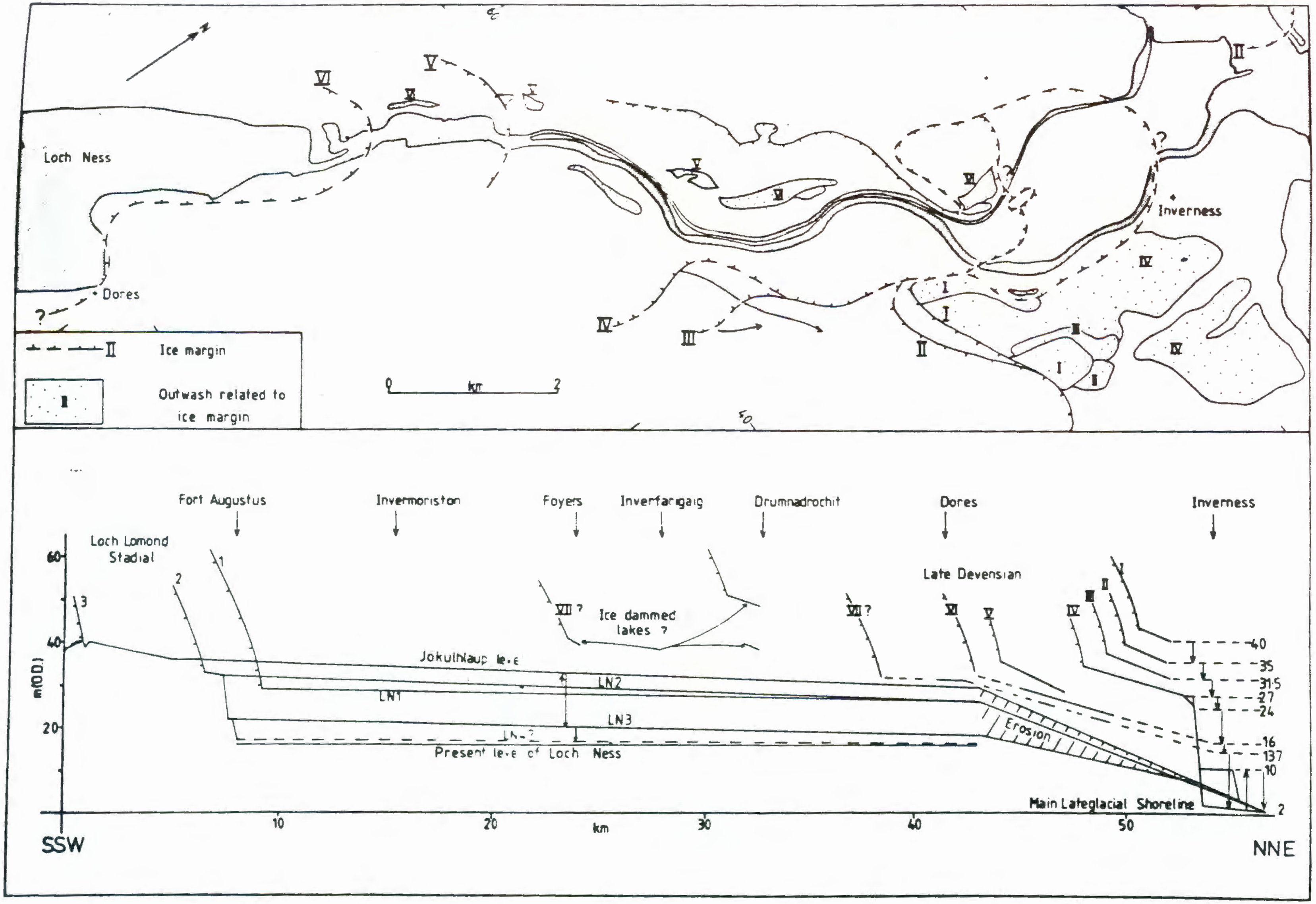


FIGURE 49 Late Devensian ice limits proposed for the Ness valley and the Late Devensian deglacial events in the Loch Ness and Inverness region represented on a schematic diagram.

and discontinuous. East of the large ridge in the vicinity of Darroch Wood (Fig. 46) a series of dead ice hollows and kames are present, and are indicative of the decay of a stagnant ice mass.

Below the extensive areas of kame and kettle topography a series of terrace fragments (T172-T190) are present on both sides of the river Ness. The highest of these terrace fragments (T172) occurs on the western side of the Ness valley and declines in altitude from 38.0 m-34.8 m. Fragment T172 merges into a lower terrace fragment (T173) which descends to 32.7 m (Figs. 46, 47). Below fragment T173 a poorly - developed terrace fragment occurs which slopes steeply downvalley. The downvalley gradient of fragments T172 and T173 suggests that the terrace surface would rise above kames and eskers 1 km to the SW in the vicinity of terrace fragment T190 (Fig. 46). Above T190 two modified terrace fragments occur at circa 40 m and these are tentatively correlated with terrace fragments T172 and T173. Since the unmeasured fragments merge into fluvio-glacial deposits to the NE and SW it is suggested that they lay adjacent to the ice margin. It is inferred that terrace fragments T172 and T173 are outwash deposits related to an ice margin in the Ness valley (Fig. 49).

The lower terrace fragments (T175-T190) are located in a broad steep-sided trench. The steep slope on the eastern side of the trench extends from Inverness Castle (NH 6665 4501) southward to Loch Dochfour (Fig. 46). Lying adjacent to the steep slope are several terrace fragments (T160, T182, T183, T186, T187). Terrace fragment T160 is the most northerly of these terrace fragments and it occurs at Inverness at circa 18 m. Farther south fragment T182 lies at 24 m but this is a very narrow terrace fragment. In contrast fragment T183 is a large alluvial fan that spreads out from the mouth of the valley of Big Burn and it descends to 14 m. Farther south terrace fragment T186 descends gradually from 28 m to 26.5 m before it rapidly declines to 22 m (Fig. 47). To the rear of the steeply declining section there is a large steep-sided channel, whilst towards the west the terrace is fronted by ground which is extensively channelled and pitted by small depressions.

West of the river Ness the steep side to the trench extends from the northern end of the Torvean esker southwards to Loch Dochfour. Terrace fragment T175 lies adjacent to this steep slope and the terrace is composed of sand and gravel. The surface of fragment T175 rises to the SW from 24.4 m at Clachnahulig (Fig. 46, K) to 27.3 m, with a gradient of 2.5 m/km. This steep gradient precludes the marine origin proposed for this terrace fragment by J.S. Smith (1968) and Synge (1977a). Below fragment T175 a lower terrace fragment (T177) is present, the surface of which is channelled and pitted by small depressions. On the basis of the gradient of the river terraces (T177 and T186) and their altitude, terrace fragment T175 may be tentatively correlated with fragment T186 (Fig. 47).

The remaining terrace fragments (T178-T181, T184, T188-T190) (Figs. 46, 47) occur on both sides of the river Ness but are often poorly-developed. Terrace fragments T180, T181, T184, T189 and T190 are correlated to form a terrace surface which descends from 18.0 m to 12.5 m. Below this terrace surface the present river floodplain occurs (T185). The higher terrace fragments (T178-T180, T188) are often short or have irregular surfaces. One of the terrace fragments (T179) has a section which rises downstream (Fig. 47) and this is interpreted as a gravel bar. Many of these terrace fragments (T178-T180, T188) pass into channelled topography or they merge downstream with each other. The large altitude range and varied gradient of terrace fragments T178-T180 and T188 make correlation between them impractical.

3. Implications of Jökulhlaup Activity in the Great Glen

a) Introduction

Sissons (1979a, 1981b) proposed that some of the landforms in the Great Glen were due to jökulhlaup activity (see pages 151-154). For this reason it is necessary to consider the possible effects of jökulhlaups of the magnitude proposed by Sissons would have had on Loch Ness and the Great Glen. Of prime importance is the possible outflow of water at the northern end of the Loch for this would have controlled the rise in the level of Loch Ness.

b) Drainage of Ice-Dammed Lakes

Ice-dammed lakes have been observed to drain in a variety of ways. Most ice-dammed lakes are emptied within a few days during annual (eg. Marcus, 1960; Stone, 1963; Magg, 1969; Higgins, 1970) or irregularly (eg. Charlesworth, 1957; Gilbert, 1971; Whalley, 1973) timed catastrophic events. However, Hallersley-Smith (1969) suggested that some ice-dammed lakes are emptied over a long time period. In most cases the ice-dammed lakes are completely emptied (Blachut and Ballantyne, 1976) unless a rock ledge or lip is present; but the rate at which they are emptied is dependant on such factors as temperature of the lake water, obstructions to water flow, rate of glacial flow, the presence of icebergs in the lake and, if it drains subglacially, the length of the ice tunnel. The form of the drainage hydrograph is also dependant on the drainage route. Lakes which overflow through supraglacial or marginal routes show an initial rise in the downstream discharge record (Fig. 50) followed by a gradual drop in the rate of flow (Maag, 1969). Subglacial or

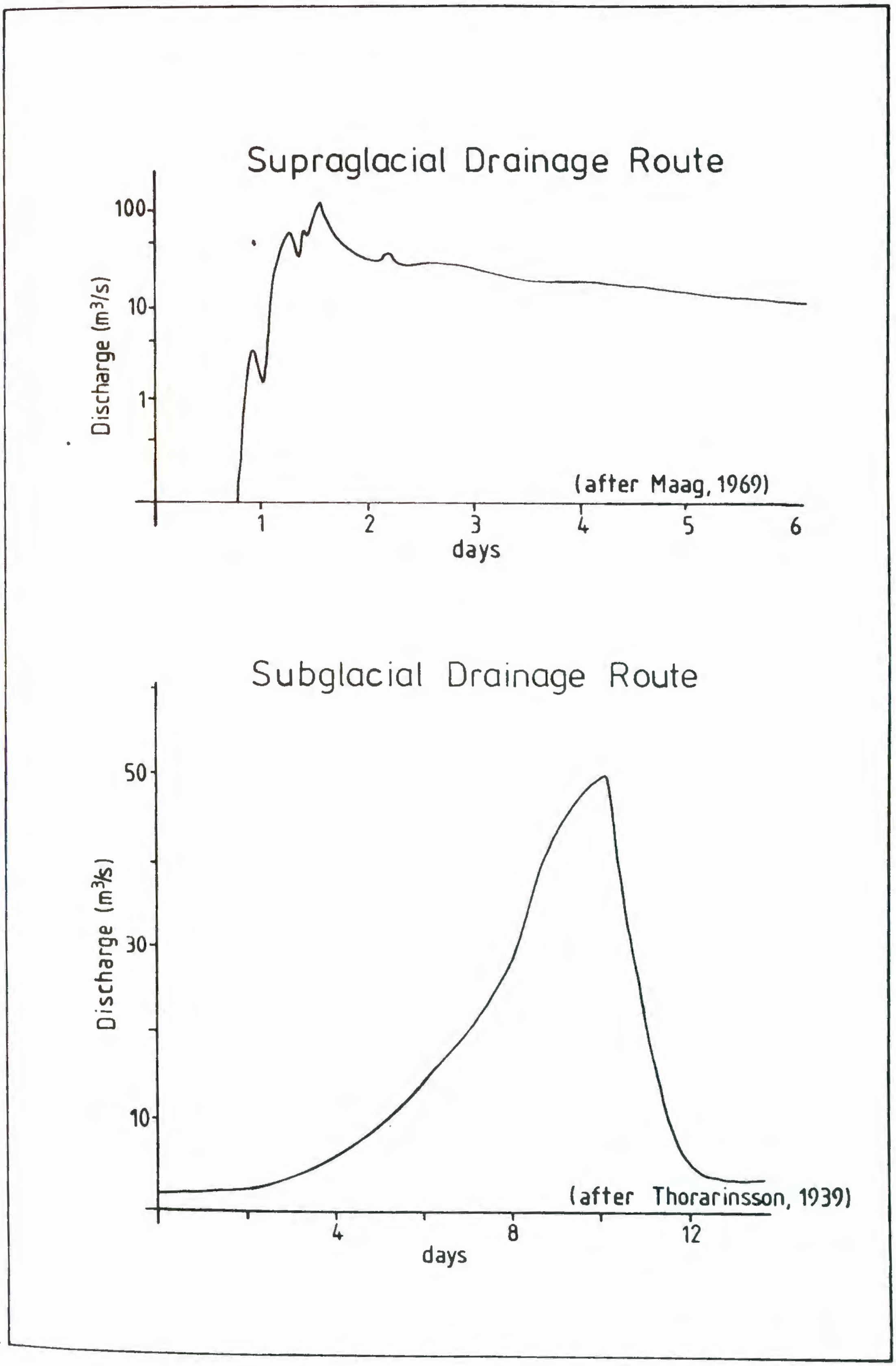


FIGURE 50 Jökulhlaup hydrographs.

englacial drainage systems generally show a sharp initial rise and a sharper, sudden fall in the hydrograph (Thorarinsson, 1939, Fig. 50). Clague and Mathews (1973) proposed that the instantaneous water discharge (Q_t) of lakes which are emptied by subglacial or englacial routes is not dependent on the time (t) since the start of the jökulhlaup but on the volume of water (V_t) released from the lake during that time. Their study of several ice-dammed lakes suggested that the relationship between maximum flood discharge (Q_{max}) (in $m^3\ s^{-1}$) and available water storage (V_{max})(in $m^3 \times 10^6$) may be represented by:-

$$Q_{max} = 75V_{max}^{0.67}$$

Sissons (1979a) suggested that the ice-dammed lake in Glen Spean and Glen Roy drained sub-glacially through the Spean Gorge. In this case the jökulhlaup hydrograph would be expected to show a sharp rise and a sharper, sudden fall. It is expected that the entire lake would have been emptied since there is no rock bar to inhibit drainage. Sissons (1979a) suggested that the level of the ice dammed-lake stood at 260 m when it drained for the first time when it contained 5 km^3 of water. On the basis of Clague and Mathews (1973) formula Sissons suggested that the maximum outflow of water would have been about 22 500 $m^3\ s^{-1}$.

It is accepted that the ice dammed-lake drained through the Spean Gorge since no evidence of submarginal drainage occurs in Glen Spean (eg. hillslopes swept clean of drift). Equally it is accepted that the ice-dammed lake stood at 260 m when it drained for the first time, and therefore 5 km^3 of water was discharged into Loch Ness. (Prior to this drainage lake level maintained several levels controlled by the various outlets as attested by the well-developed "parallel roads" in Glen Spean and Glen Roy. (Sissons, 1978). The shoreline would not have formed if the lake level had constantly varied with periodic drainage).

In order to obtain a crude estimate of the time taken (t max in seconds) to drain the ice-dammed lake the jökulhlaup hydrograph was approximated by a straight line (Fig. 51) where the maximum discharge (Q_{max}) is 22 500 m^3 s^{-1}, and after this discharge equals zero. Since the area under the line represents the volume of water discharged (V m^3) it is possible to calculate the time taken (t_{max}) to empty the ice-dammed lake. Since:-

$$0.5 \times Q_{max} \times t_{max} = V_{max}$$

it is suggested that the ice dammed-lake drained in approximately 5 days. Such an approximation underestimates the time taken to drain the ice-dammed lake since the hydrograph is better represented by the dotted line in Fig. 51. The straight line hydrograph also overestimates the discharge during the rising limb of the hydrograph whilst underestimating the falling limb.

c) Geomorphic Effects of Jökulhlaups

Blachut and Ballantyne (1976) have summarised the main geomorphic effects of catastrophic drainage of ice-dammed lakes. They noted that the presence of permafrost and cold glacier ice can greatly influence the effects of the flood. Since discharging lake waters employ little energy in sediment transport they can be aggressive erosive agents immediately below the lake outlet. They suggested that for this reason drainage of ice-dammed lakes can be associated with the formation of sub-glacial rock-cut meltwater channels, scoured bedrock and extensive erosion and modification of outwash fans. In addition, due to their high

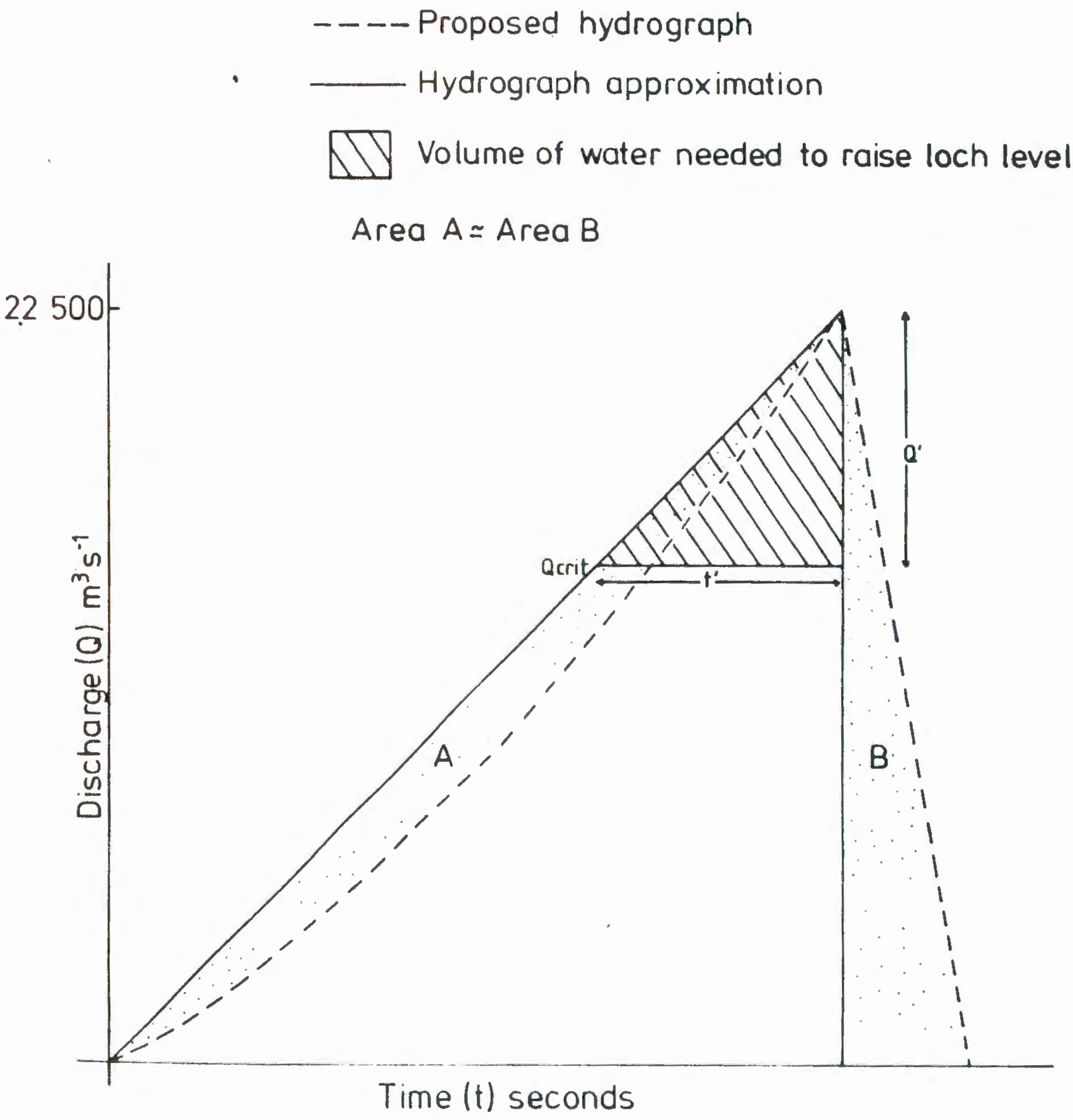


FIGURE 51 Hypothetical hydrograph of the proposed jökulhlaup which first drained the ice-dammed lake in Glen Spean and Glen Roy. For further explaination see text.

competence the flood waters will transport large volumes of gravel and boulders. These sediments are deposited to form large, poorly-sorted, strongly imbricated bars, megaripples and steeply-cross-bedded scour and fill structures in the proglacial zone (eg. Parde, 1942; Malde, 1968). Blachut and Ballantyne suggested that specialized features such as pitted outwash can also possibly be attributed to catastrophic lake drainage since ice masses are often swept downstream.

d) Possible and Proposed Geomorphic Effects in the Great Glen

Sissons (1979a) suggested that considerable subglacial erosion resulted from the drainage of the ice-dammed lake in Glen Spean and Glen Roy. He proposed that the eroded material was deposited at Fort Augustus as a large outwash fan graded to a loch level raised by 8.5 m by the influx of water. Deposition of a large volume of material in the immediate proglacial area is characteristic of jökulhlaup events. The rise of 8.5 m proposed by Sissons is harder to account for since it is dependent on the rate of outflow of water at the northern end of the loch. Loch Ness has an area of 56.4 km^2 and to raise its level by 8.5 m a water volume of 4.794×10^8 m^3 would have been required. This volume of water represents 9% of that which drained from the ice-dammed lake. For the loch to rise by 8.5 m the outflow at the northern end would have had to have been less than inflow. Since the rate of discharge into the loch may be approximated by the straight line shown in Fig. 51, and the volume needed to raise the loch level is known it is possible to calculate the maximum discharge (Q_{crit} in m^3 s^{-1}) at the northern end of the Loch. The volume (in m^3) of excess water (V_e) is represented by the shaded portion of Fig. 51. Since the ice-dammed lake is calculated to have drained in 5.14 days (444 444 seconds) the gradient (k) of the straight line is:-

$$\frac{Q_{max}}{t_{max}} = \frac{22\ 500}{444\ 444} = 0.0506$$

Also $Q^1 = Q_{max} - Q_{crit}$ and t^1 is the time (in seconds) taken to raise the loch level by 8.5 m.

Therefore

$$V_e = 0.5 \times Q^1 \times t^1 \quad \text{but } t^1 = Q^1/0.0506$$

$$V_e = 0.5 \times Q^1 \times \frac{Q^1}{0.0506}$$

$$(Q^1)^2 = V_e \times 0.0506 \times 2 \qquad V_e = 4.794 \times 10^8\ m^3$$

$$Q^1 = 7\ 000\ m^3\ s^{-1}, \quad Q_{crit} = 15\ 000\ m^3\ s^{-1}$$

By using similar criteria the maximum discharge rate was calculated for a variety of rises in loch level (Table 14).

It is of interest to compare the expected maximum discharge rate with that which could have flowed through the Ness valley. Sissons (1981b,d) suggested the steep-sided valley through which the river Ness flows was formed by the jökulhlaup event. This valley is 500 m wide at its narrowest point and it is suggested that this may be taken to represent the width of the channel during the jökulhlaup. Sissons also noted that large boulders are present in the deposit at Inverness which he attributed to the jökulhlaup event. Graphs of river competence (Hjulstrom, 1935, 1939; Nevin, 1946; Sundborg, 1956) indicate that mean river velocities of 4-5 m/s are required to transport boulders, although such values are approximations. Since the jökulhlaup is considered to have raised the loch level by 8.5 m this value plus the normal depth of the river during flood (1 m) may be considered as an approximation of the depth

Rise in loch level (m)	Volume of water required to raise loch level ($x10^6$ m^3)	Critical Discharge Q_{crit} ($m^3 s^{-1}$)
1	56.4	20 100
2	112.8	19 100
3	169.2	18 400
4	225.6	17 700
5	282.0	17 150
6	338.4	16 650
7	394.8	16 200
8	451.2	15 750
8.5	479.4	15 500
9	507.6	15 300
10	564.0	14 950

TABLE 14 The critical maximum discharge (Q_{crit}, Fig. 51) required at the outlet of Loch Ness to raise its level by a specific amount during the jökulhlaup flood.

	Proposed channel width (m)			
Depth of channel (m)	500	450	400	350
10	25 000	22 500	20 000	17 500
9.5	23 750	21 370	19 000	16 600
9	22 500	20 250	18 000	15 750
8	20 000	18 000	16 000	14 000
7	17 500	15 750	14 000	12 500
6	15 000	13 500	12 000	10 500
5	12 500	11 250	10 000	8 750
4	10 000	9 000	8 000	7 000
3	7 500	6 750	6 000	5 250

TABLE 15 Potential discharge ($m^3 s^{-1}$) that may have occured at the outlet of Loch Ness during the jökulhlaup.

of the channel during the jökulhlaup. On this basis the maximum outflow at the northern end of the loch would have been the depth of the channel x the width of the channel x the velocity of the water:-

$$(9.5 \text{ m} \quad \times \quad 500 \text{ m} \quad \times \quad 5 \text{ m})(\text{sec}^{-1})$$
$$= 23\ 750 \text{ m}^3 \text{ s}^{-1}$$

Similar maximum discharges have been calculated for narrower and shallower channels (Table 15). The calculated discharge at the northern end of Loch Ness is therefore greater than that attributed to the jökulhlaup and so it is unlikely that an 8.5 m rise in loch level would have occurred. However, if the rise in loch level was less than that proposed by Sissons or if the channel was narrower or shallower than suggested above, then a rise in loch level would have been possible.

4. Discussion

a) Morainic Limits

In the Great Glen morainic limits are present at Fort Augustus and in Glen Urquhart. Synge (1977a) and Sissons (1979c) have suggested that the ice limit at Fort Augustus is of Loch Lomond Stadial age. Pollen evidence from Loch Tarff (Fi.g 39) and Loch Oich (Pennington et al., 1972) suggests that Lateglacial Interstadial deposits are only present outside the ice limits proposed at Fort Augustus. For this reason and because the ice limit is in accord with the Stadial ice limit identified in Glen Spean (Sissons, 1979c) it is suggested the ice margin at Fort Augustus is of Loch Lomond Stadial age.

In Glen Urquhart two morainic ridges are present (Fig. 45, A, C) and it is proposed that these may represent former ice limits. The morainic ridges indicate that two separate ice lobes existed when they were formed, one in the valley of the river Enrick and the other in the Coiltie valley. Glaciers related to the Loch Lomond Stadial occur well to the south (Peacock, 1975; Sissons, 1977) and so it is thought unlikely that the ice limits in Glen Urquhart are of Stadial age. For this reason it is suggested that the ice limits in Glen Urquhart are related to the deglaciation of the Late Devensian Scottish ice sheet. One of the morainic ridges (Fig. 45, A) in Glen Urquhart lies adjacent to three outwash fans (Fig. 45, T192-T195). The highest outwash fan (T192) was formed while ice lay at the proposed ice margin (Fig. 39). While the lower outwash fans T194 and T195 were produced large masses of ice were present outside the ice margin. It is highly probable that ice still lay in the Great Glen during this time but positive evidence to support this view is not present. Synge (1977a) proposed that the three outwash fans (T192-T195) are graded to high levels of Loch Ness but there are no raised shoreline fragments to support this view.

b) Anomalous Gravel Deposits

Within the Great Glen there are anomalous deposits of gravel at Inverness and Fort Augustus. The large accumulation of gravel SW of Fort Augustus forms an outwash terrace (T218) which is graded to a raised shoreline fragment (S159) at 36 m. The outwash terrace and raised shoreline fragment are related to an ice margin 4 km inside the maximal limit of the Loch Lomond Stadial glacier in the area. The gravel deposit is anomalous in several respects:-

i) The outwash is graded to the highest level of Loch Ness identified at its southern end and this cannot be attributed to marine action. Outwash related to a more advanced Loch Lomond Stadial ice margin (T220) is graded to a 32 m loch level.

ii) Most large outwash spreads related to Loch Lomond Stadial glaciers occur at or just within the maximal limit, yet the Fort Augustus feature occurs 4 km inside the limit (Sissons, 1979a)

iii) Outwash spreads formed during the Loch Lomond Stadial in the interior of Scotland are much smaller than that present at Fort Augustus, (Sissons, 1979a).

iv) The chaotically kettled area to the south of the Fort Augustus outwash spread has no parallel with features of comparable age (Sissons, 1979a).

These anomalies can be explained if it is suggested that the outwash was deposited by the jökulhlaup which drained the 260 m lake in Glen Spean and Glen Roy, but with different loch level changes than proposed by Sissons (1979a). Firstly the altitude of the raised shoreline fragment (S159) related to the outwash can be explained by the large volume of water raising the level of Loch Ness temporarily (the amount of rise is discussed below) and it has been demonstrated that such a rise would have been possible. Secondly the position of the outwash is consistent with the amount of glacier decay that occurred prior to the jökulhlaup event. When the ice-dammed lake drained, the Trieg glacier in Glen Spean had thinned by <u>circa</u> 200 m (Sissons, 1979a) and the same amount of thinning at Fort Augustus places the snout of the glacier <u>circa</u> 4 km SW of the maximal limit. Thirdly the size of the outwash spread can be attributed to the jökulhlaup having transported a large volume of debris which it deposited rapidly once it left the ice tunnel. Finally, the chaotically kettled area may be explained by large quantities of ice blocks being transported by the jökulhlaup.

The low-level terrace at Inverness (Fig. 46, J) overlies Lateglacial marine deposits (Peacock, 1977) and is overlain by Flandrian marine deposits (Sissons, 1981b). Both Peacock and Sissons have advocated that the low-level terrace is of Loch Lomond Stadial age. Sissons has also indicated that the low-level terrace is graded to a relative sea level close to that which formed the Main Lateglacial Shoreline, which is again indicative of a Stadial age. However, Sissons (1981b) noted that the low-level terrace is anomalous in several respects.

i) The terrace covers a large area (circa 6 km^2) and is composed of gravel and large boulders (Fig. 48) which could only have been transported during a flood event.

ii) The gravel extends completely across the Kessock Narrows and infills a former channel in the Lateglacial marine sediments. If the deposit had built up from periodic floods it would have been unable to extend across the narrows.

iii) Silt and clay deposits are only found in the upper 1-2 m of the deposit yet such material would be present in sediments which accumulated from periodic deposition.

iv) The terrace surface slopes gently seaward in the form of a single alluvial fan, yet if it had accumulated over a long period of time several levels and old channels of the river Ness would be expected to be present.

These irregularities can be explained if it is suggested that the gravel was deposited in a single event of catastrophic magnitude. A single event explains the coarse grained nature of the deposit, how the buried channel in the Lateglacial marine sediments became infilled and how the alluvial fan has an apparently undissected surface. Since the volume of sediment is large and the calibre of material very coarse the event must have been of high magnitude. A single catastrophic event would have occurred in association with the jökulhlaup which drained the 260 m ice-dammed lake in Glens Spean and Roy. Since it has been proposed that the jökulhlaup event raised the level of Loch Ness it is highly likely that a major flood of water would have passed through the Ness valley to Inverness. Sediments eroded from the Ness valley by the sediment free loch waters would have been deposited at Inverness due to the loss of water competence. The view proposed by Sissons (1981b) that the large low level deposit of gravel at Inverness (Fig. 46, J) resulted from a jökulhlaup flood is therefore accepted.

c) Loch Levels in Loch Ness

Synge (1977a) suggested that there is evidence to support 5 former levels of Loch Ness at circa 56 m, 46-47 m, 39 m, 27-30 m and 18 m one of which he proposed was a marine shoreline. In contrast Sissons (1979a) advocated only two former loch levels at circa 18-22.5 m and 32 m and the latter was attributed to a temporary rise in loch level caused by a jökulhlaup flood. The outwash fans in Glen Urquhart (T192-T195), Foyers (T207) and Inverfarigaig described by Synge as evidence of his 3 highest loch levels do not grade into raised shoreline fragments. It is therefore difficult to suggest to what, if any, loch level these outwash deposits are graded to. At Dores raised shoreline fragments S145, S146 occur at circa 34.5 m but the extent of the lake at this level is unknown. It is possible that some of the outwash deposits in Glen Urquhart, Inverfarigaig and Foyers are related to this loch level. However, if Loch Ness was occupied by a stagnant ice mass (which is more likely since it is 200 m deep) then alluvial fans from tributary valleys could have formed adjacent to the ice mass. At the same time small ice-dammed lakes could have formed and these together with the alluvial fans could have occurred at a variety of altitudes so that no extensive lakes have to be proposed. For this reason it is suggested that the evidence of 34.5 m loch level is confined to the northern end of Loch Ness.

Evidence of lower loch levels is more widespread. At the northern end of the loch, shoreline fragments occur at 27-24.3 m (S139, S140, S147, S150), 18-19 m (S143, S148) and 16.5 m (S141). At Foyers raised shoreline fragments are present at circa 28 m (R37, T208) and 21.0 m (S 285). At the southern end of the loch shoreline fragments occur at circa 17 m (R38, S154), 22.4 m (S161), 29-30 m (S155-S158), 31-32 m (S153, S160) and 36 m (S159) the last being related to the jökulhlaup deposit SE of Fort Augustus and therefore of Loch Lomond Stadial age. Other than the lowest shoreline fragments (S143, S148, S154, R38) and the fragment associated with the jökulhlaup (S159) there are 2 distinct groups of shoreline fragments. One group lies between 25-32 m and the other between 18-23 m. Each group of shoreline fragments rises in altitude towards the SW and this is attributed to glacio-isostatic tilting. The lower group form a single shoreline the fragments of which truncate higher shoreline fragments at Foyers, Lochend and Fort Augustus and therefore are younger features. In contrast, the higher group of shoreline fragments form a single shoreline at the northern end of the loch but occur at two separate levels (29-30 m, 31-32 m) at the southern end. At no locality are the shoreline fragments of the 29-30 m, 31-32 m and 36m(jökulhlaup) levels related to each other so their age relative to each other is problematical.

Sissons (1979a) suggested that the jökulhlaup deposit (T218, S159) and the high-level delta (S160) at Fort Augustus were both formed when the level of Loch Ness was temporarily raised by 8.5 m. This correlation is considered unlikely for several reasons:-

i) The high-level delta (S160) is related to a more advanced ice limit than the jökulhlaup deposit.

ii) The high-level delta (S160) and the jökulhlaup deposit grade to different levels of Loch Ness.

iii) The high delta at Invermoriston (S152) is graded to a similar loch level as the high level delta (S160) at Fort Augustus. It is unlikely that both features, many kilometres apart and deposited in separate valleys are graded to the same temporary jökulhlaup loch level.

It is therefore proposed that the high-level delta (S160) at Fort Augustus can be correlated with the high-level delta (S152) at Invermoriston, and that they are older features than the jökulhlaup deposit. Since the high level delta (S160) at Fort Augustus occurs within the maximal Loch Lomond Stadial glacier limits the feature must have formed as the ice began to retreat.

The raised shoreline terraces at 29-30 m (S155-S158) are best developed outside the Stadial ice limit but may be present at or just within the maximal ice limit (S151). The shoreline terraces are erosional (locally in bedrock) and their lack of development on the higher deltas (S152, S160) suggests that they pre-date or are of the same age as the deltas. However since the high level deltas are graded to raised shoreline fragments 1-2 m above the erosional terraces it is difficult to reconcile the fact that the terraces and deltas resulted from the same level of Loch Ness. It is concluded that the erosional shoreline terraces were formed prior to the high-level deltas (S152, S160). However, this requires a rise in loch level between the formation of the erosional shoreline terraces and the high-level deltas, and also does not explain why equivalent features are not present at the northern end of Loch Ness. The fact that the erosional shoreline terraces are locally cut in rock and are circa 10-20 m wide indicates considerable erosion in a limited fetch environment. Similar features in Glen Roy (Sissons, 1978) and in coastal areas (Gray, 1978; Dawson, 1980b) have been attributed to extensive frost action during the Loch Lomond Stadial. In addition rpaid rock platform formation has been reported from contemporary ice-dammed lakes (J. Rose pers. comm.). Formation of the erosional shoreline terraces at this time also explains the proposed transgression at the southern end of the Loch which is not present at the northern end. It is suggested that the erosional shoreline terraces began to form as the climate deteriorated with the onset of the Loch Lomond Stadial. As the Stadial glaciers advanced they redepressed the earth's crust which resulted in a lacustrine transgression at the southern end of Loch Ness. The transgression is partly represented by the steep slope which characterises the surface of the erosional shoreline terraces. The transgression culminated when the ice reached its maximal limit and this level is represented by the high level delta (S160) at 32 m at Fort Augustus. In contrast, no transgression occurred at the northern end of Loch Ness because the redepression of the earth's crust did not alter the relative level of the outlet with respect to the raised shoreline fragments in this area (Fig. 52). The period of formation and the localised nature of the transgression indicate that the 24-29 m level of the loch was a lacustrine level rather than the marine level proposed by Synge (1977a).

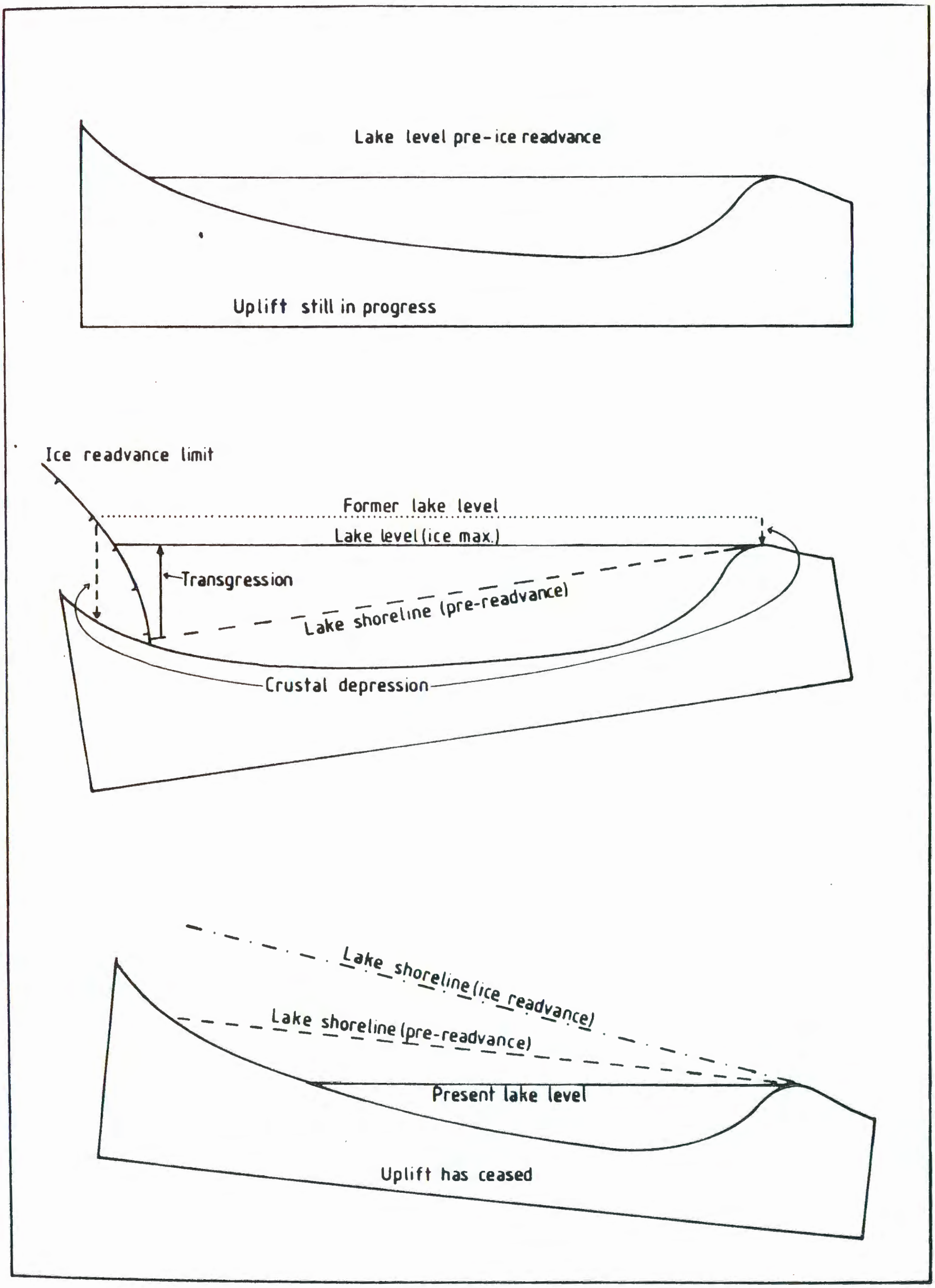


FIGURE 52 An idealised diagram to indicate the possible sequence of lacustrine shorelines which are formed during glacio-isostatic redepression of the crust and during the subsequent period of uplift.

Since the level of Loch Ness stood at 32 m when the ice began to retreat from the Stadial limits and since the jökulhlaup deposit SW of Fort Augustus is graded to a 36 m loch level it is proposed that the volume of water present in the jökulhlaup temporarily raised the level of Loch Ness by circa 4 m. Such a rise in loch level represents 4.5% of the volume of water involved in the postulated jökulhlaup and would indicate a possible maximum discharge of 17 000 m^3s^{-1} at the northern end of the Loch (see above).

Sissons (1979a) suggested that after the jökulhlaup Loch Ness returned to the level (circa 18-23 m) it had started at. Since it has been suggested that the flood was of a considerable magnitude and deposited the large low-level gravel deposit (Fig. 46, J) at Inverness considerable erosion must have occurred in the Ness valley. As the outlet of Loch Ness rests on deposits of gravel it is expected that the erosion would have both widened and lowered the outlet. The extent to which the outlet was lowered is unknown, but since the next distinct shoreline in Loch Ness occurs at circa 18-23 m the maximal lowering of the loch was by circa 6-7 m. At Fort Augustus chaotically pitted deposits occur at circa 25 m. Sissons (pers. comm.) suggested that pitting of the deposits is man made. However, these deposits may also be interpreted as gravels eroded by a later jökulhlaup. Sissons (1981d) postulated that later jökulhlaups would have occurred from the Glen Spean ice-dammed lake but that they would have been of a smaller magnitude. Such events may not have been great enough to raise the level of Loch Ness but they could have eroded deposits along the course of the river Oich. It is suggested that the pitted deposits at Fort Augustus (Fig. 42, E) were formed by a later jökulhlaup and that therefor the loch level had fallen below 25.3 m by this time. It is therefore possible to infer that the shoreline at 18-23 m around Loch Ness was occupied relatively soon after the jökulhlaup event which drained the 260 m ice-dammed lake in Glens Spean and Roy.

There is no morphological evidence to suggest the level of Loch Ness during the Lateglacial Interstadial. Haggart (1982) tentatively proposed that evidence of the Lateglacial Interstadial is however present in the lacustrine sediment cores retrieved from Dores Bay. It is proposed here that Loch Ness stood at the same level during the Lateglacial Interstadial as during the early Loch Lomond Stadial (eg. 29 m at the southern end and at 24.3 m at the northern end). During the Lateglacial Interstadial the loch therefore became free of ice but due to the limited fetch environment lacutrine shoreline fragments were unable to form.

d) Inverness and the Ness Valley

Sissons (1981b, d) suggested that the river Ness lies in a steep-sided trench eroded by the jökulhlaup flood. An approximation of the water surface in the Ness valley related to the jökulhlaup is represented by the straight line which joins the jökulhlaup deposit surface at Inverness with the temporarily raised loch level at circa 30 m at the northern margin of Loch Ness (Cambusloch Bay) (Figs. 46, 47). It is evident from Fig. 47 that several of the terrace fragments which lie in the steep sided trench (T160, T175-T177, T182, T186) lie several metres (5-10) above the approximate jökulhlaup water surface. The gradients of the more southerly terrace fragments (T175-T177, T186) suggest that they are related to loch levels above 30 m at the northern margin of Loch Ness (eg. Cambusloch Bay)(Figs. 46, 47). Below these terrace fragments (T175-T177, T182, T186) the deposits in the trench on both sides of the river have irregular surfaces. West of fragment T186 the ground is chaotically channelled and pitted by small depressions, whilst to the east a steep-sided channel is present. Lower terrace fragments on the western side of the river Ness have irregular surfaces which contain large gravel bars. It is suggested that the irregular ground below terrace fragments T175 and T186 was formed as a result of the jökulhlaup and that the steep-sided trench was in existence prior to the jökulhlaup event. The above discussion suggests that the channel related to the jökulhlaup event would have been circa 450 m wide and since it relates to a 4 m rise in loch level the depth of the channel would have been circa 6-7 m. Such a channel would have had a potential maximum discharge of circa 14 000-16 000 m^3 s^{-1} (Table 15). This is not greatly different from the calculated critical discharge of 17 700 m^3 s^{-1} required to raise the Loch level by 4 m (Table 14). As the flood waters receded several terrace fragments were formed, and after the catastrophic flood the river Ness drained along a new channel related to terrace fragments T180, T181, T184 and T189.

It is inferred that the higher terrace fragments in the steep-sided trench were formed prior to the first jökulhlaup event as were the kame terraces and high-level outwash deltas (T142-T153) at Inverness. The highest kame terrace (T161) passes into the Torvean esker so glacier ice was confined within the Great Glen when the esker was formed. Since the crest of the esker lies at 80 m at Torvean it indicates a considerable thickness of ice in the area. Since the high-level deltas at Inverness (T142-T153) occur as high as 40 m it seems unlikely that they were formed at the same time as the esker. Indeed the ice limit was probably located seaward of Inverness when the esker was formed.

The succession of kame terraces (T161-T171) indicate successive positions of the ice margin as the ice mass downwasted, and became increasingly confined within the Ness valley. The kame and kettle topography below the lowest kame terrace (T171) is indicative of in situ ice decay. Similar kame and kettle topography east of the river Ness suggests the ice-decay was widespread. At Inverness, there are several outwash surfaces but it is difficult to correlate a particular outwash surface with a particular kame terrace. However on the basis of altitude it is suggested that the lower kame terraces (T168-T171) are likely to correlate with the outwash surfaces (T142-T153) at Inverness.

Each of the four outwash surfaces at Inverness (T142-T153) is related to an ice margin which lay in the Ness valley (Fig. 49). For each ice margin it is suggested that ice occupied the ground north of the Torvean ridge and therefore lay near to the western margin of the outwash surfaces. In contrast, in the east, each lower outwash surface is related to an ice margin with a more southerly position. It is therefore inferred that the four outwash surfaces are related to a retreating ice margin. However the distance of ice retreat was only 5 km. The lowest outwash surface (T153) is graded to raised shoreline fragments at 27.0 m (S130-S132) and 24.8 m (S133, S134). Since the lower raised shoreline fragments (S133, S134) are essentially part of the same outwash surface it is suggested that they are related to the same ice margin as the 27 m shoreline fragments. The higher outwash surfaces could not be measured so it is unknown if they grade into shoreline fragments. However, if the outwash surfaces do grade into marine terraces then the latter must lie below _circa_ 40 m for the highest surface, _circa_ 35 m for the second outwash surface and _circa_ 33 m for the third. Since raised shoreline fragments occur at 30-31 m (S123-S125) east of Inverness and at 33.4 m (S162) north of the Kessock Strait it is suggested that some of the higher outwash surfaces can be correlated with these shoreline fragments. It is tentatively proposed that the third outwash surface (T150-T152) correlates with the raised shoreline fragments at 30-31 m (S123-S125) and that the second outwash surface is related to the raised marine terrace at 33.4 m (S162). The highest outwash surface is probably related to a relative sea level between 35-40 m.

Below the outwash surfaces at Inverness raised shoreline fragments occur at 16.2 m (S136) and 13.7 m (S138). Neither of these raised shoreline fragments can be directly related to a specific ice margin. However, it is considered significant that the river terrace fragment (T159) which grades into marine terrace S138 is pitted by kettleholes. It is inferred that a mass of ice lay in the area (north of the Torvean esker) until relative sea level fell below 13.7 m. Farther south S136 and S138 may correlate with river terrace fragments in the steep sided trench of the Ness valley. Projection of the terrace fragments (T175, T177 and T186) upstream (Fig. 47) suggests that Loch Ness lay at circa 37 m whilst the higher terrace fragment (T175) formed and at 33 m when the lower fragments (T177, T186) formed (unless the loch extended farther north than Cambusloch Bay). In the vicinity of Dochfour House (NH 6046 3920) an unmeasured terrace fragment at circa 35 m modified by human activity is present and this is tentatively correlated with terrace fragment T175. The lower terrace fragments (T177, T186) may correlate with the raised shoreline fragments at 34.8 m at Dores (S145, S146). However, this latter correlation is tentative since evidence for this loch level is only present at Dores. The terraces in the steep-sided trench therefore cannot be related to any ice margin, however it is suggested that ice probably lay in Loch Ness while the features were formed. The presence of glacier ice is postulated for several reasons:-

i) A kame terrace fragment at Foyers (T207) descends to circa 36 m and this could correlate with the lake shoreline fragments (S145, S146) at Dores. If such a correlation is accepted the ice margin must have lain at Foyers. However, a more northerly position of the front of the ice is possible since the kame terrace (T207) and the lake at 34.8 m at Dores could represent localised ice marginal phenomena.

ii) None of the large tributaries of Loch Ness have shoreline fragments which can be correlated with loch levels above 32 m.

iii) The presence of a circa 32 m lake in the Dores area requires the presence of glacier ice in the Great Glen in order to impound the lake.

In contrast, higher outwash terraces (T172-T174) in the Ness valley are related to an ice margin 1 km north of Dochfour House. Since the highest of the outwash terraces (T172) descends from 38 m to 33 m it cannot be correlated with the high outwash surfaces (T142-T153) at Inverness. The downstream projection of the terrace surface also indicates that it is too high to be correlated with shoreline fragments S136 and S138. The outwash is therefore related to a relative sea level above 16 m but below 27 m.

The evidence from the Ness valley indicates that relative sea level fell from circa 35 m and possibly circa 40 m to below 13.7 m while ice masses were still present in the Inverness area. However, the ice masses in question were stagnant masses and the margin of the ice sheet retreated at least 10 km and possibly 27 km in the same time period. During the initial fall in sea level the retreat of the ice margin was limited. Relative sea level fell 11 m from circa 35 m (and possibly circa 40 m) to 24 m while the ice margin retreated a maximum of 5 km. There is no evidence to suggest that the ice remained active during the period of ice retreat.

5. Sequence of Events

i) The Late Devensian ice sheet downwasted and became confined to the Great Glen. A kame terrace at circa 100 m was formed on the western side of the Great Glen and this is related to the Torvean and Tomnahurich esker. The front of the ice sheet at this time lay east of Inverness.

ii) The ice sheet continued to downwaste and formed a series of kame terraces on the western side of the Great Glen.

iii) The ice retreated south of Inverness and formed a high outwash surface (T142, T143) which is probably graded to raised shoreline fragments at circa 40 m.

iv) Relative sea level fell to form a raised shoreline fragment at 33.8 m (S162) which is correlated with a second outwash surface at Inverness (T144-T149) and an ice margin south of the city (Fig. 49).

v) The ice front retreated to Torbreck, but a mass of ice still remained north of the Torvean esker. Meltwater formed a third outwash surface (T150-T152) graded to raised shoreline fragments at 30-31 m (S123-S125).

vi) Meltwaters flowed from an ice margin 2-3 km south of Inverness via the Torbreck channel and formed a fourth outwash surface (T153) which is graded to raised shoreline fragments at 27 m (S130-S132). At the same time ice still occupied the Ness valley north of Torvean.

vii) While the ice margin maintained its position south of Inverness relative sea level fell to 24.0 m.

viii) Relative sea level fell to 16.5 m and then 13.5 m and then below this. The ice margin retreated from the Ness valley and formed progressively lower outwash surfaces. The lowest outwash terrace (T177, T168) may be correlated with a kame terrace at Foyers (T207) and an ice-dammed lake in the northern part of Loch Ness at circa 35 m at Dores. During the same time period outwash fans were formed at Inverfarigaig and in Glen Urquhart. The outwash fans in Glen Urquhart are related to separate lobes of ice in Glen Coiltie and Glen Urquhart. The extent of the ice in Loch Ness at this time is largely unknown but it is thought to have been present in much of the Loch.

ix) The Late Devensian ice sheet then retreated from the study area and Loch Ness became ice free. During the Lateglacial Interstadial the level of Loch Ness stood at circa 28-29 m at its southern end and at circa 24 m at its northern end.

x) At the start of the climatic deterioration at the end of the Lateglacial Interstadial the level of Loch Ness stood at circa 24 m at its northern end and at circa 28-29 m at its southern end. The severe periglacial climate that ensued formed erosional terrace fragments (locally in bedrock) at the southern end of Loch Ness at circa 29-30 m.

xi) The glaciers related to the Loch Lomond Stadial advanced and redepressed the earth's crust which resulted in a transgression of circa 2-3 m at the southern end of Loch Ness. The glaciers reached their maximum extent at Fort Augustus and 10 km SW of Invermoriston.

xii) The Stadial glaciers began to retreat and outwash was deposited in a loch at 32.0 m at Fort Augustus.

xiii) The stadial glacier retreated to circa 4 km south of Fort Augustus. While the ice lay at this position the ice-dammed lake at 260 m in Glen Spean and Glen Roy drained subglacially through the Spean gorge (Sissons, 1979a). The 5 km^3 of water involved in the jökulhlaup deposited a large outwash spread at Fort Augustus and because discharge into Loch Ness temporarily exceeded outflow at the northern end the level of the loch was raised by 4 m. Outflow at the northern end of the loch of the jökulhlaup waters caused extensive erosion in the Ness valley and deposited a large low level terrace at Inverness graded to a sea level at circa 2-5 m. The extensive erosion lowered the outlet of Loch Ness by up to 7 m.

xiv) Later jökulhlaup events eroded deposits at Fort Augustus and grade to a level of Loch Ness between circa 25 m and 22.4 m.

xv) Relative sea level rose to deposit Flandrian marine sediments at circa 9-10 m at Inverness and then fell to present level. During the same period of time raised lake shoreline fragments were formed at 22.4 m and 17.0 m at the southern end of the loch. The outlet of the loch was lowered during this period.

CHAPTER EIGHT

THE BEAULY FIRTH AND THE CONON VALLEY

1) Englishton

a) Previous Research

Englishton (Fig. 53, 54) lies on the southern side of the Beauly Firth, 5 km west of Inverness. Horne and Hinxman (1914) suggested that an ice marginal channel occurs in this area south of Cnoc à Chinn (Fig. 54, A) and they proposed that the channel formed while ice occupied the Beauly Firth. They also suggested that a raised shoreline fragment at 100 ft (30.5 m) is present at Englishton (Fig. 54, S181). Ogilvie (1923) suggested that the high-level marine features in the Englishton area represent a large dissected alluvial fan derived from the Bunchrew Burn. He also described lower alluvial fans at 65 ft (19.8 m) and 30 ft (9.1 m).

Synge (1977a) and Synge and Smith (1980) also described a series of alluvial fans in the Englishton area. Synge proposed that the highest alluvial fan (S181) is related to a 30 m relative sea level, and is also related to the lateral meltwater channels which pass through the Cnoc à Chinn gap (Fig. 54, A). He also suggested that whilst the ice stood at this position relative sea level fell and meltwaters produced the large alluvial fan at Bunchrew (Fig. 54, B). Synge considered that the large size of the Bunchrew alluvial fan compared with the catchment area of the present Bunchrew Burn precludes a Flandrian origin. This interpretation is disputed by Haggart (1982), who proposed that the large alluvial fan at Bunchrew may have been deposited during the Flandrian.

b) Field Evidence

In the Englishton area (Figs. 54, 55) deltas and alluvial fans are present at several levels. The highest feature (S181) descends

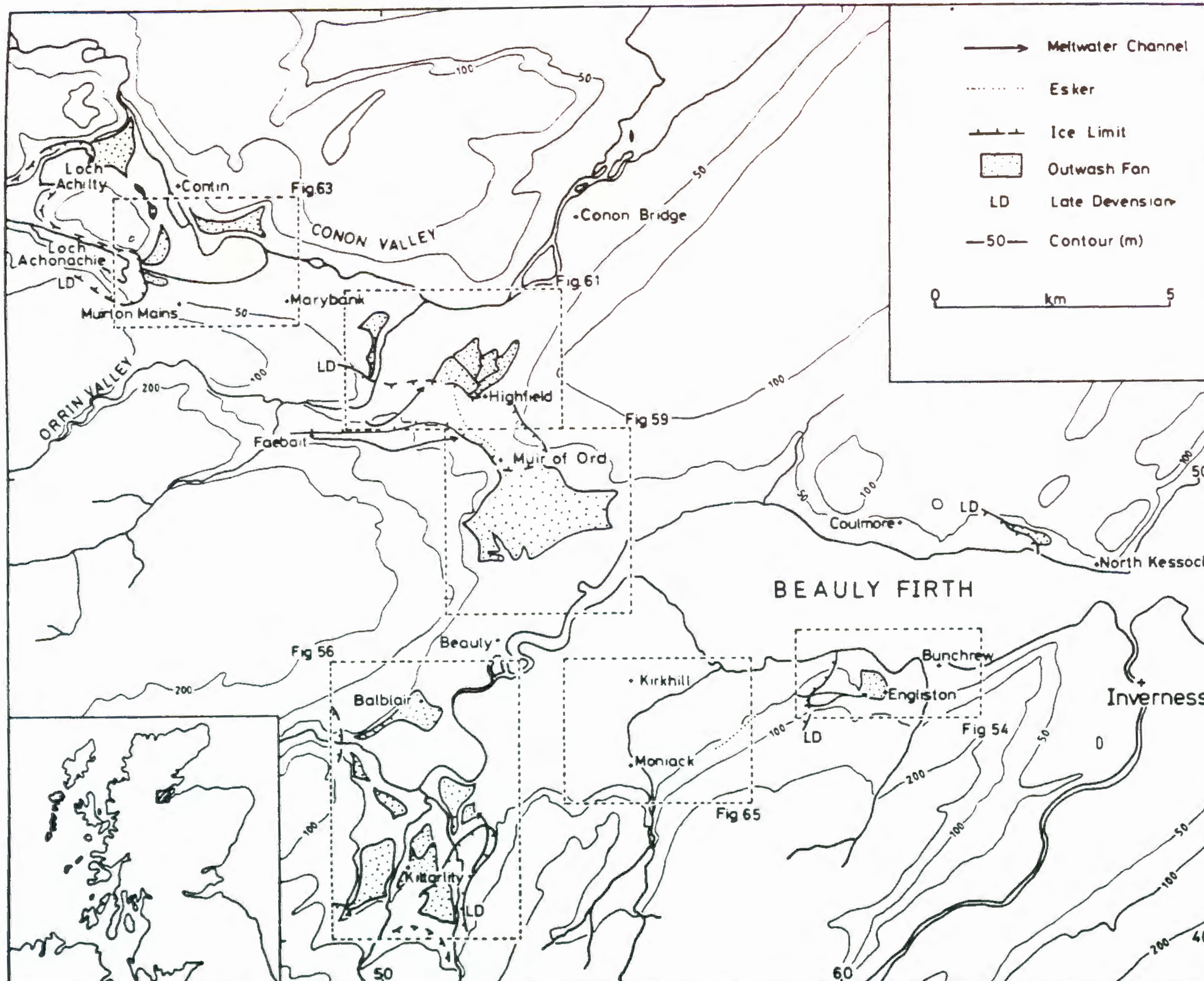


FIGURE 53 The Beauly Firth region.

Shoreline Fragment	No. of Points	Mean Grid Ref.	Mean Altitude	Quality of Measurements
S162	7	NH 6615 4820	33.37	M
S163	5	NH 6517 4812	29.90	M
S164	4	NH 6421 4871	27.79	M
S165	3	NH 6268 4857	15.50	P
S166	6	NH 6192 4838	10.95	M
S167	7	NH 6332 4844	9.46	M
S168	2	NH 6275 4849	9.85	P
S169	8	NH 6239 4835	10.11	G
S170	4	NH 6228 4827	4.39	G
S171	3	NH 6252 4831	5.07	P
S172	6	NH 6197 4828	5.36	M
S173	3	NH 6125 4840	7.89	P
S174	4	NH 6100 4854	3.35	G
S175	2	NH 6090 4867	10.04	M
S176	4	NH 6085 4883	13.00	M
S177	7	NH 5992 4860	9.39	G
S177	6	NH 6024 4857	8.51	G
S178	4	NH 5883 4930	7.45	M
S179	4	NH 6126 4533	29.60	M
S180	2	NH 6121 4539	22.12	P
S181	9	NH 6069 4562	29.03	M
S182	2	NH 6072 4579	21.35	P
S183	3	NH 5879 4567	16.10	P
S184	9	NH 5901 4570	15.34	M
S185	7	NH 5820 4535	22.03	M
S186	5	NH 5786 4524	22.56	P
S187	10	NH 5735 4526	3.38	G
S187	10	NH 5775 4552	3.12	G
S187	9	NH 5809 4565	3.09	G
S188	8	NH 5693 4492	5.31	G
S189	3	NH 5692 4481	22.50	M
S190	7	NH 5685 4438	20.35	G
S190	6	NH 5671 4416	20.61	G
S191	3	NH 5576 4407	29.05	M
S192	6	NH 5629 4442	28.80	M

TABLE 16 Raised shoreline fragments in the Beauly Firth and Conon valley region. P = Poor, M = Moderate, G = Good

Shoreline Fragment	No. of Points	Mean Grid Ref.	Mean Altitude	Quality of Measurements
S193	4	NH 5751 4469	29.36	P
S194	3	NH 5626 4528	6.04	M
S195	5	NH 5617 4526	7.17	M
S196	3	NH 5630 4551	5.76	G
S197	7	NH 5648 4610	7.87	G
S197	8	NH 5629 4626	7.33	G
S198	6	NH 5637 4585	7.87	G
S199	7	NH 5644 4582	5.10	G
S200	8	NH 5616 4642	3.41	G
S200	7	NH 5651 4628	3.07	G
S200	7	NH 5666 4606	2.87	G
S201	3	NH 5637 4563	4.84	M
S202	5	NH 5572 4631	5.92	G
S203	4	NH 5552 4636	4.28	G
S204	2	NH 5533 4623	5.77	M
S205	8	NH 5501 4616	5.76	G
S206	7	NH 5489 4627	5.84	G
S207	4	NH 5703 4490	11.15	M
S208	7	NH 5910 4918	9.21	P
S208	6	NH 5931 4900	9.38	M
S209	5	NH 5460 4599	6.74	G
S210	9	NH 5465 4610	6.01	G
S211	7	NH 5462 4614	6.49	M
S212	5	NH 5417 4600	6.56	G
S212	5	NH 5439 4602	6.32	G
S213	1	NH 5415 4639	5.06	M
S214	6	NH 5381 4593	6.56	M
S215	10	NH 5271 4520	30.50	P
S216	6	NH 5615 4916	9.28	G
S217	5	NH 5642 4919	2.52	G
S218	8	NH 5606 4907	3.24	G
S218	8	NH 5581 4887	3.03	G
S219	5	NH 5544 4873	9.80	M

TABLE 16 (cont.)

Shoreline Fragment	No. of Points	Mean Grid Ref.	Mean Altitude	Quality of Measurements
S220	10	NH 5477 4962	26.95	M
S221	10	NH 5227 4860	28.20	M
S222	8	NH 5189 4700	31.79	P
S223	4	NH 5204 4701	19.30	M
S224	3	NH 5216 4705	11.50	P
S225	3	NH 5211 4678	11.50	M
S226	7	NH 5245 4736	13.36	M
S226	6	NH 5268 4765	12.89	M
S227	4	NH 5276 4791	18.70	M
S228	4	NH 5288 4785	13.56	M
S229	8	NH 5457 4862	5.32	M
S230	6	NH 5436 4856	5.53	M
S231	10	NH 5402 4837	5.86	G
S232	3	NH 5437 4844	4.70	M
S233	6	NH 5415 4809	4.93	G
S234	8	NH 5431 4788	3.21	M
S235	7	NH 5504 4859	3.59	M
S235	6	NH 5477 4851	3.72	M
S236	10	NH 5371 4806	5.86	G
S237	9	NH 5424 4612	6.67	M
S327	9	NH 5426 4606	6.72	M
S238	3	NH 5317 4760	7.25	M
S239	3	NH 5326 4755	5.68	M
S240	4	NH 5327 4746	4.86	M
S241	2	NH 5313 4750	8.52	M
S242	2	NH 5301 4746	6.80	M
S243	10	NH 5275 4708	6.55	M
S244	6	NH 5206 4554	7.05	M
S245	3	NH 5209 4670	8.82	G
S246	2	NH 5230 4642	8.53	G
S247	8	NH 5222 4672	9.36	G
S248	3	NH 5127 4578	8.74	M
S249	8	NH 5115 4520	8.90	G

TABLE 16 (cont.)

Shoreline Fragment	No. of Points	Mean Grid Ref.	Mean Altitude	Quality of Measurements
S250	4	NH 5279 4725	8.54	G
S251	6	NH 5254 4722	9.36	P
S252	4	NH 5285 4768	8.85	M
S253	9	NH 5117 4595	29.40	M
S254	10	NH 5021 4297	28.98	M
S255	2	NH 5060 4187	28.66	P
S256	5	NH 5120 4199	28.23	P
S257	5	NH 5143 4209	29.53	M
S258	5	NH 5166 4226	29.21	P
S259	10	NH 5196 4275	29.34	P
S260	8	NH 5194 4314	16.40	M
S261	7	NH 5376 5384	19.21	M
S262	3	NH 5362 5373	18.15	M
S263	10	NH 5357 5313	27.85	M
S264	3	NH 5343 5309	20.70	P
S265	8	NH 5302 5223	28.20	M
S266	10	NH 5297 5268	22.31	P
S267	3	NH 5299 5335	11.50	P
S268	5	NH 5237 5216	24.30	M
S269	10	NH 5203 5204	26.20	M
S270	9	NH 5190 5230	25.40	P
S271	4	NH 5134 5230	25.13	P
S272	7	NH 5248 5330	10.39	P
S273	9	NH 5263 5328	8.26	M
S274	9	NH 4919 5357	10.54	M
S274	10	NH 4953 5363	10.50	M
S274	10	NH 4972 5380	10.24	M
S275	8	NH 4934 5326	26.23	M
S275	8	NH 4969 5313	26.07	M
S276	7	NH 5020 5345	19.61	M
S277	8	NH 4955 5351	18.91	M
S278	5	NH 4922 5355	19.20	M
S279	3	NH 4829 5371	17.63	P
S280	2	NH 4832 5375	15.52	M
S281	10	NH 4790 5383	15.78	M

TABLE 16 (cont.)

Shoreline Fragment	No. of Points	Mean Grid Ref.	Mean Altitude	Quality of Measurements
S282	5	NH 4730 5385	26.23	M
S282	6	NH 4779 5377	26.36	M
S283	8	NH 4671 5396	25.08	P
S284	6	NH 4598 5400	24.17	M
S284	5	NH 4571 5402	24.45	M
R39	4	NH 6177 4827	10.56	M
R40	5	NH 6117 4854	9.35	G
R41	2	NH 6044 4861	10.12	M
R42	5	NH 6061 4570	28.80	M
R43	5	NH 5313 4765	10.27	G
R44	3	NH 5221 4658	9.47	M

TABLE 16 (cont.)

in altitude from 38 m to 28 m. Its frontal margin is truncated by a degraded cliffline, whilst its surface is dissected by Kirkton Burn. A section (NH 6080 4558) reveals steeply-dipping beds of gravel with sand and cobbles. The gravels are rounded to sub-rounded and occasionally contain balls of till. These layers are overlain with unconformity (Plate 8) by a horizontal bed of well-rounded gravel with cobbles and sand. The structures are interpreted as foreset and topset bedding which indicate that the feature is a delta. The junction between the foreset and topset bedding has an altitude of 26.1 m and it has been suggested (Allen, 1976) that this is indicative of former relative sea level during the formation of deltas. However, this view is not accepted since the junction is an erosive contact and it is unknown if such a contact is related to MLWS rather than MHWS. The surface of the delta (S181) is overlain by a small sand ridge (R42) whose crest lies at 28.8 m. The apex of the delta occurs at the eastern end of two large meltwater channels (Fig. 54, A) which are eroded in bedrock. These channels extend westward to kame and kettle topography.

A flat-topped hill (S179) at 29.6 m is interpreted as a marine terrace formed at the same time as the high-level delta (S181). Lower poorly-defined terraces at 21.4 (S182) and 22.1 m (S180) which occur seaward of the delta are also interpreted as marine features.

The Bunchrew alluvial fan (Fig. 54, B) descends in altitude from *circa* 20 m to sea level. The alluvial fan has poorly-defined terraces developed on its surface below *circa* 6 m, and these lower terraces grade westwards into estuarine deposits. To the rear of the Bunchrew alluvial fan there is no degraded cliffline, yet this cliffline is well developed to the east and west of the alluvial fan. At Englishton the degraded cliffline is fronted by a lower alluvial fan at the mouth of Kirkton Burn (Fig. 54, C).

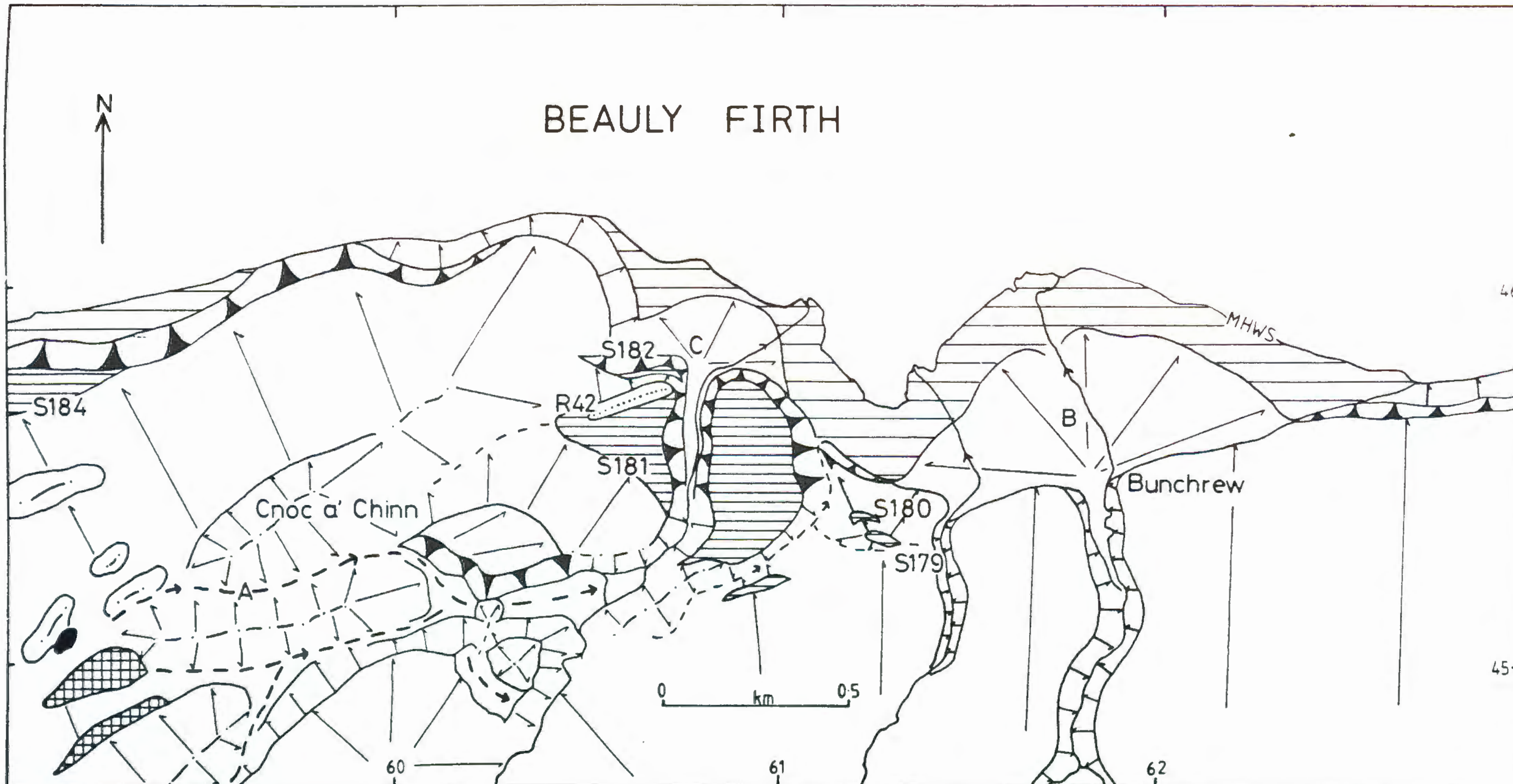


FIGURE 54 The Englishton area.

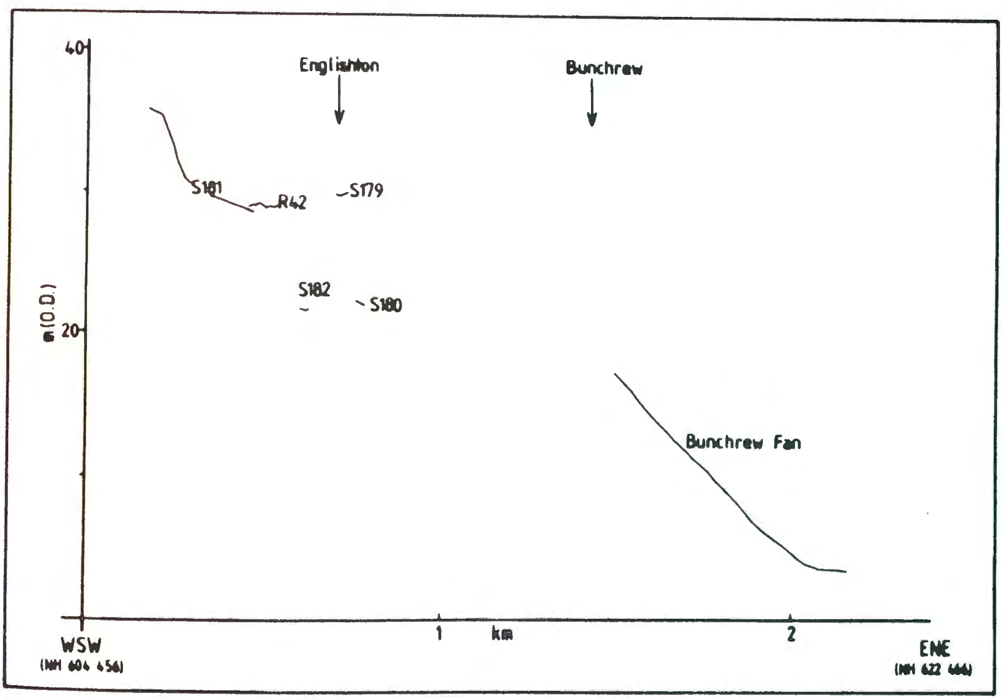


FIGURE 55 Altitude data for the Englishton area.

c) Discussion

The high-level delta at Englishton (S181) passes into meltwater channels (Fig. 54, A) which extend westward. It can be inferred that ice occupied the western end of the channels whilst the delta was formed. However, the exact position of the ice front is unknown but it is proposed that the ice occupied the Beauly Firth a short distance west of Englishton (Fig. 53). The ice front terminated in the sea and retreat was probably marked by calving. The high-level delta surface (S181) does not grade into raised shoreline fragments although a marine terrace (S179) at 29.6 m indicates marine action up to this level. The delta may be graded to a relative sea level below 29.6 m and therefore indicates a fall in relative sea level. The poorly-developed sand ridge (R42) may also be indicative of a fall in relative sea level.

The high level delta (S181) is succeeded seaward by marine terraces at circa 21-22 m (S180, S182) which are indicative of a continued fall in relative sea level. These high level marine features are truncated by a low level cliff related to an even lower relative sea level.

The alluvial fan at Bunchrew although graded to sea level is too large to have been formed by present fluvial activity. It is unlikely that the alluvial fan formed during the Flandrian (cf. Haggart, 1982) since Flandrian marine deposits lie on its surface and it is not graded to any of these deposits. It is also unlikely that the alluvial fan formed directly after the Englishton delta was produced while ice still occupied the Beauly Firth (cf. Synge, 1977a); since the low-level cliff which truncates the Englishton delta would be expected to truncate the Bunchrew alluvial fan. As the low level cliff is also not present behind the alluvial fan it is suggested that these features were formed at the same time. The degraded low-level cliff is therefore

PLATE 8 The section at Englishton (NH 608 457) showing topset and foreset delta beds.

related to a relative sea level close to that of present. At the same time water discharge along the Bunchrew Burn was great enough to form a large alluvial fan and protect this section of the coast from extensive marine erosion.

d) Sequence of Events

i) The Late Devensian ice sheet downwasted and its margin retreated into the Beauly Firth.

ii) While the ice margin lay across the Beauly Firth west of Englishton, meltwaters flowed through the meltwater channels south of Cnoc a' Chinn and formed, the Englishton delta (S181). While this delta was being formed relative sea level fell from 29.6 m (S179) to below <u>circa</u> 28 m.

iii) Relative sea level continued to fall and formed raised marine terraces at <u>circa</u> 21-22 m (S180, S182).

iv) Relative sea level then fell to <u>circa</u> 2 m and during a period of extensive marine erosion many of the higher raised marine features were truncated. In contrast, sediments transported by the Bunchrew Burn were deposited at the coast to form a large alluvial fan.

v) Relative sea level then rose and formed raised marine features on the Bunchrew alluvial fan up to <u>circa</u> 7 m. From this point relative sea level fell and alluvial fans below <u>circa</u> 7 m were deposited.

2. <u>Kiltarlity and Balblair</u>

a) Previous Research

The area of Kiltarlity and Balblair (Figs. 53, 56) lies west of the Beauly Firth. The area is dissected by the river Beauly, with

FIGURE 56 The Balblair and Kiltarlity areas.

Balblair lying to the north of the river and Kiltarlity to the south. The officers of the Geological Survey (Horne and Hinxman, 1914) suggested that the terraces in the Kiltarlity/Balblair region are fluvial in origin, and were formed by the river Beauly and the Belladrum, Bruiach and Allt Croiche streams. Above these terraces they described hummocky drift composed of sand and gravel.

J.S. Smith (1968, 1977) suggested that the high-level terrace fragments at Balblair (Figs. 56, 58, T70, T108) represent an outwash delta. He described moraines and kames near Kilmorack (Fig. 56) as contemporaneous with the delta formation. Harris and Peacock (1969) also suggested that the higher terrace fragments at Balblair and Kiltarlity are delta fragments deposited by meltwaters which flowed through the Kilmorack Gorge. They proposed that the Balblair delta (T70, T108) became dissected and a series of lower terraces were formed as relative sea level fell.

Synge (1977a) and Synge and Smith (1980) described the Balblair delta (T70) as an outwash feature with topset and foreset bedding, and related the feature to a former ice margin in the Kilmorack area (Fig. 56). They proposed that the delta formed whilst relative sea level stood at 26 m.

b) Field Evidence

On the northern side of the river Beauly east of Kilmorack Gorge there are terrace fragments at several levels (Figs. 56, 58, T70-T102). The highest terrace fragment (T70) descends in altitude from 37 m at Kilmorack Church (NH 4942 4432) to 27 m at Balblair (Fig. 56). Along most of its length T70 declines regularly in altitude, but at its eastern end the feature is stepped with horizontal sections at 30.2 m and 29.1 m. These horizontal sections are interpreted as raised

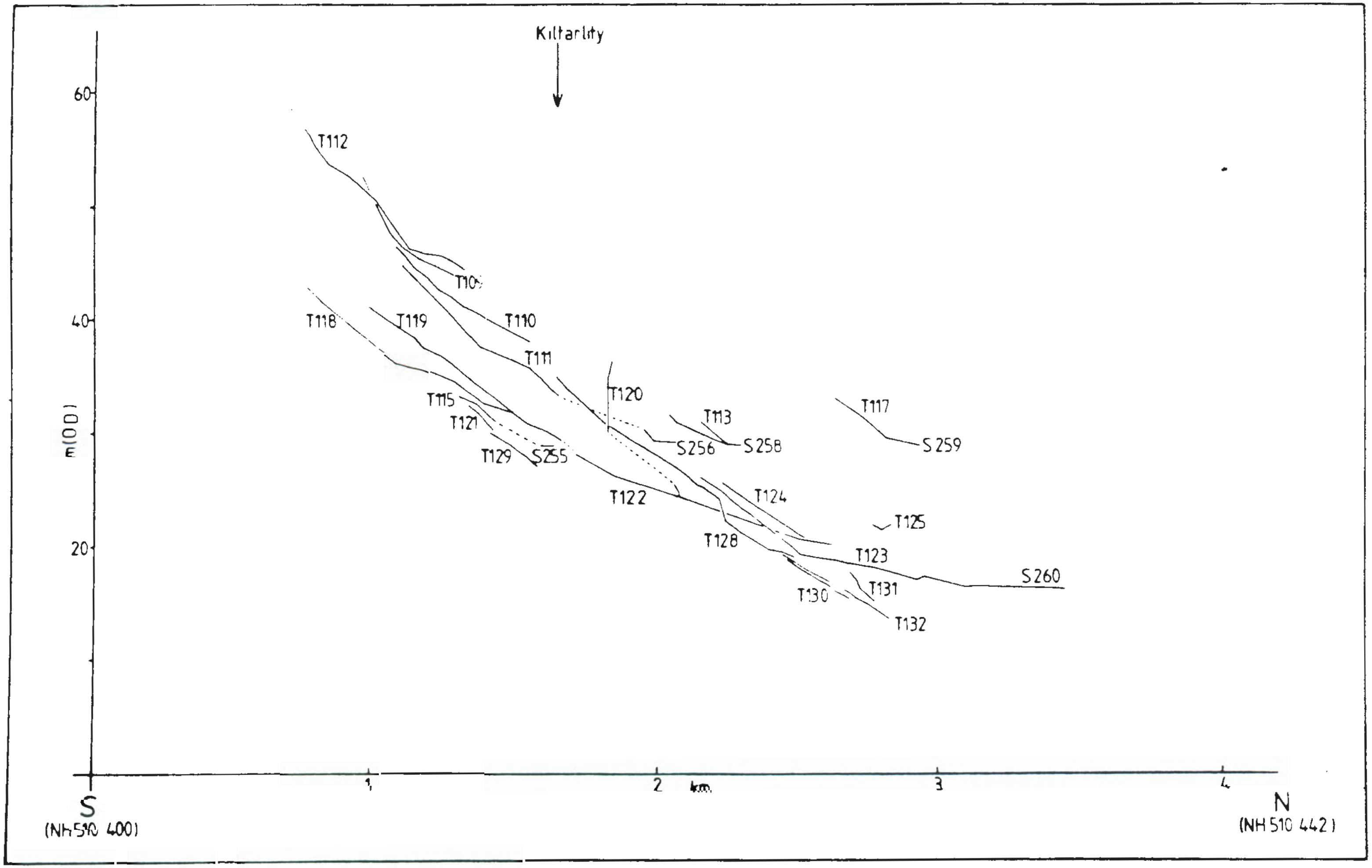


FIGURE 57 Altitude data for the Kiltarlity area.

marine terraces, a view supported by the presence of a raised marine shoreline fragment (S253) at 29.4 m located NE of T70. Sections in T70 at Balblair sand and gravel pit (NH 511 444) indicate clear topset and foreset bedding. The sections reveal coarse sub-rounded-rounded gravel with sand up to 1 m thick which overlies steeply-inclined beds of gravel and sand. The steeply-inclined beds of gravel contain sand and cobbles and are often characterised by graded bedding. At lower levels sand deposits predominate and are characterised by climbing ripples and fault structures. The deposits are interpreted as rapidly deposited sediments in a deltaic environment.

To the north of Kilmorack Gorge above terrace fragment T70 kame and kettle topography occurs. The relation of this kame and kettle topography to the high delta (T70) at Balblair is unknown. Similarly terraces developed in the gorge have an uncertain relation with the high delta (T70).

A series of river channels and terrace fragments (T71-T102) occur below the high Balblair delta (T70). Many of the terrace fragments are discrete features which are difficult to correlate with each other, but an attempt of correlation has been made (Table 17) on the basis of gradient and staircase constraints. Certain of the river terrace fragments are graded to raised shoreline fragments (eg. T81, T84, T85) but these relate to base levels below <u>circa</u> 10 m. The cross-cutting relationships of the river terrace fragments (T71-T102) suggests relative sea level fell as the fragments were formed.

The high-level delta at Balblair (T70) is truncated at its eastern margin by a degraded cliffline. Deposited against the cliff are extensive estuarine clays which form a raised shoreline terrace at 9.8 m (S249). The estuarine deposits are overlain by small alluvial fans and are succeeded seaward by a lower raised shoreline fragment

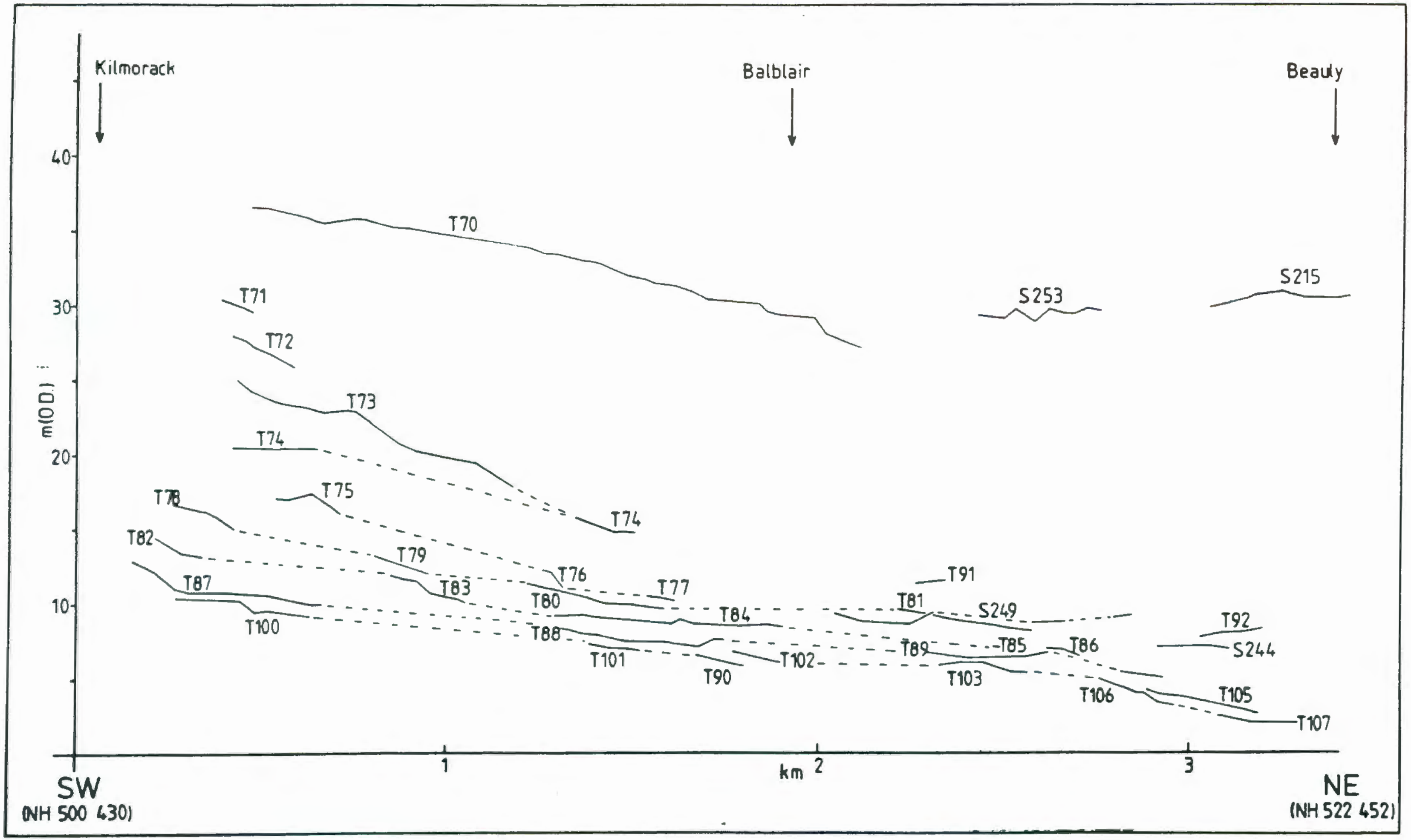


FIGURE 58 Altitude data for the Balblair area.

at 7.0 m (S244).

South of the river Beauly a series of terrace fragments are present (Figs. 56, 57, T108-T135). At the mouth of the Kilmorack Gorge a broad kettled outwash terrace fragment (T108) descends eastwards from 40.5 m to 34 m. This terrace surface is continued farther east where it descends to 28 m. This feature is considered of the same age as the high-level delta at Balblair (T70). Adjacent to T108 another terrace fragment (T127) descends from 31 m to 26.5 m. Channels on the surface of the higher terrace fragment (T108) descend onto the surface of the lower feature (T127).

The highest terrace fragments in the Kiltarlity area (T111, T115, T116) descend northward to 27-29 m. The frontal margins of these terrace fragments are dissected by river channels which are graded to a lower terrace fragment (T122). Towards the south terrace fragment T111 extends into two narrow channels (Fig. 56, A, B) which are eroded through a broad morainic ridge. South of the morainic ridge a broad terrace fragment (T112) extends southward into kame and kettle topography. Farther east at Home Farm another terrace fragment (T109) may be correlated with fragment T111. T109 either continues along the course of Belladrum Burn or passes into a meltwater channel (Fig. 56, C), which extends northward where it passes into a small delta (T117) which descends to 29 m.

A lower terrace surface is represented by several alluvial fans (T118-T121) for the streams of Allt Caoiche, Culburnie Burn and Bruiach Burn. These alluvial fans extend towards the east where they merge into terrace fragments (T122-T126) below the high Kiltarlity terrace (T111). Channels which start on the surface of the high Kiltarlity terrace fragment (T111) pass onto and end on the surface of the lower terrace fragment T122. This indicates that water continued to flow across the surface of fragment T111 whilst the lower terrace fragments (T122-T126) were being formed.

Farther east a broad channelled terrace fragment (T123) descends from 26 m to 18 m along the Dounie Burn, but surprisingly north of Dounie Farm (NH 5142 4285) it rises towards the north and this rise is attributed to the river Beauly. Towards the east T123 is graded to a raised shoreline fragment (S260) at 16.4 m. A three metre section in T123 reveals horizontal beds of fine sand (0.01-0.05 m thick) alternating with silts. Coarse sub-rounded gravels with sand are exposed 6 m above the beds of fine sands and silts. The deposits are interpreted as bottomset and topset beds of a delta.

The two higher terrace surfaces in the Kiltarlity area (T111-T117, T118-T126) are dissected by the streams of Belladrum Burn and Bruiach Burn and several lower terrace fragments are present (T128-T132). The lower terrace fragments were only measured at a few localities, but it is suggested that at least 3 lower river terrace surfaces occur. None of the lower terrace surfaces can be related to raised shoreline fragments or former ice margins.

c) Discussion

The features in the Balblair/Kiltarlity area represent a complex sequence of deltas which were dissected during a fall of relative sea level. The correlation of individual terrace fragments is presented in Table 17 although the fragmentary nature of some of the features makes certain correlations rather tentative. A more important consideration is the correlation of the deltas in the Kiltarlity area with those at Balblair and their relation to relative sea level and former ice margins. The high Balblair delta (T70, T108) occurs on both sides of the river Beauly. On the northern side of the river the delta (T70) is graded to raised marine terraces at 30.2 m and 29.1 m, but its frontal surface descends to 27 m. Shoreline fragment S253 at

Group	Correlated Fragments
A	T70, T108, T109, T111, T113, T117
B	T73, T110, T112, T118, T119, T120, T122-T125
C	T74, T91(?)
D	T75, T76, T77
E	T78-T81
F	T82-T86
G	T87-T89
H	T90, T100-T103, T106, T107

TABLE 17 Proposed correlation of fluvial and fluvioglacial terrace fragments in the Kiltarlity and Balblair areas (Figs. 56-58)

29.4 m is correlated with the high delta surface. It is possible that the high Balblair delta formed as relative sea level fell and so the feature is graded to more than one raised shoreline fragment. The relation of the high delta (T70, T108) to the ice margin is more problematical. It is possible that ice was located at the eastern end of the Kilmorack Gorge when the high Balblair delta (T70, T108) was formed. Alternatively, water may have drained through the gorge at the time of formation. The size of the delta and its kettled surface certainly indicate that the feature was formed as a result of meltwater activity.

The highest terrace fragments in the Kiltarlity area (T111, T114-T117) all descend to 27-29 m. The similarity in altitude of the frontal margins of these terrace fragments (T111, T114-T117) is considered to indicate that relative sea level was at <u>circa</u> 27-29 m when these deltas were produced. This relative sea level is at the same altitude as that proposed for the high-level delta at Balblair (T70). It is therefore suggested that the high-level delta at Balblair (T70, T108) and the high Kiltarlity deltas (T111, T114-T117) were formed at approximately the same time.

The inferred location of the ice front whilst the high Kiltarlity deltas were formed is dependent upon the interpretation of the broad terrace fragment T112 behind the morainic ridge. Under one interpretation T112 is a continuation of terrace fragment T111 and on this basis the ice margin lay south of the morainic ridge where terrace fragment T112 extends into kame and kettle topography. However this interpretation is considered unlikely since there would have been an insufficient head of water for the meltwaters from terrace fragment T109 to have flowed uphill in the meltwater channel (Fig. 56, D) which links T109 with the delta T117. The second interpretation is that the ice lay adjacent to the morainic ridge and over the meltwater channel (Fig. 56, C) when the high Kiltarlity detlas (T111, T114-T117) were formed. The ice then retreated to the kame and kettle topography south ofthe terrace fragment T112 and terrace fragments T109 and T112 were formed. At this time meltwater drained from fragments T109 and T112 through the channels (Fig. 56, A, B) which dissect the morainic ridge, across the surface of terrace fragment T111 onto the surface of the lower terrace fragment T122.

Below the high Kiltarlity deltas (T111, T114-T117) there is a lower terrace surface represented by terrace fragments T118-T126 . This lower surface is graded to a raised shoreline fragment (S260) at 16.4 m and it is correlated with the large terrace fragment (T73) on the northern side of the river Beauly. It is suggested that terrace fragment T112 also correlates with this lower terrace surface (T118-T126) and therefore ice occupied the area of kame and kettle topograph whilst relative sea level stood at circa 16 m. It is inferred that relative sea level fell 13 m from 29 m to 16 m whilst the ice margin retreated only 0.5 km.

After the marine terrace at 16.4 m (S260) was formed relative sea level fell and the higher terrace surfaces were dissected. Several terrace fragments were formed (T74-T107, T127-T132), but few of these terrace fragments can be related to specific raised shorelines. However, fragments T80 and T81 are graded to a raised shoreline fragment at circa 9 m (S249), whilst fragments T84 and T85 are graded to a circa 7 m level and are correlated with marine terrace S244 at 7.0 m.

The high-level delta at Balblair (T70) is truncated by a degraded cliffline. At the base of this degraded cliffline there are extensive estuarine deposits. Since it is unlikely that a major cliff and extensive estuarine deposits would have formed at the same time it is suggested that the cliff predates the estuarine deposits.

d) Sequence of Events

i) The Late Devensian ice sheet retreated to the Balblair area.

ii) Whilst the ice limit stood in the vicinity of Kilmorack Gorge and along the morainic ridge SE of Kiltarlity large deltas at Balblair (T70, T108) and Kiltarlity (T111, T114-T117) were produced. These deltas, which are related to relative sea levels between 27-30 m, may indicate a fall in relative sea level during their accumulation.

iii) The ice margin retreated 0.5 km in the Kiltarlity area where it decayed <u>in situ</u> and formed kame and kettle topography. Meltwaters drained from this mass of ice through channels in the morainic ridge (Fig. 56, A, B) to a lower terrace surface (T73, T118-T126) which is graded to a raised shoreline fragment (S260) at 16.4 m.

iv) Relative sea level continued to fall and the high deltas at Balblair and Kiltarlity were dissected. Terrace fragments were formed at a variety of altitudes (T74-T77).

v) Relative sea level fell and the high-level delta at Balblair (T70) was truncated by marine erosion and a low-level cliff was formed.

vi) Subsequently extensive estuarine sediments were deposited adjacent to the low-level cliff at 8.9 m (S249) and terrace fragments of the river Beauly are graded to this same level.

vii) Relative sea level then fell and the river Beauly formed a series of river terraces at successively lower altitudes (T82-T107). Some of these river terrace fragments are graded to relative sea levels below 8.9 m (eg. T84, T85, T107).

3. The Muir of Ord and Orrin Valley

a) Previous Research

Muir of Ord (Figs. 53, 59) lies on the narrow lowland that separates the Beauly Firth from Strath Conon, and the river Orrin drains into this area from the west. Horne and Hinxman (1914) claimed that lateral moraines are present on the hills west of Muir of Ord and that these pass into a series of flat-topped ridges which merge with a large raised beach at 100 ft (30.5 m) (T67, T69) south of the village. They also claimed that the raised beach (T67, T69) merges northward into kame and kettle topography. Horne and Hinxman also identified raised marine terraces at 100 ft (30.5 m) north of Highfield (Fig. 61, S263, S265) and near the confluence of the Orrin and Conon rivers (S275). They noted that the raised beaches south of Muir of Ord terminate southward in a degraded cliff which they attributed to marine erosion whilst relative sea level stood at 50 ft (15.2 m) and later at 25 ft (7.6 m).

In contrast, Ogilvie (1923) suggested that the terrace south of Muir of Ord (T67, T69) is a fluvio-glacial deposit pitted by kettleholes. He suggested that the surface is unaffected by marine activity and that it merges into kame and kettle topography towards the north. Ogilvie suggested that the kame and kettle topography in the north is truncated by marine terraces at 80 ft (24.4 m) (S263, S265, T39) whilst the outwash fan (T67, T69) south of the village is truncated by raised marine features at 80 ft (24.4 m), 50 ft (15.2 m) and 25 ft (7.6 m). Ogilvie also proposed that the river Orrin may have at one time flowed farther east in the vicinity of Highfield.

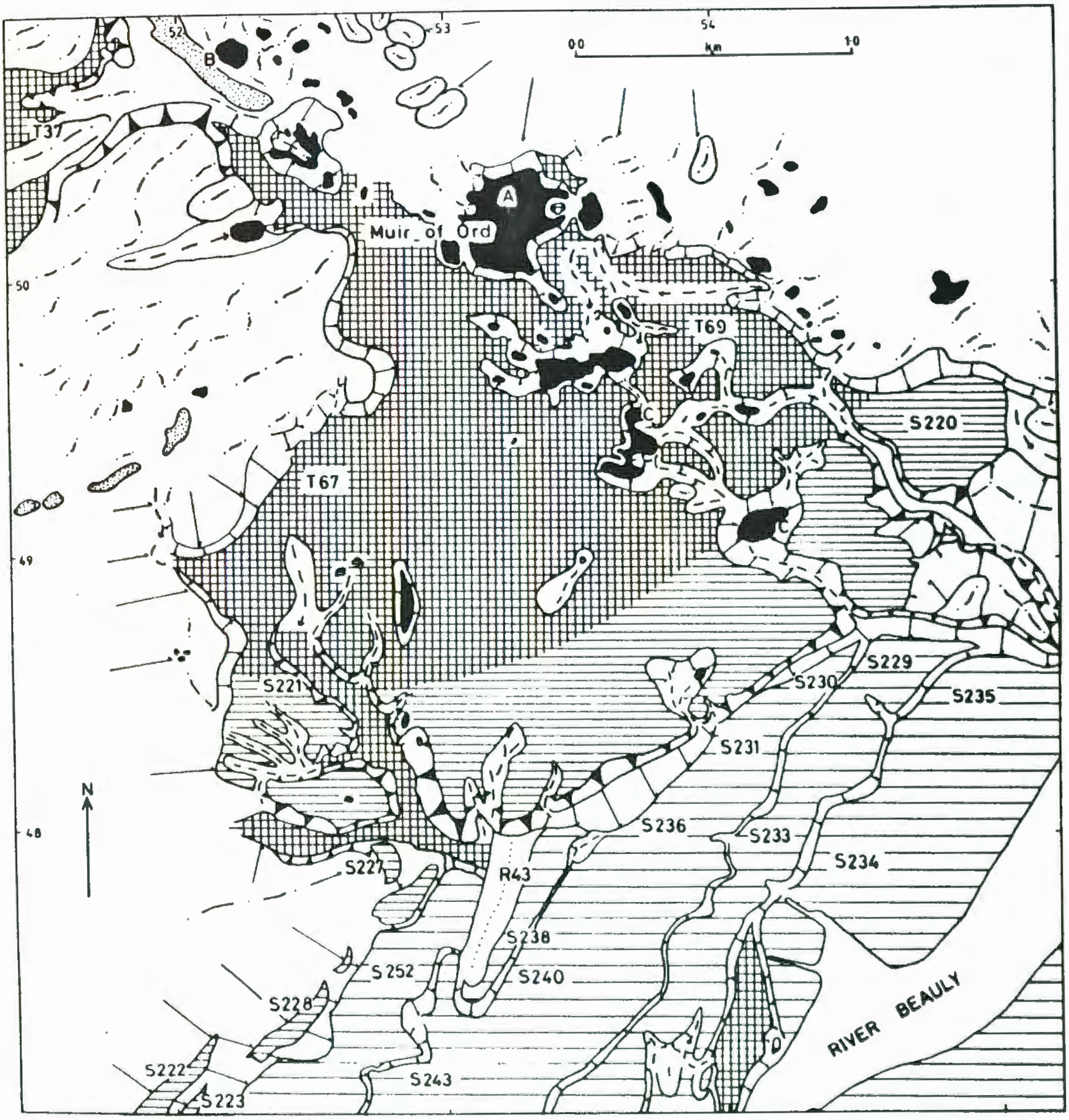


FIGURE 59 The Muir of Ord area.

Kirk et al. (1966) suggested that the terrace surface south of Muir of Ord (T67, T69) is an outwash delta graded to a 98 ft (29.9 m) relative sea level. They suggested that ice occupied the lower Conon valley whilst the delta was formed. They considered that the ice front later retreated as far west as Muirton Mains (Fig. 53) when relative sea level stood at 85 ft (25.9 m) north of Muir of Ord.

J.S. Smith (1968) suggested that the large terrace (T67, T69) south of Muir of Ord represents an outwash fan pitted by kettleholes and formed in close proximity to the ice margin. He suggested that poorly-developed shingle ridges occur on the surface of the outwash fan to an altitude of 98 ft (27.1 m). The kame and kettle topography in the vicinity of Highfield was said to have been modified by marine action up to an altitude of 89 ft (27.1 m) (J.S. Smith, 1968). In contrast, J.S. Smith (1977) suggested that the terrace fragments south of Muir of Ord (T67, T69) are a delta formed by a "... net seaward displacement of the shoreline..." (p. 75) related to the fluvioglacial outwash at Contin (Fig. 53). This interpretation inferred that the terrace fragments at Muir of Ord were formed after the reported outwash fan at Contin which lies circa 7 km to the west.

Harris and Peacock (1969) believed that fluvio-glacial deltas occur both south and north of Muir of Ord but no attempt was made to relate these deltas to former sea level. Farther east they described a large Lateglacial raised shoreline fragment at Arcan Mains (Fig. 61, S275).

Finally Synge (1977a) and Synge and Smith (1980) claimed that outwash gravel in the Muir of Ord area had been truncated by marine action at circa 30 m. They proposed that the large terrace surface south of Muir of Ord (T67, T69) was formed whilst ice occupied the Conon valley.

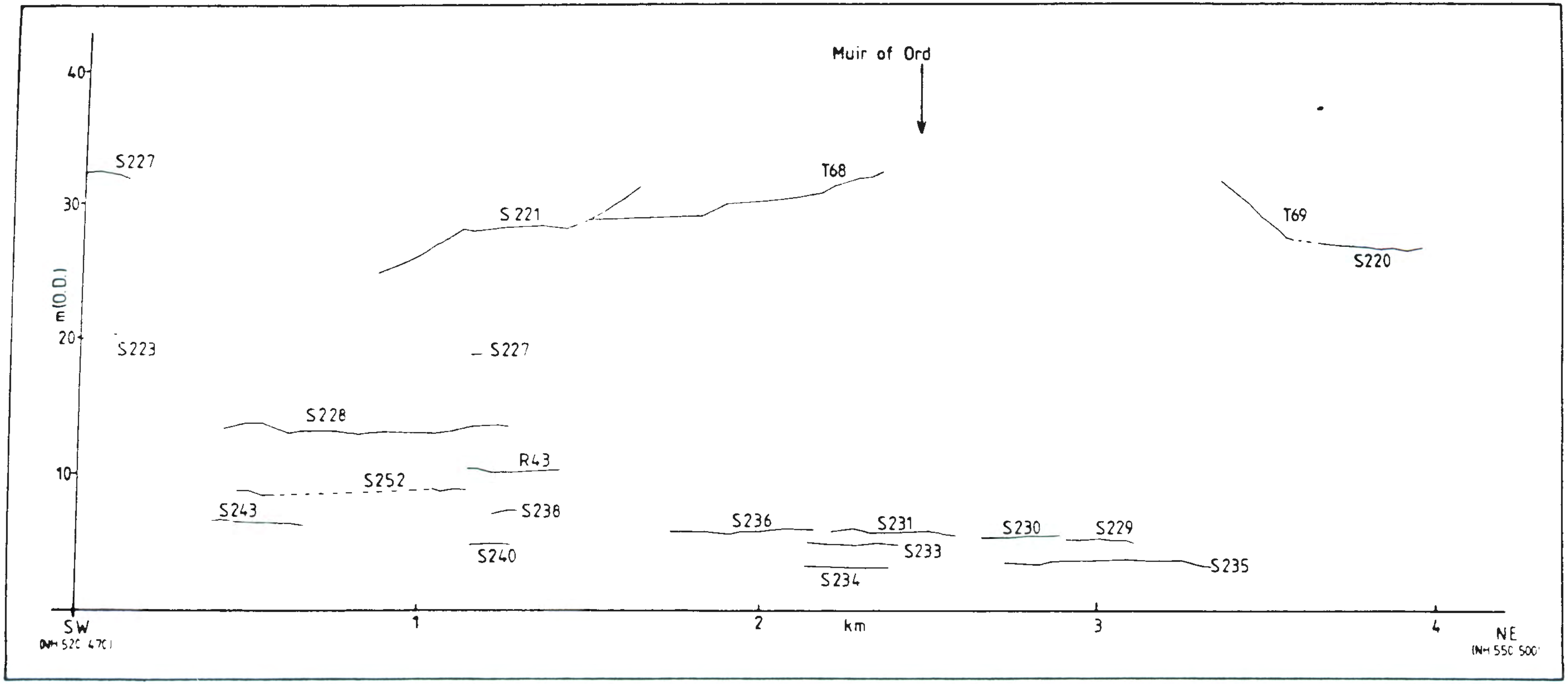


FIGURE 60 Altitude data for the Muir of Ord area.

b) Field Evidence

Muir of Ord lies in an area of kame and kettle topography (Fig. 59). Many of the kettleholes are large (eg. Fig. 59, A) and well developed. From the north an esker ridge (Fig. 59, B) extends into the area of kame and kettle topography, while a meltwater channel (T37) extends westwards from this area along the course of the present Allt Fionnaidle stream. The meltwater channel merges westward into kame and kettle topography and kame terraces (T33, T35) near Faebait (Fig. 53). Higher terrace fragments (T34, T36) occur within the meltwater channel (T37). The meltwater channel is continued southward by kame terrace T38 which is pitted by small kettleholes and flanked to the west and the east by larger kettleholes. It is therefore suggested that masses of dead ice occupied the Muir of Ord and Orrin valley whilst melt-waters flowed along this meltwater channel.

South of Muir of Ord an extensive terrace is pitted by numerous large kettleholes (Fig. 59, T67, T69, C). Sections (NH 5305 4812, NH 5446 4881) indicate that the frontal sections of the terraces are composed of finely-bedded, steeply-dipping sands with occasional gravel layers. At one site (NH 5287 4834) horizontal beds of sand with occasion-al fine gravel layers overlie steeply-dipping layers of fine sand. This is interpreted as foreset and topset beds and therefore the terrace is an outwash delta (the Muir of Ord Outwash Delta). In the east small channels extend onto the surface of the delta from kame and kettle topography and this suggests the presence of localised masses of ice in the area east of Muir of Ord while the delta was formed. In the east the surface of the delta (T69) declines in altitude from 32 m southward and is graded to a raised shoreline fragment (S220) at 27.0 m. In the west the surface of the outwash delta (T67) descends southward to 23.8 m. However, the delta surface is terraced at 28.2 m (Fig. 60) and this is interpreted as a raised marine fragment (S221).

The Muir of Ord outwash delta is truncated to the south by a degraded cliffline. In the east the degraded cliff is succeeded seaward by a steeply-sloping raised shingle beach and estuarine clays which form raised shoreline fragments at 5.5-5.9 m (S230, S231, S236), 4.9 m (S229, S232, S233) and 3.4 m (S234, S235). In the east the raised estuarine clays rise to 9.4 m (S252) and are succeeded seaward by a broad sand ridge (R43).

The kame and kettle topography at Muir of Ord extends northward where it is truncated by a river terrace fragment (Figs. 61, 62, T65). Farther north a series of outwash terraces (T39-T42) are present near Highfield and these are truncated and dissected by marine (S263-S270) and fluvial terraces (T44-T65).

The highest outwash terrace fragment (T39) near Highfield descends northward in altitude from 28 m to 24 m. Farther west lower outwash terrace fragments occur (T40, T41) and these attain maximum altitudes of 27.5 m (T40) and 28 m (T41). Sections (NH 516 528) in the lower terrace fragment (T41) reveal a horizontal layer of subrounded gravel with sand overlying steeply-inclined beds of sand and sand with gravel. Towards the base of the section (Fig. 67) fine sands are interbedded with silts and load structures are present. At one section a drop stone is present in the lower sands. It is concluded that the sediments were deposited in a prograding delta. The inclination of the beds and the general increase in sediment calibre towards the south suggests that the delta prograded northwards. It is suggested that the 3 outwash terrace fragments (T39-T41) are outwash deltas termed here the Highfield Outwash Deltas.

None of the high Highfield Outwash Deltas (T39-T41) can be related to former sea level, but in adjacent areas raised shoreline

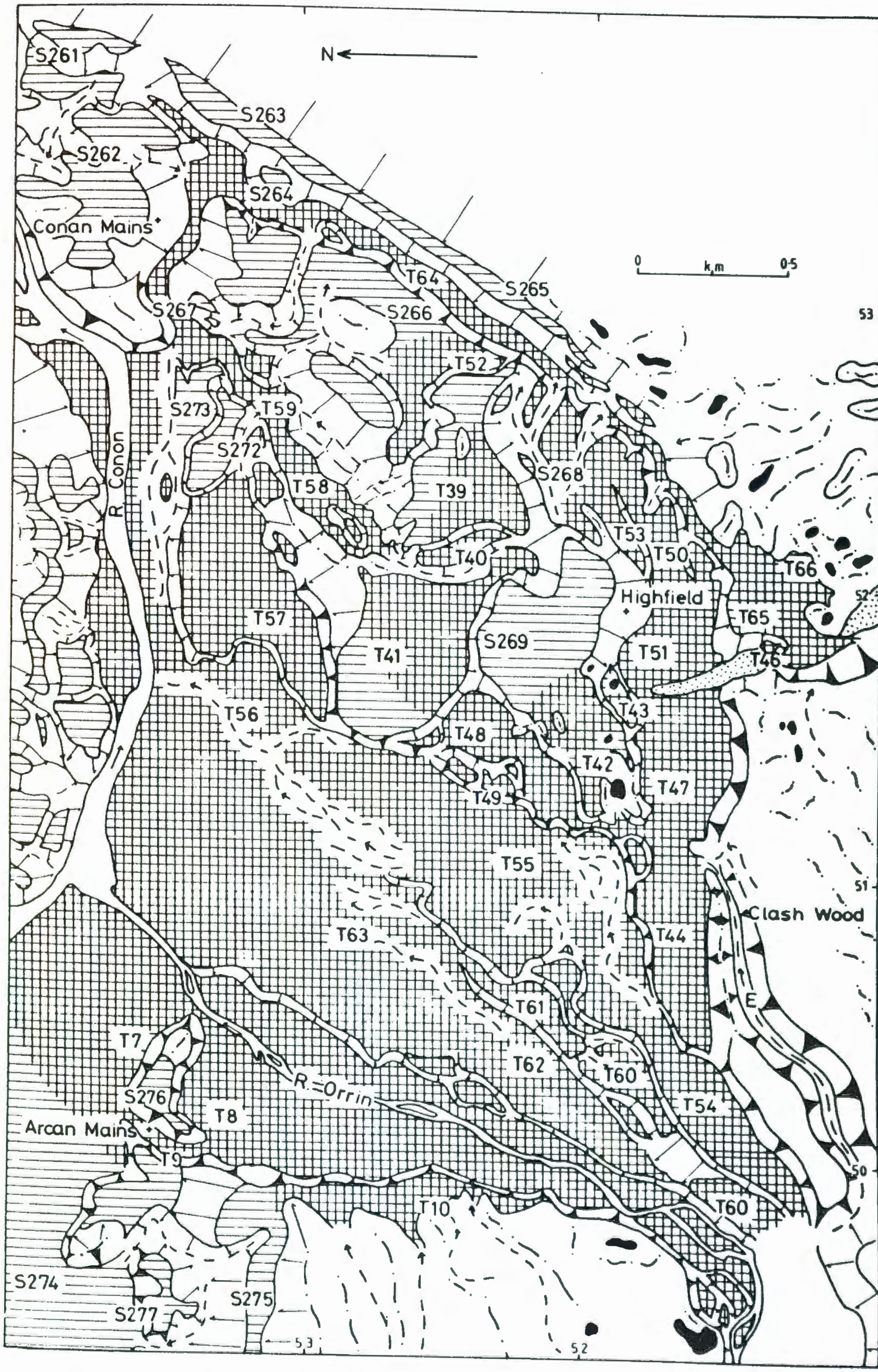


FIGURE 61 The Highfield area.

fragments occur at 28.2 m (S265) and 27.9 m (S263) (it should be noted that the altitudes determined on S263 and S265 may be too low since a road lies close to the inferred break of slope).

The ice-contact slope of the Highfield Outwash Deltas (T39-T41) lies adjacent to a raised shoreline fragment (S269) at 26.2 m. Towards the SW this raised shoreline terrace merges into a kettled outwash surface (T42) whilst to the south it ends in a steep kettled slope which descends to lower terrace fragments (T51, T53). It is suggested that the steep kettled slope is an ice-contact slope in front of which a marine terrace (S269) was formed whilst ice lay adjacent to the slope. The kettled outwash delta (T42) is of limited extent but lies adjacent to a small esker ridge (Fig. 61, D) and the large meltwater channel in Clash Wood (Fig. 61, E). Both features indicate the presence of ice in the Muir of Ord area and Orrin valley whilst the outwash delta (T42) was formed.

The lowest of the Highfield Outwash Deltas (T42) is dissected by fluvial terraces (T44-T48)(Figs. 61, 62). Terrace fragment T44 initially trends eastward, but later bifurcates and one section extends north (T48) and the other (T51) eastward below the ice-contact slope related to S269. Terrace fragment T51 is continued northward along the course of the Logie Burn by fragment T52 which merges into a raised shoreline fragment (S266) at 22.3 m. A slightly higher terrace surface (T43, T53) merges into a poorly-defined raised marine terrace (S268) at 24.3 m. However, this terrace surface (T43, T53) may also be graded to raised shoreline fragment S266.

Below T43-T53 occur two river terrace fragments (T65, T66) which are related to the present Logie Burn. These occur within the kame and kettle topography at Muir of Ord. Since the surface of

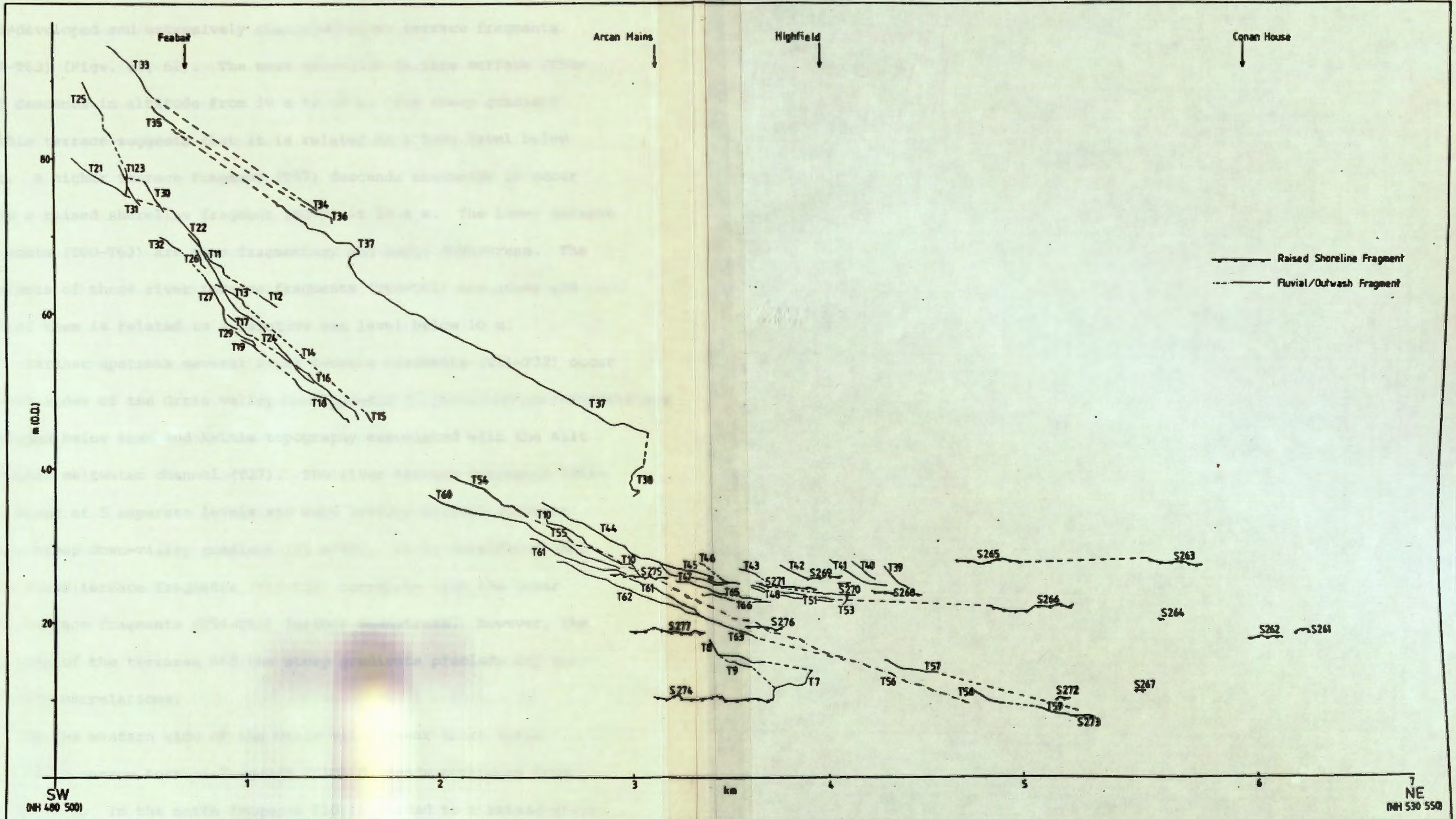


FIGURE 62 Altitude data for the Orrin valley and Highfield areas.

the Muir of Ord ice-contact deposits lie below the altitude of the higher terrace fragments (T43-T53) it is suggested that a mass of decaying ice lay in the Muir of Ord area whilst these terrace fragments were formed.

To the NE of the Highfield Outwash Deltas there are several well-developed and extensively channelled river terrace fragments (T54-T63) (Figs. 61, 62). The most extensive terrace surface (T54-T56) descends in altitude from 39 m to 10 m. The steep gradient of this terrace suggests that it is related to a base level below 10 m. A higher terrace fragment (T57) descends eastwards to occur below a raised shoreline fragment (S272) at 10.4 m. The lower terrace fragments (T60-T63) are more fragmentary and merge downstream. The gradients of these river terrace fragments (T60-T63) are steep and each of them is related to a relative sea level below 10 m.

Farther upstream several river terrace fragments (T11-T32) occur on both sides of the Orrin valley (see Appendix I). These terrace fragments are developed below kame and kettle topography associated with the Allt Fionnaidh meltwater channel (T37). The river terrace fragments (T11-T32) occur at 5 separate levels and each terrace surface exhibits a very steep down-valley gradient (25 m/km). It is considered that these river terrace fragments (T11-T32) correlate with the lower river terrace fragments (T54-T63) farther downstream. However, the multitude of the terraces and the steep gradients preclude any satisfactory correlations.

On the western side of the Orrin valley near Arcan Mains (Fig. 61) a narrow terrace fragment (T10) descends northward from 32 m to 26 m. In the north fragment T10 is graded to a raised shoreline terrace (S275) at 26.2 m, whilst to the south and east it merges into fluvio-glacial landforms. The meltwater channels which lead onto this outwash terrace (T10) suggest that ice occupied the Orrin valley up to circa 80 m. Below shoreline fragment S275 shoreline terraces occur at 19.0-19.6 m (S276-S277). Marine terraces at a similar altitude occur near Conan Mains (Fig. 61, S261, S262). Features S276 and S277 have been partially eroded by river terraces of the rivers Conon and Orrin (T6-T9). These river terrace fragments (T6-T9)are dissected by numerous channels but appear to be graded to a raised shoreline fragment at 10.4 m (S274). Haggart (1982) noted that Flandrian marine deposits occur in a gully in the surface of S274 and so this shoreline fragment is probably of Lateglacial age.

c) Discussion

Although the Muir of Ord area is characterised by a complex array of terrace fragments they may be interpreted in a straightforward manner. During ice statnation in the Orrin valley and at Muir of Ord, meltwaters flowed northward into the Conon valley and southward into the Beauly Firth and formed outwash deltas (Fig. 62a). The Muir of Ord Outwash Delta is graded to raised shoreline fragments at 28.2 m in the west (S220) and 27.0 m in the east (S221) and this difference in altitude is attributed to isostatic tilting. The surface of the outwash delta descends to 24 m and this suggests a possible lower relative sea level during its formation.

North of Muir of Ord 5 raised delta surfaces are present (T10, T39-T42). Two of these deltas (T10, T42) are graded to raised shoreline fragments at circa 26 m (S269, S275). The 3 higher deltas near Highfield (T39-T41) (Fig. 62a) cannot be directly related to raised marine features but they are correlated with the raised marine terraces (S263, S265) at circa 28 m. The 5 deltas are interpreted as having formed whilst the ice margin retreated. The lowest deltas (T10, T42) are considered to be of the same age as the Muir of Ord Outwash Delta (T67, T69) (Fig. 62a). When these outwash deltas were produced (T10, T42, T67, T69) ice

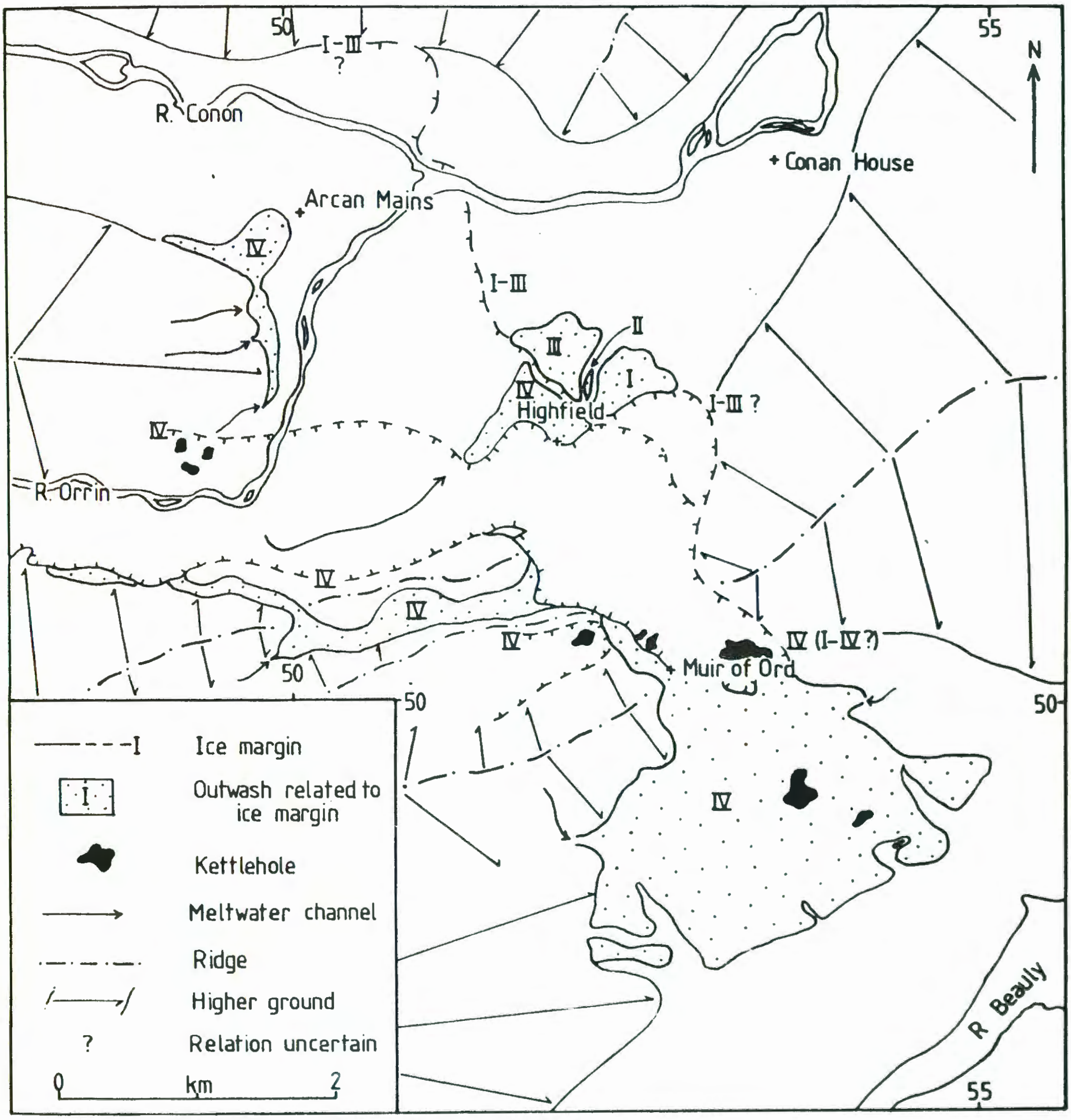


FIGURE 62a Late Devensian ice limits proposed for Muir of Ord and Highfield areas.

occupied the Orrin valley and Muir of Ord (Fig. 62a). Meltwaters flowed along the Allt Fionnaidle channel (T37) and locally from higher ground to the west and east of Muir of Ord. A raised shoreline fragment at 26.3 m some 2 km east of Arcan Mains (Fig. 61) suggests that the lower Conon valley was ice free whilst these deltas (T10, T42, T67, T69) were produced.

The higher outwash deltas at Highfield (T39-T41) are related to an ice margin which lay 0.5 km farther north than that related to outwash delta T42. It is possible that ice may have occupied the lower Conon valley (Fig. 62a) while these higher outwash deltas (T39-T41) were formed since there is no evidence of raised shoreline fragments at or above 28 m west of the deltas. A test of this hypothesis could be made on the northern slopes of the Conon valley, but this area lies outside the study area.

During ice stagnation in the Muir of Ord area, relative sea level fell from 28 m (S265) to 22.5 m (S266). The location of the ice margin in the Orrin valley whilst the lower shoreline fragment (S266) was formed is unknown but it is considered likely that meltwater still flowed through the Allt Fionnadle channel (T37) and deposited sediments at the front of the Muir of Ord Outwash Delta (T67, T69).

It is therefore concluded that whilst ice lay in the Muir of Ord area relative sea level fell <u>circa</u> 6 m from 28 m to 22.5 m. This relative fall in sea level was associated with a retreat of the ice margin of 1 km or more.

There is widespread evidence in the form of lower marine terraces from the Conon valley (S276-S262) and the Beauly Firth (S227) to suggest that relative sea level then fell to <u>circa</u> 18-19 m. Marine terraces at 13.5 m (S228), 11.5 m (S267) and 10.4 m (S272, S274) indicate a continued fall in relative sea level. The lowest marine terrace (S274) merges into fluvial terrace fragments of the river Conon (T6) and river Orrin (T7-T9). Lower fluvial terrace fragments in the Orrin valley are graded to base levels below 10 m. It is suggested that relative sea level fell below 10 m during the Lateglacial since Flandrian marine deposits have been identified in a buried gully in shoreline fragment S274 (Haggart, 1982). Subsequently a rise in relative sea level resulted in the deposition of Flandrian marine sediments to circa 9 m (S252, S273, R44) in the Beauly and Conon valleys. It is possible that during this period the river Conon reoccupied some of its abandoned terrace fragments (eg. T6). Evidence in the form of raised estuarine terraces from south of Muir of Ord indicates that relative sea level then fell.

d) Sequence of Events

i) The Late Devensian ice sheet downwasted and retreated from the Cromarty Firth to the Muir of Ord area. Whilst ice occupied the Orrin valley and Muir of Ord and possibly the lower Conon valley, three outwash deltas (T39-T41) were produced. These deltas were formed whilst relative sea level fell from circa 28 m to circa 26 m.

ii) Ice occupied the Orrin valley and Muir of Ord whilst outwash deltas were formed south of Muir of Ord (T67, T69), near Highfield (T42) and near Arcan Mains (T10). At this time relative sea level stood at 26-28 m (S220, S221, S269, S275). Locally masses of ice were present on the higher ground east and west of Muir of Ord but the lower Conon valley was ice free. Large masses of ice remained buried in the Muir of Ord Outwash Delta.

iii) Relative sea level fell to 22.3 m (S266) and outwash is graded to this level north of Muir of Ord (T44-T53) and possibly along the southern margin of the Muir of Ord Outwash Delta (T67, T69). Whilst these terrace fragments were formed ice still remained in the Muir of Ord area and it is suggested that ice may still have occupied the Orrin valley.

iv) Relative sea level fell and raised marine terraces were formed at circa 18-19 m (S227, S262, S276-S278), 13.5 m (S228), 11.5 m (S267) and 10.4 m (S272, S274).

v) Relative sea level fell below 10 m and the river terrace fragments in the Orrin valley were formed (T54-T63).

vi) Relative sea level rose to circa 9 m and deposited Flandrian marine sediments in the Conon valley and Beauly Firth (R44, S252, S273).

vii) Subsequently relative sea level fell and raised estuarine sediments were deposited at circa 5.7 m (S230, S231, S236), 4.9 m (S229, S232, S233) and 3.4 m (S234, S235). During this time the rivers Conon and Orrin dissected river terrace fragments in the upper valleys but buried river terrace fragments graded to low relative sea levels.

4. Other Sites of Interest

a) Marybank and Muirton Mains

Marybank and Muirton Mains lie at the western end of the lower Conon valley (Figs. 53, 56). Raised marine terraces have been described in this area by several authors (Horne and Hinxman, 1914;

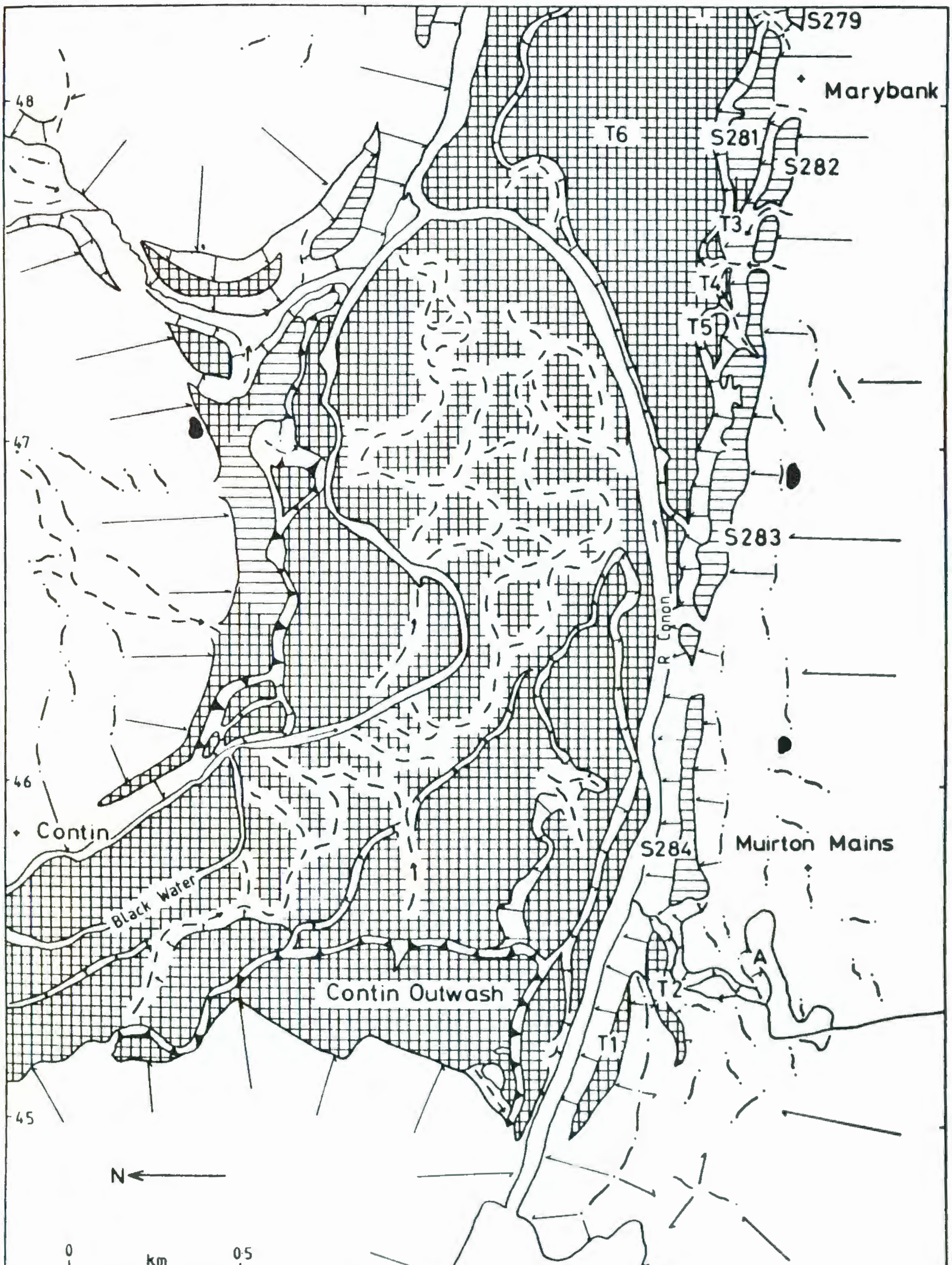


FIGURE 63 The Marybank and Muirton Mains areas.

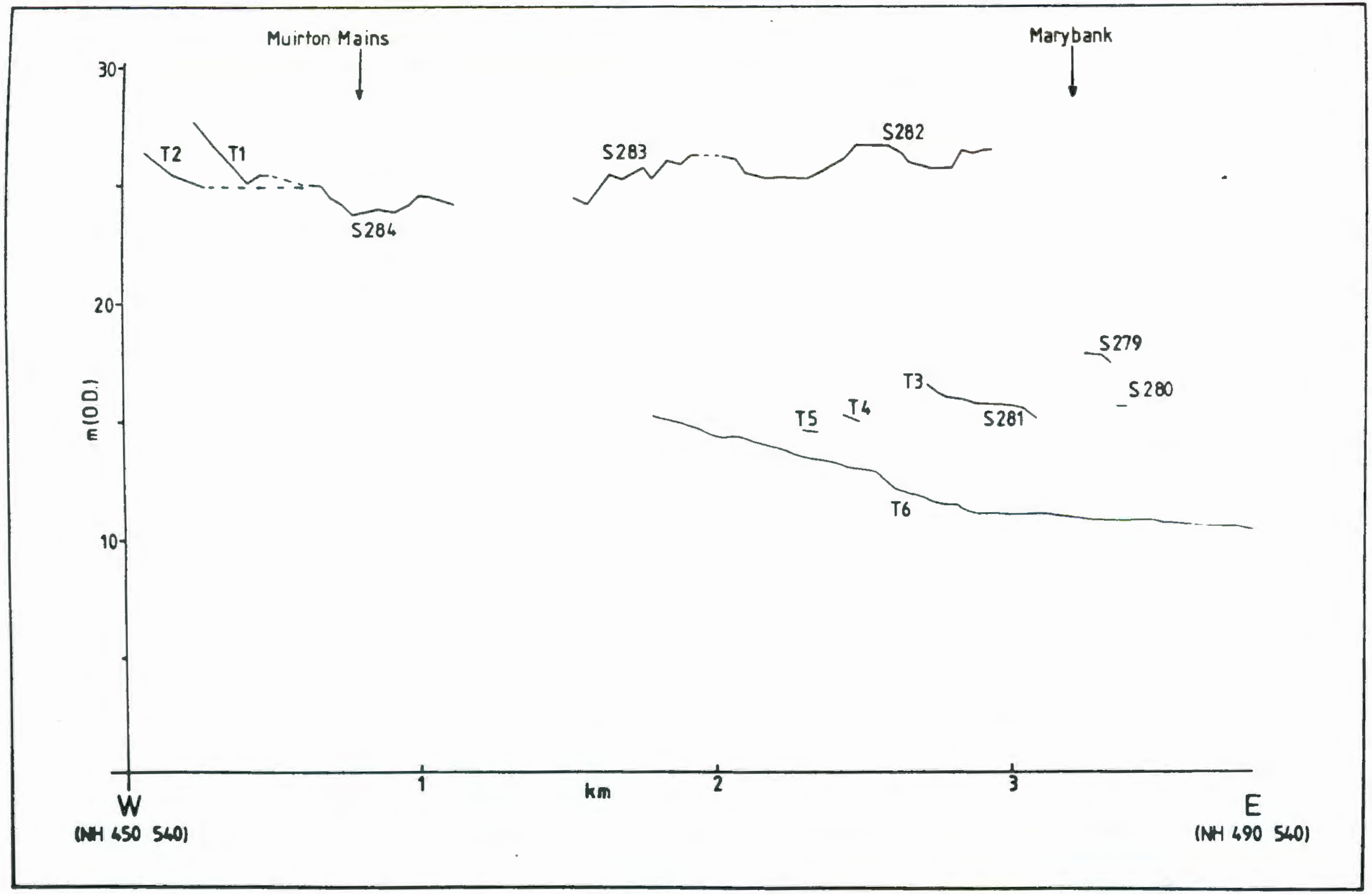


FIGURE 64 Altitude data for the Marybank and Muirton Mains areas.

Ogilvie, 1923; Kirk et al., 1966; J.S. Smith, 1968). The highest marine terrace (circa 26-28 m) has been associated with the Contin outwash fan (Kirk et al., 1966; Synge and Smith, 1980) and with well-developed shoreline fragments on the northern slopes of the Conon valley. Horne and Hinxman (1914) suggested that the highest marine terrace is composed of finely laminated blue and grey estuarine clay locally overlain by till. They also reported that marine shells had been found in this clay.

Between Marybank and Muirton Mains (Fig. 63) there are several shoreline fragments (S282-S284). The more easterly features at 25-26 m (S282, S283) are partly obscured by a road and the altitudes determined may therefore be rather low. The more westerly raised marine terrace (S284) occurs at 24.3 m and is succeeded upvalley by outwash terrace fragments (T1, T2) which merge into kame and kettle topography. South of the kame and kettle topography a small depression (NH 455 538) filled with 2 m of grey finely laminated clay occurs. Investigations have not identified any faunal remains, but the deposit is thought to represent the estuarine clays reported by Horne and Hinxman (1914).

The raised terrace fragments (S282-S284) are interpreted as representing two former relative sea levels at circa 26 m (S282, S283) and at 24.3 m (S284). The lower shoreline fragment (S284) is related to ice stagnation features west of Muirton Mains and a similar ice margin is anticipated for the higher marine features. The marine terraces are correlated with the Contin outwash fan, which is related to an ice margin at the eastern end of Loch Achilty (Bartlet pers. comm.) (Fig. 53). At Marybank lower raised shoreline fragments occur at 17.6 m (S279), 15.5 m (S280) and 15.8 m (S281). Below these there is an extensive river terrace fragment (T6) which merges eastwards into a raised shoreline fragment (S274) at 10.4 m.

b) North Kessock-Coulmore

Between Coulmore and North Kessock (Fig. 53) there is a narrow strip of low-lying land (below 35m)which lies between the shore of the Beauly Firth and a steep slope up to 30 m high to the north. Horne and Hinxman (1914) suggested that the steep slope is a cliffline associated with a shoreline fragment at 100 ft (30.5 m) which makes up much of the surface of the narrow strip of land. However, they suggested that the surface of the 100 ft beach is greatly eroded and succeeded by lower raised shoreline fragments at 25 ft (7.6 m).

In contrast Ogilvie (1923) suggested that the only well-developed raised marine feature in the area is at 15 ft (4.6 m). He suggested that higher raised marine features are only poorly-developed and that much of the surface is composed of glacial and fluvio-glacial deposits. He also proposed that the well-developed terraces at Craigton (NH 661 479) are outwash terraces, and that the highest marine terrace in the area is represented by a small notch at 80 ft (24.3 m). In contrast, J.S. Smith (1966) suggested that the high terrace at Craigton (S162) is an outwash delta graded to a 90 ft (27.4 m) sea level. He associated the delta with a major readvance stage but later (1968, 1977) reinterpreted it as an ice recessional phase. Synge (1977a) and Synge and Smith (1980) suggested that the terrace fragment at Craigton could be correlated with the outwash deltas at Inverness.

The narrow strip of land between Coulmore and North Kessock is characterised by kame and kettle topography. Many of the fluvio-glacial features lie below the possible marine limit of the area (identified at 29 m at Englishton), yet high raised marine terraces are only poorly-developed (S165, S166, S176). In the east many of the higher terrace fragments have been extensively modified by the construction of the A9 road and housing developments. However, at Craigton a raised shoreline terrace (Fig. 46, S162) occurs at 33.4 m and this merges westwards into an outwash terrace. Farther west a kame merges into an outwash terrace (T141, NH 635 489) which is graded to a raised shoreline fragment (S164, NH 644 488) at 27.8 m. Whilst these raised marine features (S162, S164) were formed ice occupied the Beauly Firth (Fig. 53). Subsequently the main channel of the Beauly Firth became ice free but small masses of ice may have remained on the northern shore and protected the fluvio-glacial deposits from marine action. Alternatively, the fluvio-glacial deposits may have been modified by marine processes but due to a limited fetch environment and limited sediment supply marine features were unable to form.

At some later date the deposits between Craigton and Coulmore were eroded and a cliffline was produced. Seaward of this cliffline a steeply-sloping raised shingle beach occurs which rises to circa 8-10 m and locally broadens to form narrow shingle terraces (S169, S177) and shingle ridges (R38, R40) (See Table 16).

c) The Moniack Alluvial Fan

The Moniack Alluvial fan lies at the mouth of Moniack Burn south of the broad ridge of Kirkhill (Figs. 53, 65). The alluvial fan is developed to the north and south of a broad fluvio-glacial ridge (Fig. 65, A) which has been reported as "... wave washed..." (Ogilvie, 1923; J.S. Smith, 1968; Synge and Smith, 1980). Ogilvie suggested that the low ground south of the ridge (Fig. 65, A) is a drained lake, whilst Haggart (1982) suggested the area may be of marine origin. Ogilvie (1923) also suggested that the cliffline, which he correlated with a shoreline fragment at 25 ft (8.7 m) can only be traced as far

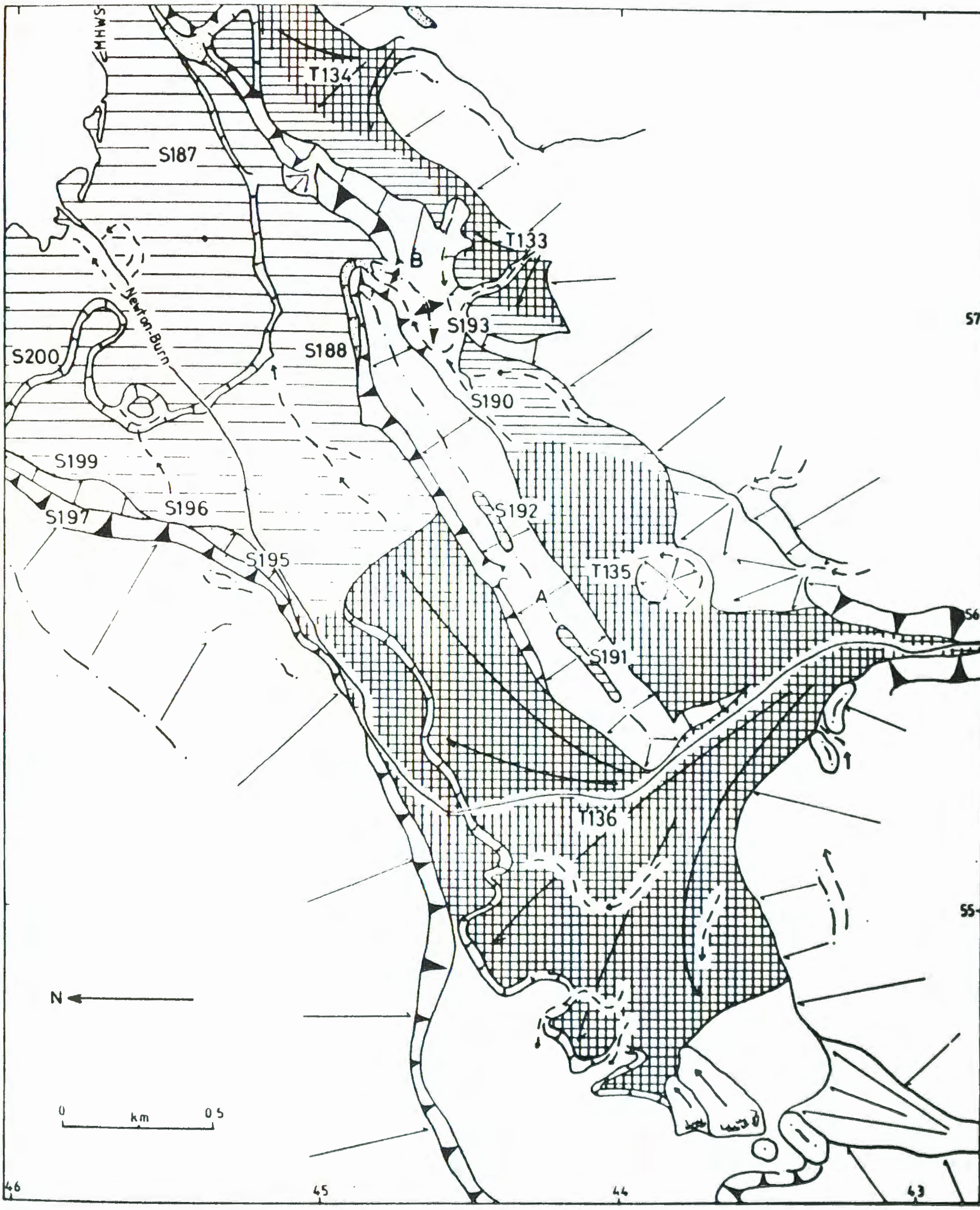


FIGURE 65 The Moniack area.

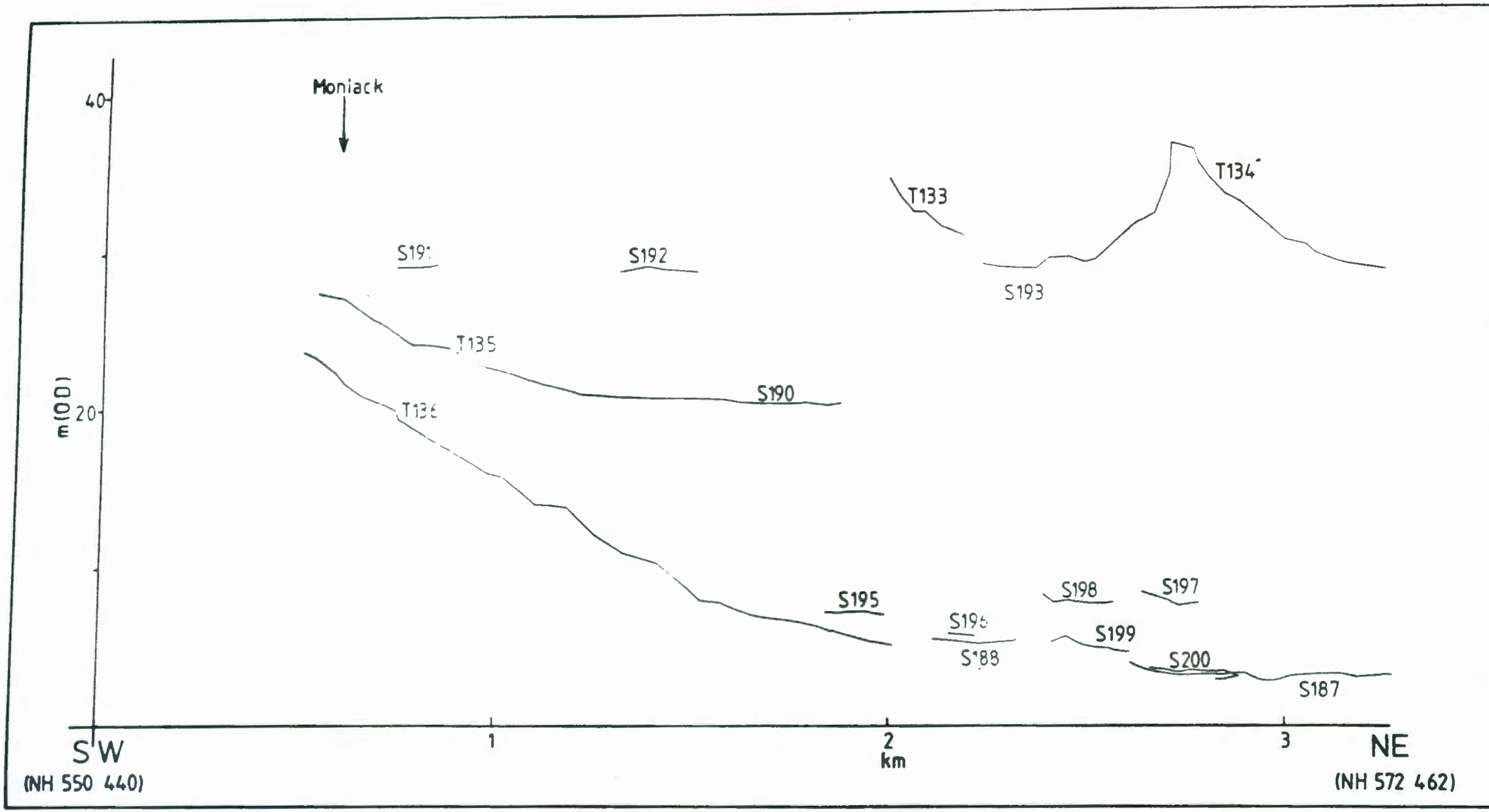


FIGURE 66 Altitude data for the Moniack area.

inland as the Moniack fan (Fig. 65).

Sissons (1981b) suggested that the cliffline is part of the Main Lateglacial Shoreline formed during the Loch Lomond Stadial when relative sea level stood at circa 2 m. The feature was later reoccupied by a higher Flandrian relative sea level. Haggart (1982) demonstrated that Flandrian marine deposits occur in a basin SW of the Moniack alluvial fan and he suggested that they were deposited when relative sea level stood at circa 10 m.

The broad ridge (Fig. 65, A) which divides the Moniack alluvial fan has a flat top at 29 m (S191, S192) and is considered to represent a kame modified by marine action. Further evidence in support of marine action to this altitude is provided by deltas T133 and T134 which occur to the east and which grade into a 29.0 m raised shoreline fragment (S193).

South of the kame ridge a river terrace fragment (T135) is graded to a raised shoreline fragment (S190) at 20.5 m. However, there is no evidence to suggest that the shoreline fragment represents a lake rather than a marine feature. After the formation of this terrace fragment (T135) the Moniack Burn passed northward into the valley of Newton Burn.

In the valley of Newton Burn a degraded cliffline extends to the limit of the Moniack alluvial fan (T136). West of this point marine erosion was arrested by the presence of the alluvial fan. Seaward of the degraded cliff steeply-sloping raised shingle beaches and estuarine deposits are present (eg. S194-S196, S200). Since Haggart (1982) has demonstrated that Flandrian marine deposits lie west of the Moniack alluvial fan it is suggested that the alluvial fan is partly Flandrian in origin. It is also concluded that the alluvial fan attained its present dimensions when the degraded cliffline was formed.

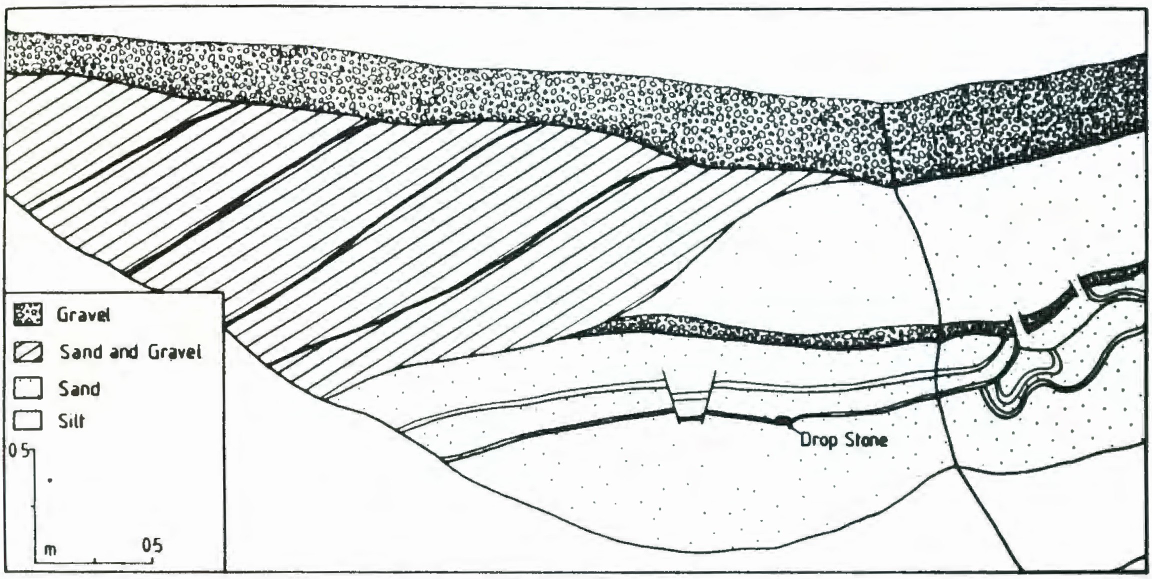


FIGURE 67 A section in the lower Highfield outwash delta (T41) (NH 516 528) which indicates topset and foreset bedding.

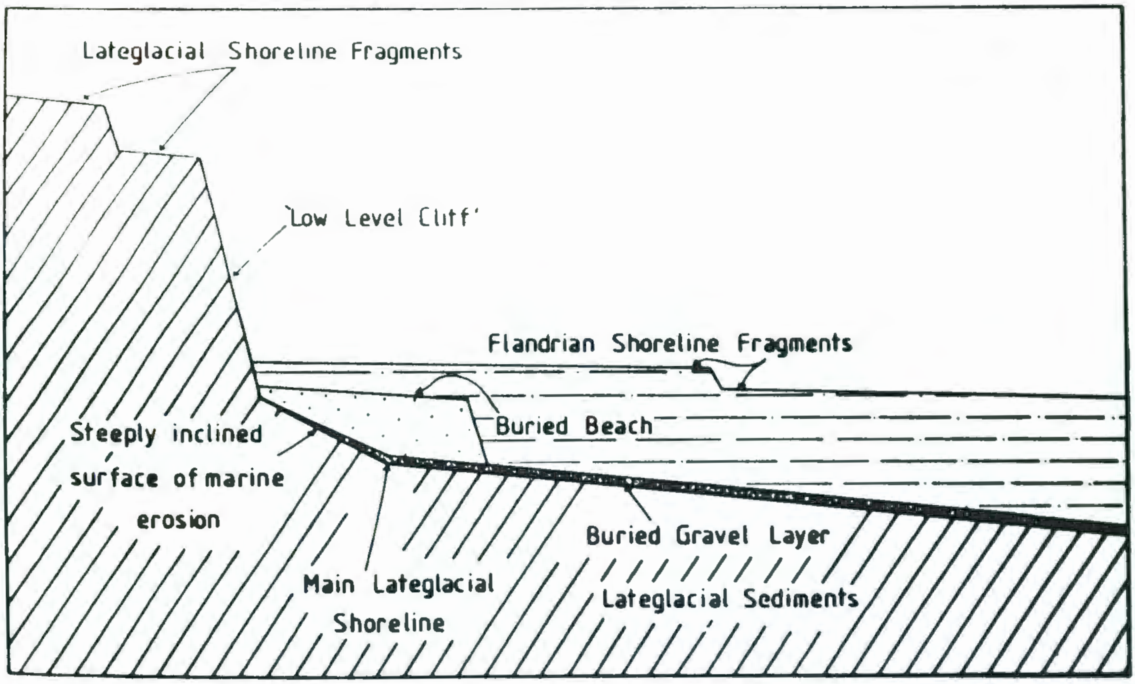


FIGURE 68 The stratigraphic position of the 'Low Level Cliff' and buried gravel layer in the Beauly area.

CHAPTER NINE

LATEGLACIAL MARINE EROSION

1. Introduction

In previous chapters a cliff at a low level (5-30 m) has been described in many parts of the study area. This cliff is well developed in fluvio-glacial and raised marine deposits (eg. at Ardersier) but locally is eroded in bedrock (eg. at the mouth of Munlochy Bay). The cliff is between 5-30 m high and is succeeded seaward by raised marine shoreline fragments which range in altitude from circa 5 m to circa 11 m. The cliffline is almost continuous throughout the study area and is only absent at 6 localities (inner Moniack valley, Munlochy valley, Bunchrew, Castle Stuart, Rosemarkie and the Conon valley)(Figs. 31, 53). It is considered likely that the cliff represents the same erosional event throughout the study area and for this reason the feature is termed the 'low-level cliff'.

Many researchers (Horne and Hinxman, 1914; Horne, 1923; Ogilvie, 1923; Steers, 1937; J.S. Smith, 1966; 1968; Synge and Smith, 1980) suggested that the 'low-level cliff' is the same age as the adjacent raised shoreline fragments. J.S. Smith (1966, 1968) and Synge and Smith (1980) suggested that the 'low-level cliff' was produced during the Flandrian as a result of a transgression which reached as high as circa 10-11 m in the study area. However, the proposed Flandrian origin is questioned since it does not explain why the 'low-level cliff' is equally well developed in exposed and sheltered fetch environments. It also does not explain the great altitude variation in the raised marine deposits which lie seaward of the 'low-level cliff'.

In contrast Sissons (1981b) suggested that the 'low-level cliff' was produced during the Loch Lomond Stadial. From detailed stratigraphical work in the Moniack area (Fig. 53) Sissons concluded that the 'low-level cliff' is related to a buried gravel layer. He indicated that the buried gravel layer is separated from the cliff by a more steeply sloping surface of marine erosion (Fig. 68). Sissons proposed that the buried gravel layer is a deposit formed by marine erosion, which overlies Lateglacial marine sediments and is overlain by Flandrian marine deposits. He correlated the buried gravel layer at Moniack with the Buried Gravel Layer near Grangemouth in the Firth of Forth (Sissons, 1969, 1976a) and concluded that they resulted from marine erosion during the Loch Lomond Stadial. On the basis of this correlation Sissons (1981b) suggested that the inner edge of the buried gravel layer (at Inverness) represents the Main Lateglacial Shoreline (Sissons, 1974b, 1976a). The erosional features (cliff, buried gravel layer, sloping surface) were considered to demonstrate "... a major period of marine erosion with a stable or slowly transgressing relative sea level followed by further erosion as sea level rose circa 7 m." (Sissons, 1981b p.4). This suggests that the 'low-level cliff' was produced at the culmination of the transgression which followed the formation of the Main Lateglacial Shoreline.

2. Distribution and Field Relation of the Buried Gravel Layer

Using techniques employed by Sissons (1981b) (see Chapter 4) the stratigraphical relationships of the 'low-level cliff' with the surrounding deposits were determined. Such investigations were restricted to areas of raised estuarine deposits (Beauly Firth, Munlochy Bay), since it was not possible to use a Hiller borer in areas covered by sand or shingle. These records were supplemented by commercial borehole records. The results indicate a general stratigraphy of dark grey clay-silt with sand layers and occasionally peat overlying a gravel layer (the buried gravel layer) which could

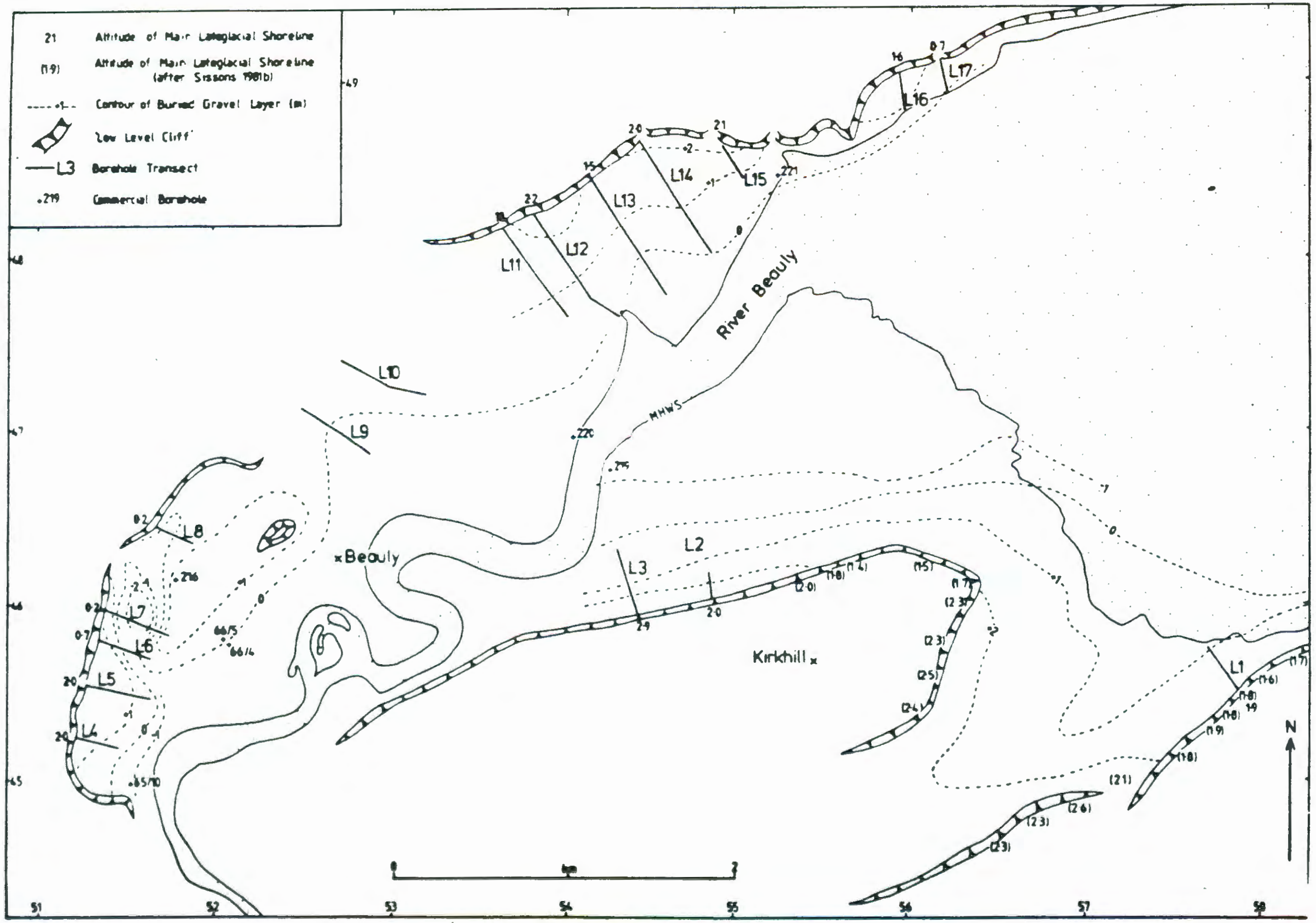


FIGURE 69 The location of the borehole transects at the head of the Beauly Firth, the altitude of the buried gravel layer and the inferred altitude of the Main Lateglacial shoreline (modified from Sissons, 1981b).

only be penetrated 1-5 cm. Occasionally the gravel layer was either absent or thin enough to be penetrated. In these areas a tough light grey-pink clay or silty sand is encountered. North of Beauly (NH 527 475) the estuarine silty clay is underlain by a tough light grey silty clay and silty sand. The surface of these deposits occurs at circa 5 m and they are impossible to penetrate by augering.

In total 24 transects of boreholes were undertaken, 17 in the Beauly area and 8 in the Munlochy area (Figs. 69-71). One transect in the Beauly area (Fig. 69, L1) followed a transect completed by Sissons (1981b) and verified his results to within ± 0.20 m. With the exception of 3 transects (L9, L10, L24) the dark grey silty clays are underlain by a gravel layer up to 1 km wide in places (Fig. 71). Contour maps (Figs. 69, 70) of the altitude of the surface of the buried gravel layer indicate that it rises gently landward in both the Beauly Firth and Munlochy Bay. In the Beauly Firth the inner edge of gravel layer occurs at circa 2 m whereas in Munlochy Bay it is at circa -1 to 0 m. From the inner margin there is a more steeply sloping gravel surface which rises towards the base of the 'low-level cliff'. At most sites it was impossible to trace the steeply sloping surface to the base of the 'low-level cliff' because of colluvium, raised shingle beaches or buildings. However along transects L11 and L13 the steeply sloping surface rises landward and terminates at 7.9 and 8.2 m respectively at the base of the 'low-level cliff'. Similar results were produced by Sissons (1981b) who also believed that the buried gravel layer locally overlies bedrock and till.

It is concluded that the raised estuarine deposits in the Beauly Firth and Munlochy Bay are underlain by an extensive shallow-sloping buried gravel layer. This layer rises gently landward and is separated from the 'low-level cliff' by a more steeply sloping

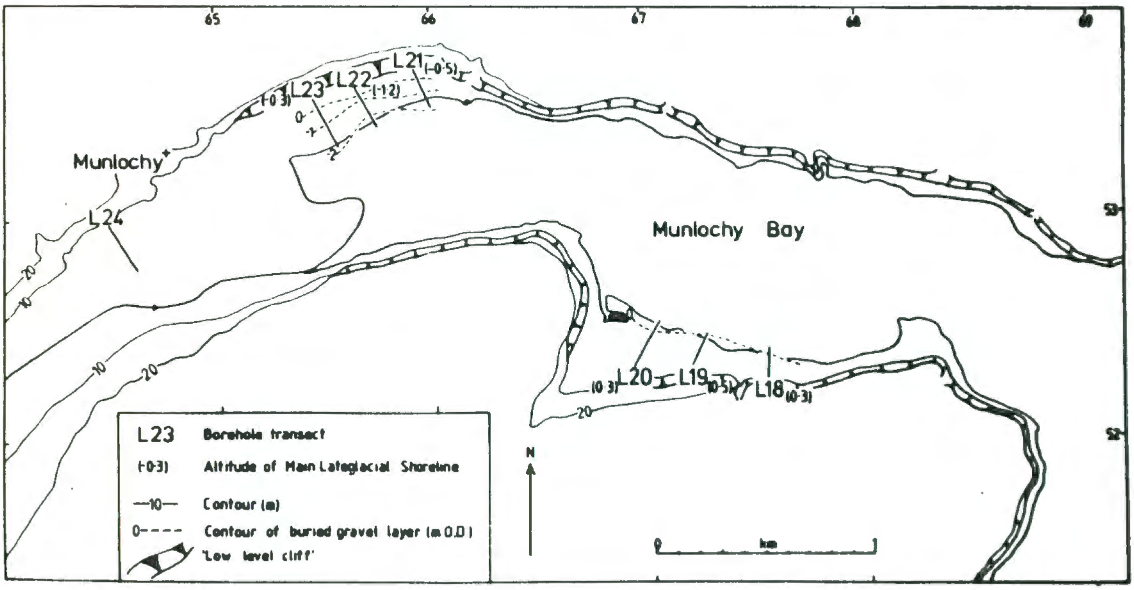


FIGURE 70 The location of the borehole transects in Munlochy Bay, the altitude of the buried gravel layer in this area and the inferred altitude of the Main Lateglacial Shoreline.

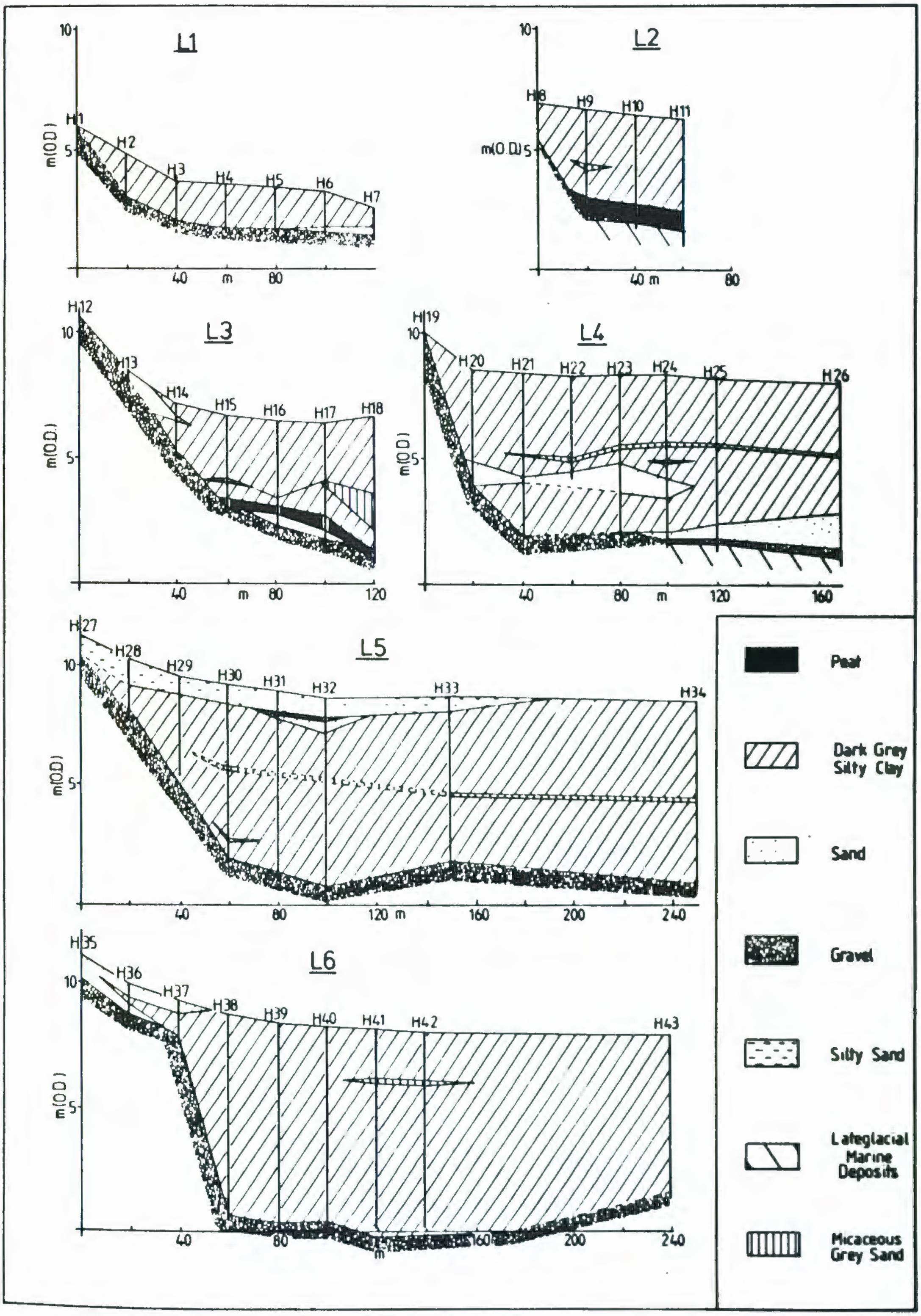


FIGURE 71 Sections drawn up along the transect lines to reveal the depth of the 'buried gravel layer'.

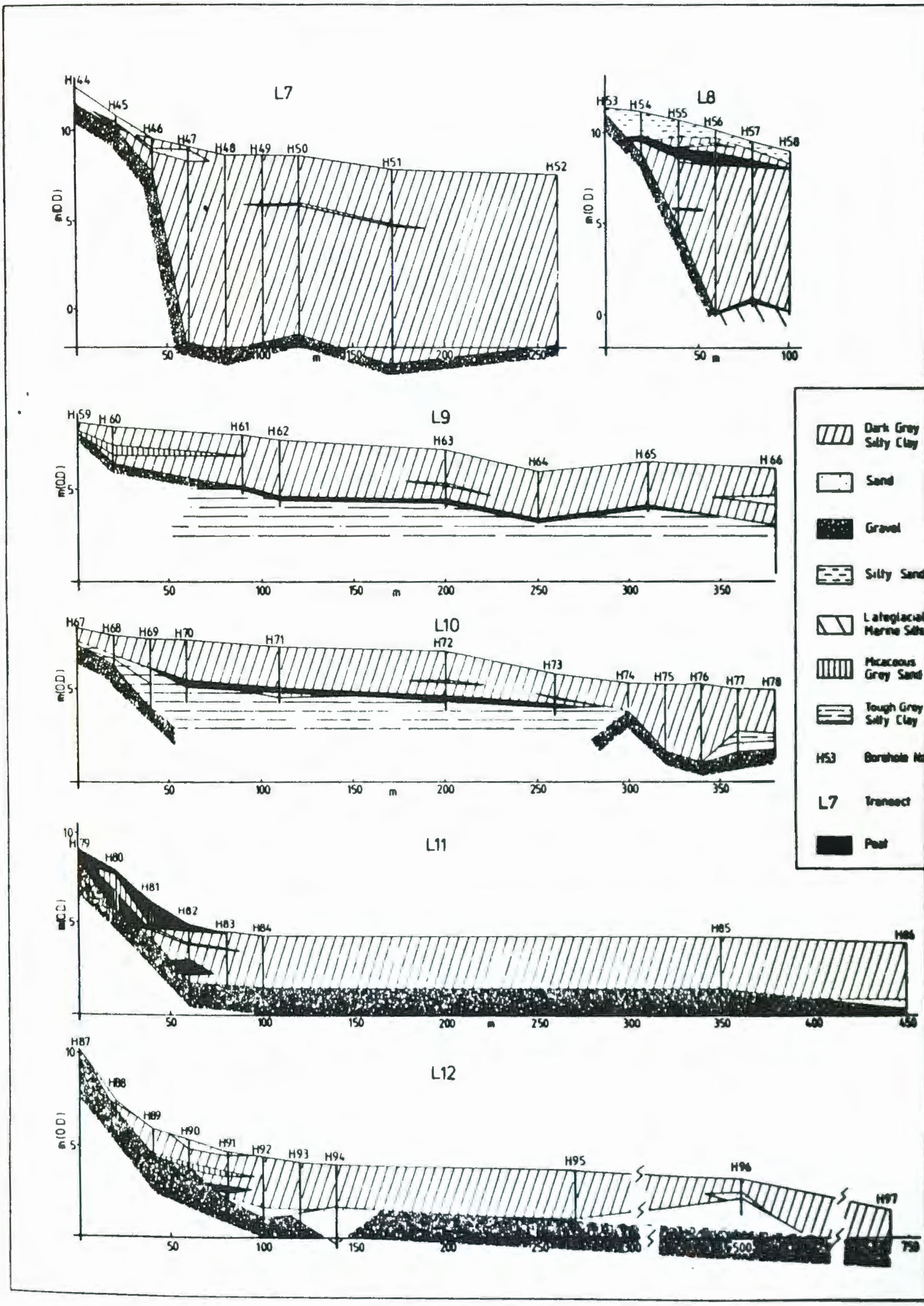


FIGURE 71 (cont.)

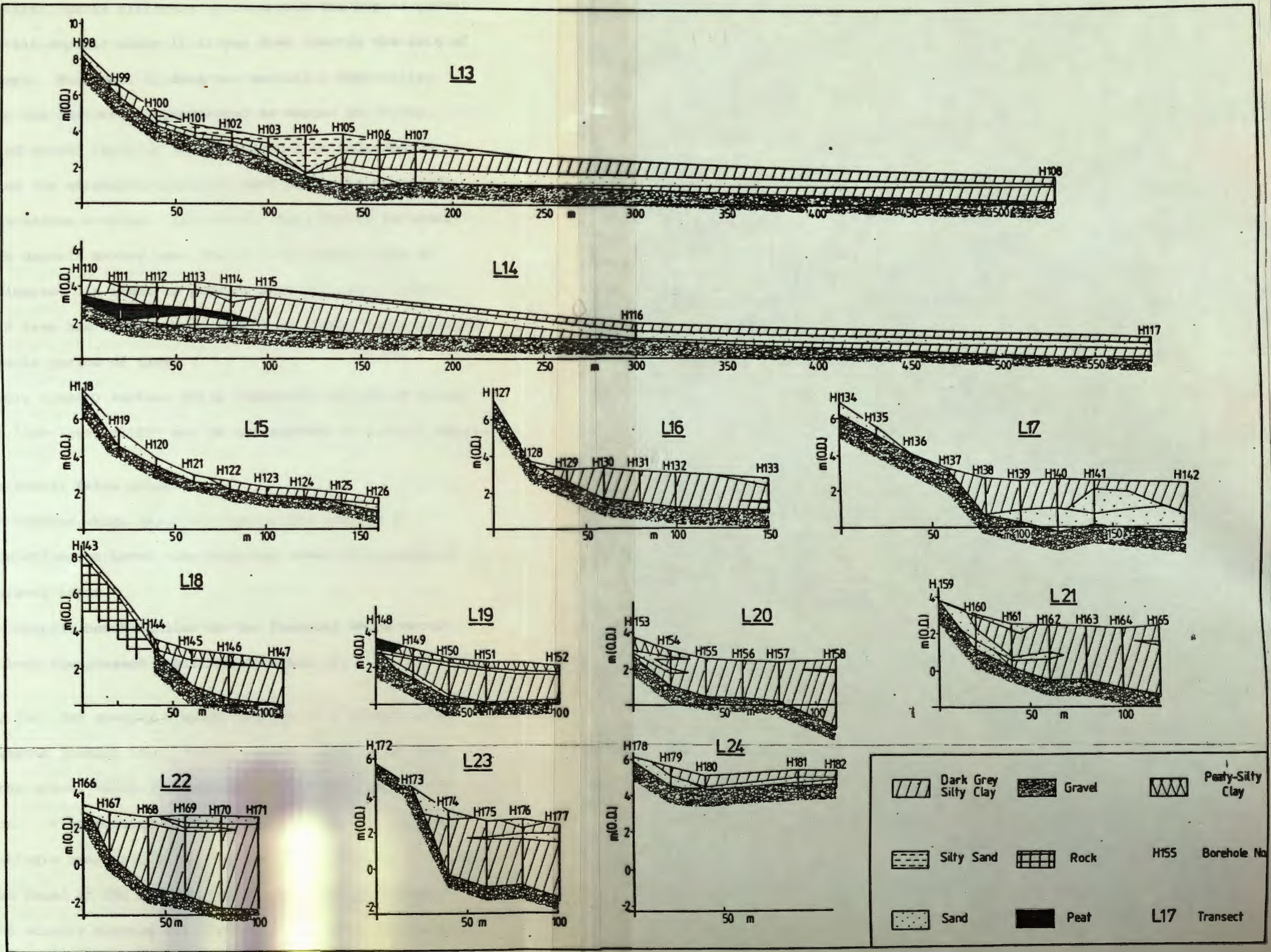


FIGURE 71 (cont.)

surface 6-7 m high. It is difficult to interpret the buried gravel layer as a fluvial deposit since it slopes down towards the axis of the river valleys. Moreover, it does not exhibit a down-valley gradient and so the feature is interpreted as marine in origin.

The buried gravel layer is locally up to 1 km wide and in view of this and its extensive nature it must represent a period of considerable marine erosion. The gravel layer itself is interpreted as a lag deposit having been derived from the erosion of underlying sediments. In order to produce such erosion relative sea level would have had to have been stable or slowly transgressing for a considerable period of time.

The steeply sloping surface which separates the buried gravel layer from the 'low-level cliff' may be interpreted in several ways:-

i) A fossil talus slope.

ii) A surface which resulted from marine erosion as relative sea level rose from the level of the buried gravel layer.

iii) A shingle beach similar to the features which occur along the present coastline (Chapter 2).

It is unlikely that the steeply sloping surface is a fossil talus slope since Sissons (1981b) identified a sloping bedrock surface (in place of the gravel which the surface is usually composed of) at one location. It is equally unlikely that the steeply sloping surface is a shingle beach since the feature is much larger than the shingle beaches found at the present coast. It therefore seems likely that the steeply sloping surface is an erosional feature and that the transgression that produced it reached as high as circa 7-8 m, this altitude is related to the base of the 'low-level cliff'. (cf. Sissons, 1981b).

Since the marine erosion in the Beauly Firth and Munlochy Bay was considerable such an event should have occurred throughout the study area, and it is proposed that the 'low-level cliff' is representative of this erosion event. However, the 'low-level cliff' lies adjacent to Flandrian marine deposits and it is possible that cliff retreat occurred during this time period. The extent of Flandrian cliff retreat is however considered to have been minor for several reasons:

i) In certain areas the 'low-level cliff' lies adjacent to Flandrian estuarine deposits and such areas are not characterised by marine erosion at the present coast.

ii) If the erosion during the Flandrian had been considerable a platform of marine erosion would occur, yet no such feature has been identified which can be related to Flandrian deposits.

iii) In areas where the cliff lies adjacent to raised Flandrian shingle beaches the shingle beaches vary in altitude from 4-11 m and grade laterally into each other. At no point does a lower shingle beach truncate a higher one, so erosion must have been minimal. Since the raised shingle beaches occupy the same position as the steeply sloping surface of marine erosion they are probably a drape of deposits on top of this surface (Fig. 68).

3. Age and Correlation of the Buried Erosional Features

Near Beauly the deposits which overlie the buried gravel layer have been studied in detail by Haggart (1982). He indicated by pollen analysis that the deposits are Flandrian in age and he also obtained ^{14}C dates from buried peats which overlie the buried gravel layer.

The oldest date is 9 610±130 B.P. (Birm-1123) and therefore provides a minimum age for the buried gravel layer. Moreover, since the peat was obtained from the surface of a proposed buried beach (Haggart, 1982) it may be inferred that the buried gravel layer is considerably older than _circa_ 9 600 years B.P.

The buried gravel layer overlies and truncates firm grey/pink silty-clays and silty sands. Commercial boreholes reveal that these deposits often contain cobbles and shells. At Inverness Peacock (1977) interpreted the latter deposits as marine in origin and Late-glacial in age. It is also important to note that the formation of the 'low-level cliff' was associated with erosion of existing Late-glacial marine sediments. In the Beauly area the 'low-level cliff' truncates all the Lateglacial marine features, including the Balblair delta, above the highest Flandrian deposits (_circa_ 10 m). On these grounds it may be argued that the buried gravel layer formed after Lateglacial sea level fell below circa 10 m and some time before 9 600 B.P.

Sissons (1981b) suggested that the buried gravel layer in the study area correlates with the Buried Gravel Layer in the Forth Valley (Sissons, 1969, 1976a; Sissons and Rhind, 1971). This correlation is accepted for a number of reasons, namely that in both areas the buried gravel layer

i) is extensive

ii) is of similar thickness

iii) is overlain by Flandrian deposits dated to at least 9 600 B.P.

iv) truncates Lateglacial marine sediments and locally till and bedrock.

v) represents a period of marine erosion between periods dominated by marine deposition.

vi) is developed in areas with restricted fetch.

vii) is separated from the cliff by a steeply sloping surface.

Sissons (1974b) also correlated the Buried Gravel Layer in the Forth valley with a broad rock platform at -18 m north of Berwick (Eden, Carter and McKeown, 1969). Eden, et al. reported that the rock platform is succeeded landward by a steeply sloping surface of marine erosion to -11 m, which terminates at the base of a submerged cliff. Morphological similarity of the rock platform, cliff, and steeply sloping surface of marine erosion with the erosion features in the study area makes this correlation acceptable. It has also been suggested that the Buried Gravel Layer in the Forth valley correlates with the Main Rock Platform in western Scotland (Sissons, 1974b; Gray, 1978; Dawson, 1980b, Sutherland, 1981b). However, it has also been suggested that the Main Rock Platform may have been formed at some earlier time and was retrimmed by the sea during the Loch Lomond Stadial (Peacock et al. 1978, Sutherland, 1981b) or during the Flandrian (Browne and McMillan, 1984).

Sissons (1974b) suggested that the break of slope at the landward margin of the Buried Gravel Layer represents a shoreline and he referred to this as the Main Lateglacial Shoreline. In view of the similarity, both of morphology and stratigraphy, of the buried gravel layer in the study area with that in the Forth valley the view proposed by Sissons 1981b that the break of slope at the landward margin of the buried gravel layer represents the Main Lateglacial Shoreline in the Inverness area, is adopted here. The altitude of the landward margin of the buried gravel layer for each of the transects is represented in Figs. 69 and 70. The altitude varies by up to 1 m in the Beauly Firth area and this may be related to factors such as exposure. However, the mean altitude of the Main Lateglacial Shoreline is 2 m at the head of the Beauly Firth and -0.2 m in Munlochy Bay. This difference in altitude between the two areas is thought to have resulted from glacio-isostatic tilting.

The period of formation of the Main Lateglacial Shoreline has been assigned to different periods by different authors (Sissons, 1974b; Synge, 1980; Paterson, Armstrong and Browne, 1981). Synge (1980) suggested that the Main Lateglacial Shoreline formed shortly after the Main Perth Raised Shoreline during a period of low relative sea level. He proposed that relative sea level fell circa 30 m in the Forth valley and then transgressed once more whilst remnants of the Late-Devensian ice sheet still remained in the area. A similar pattern of events have been described by Synge (1977a) in the Inverness area. He suggested that after the high-level delta was formed at Englishton (Fig. 53) relative sea level fell to near present level, this view being based on the occurrence of an alluvial fan at Bunchrew. Synge proposed that subsequently relative sea level rose once more to allow the formation of a high level delta at Balblair (Fig. 53). This sequence of events is considered unacceptable for several reasons:-

i) The implied relative change in sea level must have been rapid and little time would therefore have been available for the prolonged period of marine erosion necessary to form the Buried Gravel Layer.

ii) No reasonable explanation is given as to why marine erosion should have become so important.

iii) The cliff associated with the Main Lateglacial Shoreline at Beauly truncates the high-level delta at Balblair and therefore postdates this feature, rather than predating it as inferred by Synge (1980).

iv) The size of the alluvial fan at Bunchrew does not necessitate large volumes of meltwater and thus a nearby ice mass. Therefore the inferred drop in the sea level is unfounded.

Paterson et al. (1981) suggested that the Main Lateglacial Shoreline formed prior to the ice advance of the Loch Lomond Stadial. They suggested that base level during the Loch Lomond Stadial was low since channels which descend to -13 m were formed in the Earn-Tay area at this time. Tentative relative sea level curves for Ardyne (Peacock et al., 1978), does not however support the postulated low Loch Lomond Stadial relative sea level. The assignment of the channels to a Lateglacial age is based on the correlation of gravels which lie in the channels (Earn gravel) with gravels which are overlain by sands and silts (Carey Beds) formed prior to 9 640 years B.P. (Callow and Hassall, 1970). None of the gravel deposits have revealed a fauna to support their correlation and the fact that channels in which the Earn gravels are found appear to truncate the higher Carey Beds (Fig. 72) suggests that the channels may be of Flandrian age. Farther east, at Perth the deep channels are infilled by Flandrian sediments. Since it is possible that the deep channels are of Flandrian age rather than Loch Lomond Stadial age the Main Lateglacial Shoreline need not be of pre-Stadial age.

Sissons (1974b, 1976a) suggested that the Main Lateglacial Shoreline was formed during the Loch Lomond Stadial and maybe during the latter part of the Lateglacial Interstadial. Sissons (1974b) argued that semi-diurnal freeze-thaw cycles in the intertidal zone aided by wave action resulted in rapid cliff retreat. It is certainly accepted (eg. Davies, 1980) that cliff retreat can be rapid in peri-glacial areas of unconsolidated sediments, and this may account for

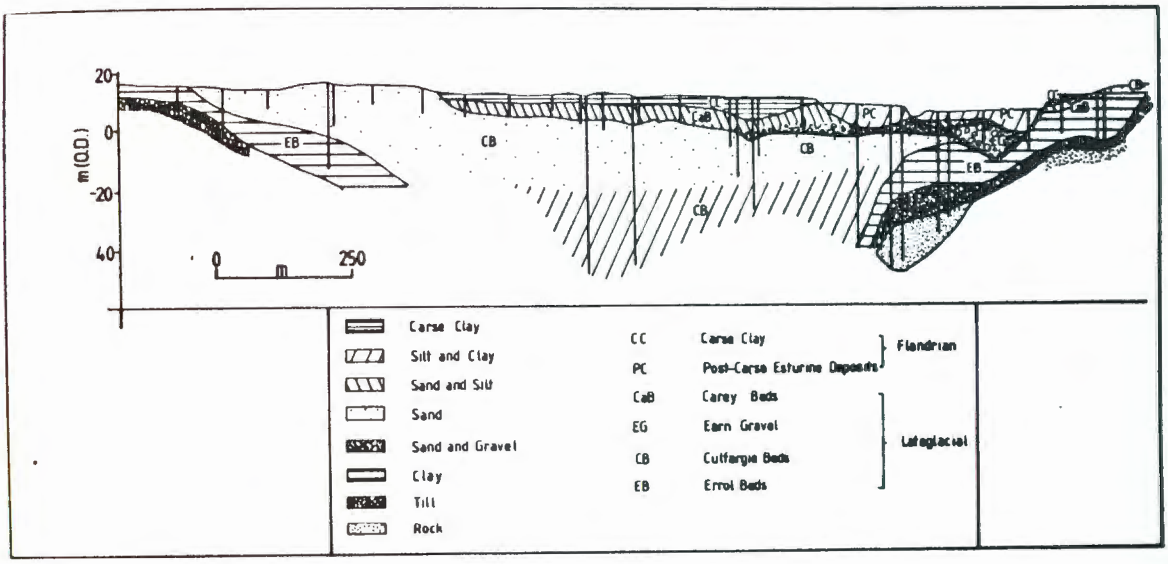


FIGURE 72 Section across Strathern at Bridge of Earn from Paterson et al. (1981).

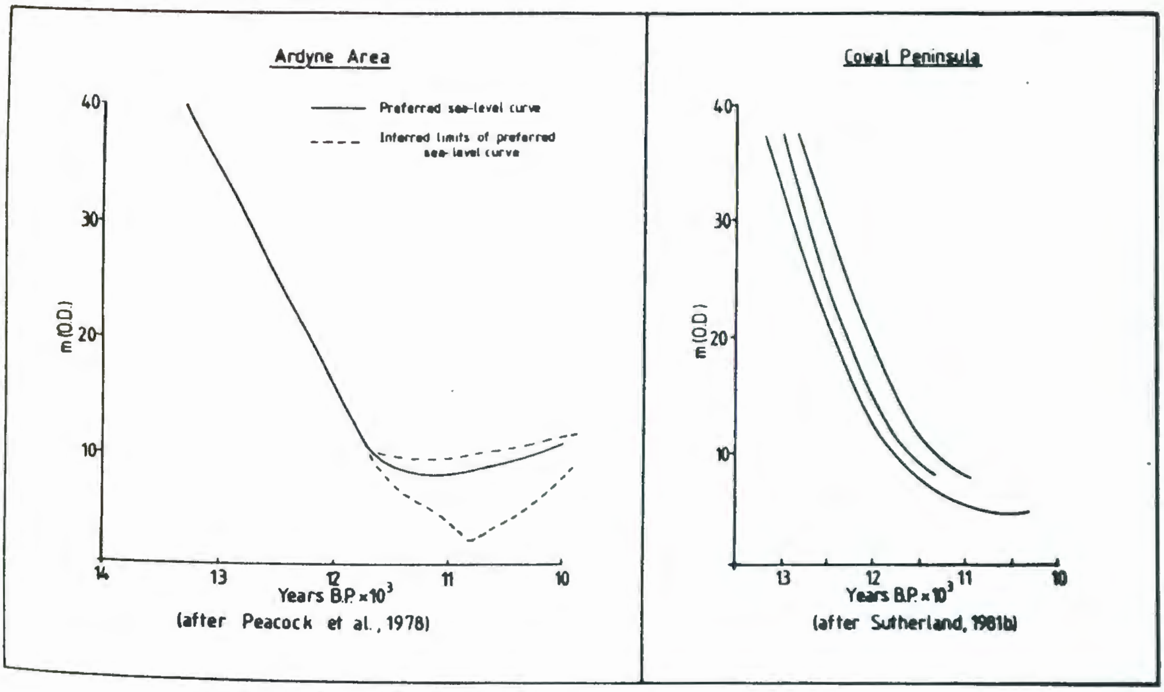


FIGURE 73 Tentative Lateglacial relative sea level curves for the Ardyne and Cowal Peninsula areas of SW Scotland.

much of the erosion which formed the Buried Gravel Layer. Rapid erosion of bedrock by periglacial coastal processes is however disputed. Many authors (eg. Zenkovitch, 1967; Davies, 1980) have argued that marine erosion is limited in periglacial areas due to the presence of sea ice. There is however a growing body of evidence (eg. Jahn, 1961; Tricart, 1969; Moign, 1974a, b; Williams and Robinson, 1981; Trenhaile, 1983; Trenhaile and Mercan, 1984) to suggest that periglacial marine erosion may be rapid in bedrock. It is suggested that the only period that occurred since circa 13 000 B.P. when periglacial conditions occurred is the Loch Lomond Stadial and possibly the end of the Lateglacial Interstadial (Sissons, 1974b, 1976a; Gray and Lowe, 1977). It is likely that the Buried Gravel Layer was produced during this period, a view supported by the relative sea level curves produced by Peacock et al. (1978) and Sutherland (1981b) for the SW Highlands. Both curves (Fig. 73) tentatively suggest a relatively stable sea level between 12 000 and 10 000 years B.P. Although it would be wrong to directly fit the SW Highlands relative sea level curves to other areas of Scotland it is possible to suggest that the form of these curves may have been similar to the changes in relative sea level in NE Scotland. On these grounds a relatively stable or slowly transgressing relative sea level may have occurred prior to and probably during the early Loch Lomond Stadial in NE Scotland.

Sissons (1969) suggested that the build up of ice during the Loch Lomond Stadial could have initiated a redepression of the earth's crust. This redepression may have resulted in a relative marine transgression which aided the formation of the Buried Gravel Layer. Shoreline evidence presented by Sutherland (1981b) may also be interpreted as representative of a redepression of the earth's crust. Certainly after the formation of the Main Lateglacial Shoreline there was a relative marine transgression which produced the steeply sloping surface of marine erosion in the Inverness area and near Berwick-on-Tweed. This transgression rose between *circa* 6-7 m in the Inverness area, whilst in the Forth valley the culmination of this transgression is correlated with the maximum limit of the Loch Lomond Stadial glaciers at the Mentieth Moraine (Sissons, 1966, 1976b, 1983b) and dated at *circa* 10 300 years B.P. On these grounds Sissons (1974b) suggested that the Buried Gravel Layer was produced between 11 000 and 10 500 B.P. and it is proposed here that the 'low level cliff' and the steeply sloping surface of marine erosion may have formed between 10 500 and 10 300 B.P. However, the inferred transgression at the end of the Loch Lomond Stadial is not represented on the sea level curves for SW Scotland (Peacock *et al*., 1978; Sutherland, 1981b). Similarily, the Main Rock Platform is not succeeded landward by a steeply sloping surface of marine erosion. In fact evidence from Loch Etive (Gray 1974a, 1975b) suggests that relative sea level was at the same level or just below the Main Lateglacial Shoreline at the end of the Loch Lomond Stadial. Sissons (1974b) suggested that the reason for this anomaly could be related to retarded glacial rebound or renewed down-warping of the earth's crust caused by the Loch Lomond Stadial glaciers.

4. Conclusions

Within the Inverness area there is a well developed 'low-level cliff' which is associated with a buried gravel layer. The buried gravel layer consists of material derived from the erosion of Lateglacial marine sediments, till and bedrock. The erosion is likely to have occurred as the result of climatic deterioration after *circa* 12 000 B.P. while relative sea level remained stable or possibly slowly transgressed. The landward margin of the buried gravel layer is correlated with the Main Lateglacial Shoreline in the Forth valley.

During the Loch Lomond Stadial relative sea level began to rise, possibly as a result of ice loading. The rise in sea level formed a steeply inclined surface of marine erosion which attains a maximum altitude of circa 7-8 m at the base of the 'low-level cliff'. The transgression probably culminated at circa 10 300 years B.P., and is correlated with the maximum extent of the Loch Lomond Stadial glaciers in the Forth Valley. Subsequently extensive Flandrian raised marine sediments were deposited against the 'low-level cliff'. Some marine erosion at the 'low-level cliff' may have occurred during the Flandrian, but this is thought to have been minor.

CHAPTER TEN

SHORELINES FORMED PRIOR TO THE MAIN LATEGLACIAL SHORELINE

1. Introduction

In the study area 186 Lateglacial raised shoreline fragments occur that predate the Main Lateglacial Shoreline. In previous chapters it has been shown that many of these shoreline fragments are associated with ice-sheet decay. It has also been proposed that at certain localities glacier retreat is associated with changes in relative sea level.

The Lateglacial shoreline fragments in the study area have been correlated by using schemes of horizontal shorelines (Horne and Hinxman, 1914; Horne, 1923; Ogilvie, 1923) and tilted shorelines (Synge, 1977a; Synge and Smith, 1980). The concept of regionally horizontal raised shorelines developed in the British Isles following the publication of the Geological Survey of Scotland Sheet 31 in 1875. Glacio-isostatic theory implies that unless ice loading is equal everywhere horizontal shorelines are not formed (Wright, 1936) and as a result the concept of horizontal shorelines has been severely criticized. In contrast considerable evidence has been presented from Scandinavia, North America and Scotland (eg. Smith and Dawson, 1983) which suggests that raised shorelines in areas affected by glacio-isostatic uplift are glacio-isostatically tilted. In the study area detailed altitude determinations indicate that Lateglacial raised shoreline fragments occur at a wide variety of altitudes and not in discrete horizontal bands (eg. '100 ft', '50 ft'). If the raised marine terraces are correlated on the basis of horizontal shorelines then fragments associated with a specific ice limit can be correlated with shoreline fragments which lie within the ice limit. Such correlations would only be tenable if relative sea level maintained a constant altitude during ice sheet retreat, a circumstance which did not occur in the study a

On these grounds the concept of horizontal shorelines is rejected.

2. Correlation of Shoreline Fragments

All the Lateglacial raised shoreline fragment altitudes were plotted on a series of height distance diagrams aligned in projection planes at 15° intervals between W-E and SE-NW. On visual inspection tilted shorelines could only be identified in the projection planes between S-N and S60°W-N50°E. For each plane of projection individual shorelines were constructed on the basis that the large deltas at the head of the Beauly Firth (Balblair delta, Muir of Ord delta, Orrin valley delta) were formed synchronously. The raised shoreline fragments associated with these deltas were used to produce a tilted line/zone which was then projected eastwards/northwards (Appendix III. Other tilted shorelines were then produced on the basis of morphological constraints (Table 6). A list of shoreline fragments associated with each shoreline for each projection plane was then compiled and compared, and this revealed two contrasting models of correlation. In the first model (applicable to projection planes between N30°E and N60°E) the shoreline fragments associated with the large deltas at the head of the Beauly Firth are correlated with the poorly-developed raised marine terraces at 24 m at Inverness. In the second model (applicable to projection planes between North and N15°E the deltas at the head of the Beauly Firth are correlated with the well developed delta at Inverness (T which is graded to raised marine terraces at 27 m. It is therefore possi that all the large deltas in the study area were produced during the same period. However this model is inconsistant since it correlates the delta at Englishton with the delta at Balblair and these deltas can not be related to the same ice margin. The problem of which model is superior was resolved by identifying the shoreline fragments that occur in the same shoreline under both models. In this way 3 shorelines were identified in which ten or more fragments are clearly

Shoreline		No. of Points	Projection Plane (degrees from North)										
			90	75	60	45	40	35	30	25	20	15	0
LG_2	Grad	12	0.0842	0.1798	0.2821	0.3659	0.3840	0.3956	0.4005	0.3989	0.3915	0.3793	0.3236
	r		0.2267	0.4549	0.6747	0.8482	0.8883	0.9175	0.9354	0.9422	0.9383	0.9248	0.8381
LG_4	Grad	12	0.1537	0.1938	0.2434	0.3089	0.3473	0.3622	0.3903	0.4176	0.4416	0.4587	0.4318
	r		0.5213	0.6467	0.7644	0.8751	0.9089	0.9396	0.9657	0.9848	0.9941	0.9900	0.8663
LG_7	Grad	16	0.1201	0.1262	0.1393	0.1629	0.1740	0.1871	0.2026	0.2205	0.2406	0.2619	0.2854
	r		0.7764	0.8221	0.8614	0.8964	0.9067	0.9158	0.9229	0.9267	0.9250	0.9139	0.7474

Shoreline	Fragments used in calculation of above figures	Grad=gradient m/km r=correlation coeff.
LG_7	S40, S53, S60, S79, S86, S105, S107, S114, S116, S165, S183, S260, S280, S281.	
LG_4	S61, S110, S191, S192, S220, S221, S253, S269, S275.	
LG_2	S49, S80, S91, S100, S101, S103, S108, S123-S125, S163.	

TABLE 18 **Preliminary regression analysis of the three best developed shorelines to determine the general trend of the shoreline isobases.**

present. For each shoreline a gradient and correlation coefficient was calculated for projection planes at 5^{o} intervals between W-E and S-N (Table 18), and trend surface analysis was also undertaken. The results indicate that for two of the shorelines the correlation coefficient is greatest along the plane S25^{o}W-N25^{o}E. For the third shoreline the correlation coefficient is greatest along the plane S20^{o}W-N20^{o}E.

Height distance diagrams were then produced for projection planes aligned S25^{o}W-N25^{o}E and S20^{o}W-N20^{o}E. Inspection revealed that in both cases the shoreline fragments associated with the deltas at the head of the Beauly Firth correlate with the shoreline fragments at 24 m at Inverness. It was also noted that the projection plane S25^{o}W-N25^{o}E produces a more coherent shoreline sequence for the Beauly Firth area and for this reason it is taken as being normal to the isobases of the Lateglacial shorelines.

On the basis of morphological constraints and marked alignments of points, tilted shorelines were derived for the projection plane S25^{o}W-N25^{o}E (Fig. 74). Inspection of the height distance diagram indicates 3 bands of shoreline fragments. In the upper and lower bands shoreline fragments were correlated to form discrete shorelines. In the central band the shorelines fragments can be correlated in two ways (Scheme A and Scheme B) (Fig. 75) to form 7 shorelines (ILG_3-ILG_9). The difference between the two schemes is minor and essentially depends upon how the raised marine features east of Nairn correlate with those west of Nairn. The problem of which scheme is more appropriate was resolved by obtaining the correlation coefficient and regional gradient of each shoreline along projection planes at 5^{o} intervals from S-N to S45^{o}W-N45^{o}E for:-

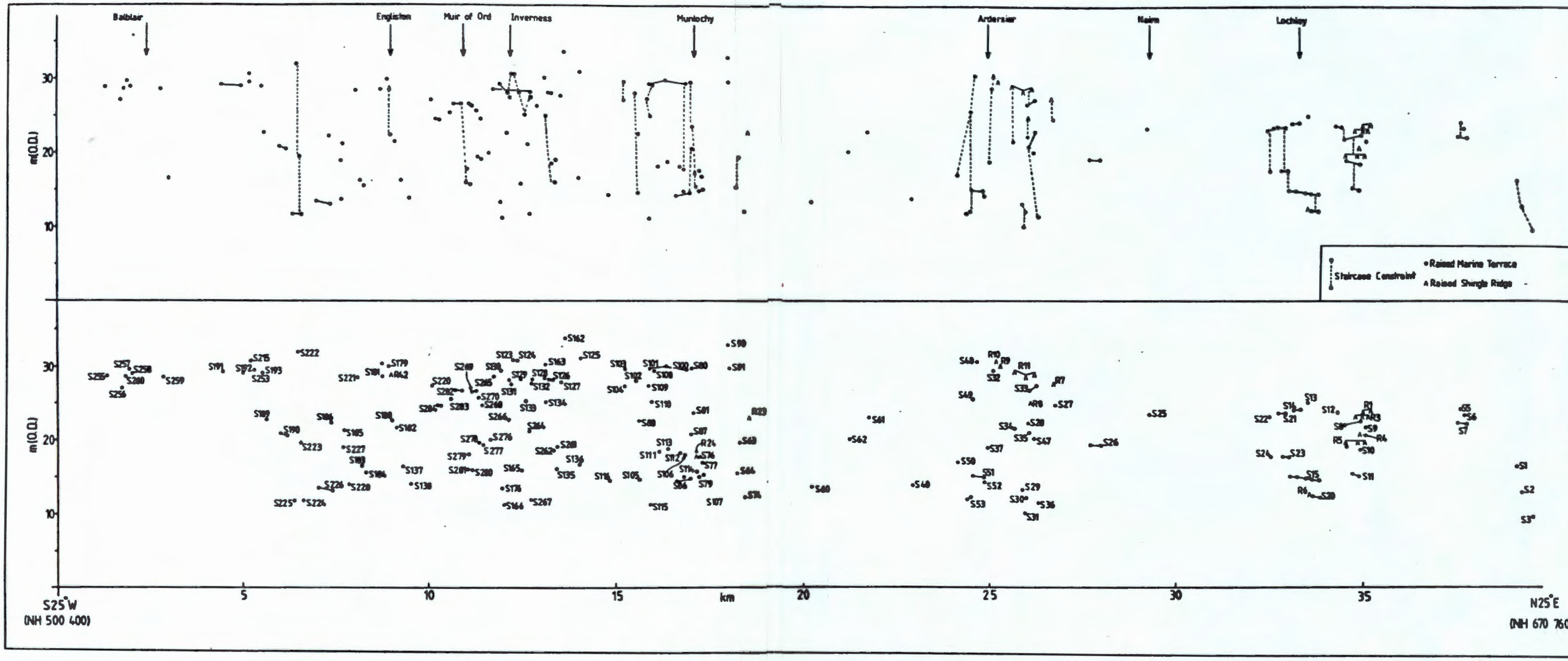


FIGURE 74 Height-distance diagram for all the Lateglacial shoreline fragments aligned along the projection plane S25° W-N25° E. for the inner Moray Firth area. The bottom diagram indicates the location of each of the shoreline fragments, whilst the upper diagram introduces the staircase constraint to the data set.

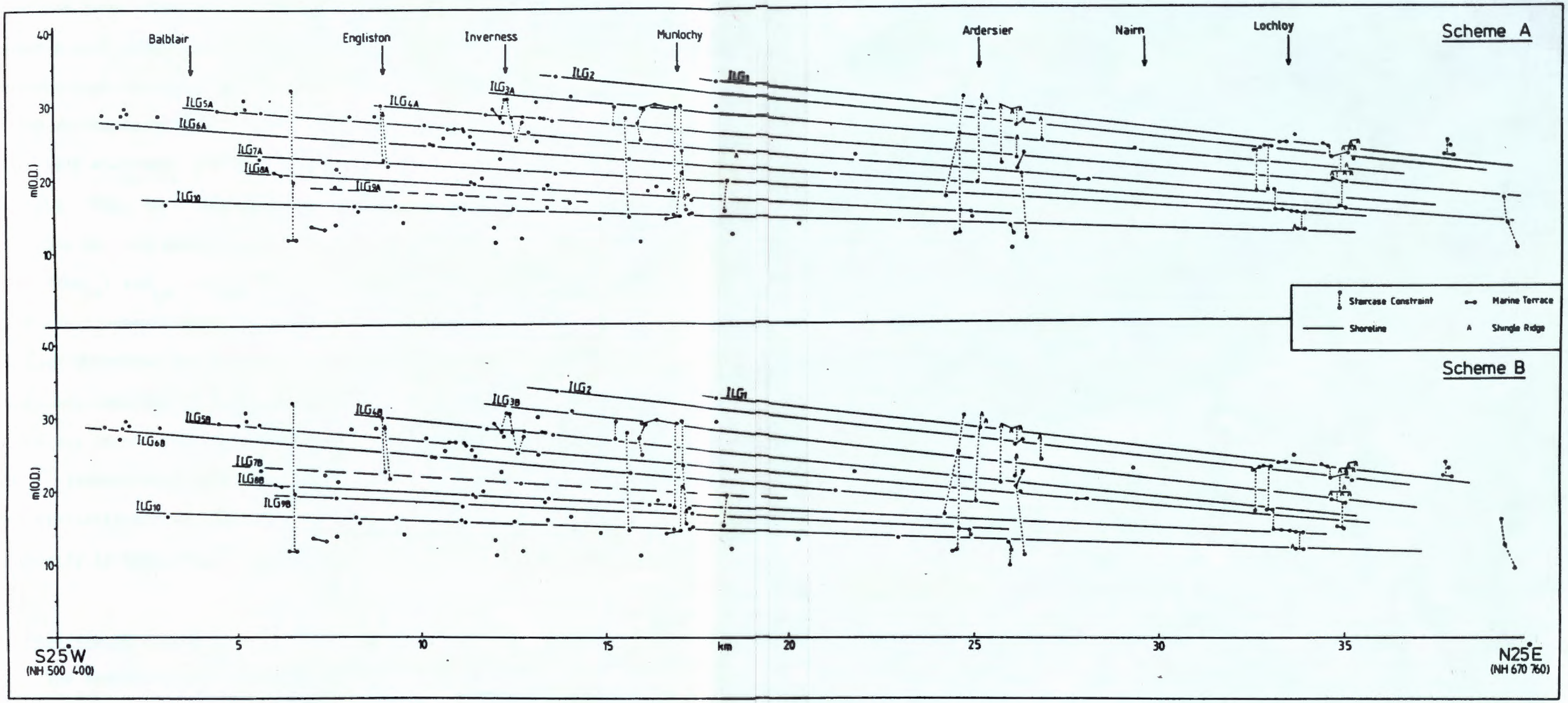


FIGURE 75 Height-distance diagram aligned along the plane of projection S25° W-N25° E to show the two possible schemes of correlation of the Lateglacial shoreline fragments in the inner Moray Firth area.

i) Scheme A

ii) Scheme B

iii) the data common to Scheme A and Scheme B (Test).

The resulting data (Table 19) was analysed with specific attention being directed at how the gradient for each shoreline under Scheme A or B compared with that from the common data set. It was expected that the added data set would not greatly alter the gradient of the shoreline and it is concluded that Scheme A is applicable for shorelines ILG_3-ILG_5 and that Scheme B is applicable for shorelines ILG_6-ILG_9 (Fig. 76). A list of shoreline fragments and associated gradients for the shorelines is presented in Table 20. The shorelines (ILG_{4A}, ILG_{5A}, ILG_{8B}, ILG_{10}) with the greatest number of shoreline fragments were analysed by Trend Surface Analysis (Table 21). For each shoreline the linear trend surface is statistically significant, but surfaces of higher order produce no significant improvement in the fit of the data, except for the quadratic surface for shoreline ILG_{5A}. Isobase maps were only produced for the trend surfaces which were statistically significant (Fig. 77) and on inspection a marked similarity in these maps is evident.

3. <u>Analysis of Residuals</u>

The residuals produced from the Trend Surface Analysis (Fig. 78) and linear regression (Fig. 79) were analysed for the best developed shorelines (ILG_{4A}, ILG_{5A}, ILG_{8B}, ILG_{10}). In both cases the residuals could not be related to external factors nor did the residuals indicate excessive curvature of the isobases; indeed in most cases the residuals produced lay within the error limits introduced into the study by altitude determination.

Shoreline		No. of Points	90	75	60	45	35	30	25	20	15	10	0
			Projection Plane (degrees from North)										
ILG_1	Grad	5	0.3360	0.3300	0.3474	0.3951		0.4973	0.5539		0.7380		1.6391
	r		0.9991	0.9990	0.9989	0.9987		0.9983	0.9981		0.9973		0.9914
ILG_2	Grad	8	0.3218	0.3201	0.3415	0.3944		0.5071	0.5704	0.6571	0.7812	0.9701	1.8827
	r		0.9782	0.9789	0.9793	0.9800		0.9793	0.9789	0.9781	0.9766	0.9732	0.9378
ILG_{3A}	Grad	11	0.2620	0.2716	0.2961	0.3419		0.4208	0.4570	0.4985	0.5439		0.6227
	r		0.8481	0.8924	0.9297	0.9622		0.9863	0.9896	0.9880	0.9779		0.8218
ILG_{3B}	Grad	11	0.3458	0.3437	0.3632	0.4106		0.5030	0.5497	0.6078	0.6799		0.9539
	r		0.9386	0.9572	0.9722	0.9847		0.9929	0.9934	0.9912	0.9844		0.8697
ILG_{3T}	Grad	9	0.2379	0.2634	0.3003	0.3555	0.4052	0.4353	0.4668	0.4987	0.5277	0.5485	0.5332
	r		0.7178	0.7993	0.8700	0.9321	0.9660	0.9787	0.9864	0.9869	0.9764	0.9504	0.8294
ILG_{4A}	Grad	18	0.2804	0.2822	0.2990	0.3352		0.3999	0.4302	0.4654	0.5053		0.6102
	r		0.8902	0.9258	0.9534	0.9751		0.9878	0.9879	0.9840	0.9738		0.8506
ILG_{4B}	Grad	19	0.3305	0.3304	0.3481	0.3885	0.4328	0.4618	0.4963	0.5367	0.5828		0.7078
	r		0.9102	0.9416	0.9654	0.9832	0.9906	0.9919	0.9907	0.9853	0.9736		0.8465
ILG_{4T}	Grad	16	0.2648	0.2851	0.3164	0.3644	0.4079	0.4324	0.4588	0.4843	0.5059	0.5199	0.4929
	r		0.7889	0.8586	0.9151	0.9594	0.9786	0.9828	0.9815	0.9722	0.9514	0.9154	0.7763
ILG_{5A}	Grad	21	0.2448	0.2482	0.2675	0.3089	0.3557	0.3877	0.4273	0.4760	0.5349	0.6020	0.6872
	r		0.9261	0.9481	0.9667	0.9827	0.9910	0.9936	0.9939	0.9903	0.9792	0.9539	0.7938
ILG_{5B}	Grad	19	0.2665	0.2709	0.2925	0.3382	0.3896	0.4245	0.4676	0.5202	0.5832	0.6535	0.7315
	r		0.9245	0.9479	0.9676	0.9846	0.9934	0.9960	0.9962	0.9922	0.9802	0.9532	0.7868
ILG_{5T}	Grad	17	0.2326	0.2457	0.2740	0.3255	0.3793	0.4141	0.4544	0.4994	0.5450	0.5806	0.5286
	r		0.8585	0.9001	0.9368	0.9696	0.9871	0.9924	0.9931	0.9857	0.9642	0.9186	0.6961
ILG_{6A}	Grad	8	0.1892	0.1916	0.2080	0.2449	0.2898	0.3228	0.3668	0.4271	0.5128	0.6392	0.1010
	r		0.9791	0.9836	0.9876	0.9913	0.9932	0.9938	0.9936	0.9919	0.9867	0.9722	0.7837
ILG_{6B}	Grad	5	0.1689	0.1768	0.1989	0.2447	0.3007	0.3425	0.3992	0.4774	0.5853	0.7164	0.3409
	r		0.9549	0.9659	0.9766	0.9879	0.9953	0.9982	0.9992	0.9951	0.9771	0.9179	0.2875
ILG_{7A}	Grad	11	0.1994	0.1952	0.2038	0.2282	0.2577	0.2783	0.3046	0.3381	0.3815	0.4384	0.6052
	r		0.9502	0.9627	0.9731	0.9822	0.9876	0.9899	0.9916	0.9922	0.9909	0.9854	0.9371
ILG_{7B}	Grad	6	0.1075	0.1206	0.1405	0.1712	0.1999	0.2168	0.2350	0.2530	0.2684	0.2772	0.2530
	r		0.6826	0.7582	0.8273	0.8916	0.9288	0.9431	0.9519	0.9519	0.9383	0.9046	0.7516
ILG_{7T}	Grad	5	0.0842	0.0977	0.1184	0.1516	0.1835	0.2025	0.2223	0.2408	0.2535	0.2543	0.2020
	r		0.6258	0.7014	0.7757	0.8509	0.8977	0.9164	0.9279	0.9269	0.9058	0.8559	0.6520
ILG_{8A}	Grad	13	0.1577	0.1709	0.1937	0.2310	0.2670	0.2886	0.3121	0.3359	0.3565	0.3676	0.3256
	r		0.7951	0.8549	0.9075	0.9536	0.9770	0.9838	0.9846	0.9757	0.9518	0.9053	0.7120
ILG_{8B}	Grad	17	0.1180	0.1190	0.1280	0.1482	0.1719	0.1886	0.2099	0.2373	0.2724	0.3177	0.4077
	r		0.9420	0.9565	0.9689	0.9803	0.9869	0.9893	0.9905	0.9892	0.9827	0.9652	0.8205
ILG_{8T}	Grad	11	0.0889	0.1079	0.1371	0.1834		0.2487	0.2688		0.2791	0.2578	0.1689
	r		0.6224	0.7109	0.8020	0.8963		0.9682	0.9709		0.9000	0.8133	0.5570
ILG_{9A}	Grad	4	0.0737	0.0813	0.0973	0.1298	0,1712	0.2028	0.2441	0.2900	0.3046	0.2024	0.0923
	r		0.8332	0.8514	0.8710	0.8932	0.9071	0.9094	0.9000	0.8573	0.7261	0.4302	0.2601
ILG_{9B}	Grad	6	0.1150	0.1228	0.1377	0.1632	0.1884	0.2039	0.2210	0.2384	0.2536	0.2613	0.2220
	r		0.8343	0.8817	0.9225	0.9566	0.9718	0.9742	0.9704	0.9563	0.9260	0.8708	0.6459
ILG_{10}	Grad	22	0.0885	0.0902	0.0972	0.1115	0.1271	0.1375	0.1501	0.1651	0.1824	0.2013	0.2255
	r		0.8365	0.8675	0.8934	0.9160	0.9283	0.9328	0.9350	0.9335	0.9254	0.9054	0.7864

TABLE 19 Results of the regression analysis for the different schemes of shorelines derived from the projection plane S25°W-N25°E. ILG_{3A}=Scheme A, ILG_{3B}= Scheme B, ILG_{3T}=data set common to Scheme A and B, Grad= gradient (m/km), r= correlation coeff.

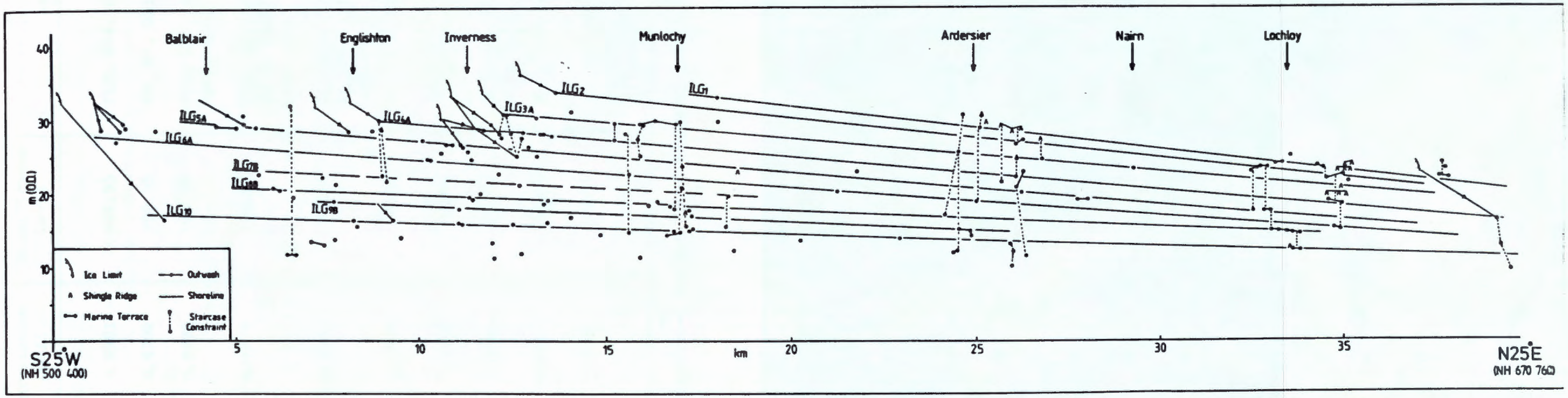


FIGURE 76 Height-distance diagram aligned along the plane of projection S25°W-N25°E to indicate the preferred scheme of correlation of Lateglacial shorelien fragments in the inner Moray Firth area. Where possible associated outwash surfaces are shown diagramatically.

Shoreline	Gradient m/km	Correlation Coeff.	Significance Level	Shoreline Fragments used in analysis	Other Frags.
ILG_1	0.554	0.9981	>99.95	S12, S14, S32	S105, R9, R10
ILG_2	0.570	0.9789	>99.95	S8, S9, S21, S22, S33	R1-R3, R7,R11
ILG_{3A}	0.457	0.9896	>99.95	S25, S27, S49, S80, S100,S101, S103 S125, S163	S123, S124, R4, R8
ILG_{4A}	0.430	0.9879	>99.95	S10, S28, S34, S35, S104, S109, S126, S127, S129-S132, S164, S179, S263, S265	S102,S181 R5
ILG_{5A}	0.427	0.9939	>99.95	S23,S24,S26,S47,S61,S81,S110,S133 S134,S191,S192,S220,S221,S252,S253 S269,S282	R46
ILG_{6A}	0.367	0.9936	>99.95	S11, S37, S62, S88, S266, S284	S255-S260
ILG_{7B}	0.235	0.9519	>99.95	S63, S87, S180, S182, S189, S264	S185, S186
ILG_{8B}	0.210	0.9905	>99.95	S15,S50,S76,S106,S111,S112,S190,S261 S262, S276-S278	
ILG_{9B}	0.221	0.970	>99.95	S51, S77, S136, S227, S279	S223, R24
ILG_{10}	0.150	0.935	>99.95	S20,S29,S40,S52,S64,S78,S79,S86,S105 S107,S114,S116,S135,S183,S184,S260, S280,S281	R6

TABLE 20 The proposed shorelines for the Inner Moray Firth area, each shoreline declines towards N25° E

Shoreline	Gradient of Linear TSA (m/km)	Direction of Linear TSA (declines towards)		Sum of squares (m)	Degrees of freedom	Variance (m)	F	Confidence level (%)
ILG_{4A}	0.417	27.16° N of E	Due to Linear	216.576	2	108.288	315.03	> 99.9
			Deviation from Linear	5.156	15	0.344		
			Due to Quadratic	1.376	3	0.459	1.45	< 95
			Deviations from Quad.	3.778	12	0.315		
			Due to Cubic	1.806	4	0.452	1.18	< 95
			Deviations from cubic	3.051	8	0.381		
ILG_{5A}	0.412	26.82° N of E	Due to Linear	331.990	2	165.995	757.30	> 99.9
			Deviation from Linear	3.945	18	0.219		
			Due to Quadratic	2.783	3	0.928	11.97	> 99.9
			Deviation from Quad.	1.163	15	0.078		
			Due to Cubic	0.387	4	0.097	1.43	< 95
			Deviation from Cubic	0.745	11	0.068		
ILG_{8B}	0.212	24.56° N of E	Due to Linear	72.428	2	36.214	363.92	> 99.9
			Deviation from Linear	1.393	14	0.099		
			Due to Quadratic	0.637	3	0.212	3.09	< 95
			Deviation from Quad.	0.756	11	0.069		
			Due to Cubic	0.578	4	0.145	1.61	< 95
			Deviation from Cubic	0.629	7	0.089		

TABLE 21 The gradient and direction of decline of the linear trend surface for the 4 best developed Lateglacial shorelines in the Inner Moray Firth area and the calculation of F-ratios for the contribution of successively higher-order trend surfaces.

Shoreline	Gradient of Linear TSA (m/km)	Direction of Linear TSA (declines towards)		Sum of Squares (m)	Degrees of freedom	Variance (m)	F	Confidence Level (%)
ILG_{10}	0.153	24.06 N of E	Due to Linear	28.149	2	14.075	66.13	>99.9
			Deviation from Linear	4.044	19	0.213		
			Due to Quadratic	1.434	3	0.478	2.93	<95
			Deviation from Quad.	2.610	16	0.163		
			Due to Cubic	1.027	4	0.257	1.99	<95
			Deviation from Cubic	1.548	12	0.129		

TABLE 21 (cont.)

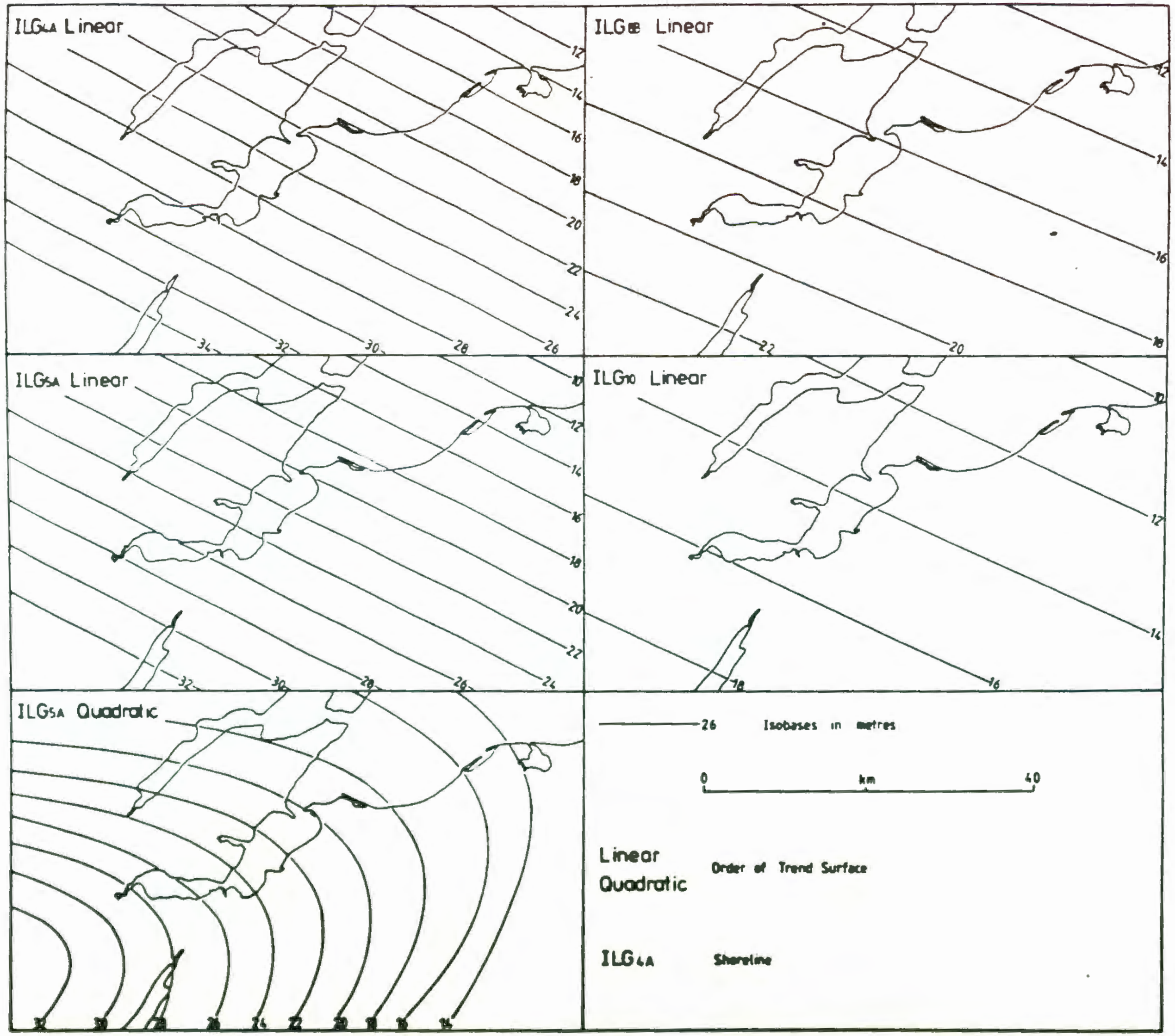


FIGURE 77 Trend surface maps produced for the best developed Lateglacial shorelines in the study area.

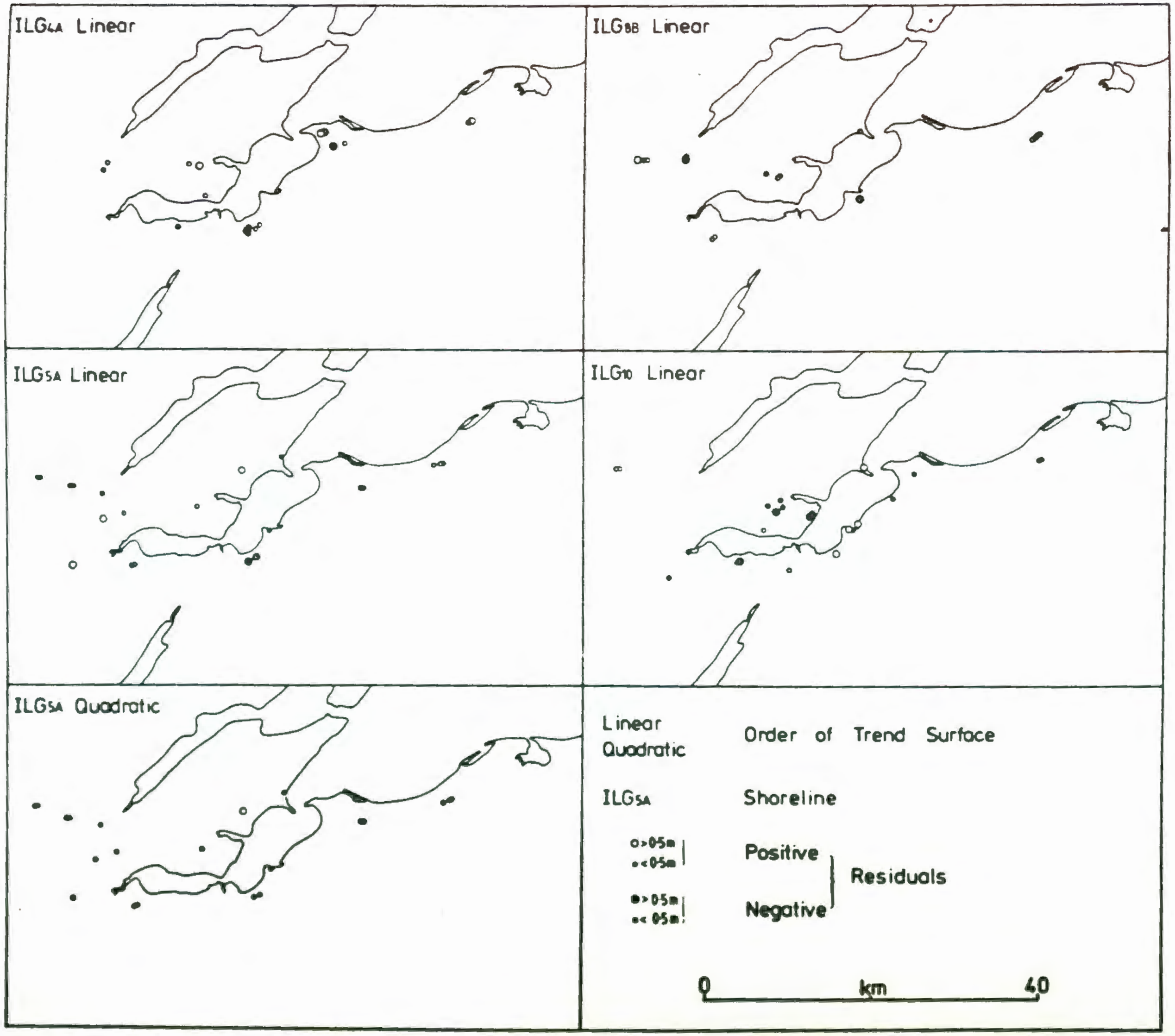


FIGURE 78 The residuals produced from the trend surface maps of the best developed Lateglacial shorelines.

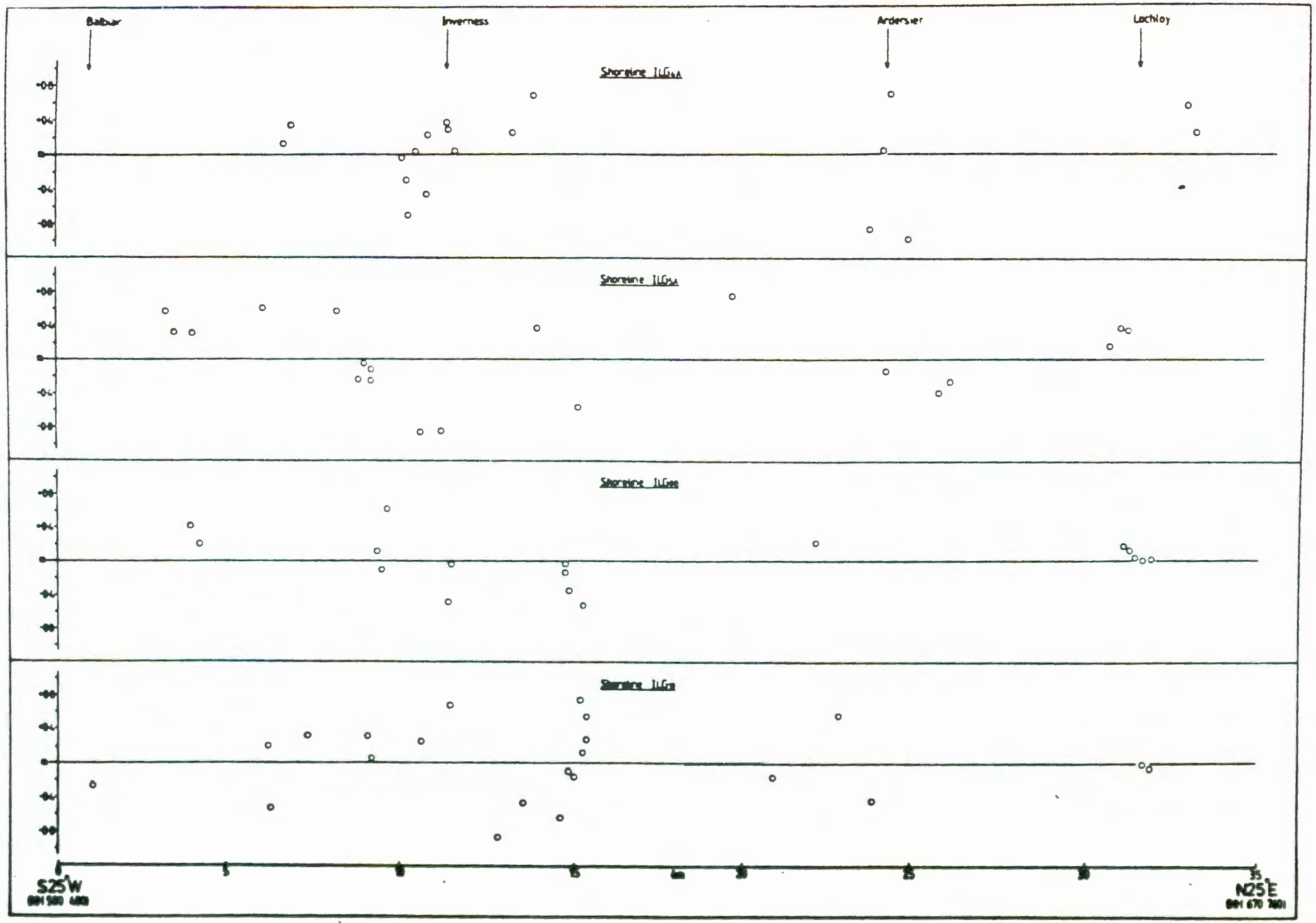


FIGURE 79 The residuals produced from the regression analysis of the four best developed Lateglacial shorelines in the inner Moray Firth area.

4. <u>The Shorelines and Associated Ice Limits</u>

a) ILG_1 and ILG_2

The highest shoreline fragments in the Ardersier area are correlated with the highest shoreline fragments in the Lochloy area (Fig. 76). In both these areas the higher raised marine terraces and raised shingle ridges form a distinct group of features. However the large vertical range of these marine features suggests that the shoreline fragments are composite, having been produced during at least 2 periods of relative sea level stability. The two clearest shorelines are referred to as ILG_1 and ILG_2 and exhibit regional gradients of 0.554 m/km and 0.570 m/km respectively. Shoreline ILG_1 occurs at Ardersier and may correlate with the poorly-developed shoreline terrace fragment (S90) at 32.5 m at the entrance of Munlochy Bay and also with the highest outwash surface (T 142, T 143) at Inverness. Shoreline ILG_2 occurs at 26.6 m at Ardersier (S33) and possibly may be correlated with the raised marine terrace at Craigton (S162) at 33.4 m and the outwash delta surface at Inverness which descends to <u>circa</u> 35 m (T 144).

During the formation of shorelines ILG_1 and ILG_2, remnants of the last ice sheet lay directly inland of the coastal zone. During this period a mass of ice was located inland of Lochloy whilst farther west the ice margin was located in the vicinity of the Flemington esker and probably occupied most land areas south of Ardersier (Fig. 80). The correlation of the high deltas at Inverness with shorelines ILG_1 and ILG_2 indicates that the ice had retreated from the deep water channel of the Inverness Firth by this time and that the ice margin lay immediately south of Inverness and just west of Craigton (Fig. 80).

b) ILG_{3A}

Shoreline ILG_{3A} has a gradient of 0.457 m/km and is locally

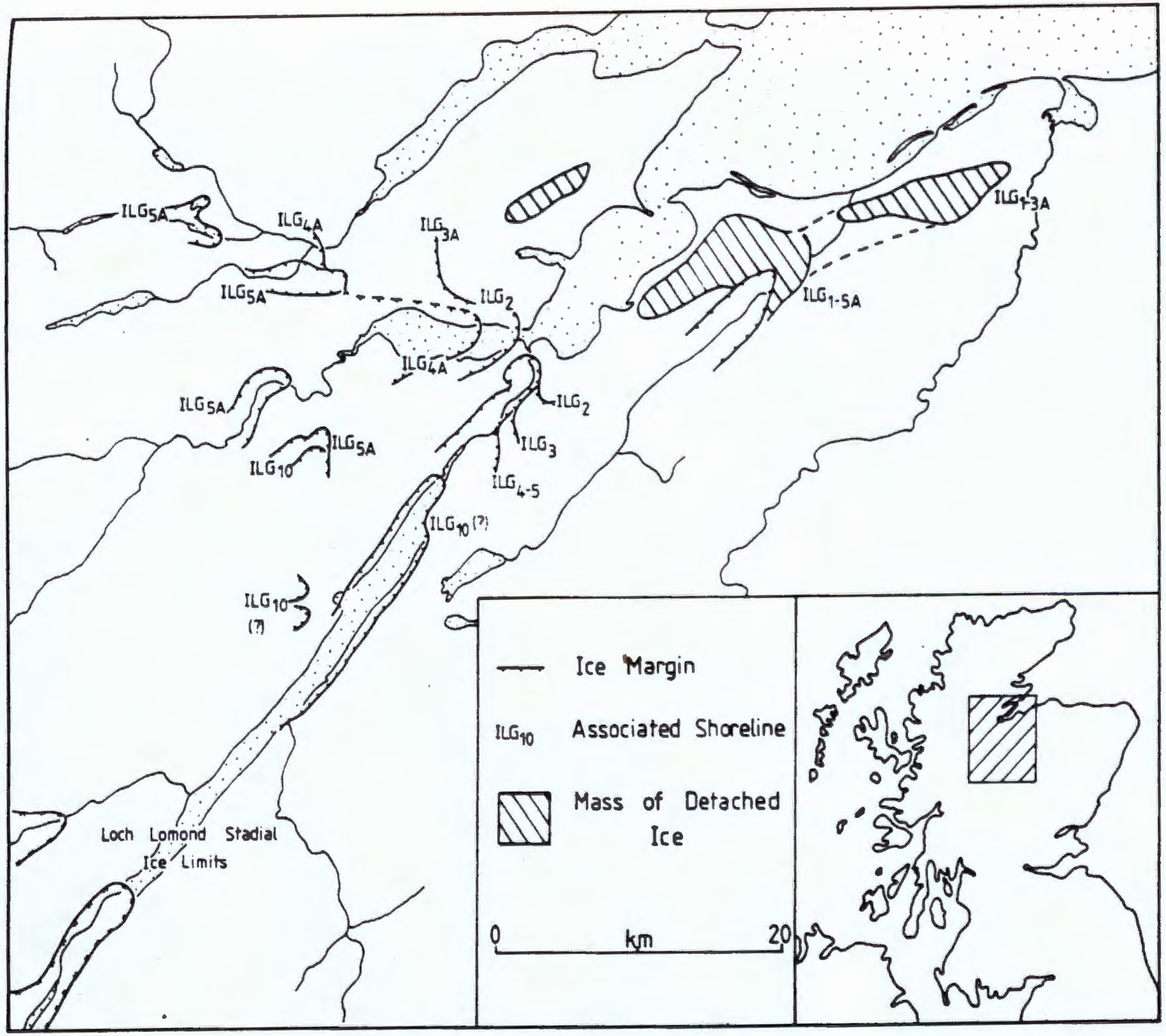


FIGURE 80 The proposed synchronous ice margins and associated Lateglacial shorelines in the inner Moray Firth and Loch Ness areas.

(S123-S125) (which grade into Inverness outwash delta T 151), with the shoreline terrace fragments at 29 m in Munlochy Bay (S100, S101) and with well developed terrace fragments in the Fortrose/Ardersier area. Also associated with this shoreline is the poorly-developed marine terrace at Nairn (S25) which is related to an ice margin near Kildrummie Gap (Figs. 25, 80). It has also been suggested that the well developed marine terrace fragments in Munlochy valley resulted from meltwaters which flowed into the area from the Beauly Firth. It is therefore proposed that when shoreline ILG_{3A} was produced ice occupied the Ness valley as far north as the Torvean esker. Farther east large masses of stagnant ice were still present inland from the coast and some of these masses of ice may have been associated with a tongue of ice in the Nairn valley. However the limited thickness of the ice at Kildrummie suggests that the ice in this area was inactive. In the Beauly Firth the ice occurred up to an altitude of 80 m east of Gallowhill (Fig. 31). From Gallowhill the ice front may have extended inland to Tore (Fig. 80) and possibly to the complex of moraines at Easter Kinkell (Horne and Hinxman, 1914). Between the formation of shoreline ILG_2 and shoreline ILG_{3A} relative sea level fell circa 4.5 m at Inverness and this coincided with a 1-2 km retreat of the ice front in the Ness valley.

c) ILG_{4A}

Shoreline ILG_{4A} has a gradient of 0.430 m/km. It is locally represented by the highest shoreline terrace fragments north of Muir of Ord at 28 m (S263, S265), the high level delta and associated raised marine terrace at Englishton at 29 m (S179, S181), the small outwash delta and marine terrace fragment at Charleston (T 141, S164), the most extensive delta surface at Inverness (T 153) which is graded to raised shoreline fragments at 27 m (S129, S130) and by well developed shoreline fragments in the Ardersier and Lochloy areas.

The shoreline terrace fragments north of Muir of Ord (S263, S265) have been associated with three small outwash deltas in the Highfield area (Fig. 61, T 39-T 41). It has been suggested (see page 240) that these deltas (T 39-T 41) indicate the presence of ice in both the Orrin and Conon valleys. The 27 m proglacial delta surface at Inverness (T 153) was produced whilst ice occupied the Ness valley as far north as Torvean. Thus the ice margin in the Ness valley retreated only a short distance between the formation of shorelines ILG_{3A} and ILG_{4A}. To the west of Inverness the small outwash deltas at Charleston (T 141) and Englishton (S181) indicate the presence of ice in the Beauly Firth at this time. The exact location of the ice front in the Beauly Firth may be interpreted in three ways:-

i) The deltas at Englishton (S181) and Charleston (T 141) formed in relation to the same ice front (Fig. 80) which crossed the Beauly Firth diagonally (being more advanced on the northern shore of the Beauly Firth). Such irregular ice fronts are not uncommon where the snout of the glacier ends in water as for example at Steensby Gletscher in north Greenland (Ahnert, 1963) and at Sydglelscher in south Greenland (Dawson, 1983b).

ii) The ice front lay across the Beauly Firth at Englishton and a mass of stagnant ice lay along the northern shore between Coulmore and Charleston. This interpretation is aided by the poor development of Lateglacial shoreline fragments along the northern shore of the Beauly Firth.

iii) The delta at Charleston was produced prior to that at Englishton, the ice margin having retreated rapidly due to calving and thus relative sea level having been unaltered in the time. Examples of suggested rates of calving from Antarctica range between 300-2 000 m/yr (Loewe, 1960; Robin, 1972) and with such high rates of ice front retreat it would be possible for two shoreline fragments only 3 km apart to be formed in relation to the same relative sea level yet at different ice margins.

d) ILG_{5A}

Shoreline ILG_{5A} has a regional gradient of 0.427 m/km. This shoreline correlates the deltas at Balblair (T 70) (which is graded to a raised shoreline fragment at 29.4 m (S253)), Muir of Ord (T 67, T 69), in the Orrin valley (T 10, T 42) and with the raised shoreline fragments at 24 m at Inverness (S133, S134). It is also thought likely that the deltas at Kiltarlity (T 111) and Contin (T 1) were also being produced at this time. These various deltas are correlated with well developed shoreline terrace fragments in the Conon valley at 26 m, Beauly Firth, Ardersier area and Lochloy area.

By the time this shoreline had been produced ice had retreated from the lower Conon valley to Loch Achonachie and Loch Achilty. A mass of ice still lay at Muir of Ord and in the Orrin valley but much of the eastern end of this ice mass was stagnant. In the Kiltarlity area the ice front lay just south of Kiltarlity (Fig. 80), whilst another mass of ice lay in the vicinity of the Kilmorack Gorge. In the Ness valley the limit of the ice is considered to have been similar to the limits proposed for shoreline ILG_{4A}, that is, lying south of Inverness near Torbreck and in the Ness valley as far north as Torvean.

e) ILG_{6A}

This is a poorly-developed shoreline with a regional gradient of 0.367 m/km. The shoreline consists of an outwash delta at Muirton Mains (T 1, S284) at 24.8 m and is also thought to correlate with the lowest sections of the deltas at Kiltarlity (T 111), Balblair (T 70) and Muir of Ord (T 67, T 69). The ice limits are identical to those proposed for shoreline ILG_{5A} except for the Inverness area where no equivalent fragment of shoreline ILG_{6A} appears to be present. However, a mass of ice must still have been present north of the Torvean esker ridge.

f) ILG_{7B}

This is a very poorly defined shoreline, with many of the shoreline fragments being of poor quality. At no point could the shoreline fragments be associated with an ice front. The gradient of the shoreline is 0.235 m/km and this figure is only accepted as an approximation. The most westerly shoreline fragment S189 occurs at 22.5 m in the Beauly Firth whilst in the east the shoreline is represented by fragment S63 at 19.4 m.

g) ILG_{8B}

Shoreline ILG_{8B} is a well developed shoreline with a regional gradient of 0.210 m/km. Shoreline fragments correlated with this shoreline were identified in the Beauly Firth at 20.5 m (S190) in the Conon valley at 19-19.5 m (S276-S277), in Munlochy valley at circa 17-18 m (S106, S111), in the Fortrose area at 16.6 m (S50) and in the Lochloy area at 15 m (S11). This shoreline could not be related to an ice front, although it does lie above kettled shoreline fragments.

h) ILG_{9B}

This shoreline is very poorly-developed and at no point could it be related to an ice margin. Its gradient of 0.221 m/km is thought to only represent a general slope of the shoreline. This shoreline rises from 14.5 m at Fortrose to 18.6 m in the Beauly Firth.

i) ILG_{10}

Shoreline ILG_{10} is very well-developed and has a regional gradient of 0.150 m/km. Shoreline fragments related to this shoreline occur at Kiltarlity at 16.4 m (S260), in the Beauly Firth, in Munlochy valley, in the Conon valley, at Ardersier, at Fortrose and at Lochloy at 12.0 m (S20). In the Kiltarlity area the shoreline is related to an ice limit circa 1 km south of Kiltarlity (Fig. 80). This represents a 0.5 km retreat in the ice margin since the formation of shoreline ILG_{6A} whilst in the same time sea level fell 12.5 m. It has been suggested that shoreline ILG_{10} may be correlated with an ice margin at the northern end of Loch Ness (see pages 200-201), and this ice margin indicates that the ice sheet retreated approximately 7 km since the formation of shoreline ILG_2. During the same period of time relative sea level fell 19 m.

j) Shoreline Fragments below ILG_{10}

Below shoreline ILG_{10} there are a group of shoreline fragments which can not be correlated to form distinct shorelines. All these shoreline fragments lie below 15 m and therefore they usually only occur where the 'low level cliff' is absent or only poorly-developed. The shoreline fragments below shoreline ILG_{10} are thought to represent more than one shoreline but the limited amount of data does not permit correlation. At Inverness one of the shoreline fragments (S138) at 13.5 m is graded into a kettled outwash terrace (T 159). It has been suggested (see pages 200-201) that this kettled outwash terrace fragment may be related to a loch at a 32 m level at the northern end of Loch Ness. It is possible the ice limit associated with this loch was located at Foyers, however it is equally possible that the lake was a small ice marginal feature and that ice occupied the greater part of Loch Ness.

k) Remaining Shoreline Fragments

There are only 5 raised shoreline fragments which are not part of the proposed shoreline sequence (S1-S3, S215, S222). Shoreline fragments S215 and S222 are both poorly-developed features which occur at the head of the Beauly Firth. The break of slope of fragment S215 is partially obscured by a road, whilst the 1.5 m range in altitude of S222 makes it one of the poorest marine terraces in the study area. Since the altitudes determined on shoreline fragments S215 and S222 are of a poor quality correlation of the fragments with specific shorelines must remain speculative, but on the basis of altitude these features may be correlated with shoreline ILG_{4A}. However, shoreline ILG_{4A} is related to an ice margin at Englishton and the shoreline fragments in question (S215, S222) lie inside this ice margin. The correlation of the marine terraces S215 and S222 with shoreline ILG_{4A} can only be proposed if relative sea level maintained the same level whilst the ice front retreated from Englishton to Balblair (a distance of 10 km) and this infers a rapid retreat of the ice margin.

Shoreline fragments S1-S3 at Kintessack can be correlated with specific shorelines, but the correlations have associated problems. Shoreline fragment S1 may be related to shoreline ILG_{4A} but this correlation is not in accord with the proposed ice margin near Brodie Castle (Figs. 21, 80) (see pages 102-105). It is possible that the ice margin near Brodie Castle relates to a stagnant mass of ice but the size of the outwash surface in this area suggests a considerable flow of meltwaters and therefore a larger mass of ice. Shoreline fragment S3 may be correlated with shoreline ILG_{10}, but the presence of a large kettlehole which pits this shoreline fragment is difficult to reconcile with the proposed shoreline. The shoreline fragments identified by Peacock et al. (1968) directly east of Kintessock suggest that further study in this area may solve the problems associated with shoreline fragments S1-S3. However since glacio-lacustrine deposits (Peacock et al., 1968) and shoreline fragments (see page 104) have been identified in the same general area it is considered premature to attempt the proposed correlations until further study is undertaken.

5. Implications of the Shoreline Sequence

a) Patterns of Deglaciation

The shoreline sequence provides ample information on the pattern of deglaciation and basically suggests that large masses of ice remained at inland sites whilst coastal areas and the areas presently covered by the sea became deglaciated. The broad area of lowland east of Inverness was still covered by large masses of stagnant ice whilst coastal areas had become deglaciated as far west as Inverness. Similarily it can be demonstrated that in the same amount of time it took the Beauly Firth to become deglaciated the ice front at Inverness and north of Muir of Ord only retreated 0.5-3 km. The ice margin therefore retreated rapidly in the broad deep water channels (Inverness Firth, Moray Firth, Beauly Firth, Cromarty Firth) where the snout of the glaciers terminated in the sea, whilst inland of these areas ice wastage was slower. It is proposed that ice retreat in the broad deep water channels was the result of calving rather than ablation. It would also seem that the broader Cromarty Firth became deglaciated earlier than the Beauly Firth whose narrow entrance may have slowed ice sheet retreat. Similar patterns of deglaciation have been observed in Spitsbergen (Peacock in Armstrong et al., 1975) and have been proposed for the Forth and Tay estuaries (Armstrong et al., 1975; Browne et al., 1981a).

The field evidence in the Ness valley and from the slopes bordering the Beauly Firth indicates a progressively downwasting ice mass. It is possible that these ice decay features represent the final decay of stagnant ice masses whilst in other areas the ice remained active. However since the only morphological evidence indicative of Late Devensian active ice in the study area is the morainic ridge in Glen Urquhart, it is considered unlikely that the ice remained active in the Beauly Firth and Ness valley during ice decay.

b) Relative Sea Level Movements in Association with Ice Sheet Decay

The shoreline sequence indicates a progressive fall in Lateglacial relative sea level. Some of the shorelines (ILG_{3A}-ILG_{5A}) indicate a progressive retreat of the ice margin in the Beauly and Cromarty Firths, whilst relative sea level fell; yet these same shorelines are also associated with a near stable ice margin in the Ness valley. In the Beauly Firth whilst the ice front retreated from North Kessock to Balblair (a distance of 16 km) relative sea level fell at least 11 m at Inverness from shoreline ILG_2 (at <u>circa</u> 35 m) to shoreline ILG_{5A} (at 24 m). The drop in the marine limit between North Kessock at 33.4 m and Balblair at 29 m is however small. In contrast evidence of substantial falls in relative sea level associated with near stable ice margins occurs at Inverness, Kiltarlity and Muir of Ord. At Inverness relative sea level fell at least 11 m from <u>circa</u> 35 m (ILG_2) (and possibly from <u>circa</u> 40 m (ILG_1)) to 24 m (ILG_{5A}) whilst the ice margin remained 1-3 km south of the city. In addition it has been suggested that the limit of the ice mass had only retreated 10 km to the northern end of Loch Ness by the time relative sea level had fallen to 16.0 m (ILG_{10}) some 19 m below shoreline ILG_2. It has also been demonstrated (see pages 200-201) that masses of stagnant ice still remained in the Inverness area after relative sea level had fallen to 13.5 m. In the Kiltarlity area relative sea level fell from 29 m (ILG_{5A}) to 16 m (ILG_{10}) whilst the ice front retreated 0.5 km, whilst at Muir of Ord relative sea level fell 6 m between the formation of shorelines ILG_{4A} (at 28 m) and ILG_{6A} (at 22.5 m) yet during the same period of time the ice front only retreated 1 km. The ice fronts therefore appear to have stabilized once the ice became confined to the narrow valleys of the Ness, Orrin, Glass and Conon. The slower rates of ice decay in the narrow valleys may be interpreted as a stand-still of the ice, but the standstill may have resulted from the narrowing of the valleys rather than from climatic change. However, since there is little evidence in the study area to suggest that the ice remained active (and active ice would be implied by a standstill) it is considered premature to infer a standstill.

c) Isostatic Considerations

The shoreline sequence is indicative of continued uplift during deglaciation. The tilt of the shorelines indicates that the major ice mass lay to the south west of the study area. Except for one shoreline (ILG_{9B}) (which is poorly developed) each shoreline has a lower regional gradient than the one above it. The change in gradient between ILG_{3A} and ILG_{10} indicates that 66% of the tilting occurred whilst ice remained in the area. This implies that initial glacio-isostatic uplift was rapid. In contrast shorelines ILG_{3A}-ILG_{5A} have almost identical gradients, and except for the Beauly Firth these three shorelines are associated with near stationary ice limits. It is proposed that during the time these shorelines were formed differ-ential glacio-isostatic uplift was limited. There then followed a period of rapid glacio-isostatic uplift during which relative sea level fell some 13 m. The reduced rate of uplift may be explained in several ways:-

i) The three shorelines (ILG_{3A}-ILG_{5A}) were formed very rapidly in response to high sediment input rates from the decaying ice sheet As a result they represent only a short time period of shoreline formation.

ii) During the period of formation of ILG_{3A}-ILG_{5A} the ice sheet stabilized so that isostatic uplift slowed. After this period of ice stabilization rapid ice decay resumed. As the ice margin did not retreat a great distance during the subsequent uplift much of the ice wastage must have been achieved by downwasting of the ice mass. This of course assumes that eustatic change at the time was positive.

6. Dating and Correlation with Other Areas of Scotland

a) Dating

During the study no organic material was found which could be associated with the Lateglacial shorelines. The oldest ^{14}C date available in the study area at 9 610±130 B.P. (BIRM 1123; Haggart, 1982) refers to a buried peat which overlies marine deposits that cover the buried gravel layer. Outside the area ^{14}C dates have been obtained from deposits at Teinland to the east (28, 140^{+480}_{-450} B.P., Edwards et al., 1976) and at Loch Droma (12 810±155 B.P., Kirk and Godwin, 1963) to the west (see Chapter 3). The Loch Droma date has often been quoted as evidence of deglaciation of most of the Northern Highlands by 12 800 B.P. (Sissons, 1967, 1974a, 1976b; Price, 1983). If this date is accepted than the study area must have been deglaciated prior to this by several hundreds of years. Sutherland (1980, 1981b) has suggested that the Loch Droma date is in error because it is composed of derived allochthonous plant debris from a recently deglaciated area, indicating that the date may be too old.

It has been argued elsewhere (Chapter 5) that the Buried Gravel Layer formed early in the Loch Lomond Stadial, so the Lateglacial shorelines ILG_1-ILG_{10} predate circa 11 000 B.P. Peacock (1974) and Peacock et al., (1980) in their study of Late Devensian and Flandrian stratigraphy and marine faunas from two boreholes in the Cromarty Firth suggested that deglaciation was relatively late in the area. The lowest marine strata (Lower Findhorn Beds) encountered in the boreholes contain high boreal to low arctic faunas similar to the Late Devensian Clyde Beds of western Scotland. The Clyde Beds have been dated to between 13 500 and 10 000 B.P. (Peacock, 1981). Peacock (1974, 1981) suggested that the lack of a stratum in the Cromarty Firth equivalent to the Errol Beds of the Tay Estuary, (with their characteristic arctic fauna, Peacock, 1975) may reflect either ice coverage in the Cromarty Firth prior to 13 500 B.P. or an incomplete sedimentary record produced by the boreholes. Since the Cromarty Firth must have been deglaciated when shoreline ILG_{4A} was formed it is inferred that shorelines ILG_{4A}-ILG_{10} may have formed after 13 500 B.P.

b) Correlations with Other Areas of Scotland

Due to the lack of absolute dates the Lateglacial shoreline sequence in the Inner Moray Firth area can only be compared with other areas of Scotland on the basis of morphology. The salient characteristics of the Inner Moray Firth shoreline sequence are:-

i) Rapid calving of ice in deep water Firths.

ii) Markedly similar gradients of three shorelines (ILG_{3A}-ILG_{5A}), with the possible implication of a reduction in ice wastage.

iii) A drop in relative sea level of at least 19 m and possibly 23 m whilst the ice margin retreated a limited distance.

Only four areas exist in Scotland which have broadly similar characteristics to those of the Inner Moray Firth area, these being the Cowal Penninsula, Wester Ross, the Firth of Forth and the Firth of Tay.

1) Firths of Forth and Tay

In the Forth, Earn and Tay valleys distinct shorelines (Sissons and Smith, 1965a; Sissons et al., 1966; Cullingford, 1972, 1977) were associated with the Perth Readvance limit identified by Sissons (1963b, 1964). In the Forth the highest of these shorelines has a gradient of 0.43 m/km and it is called the Main Perth Raised Shoreline (Sissons and Smith, 1965a). In the Forth the Main Perth Raised Shoreline is succeeded by two lower shorelines which have markedly similar gradients to the Main Perth Raised Shoreline, and these lower shorelines are associated with an 8 km retreat in the ice margin (Sissons and Smith, 1965a). Sissons and Smith inferred that relative sea level fell rapidly before the ice retreated west of Stirling. They suggested that relative sea level fell 25 m whilst ice stood near the Stirling Gap and at least 9.5 m whilst ice occupied the lower Carron valley. Similarly a major drop in relative sea level with limited ice margin retreat has been proposed for the Earn and Tay valleys (Sissons et al., 1966; Cullingford, 1972, 1977). Cullingford (1977) suggested that relative sea level fell by at least 17 m in the Tay valley. In this area he also identified several shorelines (LP1-LP4) below the Main Perth Raised Shoreline and these have gradients between 0.32-0.23 m/km. He related these lower shorelines to ice limits similar to those proposed for the Main Perth Raised Shoreline. Smith (1965) also tentatively identified one shoreline (LG8) below the Main Perth Raised Shorelines in the Forth valley, and this lower shoreline has a gradient of 0.14 m/km. In contrast to Cullingford the lower shoreline in the Forth valley lies inside the ice limits proposed by Sissons and Smith to be synchronous with the Main Perth Raised Shorelines.

The concept of the Perth Readvance has since been revised and it has been suggested that the ice front may relate to a minor readvance or standstill of the ice sheet (Sissons, 1974a, 1976b). In addition the extent of the drop in the marine limit at Stirling and in the Earn-Tay area has been disputed (Francis et al., 1970; Armstrong et al., 1975; Browne et al., 1981a, b; Laxton, 1984). In the Forth valley Francis et al., Browne et al., 1981a) and Laxton have outlined the occurance of marine deposits inside the ice limit at Stirling at altitudes in excess of those proposed by Sissons and Smith (1965a). On the basis of the supposed marine deposits a fall in the marine limit of only 5 m at Stirling is proposed by the various authors rather than the 15 m fall postulated by Sissons and Smith. However, the stratigraphical evidence presented by Francis et al.,Browne et al. and Laxton is at variance with the morphological evidence according to Smith and Cullingford (1981), and the faunal remains could have been re-worked. It may be concluded that probably significant falls in the marine limit occurred at Stirling and in the Carron valley at this time, although the amount is uncertain.

The Forth-Tay area is similar in many respects to the Inner Moray Firth. Firstly both areas have a shoreline sequence which demonstrates 3 shorelines with similar gradients followed by lower shorelines with considerably lower gradients. Secondly the actual gradients of the shorelines are similar; ILG_{3A}-ILG_{5A} (0.457-0.427 m/km) are similar to the Main Perth Raised Shoreline (0.43 m/km), whilst ILG_{6A}-ILG_{10} (0.367-0.150 m/km) are similar to the Lower Perth Shorelines (0.32-0.23 m/km). Thirdly both areas may demonstrate a limited retreat in the ice margin associated with a substantial drop in relative sea level. However, it is possible that the proposed drops in relative sea level in the Earn-Tay and Inverness areas are related to stagnant ice masses rather than an active ice margin. Finally in both areas it has been suggested that ice retreat occurred at a faster rate in the broad deep water channels which resulted in the presence of stagnant masses of detached ice inland of the coastal zone. On the basis of these morphological similarities it is tentatively proposed that Inverness shorelines ILG_{3A}-ILG_{5A} may be correlated with the Main Perth Raised Shorelines. Similarly shorelines ILG_{6A}-ILG_{10} can be correlated with the Lower Perth Shorelines in the Earn-Tay valleys (LP1-LP4) and possibly with the lower Lateglacial shoreline in the Forth Valley (Smith, 1965, LG8). It should be noted that the tentative correlations relate to the shorelines and not the various ice margin positions.

ii) Cowal Peninsula

Sutherland (1981b) identified a series of shorelines in the Cowal Peninsula, some of which he related to a near stable ice margin (CLG_2-CLG_5). He suggested that a 20 m drop in relative sea level occurred at Otter Ferry whilst ice remained in the area. He outlined other drops in the marine limit of 22 m in Glendariel and 26 m at the southern end of Loch Long. He correlated the most extensive shoreline (CLG_2), which has a regional gradient of 0.327 m/km, with the limit of a readvance or stillstand of the ice. Lower shorelines related to the same ice front have gradients between 0.286 m/km and 0.204 m/km, and below this shoreline gradients lie between 0.129 m/km and 0.112 m/km (Sutherland, 1981b). Sutherland also revised the Lateglacial sea level curve proposed by Peacock et al. (1977, 1978). Sutherland's curve (Fig. 73) indicates a rapid fall in relative sea level between circa 13 000 and 12 000 yrs. B.P. and was used to tentatively date the maximum of the ice limit to 12 900±200 yrs. B.P. Sutherland also inferred that the ice front remained stable for 50-850 yrs. He suggested that the stable ice front had been caused by a readvance of ice initiated by increased precipitation.

The Lateglacial relative sea level changes in the Cowal Peninsula are comparable to those in the Inner Moray Firth for three reasons. Firstly faunal evidence from the Cromarty Firth (Peacock, 1974; Peacock et al., 1978) suggests that the Lateglacial shorelines in the Inner Moray Firth area were formed at a similar time as those in the Cowal Peninsula. Secondly, both areas demonstrate substantial falls in relative sea level associated with limited ice retreat. Finally the gradient of shorelines ILG_{3A} - ILG_{5A} (0.457-0.427 m/km) is not greatly dissimilar to the gradient of shoreline CLG_2 (0.327 m/km), a view advocated by Sutherland (1981b) and supported by Sissons and Dawson (1981) Dawson (1984) and Gray (1983). Gray (1983) noted that raised shorelines on the west coast of Scotland have lower regional gradients than the same shoreline on the east coast.

In contrast there are several differences between the Cowal Peninsula and the Inner Moray Firth areas. Firstly the shoreline sequence in the Cowal Peninsula demonstrates a progressive change in the tilt of the shorelines, whereas in the Inner Moray Firth area shorelines with a similar gradient are succeeded by shorelines with a markedly lower regional gradient. Secondly, a moraine at Otter Ferry is interpreted as evidence of a readvance or stillstand of the ice sheet and therefore an active ice mass, whereas evidence for active ice in the Inner Moray Firth area is lacking. The lack of a readvance or stillstand in the Inner Moray Firth may reflect the location of the area in relation to the patterns of precipitation. A readvance of an ice sheet may be expected to be most pronounced on the western side of the Highlands since the glaciers in the area are more likely to receive precipitation inputs. However the glaciers which extended into the Inner Moray Firth area are likely to have been less sensitive to climatic change due to rain shadow effects.

It is tentatively suggested that the Lateglacial relative sea level changes in the Cowal Peninsula are approximately synchronous with those in the Inner Moray Firth. Shoreline CLG_2 in the Cowal Peninsula may correlate with any of the Inverness shorelines

ILG_{3A} - ILG_{6A}, especially as there is no reason to suggest synchroneity of the Lateglacial ice margins. On this basis the lower shorelines in the Inner Moray Firth (ILG_{7B}-ILG_{10}) can be tentatively correlated with the lower shorelines in the Cowal Peninsula (CLG_3-CLG_8).

iii) Wester Ross

Sissons and Dawson (1981) related a shoreline (the Main Wester Ross Shoreline) with the Wester Ross Readvance limit identified by Robinson and Ballantyne (1979). The regional gradient of the Main Wester Ross Shoreline lies between 0.33-0.39 m/km depending on the plane of projection used (Sissons and Dawson, 1981). In the Wester Ross area there is no substantial drop in the marine limit, instead Sissons and Dawson suggested that relative sea level fell as the ice retreated from the Wester Ross Readvance limit. They suggested that in Loch Ewe a drop in relative sea level of circa 11 m is associated with a retreat of the ice front of circa 17 km.

The relative sea level changes in the Inner Moray Firth are only similar to those in Wester Ross in two respects. Firstly the gradient of the Main Wester Ross Shoreline is not dissimilar (see above) to the regional gradients of the Inverness shorelines ILG_{3A}-ILG_{6A}. Secondly in both areas rapid ice retreat associated with a falling relative sea level is recorded in the broad sea lochs. In the Beauly Firth the ice sheet retreated circa 10 km from Englishton to Balblair whilst relative sea level fell only 3 m.

The relative sea level events in the Wester Ross area differ from those in the Inner Moray Firth area for several reasons. Firstly the Wester Ross area does not demonstrate a major drop in the marine limit, and at no location are large stagnant ice masses reported stranded on land due to rapid calving in the deep water lochs. However the lack of substantial drops in the marine limit in the Wester Ross area may reflect an ice margin which was maintained during a period of high mass balance and with reduced accumulation the ice margin retreated rapidly. Secondly, the shoreline sequence at Wester Ross only provides information about one shoreline and so no comparison with lower shorelines can be made. Finally, the Main Wester Ross Shoreline is related to a readvance limit and therefore active ice, whilst it is uncertain if the ice remained active in the Inner Moray Firth area (although a possible explanation of the lack of active ice has been cited above).

Due to the lack of comparable shoreline data, and the uncertainty of the age of the Main Wester Ross Shoreline it is thought premature to correlate the relative sea level events in the two areas.

c) Correlations with Areas Perhipheral to the inner Moray Firth

Raised shoreline fragments have been identified in the Cromarty, Dornoch and Outer Moray Firths (Ogilvie, 1926; Peacock et al., 1968; Smith, 1968) at a variety of altitudes. Although it is accepted that correlations should be possible with these peripheral areas they are not proposed for several reasons:-

i) The method of altitude determination in some of the other studies was inaccurate (eg. Ogilvie, 1926).

ii) The altitude, location and geomorphic relationship of all the raised marine features are not recorded in some of the published works (eg. Peacock et al., 1968; J.S. Smith, 1968)

iii) As distance increases so miscorrelations from isobase curvature become more likely.

7. Summary

In the Inner Moray Firth area 10 tilted shorelines related to the deglaciation of the Late Devensian ice sheet have been identified. The shoreline sequence indicates that deglaciation occurred rapidly in the deep water sea lochs probably due to calving. Rapid ice recession left large masses of stagnant ice stranded inland. Once the ice retreated into the narrow valleys (Ness, Glass, Conon, Orrin) ice wastage slowed and was associated with a fall in relative sea level of 19 m and possibly 23 m. It has been inferred from the shoreline sequence that glacio-isostatic uplift was retarded whilst the ice fronts maintained almost stationary positions. Subsequently rapid thinning of the ice mass (rather than retreat) resulted in rapid uplift and shorelines with a significantly lower gradient were formed. Evidence is lacking to suggest that the ice remained active in the area during the fall in relative sea level, but this may reflect relatively low precipitation input into the glaciers which extended into the study area.

The relative changes in Lateglacial sea level in the Inner Moray Firth are tentatively dated at after 13 500 yrs. B.P. and prior to 11 000 yrs. B.P. on the basis of faunal evidence (Peacock, 1974; Peacock et al., 1980) and the identification of the Main Lateglacial Shoreline in the study area. On the grounds of marked similarities in shoreline sequences the relative sea level events in the Inner Moray Firth area are correlated with those in the Cowal Peninsula (Sutherland, 1981b) and Forth-Earn-Tay valleys (eg. Sissons et al., 1966). It is suggested that the Main Perth Raised Shorelines, Cowal shoreline CLG_2 and Inverness shorelines ILG_{3A} - ILF_{5A} may be of a similar age.

CHAPTER ELEVEN

FLANDRIAN AND LOCH LOMOND STADIAL SHORELINES

1. Introduction

Evidence for Loch Lomond Stadial shorelines has been cited from the Beauly Firth, Munlochy Bay and Loch Ness areas (see Chapter Nine). In the Beauly Firth, a buried gravel layer has been identified and correlated with the Main Lateglacial Shoreline of Sissons (1974b), whilst around Loch Ness raised lacustrine shoreline fragments have been correlated with Loch Lomond Stadial ice. The buried gravel layer is thought to be present throughout the study area and is often overlain by Flandrian marine deposits which rise to circa 10 m. The Flandrian deposits often occur in staircases of raised shoreline fragments so it is inferred that several Flandrian raised shorelines are present in the study area.

Haggart (1982) determined Flandrian relative sea level movements for 3 locations in the present study area (Barnyards, NH 5231 4725; Moniack, NH 5454 4350 and Arcan Mains, NH 4961 5371) by detailed analysis of sedimentary cores (pollen analysis, diatom analysis, sediment analysis and radio-carbon dating). He concluded (Fig. 81) that between circa 9 600 and 9 200 B.P. the area was characterized by a fall in relative sea level, which probably continued after 9 200 B.P. and according to Peacock et al. (1980) may have reached a minimum level of -6m some time after 8 750 B.P. Haggart's sea level curve indicates that relative sea level was rising by circa 8 200 B.P. and that the rise continued until it culminated at circa 9 m between 7 100±120 B.P. and 5 775±85 B.P. He correlated the culmination of the rise with the Main Postglacial Shoreline (Sissons et al., 1966). After 6 100 B.P. relative sea level fell towards present level.

Haggart (1982) also identified a buried beach in the Barnyards area (NH 5231 4725) which is overlain by a peat whose base has been

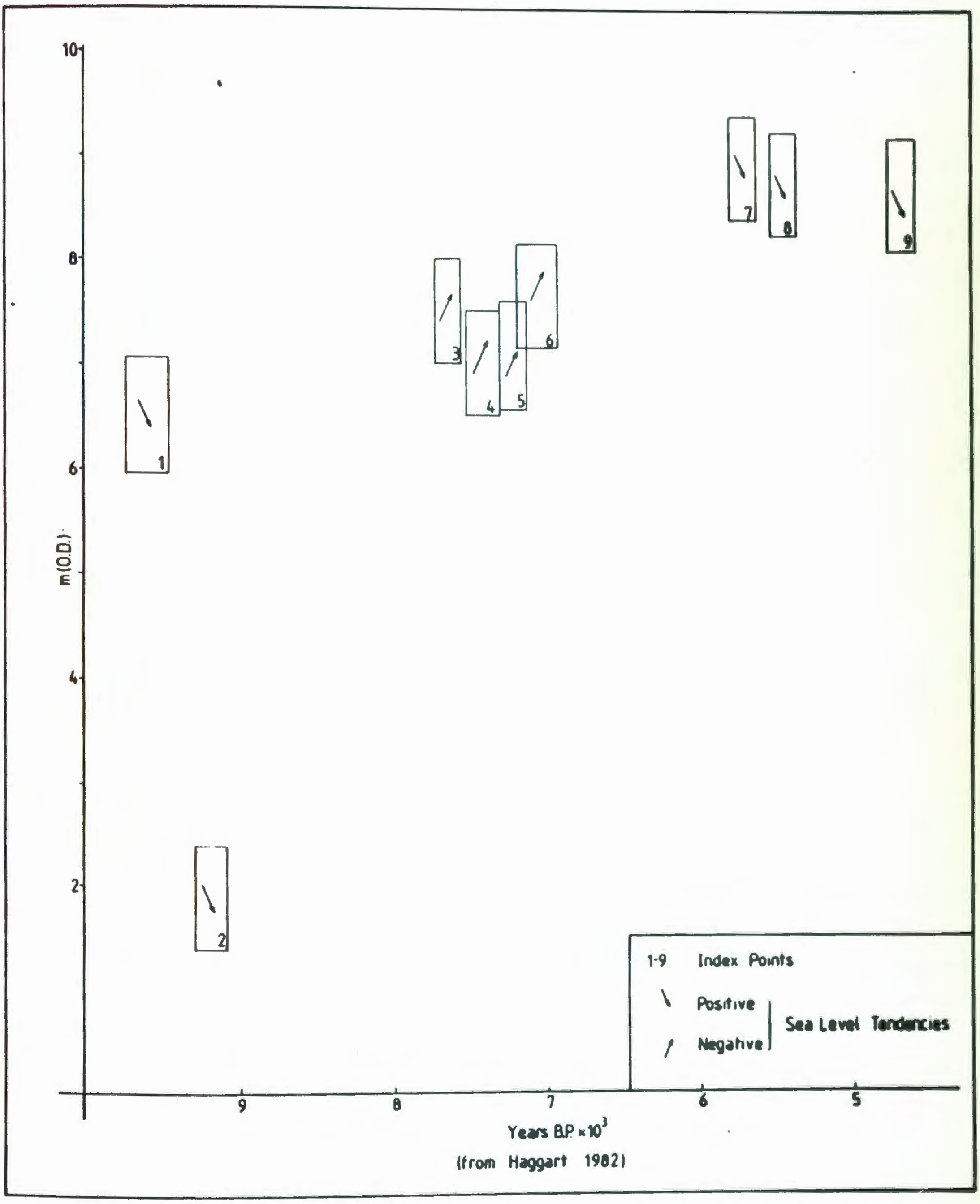


FIGURE 81 The Flandrian relative sea level curve proposed by Haggart (1982) for the Beauly Firth area.

Shoreline		No. of Points	90	75	60	45	30	25	20	15	10	0
			Projection Plane (degrees East of North)									
IF_1	Grad	15	0.0383	0.0380	0.0401	0.0453	0.0557	0.0608	0.0675	0.0761	0.0869	0.1159
	r		0.7545	0.7751	0.7929	0.8099	0.8265	0.8318	0.8363	0.8394	0.8390	0.8057
IF_2	Grad	5	0.0099	0.0119	0.0146	0.0190	0.0271	0.0312	0.0365	0.0434	0.0521	0.0730
	r		0.3255	0.3923	0.4586	0.5324	0.6243	0.6615	0.7028	0.7482	0.7964	0.8757
IF_3	Grad	8	0.1072	0.1259	0.1486	0.1664	0.1760	0.1691	0.1567	0.1388	0.1167	0.0672
	r		0.5730	0.6333	0.6776	0.6897	0.6347	0.5941	0.5411	0.4766	0.4032	0.2424
IF_4	Grad	18	0.0554	0.0509	0.0502	0.0528	0.0599	0.0637	0.0685	0.0746		0.1063
	r		0.9547	0.9598	0.9631	0.9651	0.9657	0.9653	0.9646	0.9632		0.9488
IF_5	Grad	9	0.0570	0.0524	0.0513	0.0534	0.0592	0.0622	0.0660	0.0706	0.0763	0.0916
	r		0.7138	0.7251	0.7317	0.7352	0.7353	0.7342	0.7322	0.7289	0.7238	0.7029
IF_6	Grad	17	0.0288	0.0255	0.0240	0.0240	0.0253	0.0261	0.0270	0.0281	0.0294	0.0319
	r		0.5586	0.5454	0.5309	0.5137	0.4909	0.4811	0.4696	0.4557	0.4387	0.3891
LN_{1A}	Grad	10	0.1914	0.1467	0.1257	01169	0.1165	0.1182	0.1209	0.1246	0.1296	0.1443
	r		0.9660	0.9654	0.9644	0.9633	0.9620	0.9614	0.9609	0.9603	0.9595	0.9577
LN_{1B}	Grad	7	0.3473	0.2690	0.2319	0.2166	0.2168	0.2202	0.2254	0.2326	0.2422	0.2705
	r		0.9723	0.9779	0.9805	0.9821	0.9831	0.9833	0.9835	0.9836	0.9837	0.9836
LN_2	Grad	3	0.1833	0.1417	0.1223	0.1143	0.1147	0.1166	0.1195	0.1234	0.1287	0.1442
	r		0.9943	0.9964	0.9975	0.9983	0.9989	0.9904	0.9992	0.9996	0.9995	0.9998

TABLE 22a Results of the regression analysis for the Flandrian marine shorelines in the Inner Moray Firth area and the lacustrine shorelines of Loch Ness. Grad = gradient (m/km), r = correlation coeff.

Shoreline	Gradient (m/km)	Correlation Coeff.	Signif. Level (%)	Shoreline Fragments used in regression analysis	Other Shoreline Fragments
IF_1	0.056-0.076	0.82-0.84	>99.95	S39,S55,S71,S72, S117, S241, S245-S250 S252, S273	S38,S44,S46,S54, S65,S69 S82, S85,S92,S93,S99,S167 S168,S169,S175,S177,S208, S216,S219,R11,R12,R14-R19 R22,R27-R29,R31,R38,R40.
IF_2	0.027-0.043	0.62-0.75	<95	S119, S120, S175, S194, S238	S209,S211,S214,S237,S242-S244.
IF_3	0.176-0.139	0.63-0.48	<95	S209,S211,S214,S237,S242-S244	
IF_4	0.060-0.075	0.95-0.96	>99.95	S58,S59,S121,S122,S194,S196,S202,S204-S206,S210,S230,S231,S236,S239	S41, S172, R29, R39.
IF_5	0.059-0.070	0.73-0.74	<95	S98,S199,S201,S203,S213,S232,S233,S240	S89, S170
IF_6	0.025-0.028	0.49-0.44	<95	S94,S96,S97,S187,S200,S218,S234,S235	S174
LN_{1A}	0.116-0.125	0.96-0.96	>99.95	S139,S140,S147,S149,S150,S155-S158	R33, R34, R37
LN_{1B}	0.217-0.233	0.98-0.98	>99.95	S139,S140,S147,S149,S150,S152,S160	R33, R34, R37
LN_2	0.115-0.123	0.99-0.99	<95	S143, S148, S161	R32, R34

TABLE 22b The proposed Flandrian marine shorelines in the Inner Moray Firth area and the raised lacustrine shorelines identified around Loch Ness. Each shoreline generally declines towards the NNE.

dated to 9 610±130 B.P. He showed that this buried beach attains a maximum altitude at its landward margin of 5.98-7.03 m and on the basis of ^{14}C dates and pollen analysis he correlated it with the Main Buried Beach of the Forth and Tay valleys (Sissons, 1966, 1976b).

Haggart (1982) also identified a widespread layer of marine grey silty fine sand which occurs up to circa 8 m and which was deposited between circa 7 400 and 7 200 yrs. B.P. He correlated this layer with a similar deposit identified in several areas of eastern Scotland (Sissons and Smith, 1965b; Smith et al., 1980; Morrison et al., 1981; Smith, Cullingford and Brooks, 1983) but was unsure of the nature of the event which it represented.

2. Correlation and Analysis of Shoreline Fragments

All Loch Lomond Stadial and Flandrian shoreline fragments were plotted on a series of height distance diagrams. The diagrams were produced for projection planes at 15° intervals between the planes W-E and SE-NW. The shoreline fragments were correlated by identifying marked alignments of points within the constraints of morphology. Distinct shorelines could only be identified in the projection planes between W-E and S-N. On each projection plane 6 Flandrian marine shorelines (IF_1-IF_6) and three Loch Ness shorelines (LN_{1A}-LN_2) are present, and the shoreline fragments could only be correlated in one way.

For each shoreline the gradient and correlation coefficient were calculated for projection planes at 5° intervals between W-E and S-N (Table 22). It has been demonstrated (see Chapter 4) that the correlation coefficient should be greatest along the projection plane that lies normal to the isobases. For these shorelines it was found that the correlation coefficient was greatest along different projection planes for different shorelines. However, some of the shorelines are composed of shoreline fragments which have a limited spatial distribution (IF_2, IF_3, IF_5, IF_6) while others are composed of a limited number of shoreline fragments (IF_2, LN_2). Poorly defined shorelines are unlikely to give representative data in the determination of the projection plane normal to the isobases. The correlation coefficients of the remaining shorelines are greatest along the projection planes S30° W-N30° E (IF_4) and S15° W-N15° E (LN_{1B}, IF_1). It is likely that the projection plane which lies normal to the isobases of the Flandrian shorelines lies close to one of these directions, but the precise direction can not be ascertained. It can be argued that since the Lateglacial shorelines in the study area are normal to the isobases when projected along the plane S25° W-N25° E, that the same plane of projection may be appropriate for the Stadial and Flandrian shorelines (following Sutherland, 1981b). However this proposal is rejected because it presupposes that the pattern of glacio-isostatic uplift has not altered since the Lateglacial, a point refuted by Gray (1983). Since no plane of projection can be identified which lies normal to the isobases of the Flandrian and Loch Lomond Stadial shorelines the gradients of these shorelines are quoted as a range of values. The range of values is derived from the maximum to the minimum gradient values found between the projection planes S30° W-N30° E and S15° W-N15° E. The projection plane S25° W-N25° E is used however to portray the shoreline data (Fig. 82).

Trend surface analysis was undertaken on the two best developed Flandrian shorelines (IF_1, IF_4). The results (Table 23) indicate that for each shoreline the linear surface is statistically significant, but surfaces of higher order produce no significant improvement in the explanation of the results. For the latter reason trend surface maps were only produced for the linear trend surfaces (Fig. 83).

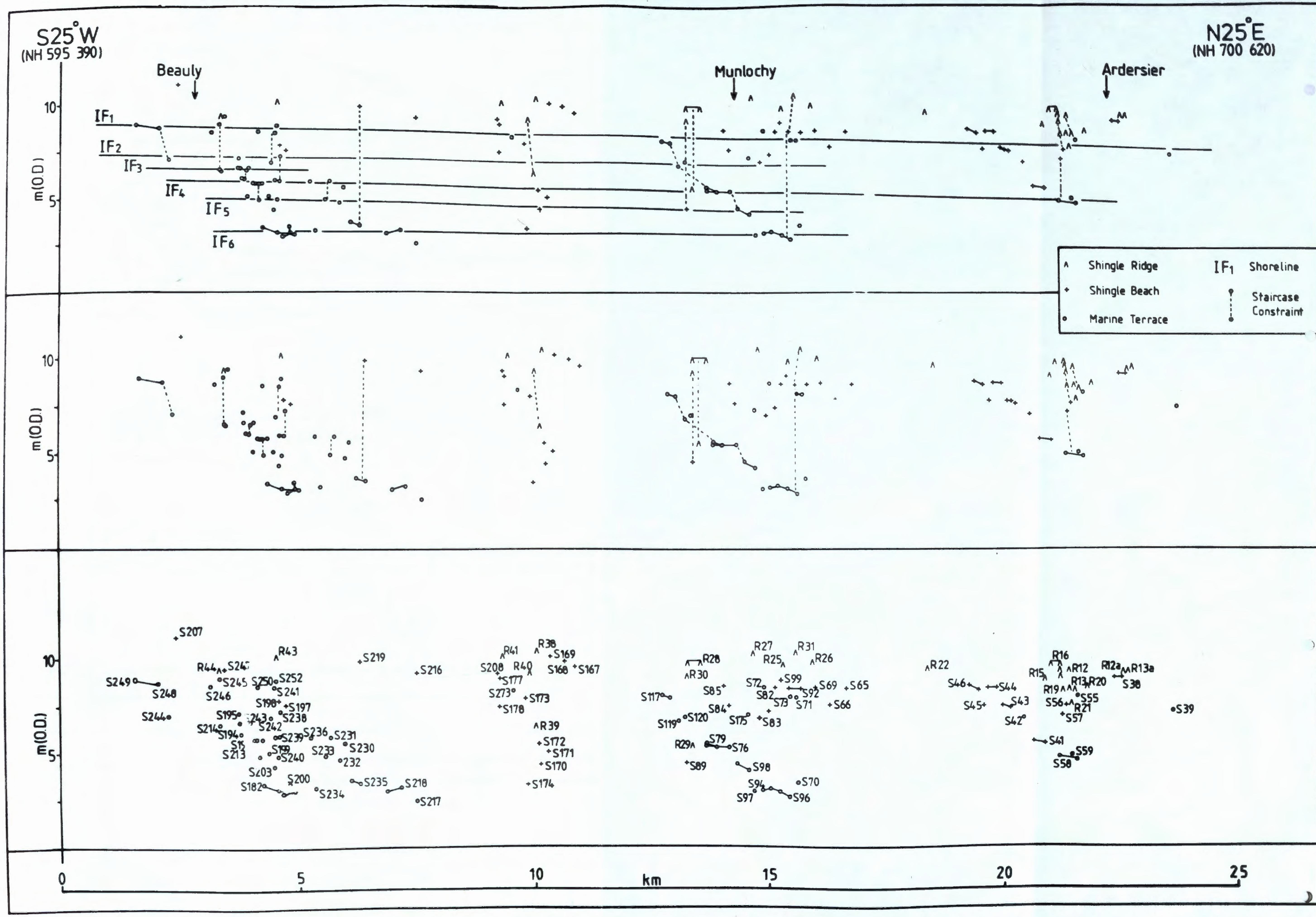


FIGURE 82a. Height-distance diagram aligned along the plane of projection S25 W-N25 E to show the location and coeeelation of Flandrian marine shoreline fragments in the inner Moray Firth area.

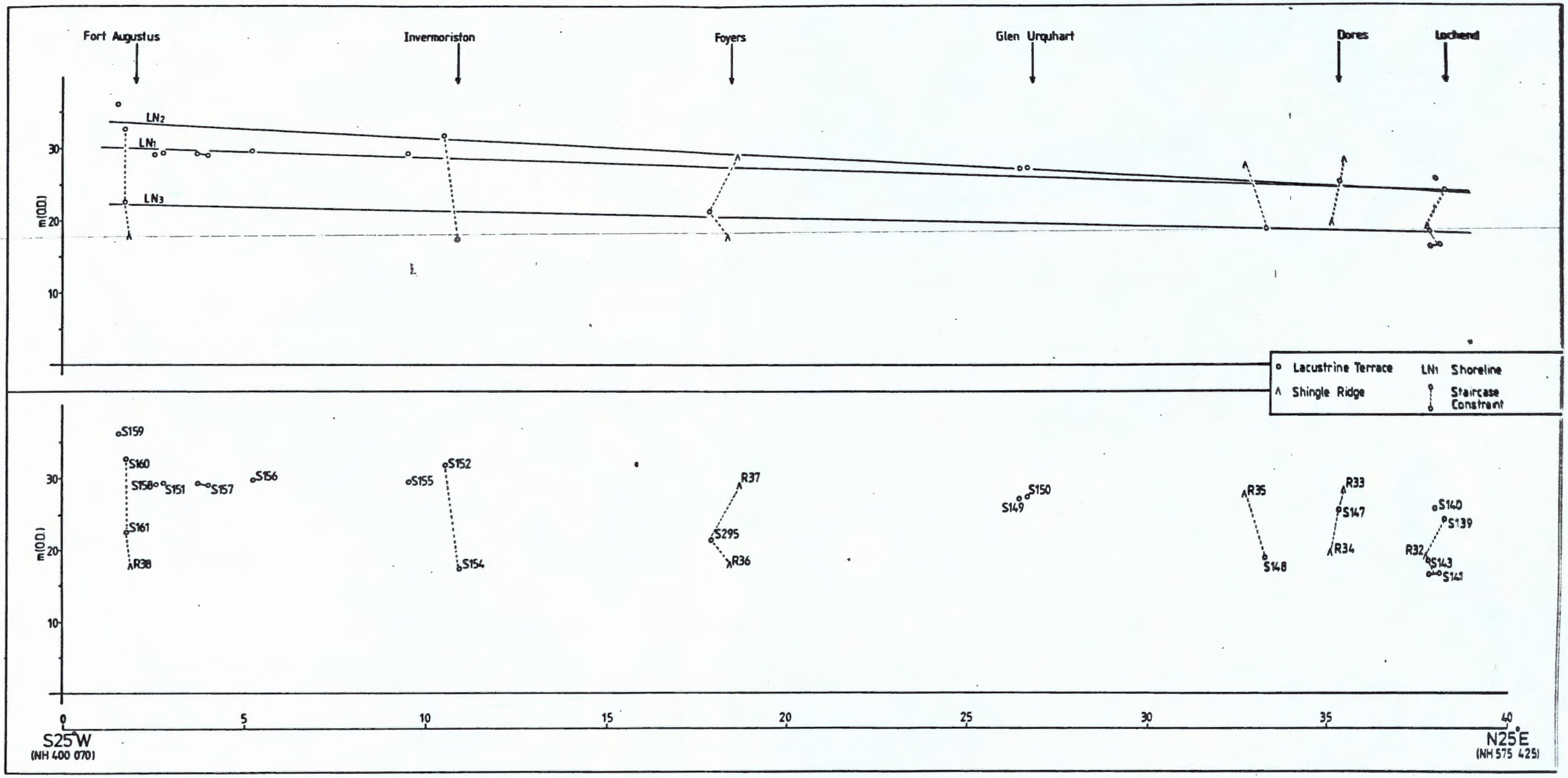


FIGURE 82b Height-distance diagram aligned along the plane of projection S25° W-N25° E to show the location of shoreline fragments, the staircase constraint and the correlation of the shoreline fragments in the Loch Ness area.

Shoreline	Gradient of Linear TSA (m/km)	Direction of Linear TSA (declines towards)		Sum of Squares (m)	Degrees of freedom	Variance	F	Confidence level (%)
IF_1	0.081	23.68° N of E	Due to Linear	3.141	2	1.571	103.69	> 99.9
			Deviations from Linear	0.227	15	0.015		
			Due to Quadratic	0.051	3	0.017	1.14	< 95
			Deviations from Quad.	0.177	12	0.015		
			Due to Cubic	0.048	4	0.012	0.58	< 95
			Deviations from Cubic	0.173	8	0.020		
IF_4	0.058	32.67° N of E	Due to Linear	2.784	2	1.392	14.35	> 99.9
			Deviations from Linear	1.163	12	0.097		
			Due to Quadratic	0.252	3	0.084	0.83	< 95
			Deviations from Quad.	0.911	9	0.101		
			Due to Cubic	0.210	4	0.053	0.37	< 95
			Deviations from Cubic	0.720	5	0.144		

TABLE 23 The gradient and direction of decline of the linear trend surfaces for the two best developed Flandrian marine shorelines in the Inner Moray Firth area and the calculation of F-ratios for the contribution of successively higher-order trend surfaces.

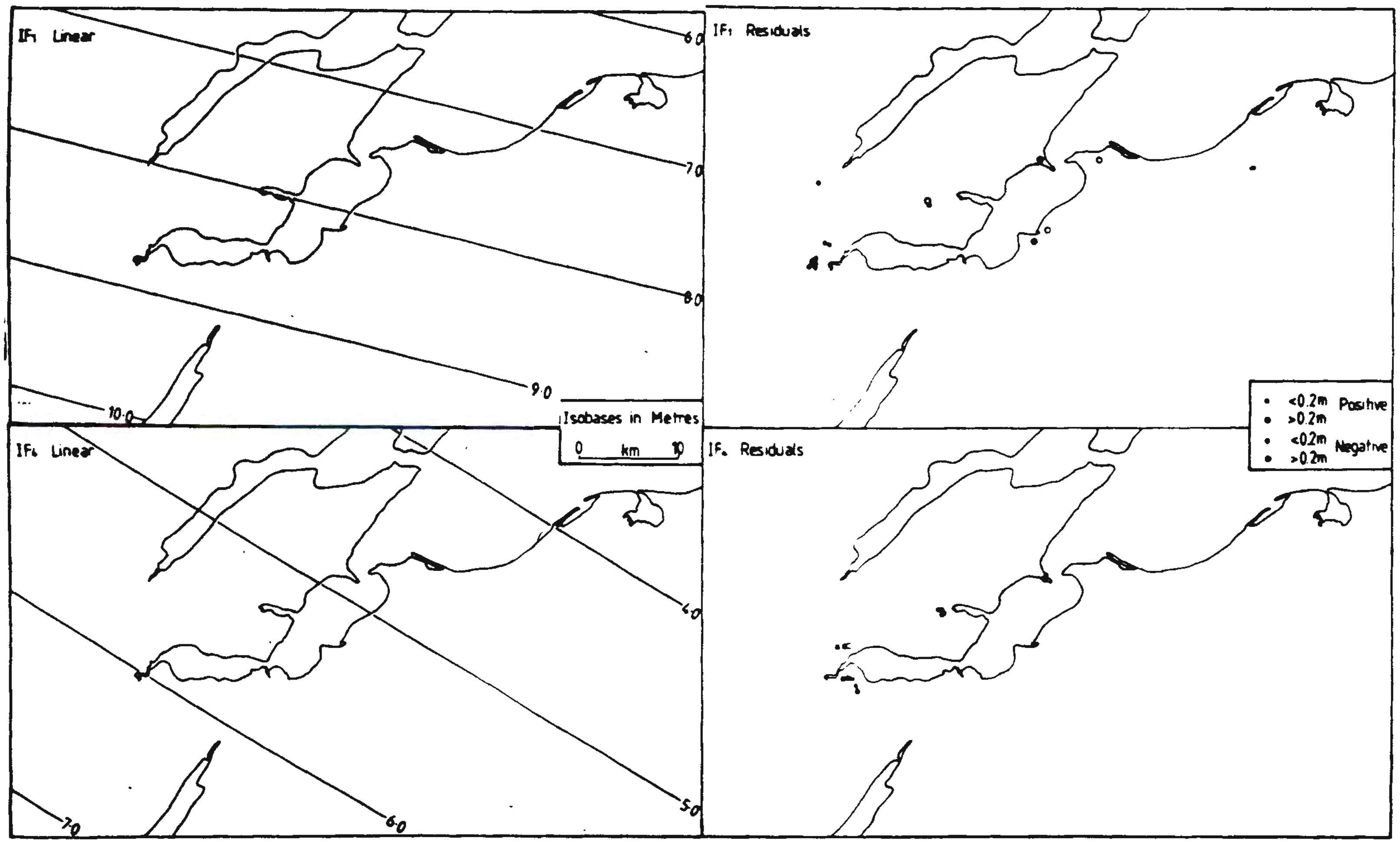


FIGURE 83 Trend surface maps produced for the best developed Flandrian shorelines in the inner Moray Firth area, and the residuals produced from these maps.

The residuals from the linear regression analysis for the best developed shorelines (IF_1, IF_4, $LN_{1A/B}$) were plotted on height distance diagrams for the projection plane S25°W-N25°E (Fig. 84). The residuals from the marine shorelines (IF_1, IF_4) can not be related to external factors. In contrast, both LN_{1A} and LN_{1B} show that the shoreline fragments at the southern end of Loch Ness are less steeply inclined than is suggested by the gradients for the shorelines as a whole.

For this reason the shoreline fragments at the northern and southern ends of Loch Ness were analysed separetely for shoreline LN_{1A}. The results (Table 24) indicate that both sub-sets of data produce lower gradients than those proposed for the shoreline as a whole. This may be interpreted in three ways:-

i) The shoreline fragments have been correlated incorrectly and do not represent the same shoreline, but this is considered unlikely on morphological grounds.

ii) The shoreline is composed of several sections which have markedly different gradients (Fig. 85).

iii) The shoreline gradients for the sub-sets are correct for the shoreline as a whole, but the two sections are separated by a dislocation (Fig. 85).

Unless more data can be obtained it is impossible to deduce which of these interpretations is correct.

3. Shorelines Around Loch Ness

a) LN_{1A}

This shoreline has a gradient between 0.116 and 0.124 m/km and it is composed of the rock platform fragments at the southern end of Loch Ness (S155-S158) and the terrace fragments at *circa* 27-24 m at the northern end of the Loch. It is suggested that this shoreline was produced during the Loch Lomond Stadial (see Chapter Seven). The

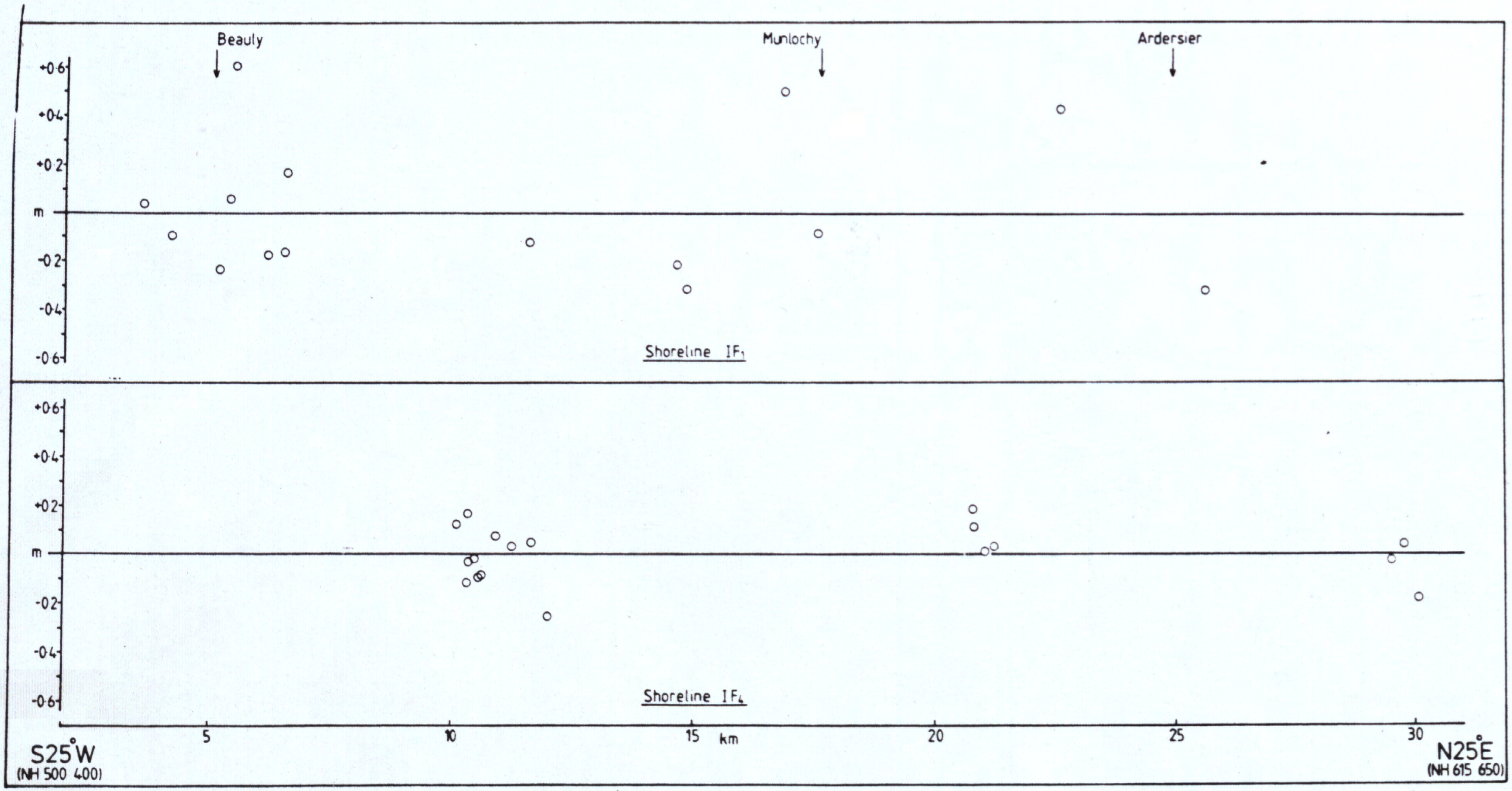


FIGURE 84 The residuals produced from the regression analysis on the two best developed Flandrian marine shorelines in the inner Moray Firth area.

Shoreline	Gradient (m/km)	Constituent Shoreline Fragments
LN_{1A}	0.1182	S139,S140,S147,S149,S150,S155-S158
LN_{1A} (North)	0.0823	S139,S140,S147,S149,S150
LN_{1A} (South)	0.0174	S155-S158

TABLE 24 Comparison of the shoreline gradients of shoreline LN_{1A} as a whole and its northern and southern components.

rock platform fragments indicate erosion of bedrock in an environment of limited fetch and this is attributed to erosion by periglacial processes. Since the buried gravel layer is also thought to have formed during the Loch Lomond Stadial and both the lacustrine rock platform and buried gravel layer were formed by periglacial processes, it is suggested that the two features were formed at a similar time. On these grounds shoreline LN_{1A} may be equivalent to the Main Late-glacial Shoreline.

b) LN_{1B}

Shoreline LN_{1B} consists of the shoreline fragments which are graded into outwash deltas (S152, S160) at the southern end of Loch Ness and the terrace fragments at circa 27-24 m at the northern end of the Loch. Shoreline LN_{1B} is related to Loch Lomond Stadial ice which lay just within its maximal limits and the shoreline has a gradient between 0.216 and 0.232 m/km. It is suggested that this shoreline formed after the Stadial ice had depressed the crust. The depression resulted in a lacustrine transgression at the southern end of Loch Ness but because it did not alter the relative position of the outlet no transgression is recorded at the northern end of the Loch (Fig. 52). For this reason shorelines LN_{1A} and LN_{1B} are represented by the same terrace fragments at the northern end of the Loch.

Shoreline LN_{1B} was therefore formed at the culmination of the transgression from the Loch Ness equivalent of the Main Lateglacial Shoreline (LN_{1A}). Since shoreline LN_{1B} is also related to a retreat margin of Loch Lomond Stadial ice it is possible to suggest that the shoreline formed at circa 10 300±200 yrs. B.P. (for this is the date placed upon the initial decay of Loch Lomond Stadial glaciers in Scotland). It has also been suggested that the formation of the Main Lateglacial Shoreline in the Beauly Firth was followed by a marine transgression which formed the steeply inclined surface of marine

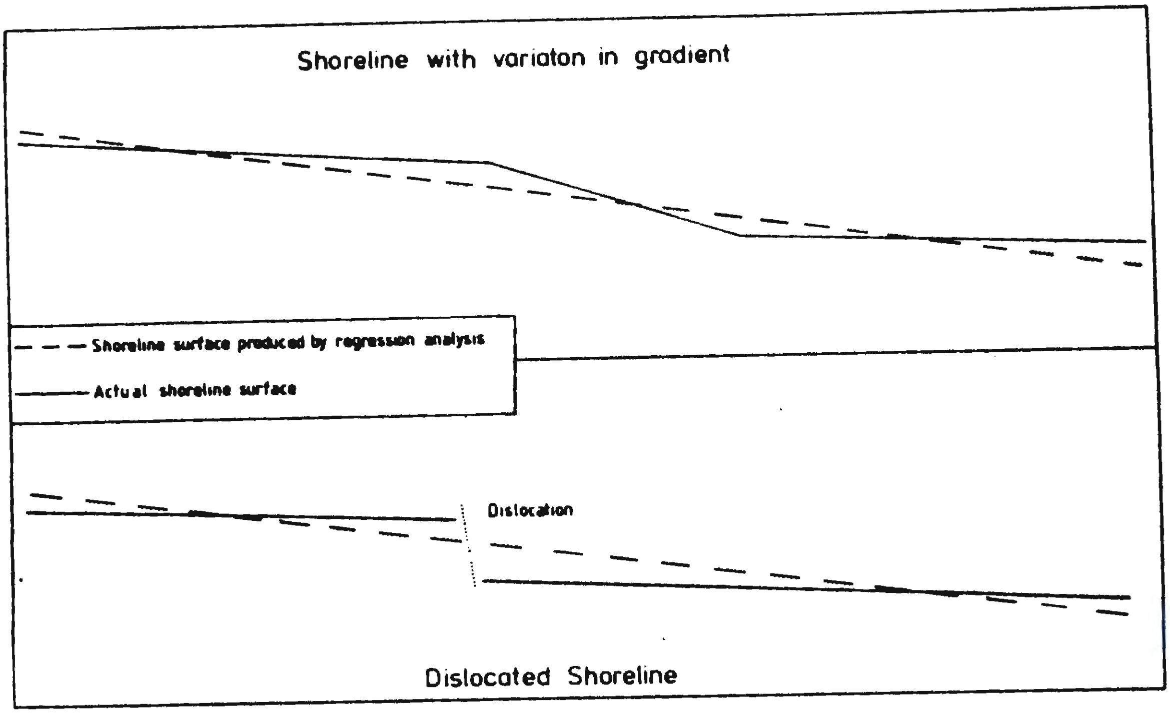


FIGURE 85 The possible explanations for the marked variation in gradient between shorelines LN_{1A} and LN_{1B} as a whole and subfragments of these shorelines.

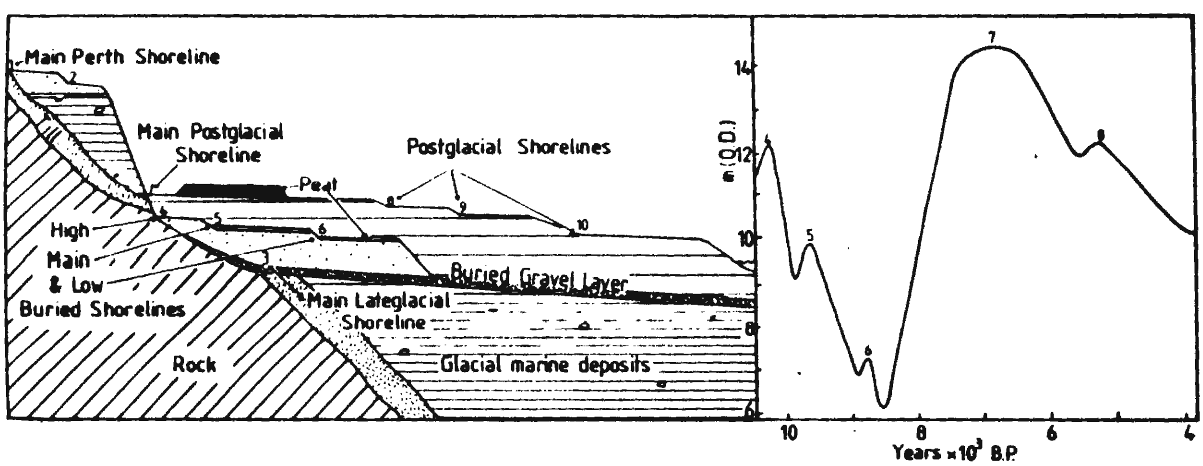


FIGURE 86 Diagrammatic representation of morphology, buried morphology and stratigraphy at the head of the Firth of Forth (modified from Sissons, 1983b) and a relative sea level curve for the same area (from Sissons and Brooks, 1971).

erosion. It has also been argued that the steeply inclined surface of marine erosion formed prior to circa 9 600 yrs. B.P., probably at the end of the Loch Lomond Stadial. Since both the steeply inclined surface of marine erosion in the Beauly Firth and shoreline LN_{1B} represent a transgression at the end of the Loch Lomond Stadial it is proposed that they were formed at the same time. On these grounds the top of the steeply inclined surface of marine erosion is equivalent to shoreline LN_{1B}.

c) LN_2

Uniquely this shoreline is derived from only 3 shoreline fragments. These 3 fragments give a shoreline gradient between 0.096 and 0.087 m/km according to the plane of projection used, however, such values must be regarded as tentative in view of the paucity of the data. It is suggested that Loch Ness occupied shoreline LN_2 soon after the jökulhlaup occurred which drained the 260 m ice-dammed lake in Glen Roy and Glen Spean. The proposed gradient of the shoreline is, however, markedly shallower than shoreline LN_{1B} which is thought to have been abandoned directly after the jökulhlaup event. The marked change in gradient between shorelines LN_{1B} and LN_2 may be interpreted in two ways. Either shoreline LN_2 was formed some time after LN_{1B} or that rapid uplift and possibly dislocation of LN_{1B} occurred soon after it was abandoned. The evidence presented for Fort Augustus suggests that a jökulhlaup which occurred after the first catastrophic flood (which emptied into the loch represented by shoreline LN_{1B}) emptied into a loch at a level near to that of shoreline LN_2. The period of time between the formation of the shorelines is therefore considered to have been short. As a result it is inferred that isostatic uplift must have been rapid at the time.

Commercial Borehole Records :- Sources

M1-M4, L5-L8, L10, L11 :-	A9 Beauly and Cromarty Firth diversions: Proposed Kessock-Inverness Bridge. Lab. Ref. S/10442. June 1974. Scottish Development Dept.
66/4. 66/5 :-	Highland Regional Council (1974) Beauly Railway Bridge. 23p.
216, 219-221 :-	Dredging Investigations Ltd. (1975) Preliminary site investigation of shoreline routes A9 trunk road Inverness-Highfield. Highland Regional Council. 123p.

4. Flandrian Marine Shorelines and Marine Sediments

a) IF_1

This shoreline correlates the highest shoreline terrace fragments which postdate the formation of the buried gravel layer. At the head of the Beauly Firth the shoreline fragments occur at circa 9 m and they decline in altitude towards the NNE, occurring at 7.9 m in Munlochy valley and at 7.4 m at Kintessack. The distribution of the terrace fragments is limited and the calculated gradient lies between 0.055 and 0.076 m/km. Flandrian shingle beaches and shingle ridges occur 0.5-2.0 m higher than this shoreline and lie against the 'low level cliff'. These shingle marine features are correlated with IF_1 but like other shingle features they were not used in the calculation of the shoreline gradient.

b) IF_4

Shoreline IF_4 is the best developed and spatially most extensive Flandrian marine shoreline, and it has a gradient between 0.059 and 0.074 m/km. The shoreline declines in altitude from circa 6 m at the head of the Beauly Firth to 4.8 m at Fortrose.

c) IF_6

Shoreline IF_6 is another well developed shoreline which consists of wide terraces which are often composed of estuarine deposits. The shoreline declines in altitude from 3.4 m at the head of the Beauly Firth to 3 m at Munlochy Bay with a gradient between 0.024 and 0.028 m/km depending on which projection plane is used.

d) IF_2, IF_3, IF_5

These shorelines are poorly developed and could only be identified at the head of the Beauly Firth and in Munlochy valley. Since these shorelines are only defined by a small number of terrace fragments which are spatially localised it is considered inappropriate to place any significance on the gradients calculated.

e) Buried Deposit of Tough Grey Silty Sand

Stratigraphical investigations north of Beauly (Figs. 69, 71, L9, L10) identified a tough grey silty sand beneath a buried layer of peat. The surface of the tough grey silty sand rises to over 5 m at its landward margin. In the same area Haggart (1982) found that the surface of this deposit lies mainly at 4-5 m, but attains a maximum altitude of 6-7 m at its landward margin. The uniform nature of the surface and its wide extent suggests that it is a buried beach, but until further, very detailed stratigraphical studies are undertaken it is not possible to give a precise altitude for the shoreline associated with these deposits. Haggart dated the peat deposits which lie on the surface of the grey silty sand by pollen analysis and ^{14}C assay. The ^{14}C date gave an age of 9 610±130 yrs. B.P. (Birm 1123, Haggart, 1982) whilst pollen analysis suggested that the grey silty sand was deposited before the rational rise in Corylus which is traditionally considered as the Pollen Zone IV/V boundary (Godwin, 1940). Haggart therefore concluded that the beach formed around circa 9 600 yrs. B.P.

f) Grey Micaceous Silty Fine Sand Layer

Stratigraphical investigations at the head of the Beauly Firth revealed a layer of grey micaceous silty fine sand, which wedges out landward, within the dark grey estuarine silty clays in a number of borehole transects (Figs. 69, 71, L1-L4, L11, L13, L14). The silty sand layer is between 0.1 and 0.7 m thick and attains a maximum altitude of circa 8 m. Haggart (1982) also identified this grey micaceous silty fine sand layer and attributed it to a marine inundation. ^{14}C dated peat samples from above and below the silty sand layer in the Moniack area indicate that it formed between circa 7 400 B.P. and circa

7 200 yrs. B.P. (Haggart, 1982). Haggart notes the similarities of the deposit with a layer found farther south by Smith et al. (1980), Morrison et al. (1981) and Smith et al. (1983). Smith, Cullingford and Haggart (in press) conclude that the grey micaceous silty fine sand layer may either represent a period of increased marine transgression or that the deposit may have resulted from a storm surge.

5. Relative Sea Level Movements

By using the detailed information presented by Haggart (1982) and Peacock et al. (1980) in conjunction with the morphological evidence presented here the relative sea level movements in the Inner Moray Firth area since the Loch Lomond Stadial are outlined. The evidence is most detailed at the head of the Beauly Firth and as a result altitudes of relative sea level are quoted for this area unless stated otherwise. The suggested sequence of events are:-

i) Lateglacial Interstadial-Early Loch Lomond Stadial. Relative sea level was stable or slowly transgressing. Extensive marine erosion by periglacial shore erosion resulted in the formation of the buried gravel layer. This period ended with the formation of the Main Lateglacial Shoreline at circa 2 m.

ii) Late Loch Lomond Stadial. Relative sea level rose rapidly, and resulted in the formation of the steeply inclined surface of marine erosion. Relative sea level rose at least 5-7 m during this period since the steeply inclined surface rises from the Main Lateglacial shoreline to circa 7-9m. In most areas the 'Low Level Cliff' was formed when relative sea level reached the top of the steeply inclined surface of marine erosion.

iii) Early Flandrian. (Prior to 9 600 B.P.) Relative sea level fell to form the buried beach whose surface rises to circa 7 m at its landward margin. The surface of the beach was deposited at or just prior to 9 600 B.P.

iv) Circa 9 600 to 8 200 B.P. Relative sea level fell during this period. Peacock et al. (1980) have suggested that sea level may have reached a minimum altitude of -6 m in the Cromarty Firth some time after 8 750 B.P. On the basis of tilted shorelines it may be infered that relative sea level attained a higher altitude at the head of the Beauly Firth, but what this level is remains unknown.

v) Circa 8 200 to 5 800 B.P. By circa 8 200 B.P. sea level had started to rise and culminated at circa 9 m between 7 100±120 B.P. and 5 775±85 B.P. (Haggart, 1982). The culmination of the rise is correlated with shoreline IF_1. During the rise in relative sea level a storm surge or period of increased marine transgression between circa 7 400 and 7 200 yrs. B.P. deposited a layer of grey micaceous silty fine sand up to an altitude of circa 8 m.

vi) Circa 5 800 B.P. to Present. Relative sea level had started to fall by circa 5 800 B.P. As the fall progressed towards present sea level, five lower Flandrian shorelines were formed (IF_2-IF_6). The wide estuarine terrace fragments associated with shorelines IF_4 and IF_6 may indicate temp-orarily stable sea levels.

6. Correlations with Other Areas of Scotland

The most detailed evidence of the changes in relative sea level since circa 11 000 B.P. in Scotland occur in the Forth valley. The sequence of events outlined for the Forth valley has been summarised on several occasions (eg. Sissons, 1976b, 1983b) and is presented here as a relative sea level curve and a sectional diagram (Fig. 86). The sequence of events outlined in the Forth valley is essentially the same as that proposed in the Inner Moray Firth. As a result direct correlations are possible.

Sissons (1976a, b, 1983b) indicated that the transgression which followed the formation of the Main Lateglacial Shoreline culminated in the formation of the High Buried Beach. Sissons (1966) noted that the High Buried Beach lies on outwash associated with the Menteith moraine and that it is absent from within the morainic arc. He suggested that ice was still present at the moraine when the High Buried Beach was formed, and proposed a date of formation between 10 300 to 10 100 B.P. (Sissons, 1976b). In the Inner Moray Firth area the transgression which followed the formation of the Main Lateglacial Shoreline formed the steeply inclined surface of marine erosion, and this has been associated with shoreline LN_{1B} which is related to Loch Lomond Stadial ice which lay just within the maximal ice limit. The exact dates of formation of the inclined surface and shoreline LN_{1B} are unknown, however, it is suggested that these features are approximate correlations of the High Buried Beach in the Forth valley.

In the Forth valley the formation of the High Buried Beach is followed by a fall in relative sea level (Sissons, 1966). Associated with this regression are the Main and Low Buried Beaches dated at <u>circa</u> 9 600 B.P. and <u>circa</u> 8 800 B.P. respectively by pollen analysis and ^{14}C dates (Sissons, 1966; Newey, 1966; Kemp, 1971; Sissons and Brooks, 1971). Cullingford <u>et al</u>. (1980) also identified a buried beach in the Tay valley dated to 9 640±140 B.P. which they correlated with the Main Buried Beach in the Forth valley. The buried beach identified by Haggart (1982) and in this study at the head of the Beauly

Firth is similar in composition to those found in SE Scotland. The ^{14}C date of 9 610±130 B.P. (Birm 1123, Haggart, 1982) obtained from the peat resting on the buried beach is comparable with those obtained for the Main Buried Beach in the Tay and Forth estuaries. On this basis the buried beach at the head of the Beauly Firth is correlated with the Main Buried Beach. However, the absence of an equivalent to the Low Buried Beach in the Inner Moray Firth area may reflect the limited nature of the stratigraphical work carried out in the area.

In the Beauly Firth area, Haggart (1982) indicated that sea level had begun to rise by 8 200 B.P. He suggested that the transgression culminated at circa 9 m at the head of the Beauly Firth between 7 100±120 B.P. and 5 775±85 B.P. The deposits formed at the culmination of the transgression are represented by shoreline IF_1 which is the highest visible Flandrian shoreline in the area. Sissons et al. (1966) called the highest visible Flandrian shoreline in the Forth valley the Main Postglacial Shoreline. Shorelines from other areas of Scotland (Table 25) have been correlated with the Main Postglacial Shoreline which is thought to have been abandoned before 6 500 B.P. in the western Forth valley (Sissons and Brooks, 1971). However, Smith et al. (1983) have suggested that the culmination of the transgression may have been time transgressive, occurring progressively later at sites farther from the centre of isostatic uplift. Shoreline IF_1 is considered equivalent to the Main Postglacial Shoreline for several reasons. Firstly it forms the highest visible Flandrian shoreline in the study area. Secondly its gradient between 0.055 and 0.076 m/km is similar to those derived elsewhere for the Main Postglacial Shoreline (Table 25). Finally the time of formation of IF_1 is comparable with the date of formation of the Main Postglacial Shoreline.

Shoreline	Location	Gradient (m/km)	Source
MPG PG-2 PG-3 PG-4	Forth Valley	0.076 0.071 0.047 0.000 (short)	Sissons, 1976b D.E. Smith, 1968
MPG LC1 LC2 LC3 LC4 LC5	Tay Valley	0.090 0.032 (short) 0.019 0.000 (short) 0.027	Cullingford,1972
PS1 PS3 PS5	Firth of Lorne	0.05 0.01 0.01	Gray, 1974b
MPG	Jura and Islay	0.05	Dawson, 1979
CF1 CF2 CF3 CF4 CF5 CF6	Cowal Peninsula	0.062 0.051 0.030 (short) 0.039 0.030 0.025	Sutherland, 1981b

TABLE 25 The location and gradients of Flandrian shorelines identified in Scotland. MPG = Main Postglacial, (short) = gradient calculated from too small a data set.

Shoreline identified in present study	Suggested correlation
IF_1	MPG, PS1, CF1
IF_4	PG-3, LC1, PS3, CF4
IF_6	LC4 or LC5, PS5, CF6

TABLE 26 Correlation of marine Flandrian shorelines in the Inner Moray Firth area with shorelines identified in other areas of Scotland (see Table 25).

Below the Main Postglacial Shoreline several lower Flandrian shorelines have been identified throughout Scotland (Table 25). D.E. Smith (1968) identified 3 lower shorelines in the Forth valley, (PG1-PG3), whilst Cullingford (1972) identified 5 (LC1-LC5) in the Tay. Gray (1974b) identified 4 lower Flandrian shorelines (PS2-PS5) in the Firth of Lorne area and Sutherland (1981b) outlined 5 shorelines (CF2-CF6) in the Cowal Peninsula. Dates for these shorelines are largely absent and tentative correlations have been attempted on the basis of morphology (Cullingford, 1972). In each area certain of the lower Flandrian shorelines are well developed and they have been correlated on this basis (Table 26). It is tentatively suggested that the two well developed lower Flandrian shorelines (IF_4, IF_6) in the Inner Moray Firth area can be correlated with other parts of Scotland in a similar way. Therefore shoreline IF_4 may be tentatively correlated with PG3 in the Forth (Sissons et al., 1966), LC1 in the Tay (Cullingford, 1972), PS3 in the Firth of Lorne (Gray, 1974b) and CF4 in the Cowal Peninsula (Sutherland, 1981b). Similarly shoreline IF_6 may be correlated with shorelines LC4 or LC5, PS5, and CF6 (Table 25). The gradients of shorelines IF_6, LC4, LC5, PS5 and CF6 (Table 25) are markedly similar and therefore are in accord with the proposed correlation. In contrast, shoreline IF_4 has a markedly steeper gradient than those calculated for shorelines LC1, PG3, PS3 and CF4. Although the steeper gradient for shoreline IF_4 could reflect complications in isostatic movements, it is thought more likely to be due to limitations in the extent of the data available.

7. Isostatic Considerations

A redepression of the crust is indicated when the Loch Lomond Stadial and Flandrian shoreline sequence is combined with the Lateglacial shoreline sequence. The gradients of shorelines ILG_{10} and LN_{1A} are significantly lower than the gradient of LN_{1B} which is associated with ice near the maximum of the Loch Lomond Stadial ice limits at Fort Augustus. The steeper gradient (although possibly complicated by dislocations of the shoreline) implies that isostatic tilting initiated by Loch Lomond Stadial ice was greater than that associated with the final decay of the Late Devensian ice sheet. Since it has been suggested that ice lay in Loch Ness and therefore beyond the Stadial ice limits when shoreline ILG_{10} was formed it is inferred from the shoreline gradient evidence that this ice mass was not of a considerable thickness. It is suggested that the ice that occupied Loch Ness was a dead ice mass, which was either unrelated to the main ice sheet or representative of an ice sheet that was stagnant and confined to the bottoms of valleys.

The shorelines also indicate that initial isostatic recovery at the end of the Loch Lomond Stadial was rapid. It is suggested that shoreline LN_2 formed shortly after LN_{1B} since a later jökulhlaup deposit at Fort Augustus is associated with this shoreline (LN_2). The gradients indicate that nearly half of the isostatic uplift since the formation of LN_{1B} occurred before the formation of LN_2. The Flandrian shorelines indicate that differential uplift continued between the formation of shorelines IF_1 and IF_6.

Isostatic readjustments since the Loch Lomond Stadial may not have been uniform. Specific shorelines in Loch Ness (LN_{1A}, LN_{1B}) indicate that subsections of the shorelines have a lower gradient than each shoreline as a whole. Similar variations in tilt have been noted in the Forth valley (Sissons, 1972) and in Glen Spean (Sissons and Cornish, 1982). It is also possible to suggest that some of the shorelines in Loch Ness may be dislocated (Fig. 84). Limited evidence is therefore available to suggest that the glacio-isostatic uplift in the Inner Moray Firth area may have been complex. However, until more data becomes available it remains difficult to tell how these complications arose.

8. Summary

The shorelines formed during the Loch Lomond Stadial and the Flandrian for the Inner Moray Firth area indicated complex movements in relative sea level. Essentially relative sea level rose from the Main Lateglacial Shoreline to form the steeply inclined surface of marine erosion in the Beauly Firth. This rise in sea level is attributed to a redepression of the earth's crust (as indicated by the shorelines of Loch Ness) initiated by a build up of ice during the Loch Lomond Stadial. At the end of the Loch Lomond Stadial relative sea level began to fall and it formed a buried beach at *circa* 9 600 B.P. which is correlated with the Main Buried Beach in the Forth Valley. Soon after 9 200 B.P. relative sea level attained a minimum altitude of *circa* -6 m (Peacock *et al.*, 1980) before it rose once more to culminate at 9 m between 7 100 and 5 800 B.P. when shoreline IF_1 was formed (this is equivalent to the Main Postglacial Shoreline). Since *circa* 5 800 B.P. isostatic uplift has continued and relative sea level has fallen to produce 5 lower Flandrian shorelines (IF_2-IF_6), two of which (IF_4, IF_6) may correlate with Flandrian shorelines identified elsewhere in Scotland.

CHAPTER TWELVE

CONCLUSIONS

1. Methodology

All identifiable marine, fluvial and glacial features and deposits below 100 m. O.D. in the study area have been examined by detailed morphological mapping at a scale of 1:10 000. In addition, all terrace fragments and some dead-ice deposits have been accurately instrumentally levelled in relation to Ordnance Datum (Newlyn), whilst stratigraphical studies have been undertaken on some deposits. In evaluating the accuracy of the altitude data, it has been suggested that individual shorelines can be separated if the surface altitudes are more than one metre apart. Interpretations of the sequence of deposits and landforms has mainly been based on morphology because of limited stratigraphical evidence, but has enabled detailed local sequences of events to be outlined. Correlation of the shoreline fragments within the study area has been aided by the construction of height-distance diagrams with their x-axes aligned normal to the inferred isobase pattern. Alternative schemes of fragment correlation have been considered but by applying morphological constraints and isostatic theory it has been possible to reduce the schemes to a single sequence of shorelines.

2. Lateglacial Shorelines and Deglaciation

In the Inner Moray Firth area 10 tilted shorelines related to the deglaciation of the Late Devensian ice sheet have been identified. The shorelines are best represented on a height-distance diagram aligned along the plane S25^{o}W-N25^{o}E, with individual shorelines declining in altitude towards N25^{o}E. Each shoreline has a lower regional gradient than the one above it and on the basis of gradient the shorelines may be divided into 3 groups.

The highest group of shorelines, ILG_1 and ILG_2, extend as far west as Inverness and have regional gradients in excess of 0.55 m/km. Shoreline fragments related to these two shorelines are best developed east of Ardersier where they attain altitudes of 28.5 m (ILG_1) and 27 m (ILG_2). However, these shorelines rise up to circa 35 m (ILG_2) and possibly circa 40 m (ILG_1) at Inverness where they are related to a former ice margin just south of Inverness.

The second group of shorelines, ILG_{3A}-ILG_{6A}, have regional gradients which are markedly similar to each other (0.457-0.367 m/km). Each shoreline also extends farther west than the one which precedes it, reflecting ice recession westwards. Shoreline ILG_{3A} rises up from 23.0 m near Nairn to 30.6 m at Inverness and is related to ice in the Ness valley and in the Beauly Firth. It has been suggested that the ice in the Beauly Firth was extensive enough for meltwaters to overflow into Munlochy valley. Farther east stagnant masses of ice were present in the Nairn valley and probably south of Ardersier. Shoreline ILG_{4A} rises from 18.8 m at Lochloy to 29.6 m at Englishton. The fluvio-glacial features associated with this shoreline indicate that ice still lay in the Ness valley but had retreated just west of Englishton in the Beauly Firth and entirely from the Cromarty Firth. By the time shoreline ILG_{5A} was formed the ice had retreated west of Balblair, south of Kiltarlity and from the lower Conon valley and large deltaic deposits were formed in these areas. However ice retreat in the Orrin and Ness valleys was limited during this same period of time. Shoreline ILG_{6A} is only poorly developed and rises from 14.8 m at Lochloy to 24.2 m in Strath Conon. This shoreline is related to limited ice retreat in Glen Orrin, Strath Conon and Strath Glass.

The lowest group of shorelines, ILG_{7B}-ILG_{10}, have gradients which are significantly lower (0.235-0.150 m/km) than those in group two. Of these shorelines only ILG_{8B} and ILG_{10} are well developed, the former rising to 20.4 m in the Beauly Firth and the latter to 16.4 m near Kiltarlity. Shorelines ILG_{7B}-ILG_{9B} are not related to a specific ice margin but it is inferred that ice retreat during shoreline formation was limited in the Kiltarlity and Ness valley areas. In contrast shoreline ILG_{10} is related to an ice margin south of Kiltarlity and probably also to an ice margin at the northern end of Loch Ness.

The sequence of shorelines indicates that deglaciation occurred rapidly in the deep water channels of the Moray, Inverness, Beauly and Cromarty Firths, probably as a result of ice calving. Rapid ice recession in the deep water Firths left large masses of dead ice inland, whilst in the narrow valleys (Ness, Glass, Conon, Orrin), where the ice sheet became land-based, ice wastage would have been considerably slower.

The retreat of the ice margin in the Ness valley is associated with a substantial fall in relative sea level at Inverness from circa 35 m (and possibly circa 40 m) to 16 m, whilst significant falls in relative sea level also occur at Balblair (at least 13 m) and Muir of Ord (at least 6 m) each being related to limited retreat of the associated ice margin. On the basis of faunal evidence from the Cromarty Firth (Peacock, 1974; Peacock et al., 1980) this fall in relative sea level is tentatively dated to more recent than 13 500 yrs. B.P. but prior to 11 000 yrs. B.P. There is insufficient evidence to suggest that the majority of the ice remained active during the fall in relative sea level and it is proposed that much of the fall took place whilst a mass of dead ice occupied the Ness valley and probably Loch Ness. This view of stagnant ice decay is also supported by the low regional gradient of the lowest Lateglacial shoreline (ILG_{10}). It is suggested that Loch Ness became ice free during the Lateglacial Interstadial.

The shoreline sequence has also been used to correlate the

Lateglacial events in the Inner Moray Firth with other areas of Scotland. It is tentatively proposed that shorelines ILG_{3A}-ILG_{5A} can be correlated with the Main Perth Raised Shorelines in the Forth and Tay valleys and with shoreline CLG_2 in the Cowal Peninsula. The lower shorelines in the study area (ILG_{7B}-ILG_{10}) may be tentatively correlated with the Lower Perth Shorelines (LP1-LP4) in the Tay valley and shorelines CLG_3-CLG_8 in the Cowal Peninsula.

3. Events of the Loch Lomond Stadial

With the deterioration of climatic conditions associated with the commencement of the Loch Lomond Stadial periglacial marine erosion became important and formed the buried gravel layer. The landward margin of the buried gravel layer is correlated with the Main Lateglacial Shoreline of Sissons (1974b). In Loch Ness a well-developed rock platform which makes up part of shoreline LN_{1A} is tentatively considered as the lacustrine equivalent of the Main Lateglacial Shoreline around Loch Ness. The accumulation of Loch Lomond Stadial ice initiated a lacustrine transgression in Loch Ness and possibly at the coast where it formed the steeply-inclined surface of marine erosion landward of the Main Lateglacial Shoreline. It is proposed that the Loch Lomond Stadial ice reached its maximum limit at the southern end of Loch Ness and that as it began to decay a prominent shoreline, LN_{1B}, was formed. After the ice had retreated some 8 km the level of the loch was temporarily raised as a result of the catastrophic drainage of the ice-dammed lake in Glen Spean and Glen Roy. It is proposed that water from the jökulhlaup which drained the ice-dammed lake deposited a large outwash fan at the southern end of Loch Ness and temporarily increased the level of the loch by 4 m, this change in level being in contrast to the view of Sissons (1979a). Outflow of this water at the northern end of the loch resulted in extensive erosion in the Ness valley and the deposition of a large alluvial fan at Inverness. This erosion is considered to have lowered the outlet of the loch and resulted in a fall of loch level of up to 8 m.

4. Flandrian Events

From the top of the steeply inclined surface of marine erosion landward of the Main Lateglacial Shoreline, at circa 7-9 m, relative sea level fell to 5-7 m to form a buried beach dated at 9 600 yrs. B.P. (Haggart, 1982) which is correlated with the Main Buried Beach in the Forth valley. After 9 600 yrs. B.P. relative sea level fell and it has been suggested that it may have reached a minimum altitude of -6 m in the Cromarty Firth after 9 200 yrs. B.P. but prior to 8 200 yrs. B.P. (Peacock et al., 1980; Haggart, 1982). Subsequently relative sea level rose to form shoreline IF_1 which is dated between 7 100±120 yrs. B.P. and 5 775±85 yrs. B.P. (Haggart, 1982). This shoreline is correlated with the Main Postglacial Shoreline identified in other areas of Scotland and therefore its date of formation may be between 6 800 and 6 000 yrs. B.P. (eg. Smith et al., 1983). After 6 000 yrs. B.P. relative sea level fell and five lower Flandrian shorelines were formed (IF_2-IF_6). Two of the lower Flandrian shorelines (IF_4, IF_6) are well developed and are tentatively correlated with well-developed Flandrian shorelines in the Cowal Peninsula (CF_4, CF_6, Sutherland, 1981b), the Firth of Lorne (PS3, PS5, Gray, 1974b) and in SE Scotland (PG3, D.E. Smith, 1968; LC1, LC4 or LC5, Cullingford, 1972).

5. Isostatic Considerations

The Lateglacial and Flandrian shoreline sequences indicate a period of glacio-isostatic uplift interrupted by crustal depression during the Loch Lomond Stadial. During the decay of the Late Devensian ice sheet glacio-isostatic uplift was continuous, as indicated by the successively lower regional gradients of Lateglacial shorelines ILG_1-ILG_{10}. However it is possible that whilst shorelines ILG_{3A}-ILG_{5A} were formed isostatic tilting was reduced due to a stillstand of ice at Inverness. Thereafter isostatic uplift was rapid with 60% of the tilting of the pre-Loch Lomond shorelines being achieved between the formation of shorelines ILG_{5A} and ILG_{10}.

Accumulation of ice during the Loch Lomond Stadial resulted in a redepression of the earth's crust and the formation of a shoreline (LN_{1B}) with a steeper gradient than shoreline ILG_{10}. Subsequent uplift and tilting may not have been uniform since shoreline fragments at the southern end of Loch Ness are less steeply inclined than the shoreline in which they occur. Isostatic recovery was also rapid at the end of the Loch Lomond Stadial with 70% of the subsequent tilting occurring between the formation of shorelines LN_{1B} and IF_1.

6. Future Research

There are several areas of future research which arise from the present study.

a) Detailed studies of the stratigraphy and micro/macro-fossil content of the sediments in the Beauly, Inverness and Moray Firths may provide more information on the time scale, sequence of events and environmental changes which accompanied the Lateglacial shoreline sequence. Rediscovery of shell sites recorded in the literature may also be of value.

b) Stratigraphical studies of cores from Loch Ness may reveal environmental changes since deglaciation and cast further light upon the effects and timing of the catastrophic flood event.

c) Stratigraphical studies from some of the large kettleholes around the Beauly and Inverness Firths may reveal marine incursions and produce information relating to the marine limit of the area.

d) Investigation of the relationship between the moraines in the Loch Ashie and Easter Kinkell areas and the proposed shoreline sequence may provide information on whether a large amount of the ice remained active in the study area prior to or during the fall in Lateglacial relative sea level at Inverness.

7. Final Remarks

Until more ^{14}C dates become available, determination of the time scale of the events described here and the correlations proposed with Late Devensian events elsewhere in Scotland will remain problematical. However, the fall in relative sea level associated with the deglaciation of the Late Devensian ice sheet, the subsequent ice advance during the Loch Lomond Stadial and the effects of the Main Postglacial transgression are all recorded here and elsewhere in Scotland. In contrast, the fluctuations in the levels of Loch Ness are unique and as such are possibly the most distinctive events in the study area. The pattern of land movements, in which crustal recovery during the Late Devensian was interrupted by crustal depression during the Loch Lomond Stadial before resuming during the Flandrian, demonstrates the sensitivity of crustal response to ice loading and unloading in this area.

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APPENDIX I

ALTITUDE DATA

1. PRESENT COASTAL DEPOSITS

1. Saltmarshes

i)

NH 5652 4916	2.15
NH 5650 4913	2.26
NH 5646 4910	2.33
NH 5642 4911	2.48
NH 5639 4910	2.52
NH 5634 4909	2.55
NH 5631 4908	2.51
NH 5627 4907	2.54
NH 5622 4906	2.51
NH 5616 4902	2.52
NH 5611 4900	2.56
NH 5607 4898	2.62
NH 5604 4896	2.54
NH 5601 4895	2.66
NH 5600 4893	2.49

ii)

NH 5563 4866	2.29
NH 5559 4878	2.53
NH 5554 4870	2.23
NH 5548 4870	2.30
NH 5543 4867	2.21
NH 5540 4865	1.86

iii)

NH 5922 4588	2.90
NH 5925 4589	2.85
NH 5929 4590	2.81
NH 5934 4591	2.70
NH 5936 4592	2.79

iv)

NH 6535 5307	2.07
NH 6532 5305	2.17
NH 6529 5304	2.34
NH 6527 5313	2.32
NH 6530 5315	2.24
NH 6532 5316	2.23
NH 6584 5346	2.09
NH 6581 5345	2.13
NH 6578 5344	2.27
NH 6575 5342	2.26
NH 6572 5340	2.27
NH 6568 5338	2.13
NH 6566 5335	2.10
NH 6563 5334	2.23
NH 6559 5332	2.01

v)

NH 7386 4978	2.74
NH 7383 4979	2.39
NH 7377 4979	2.16
NH 7374 4977	2.10
NH 7371 4974	2.21
NH 7364 4973	2.15
NH 7358 4971	2.04
NH 7355 4970	2.22
NH 7353 4968	2.33
NH 7351 4967	2.27
NH 7348 4964	2.35

2. Mudflats

i)

NH 6580 5337	1.39
NH 6584 5339	1.29
NH 6587 5340	1.38
NH 6589 5342	1.31
NH 6564 5327	1.39
NH 6567 5330	1.30
NH 6570 5332	1.35
NH 6573 5334	1.27
NH 6575 5335	1.27

ii)

NH 5580 4871	1.78
NH 5584 4873	1.57
NH 5587 4874	1.47
NH 5591 4877	1.59
NH 5594 4879	1.87
NH 5597 4882	1.62

3. Shingle Beach

i)

NH 7536 5218	2.57
NH 7541 5220	2.94
NH 7546 5223	2.76
NH 7553 5226	3.21
NH 7557 5229	3.04

ii)

NH 6159 4817	2.90
NH 6165 4815	3.42
NH 6172 4816	3.69
NH 6178 4817	2.74
NH 6183 4817	3.04

2. RAISED SHORELINE FRAGMENTS

Grid Ref	Alt.	Grid Ref.	Alt.	Grid Ref.	Alt.
S1		S3		S7	
NJ 0018 6043	16.08	NJ 0053 6070	9.71	NH 9906 5956	22.96
NJ 0022 6044	16.06	NJ 0057 6068	9.69	NH 9902 5954	22.56
NJ 0029 6047	15.71	NJ 0062 6069	6.70	NH 9897 5952	22.67
NJ 0034 6046	15.87	NJ 0068 6070	9.33	NH 9893 5951	23.35
NJ 0039 6043	16.17	NJ 0073 6070	9.06	NH 9888 5959	23.54
NJ 0043 6042	16.18	NJ 0077 6070	9.02	NH 9884 5948	23.52
NJ 0047 6040	16.08			NH 9881 4946	23.42
NJ 0051 6039	16.18	S4		NH 9878 4945	23.18
NJ 0054 6037	16.07	NJ 0104 6046	7.68		
NJ 0058 6035	15.88	NJ 0100 6050	7.22	S8	
NJ 0062 6034	15.86	NJ 0098 6052	7.33	NH 9439 5851	21.92
NJ 0065 6032	15.60	NJ 0095 6055	7.65	NH 9443 5854	22.28
NJ 0069 6030	15.24	NJ 0092 6059	7.49	NH 9447 5855	22.43
NJ 0072 6030	15.29	NJ 0090 6063	7.47	NH 9451 5856	22.48
				NH 9455 5856	22.21
S2		S5		NH 9459 5857	22.50
NJ 0100 6033	11.62	NH9923 5922	24.04	NH 9389 5840	21.71
NJ 0097 6035	11.98	NH9927 5924	23.98	NH 9386 5839	21.66
NJ 0093 6036	12.07	NH9929 5927	24.03	NH 9381 5838	21.78
NJ 0084 6038	12.24	NH9930 5930	23.88	NH 9376 5836	21.74
NJ 0080 6038	12.33	NH9928 5928	24.09	NH 9372 5834	21.82
NJ 0076 6038	12.50			NH 9367 5833	21.69
NJ 0073 6039	12.61	S6			
NJ 0069 6040	12.67	NH 9940 5950	21.68	S9	
NJ 0065 6042	12.65	NH 9939 5946	21.92	NH 9466 5859	21.82
NJ 0061 6045	12.67	NH 9938 5942	22.11	NH 9465 5859	21.98
NJ 0058 6048	12.81	NH 9938 5938	22.17	NH 9469 5859	21.90
NJ 0056 6050	12.81	NH 9936 5935	22.07	NH 9475 5861	21.94
NJ 0053 6056	12.43	NH 9934 5930	21.97		
NJ 0049 6059	12.61	NH 9932 5925	21.79	S10	
NJ 0046 6060	12.76	NH 9931 5922	21.79	NH 9437 5863	18.44
NJ 0042 6059	12.93	NH 9929 5919	21.99	NH 9440 5864	18.61
NJ 0038 6058	12.95	NH 9926 5916	22.35	NH 9442 5865	18.43
NJ 0034 6057	12.94	NH 9923 5914	22.32	NH 9445 5866	18.41
NJ 0030 6055	13.36	NH 9919 5911	22.10	NH 9448 5868	18.05

S10 (cont.)

NH 9412	5855	18.42
NH 9416	5856	18.39
NH 9421	5856	18.13
NH 9425	5858	18.28
NH 9365	5841	18.31
NH 9369	5843	18.97
NH 9373	5845	19.01
NH 9377	5847	18.77
NH 9380	5848	18.86
NH 9383	5849	18.97

S11

NH 9372	5855	15.15
NH 9376	5856	15.05
NH 9379	5857	15.07
NH 9383	5859	15.10
NH 9386	5861	15.05
NH 9390	5863	15.01
NH 9393	5864	15.13
NH 9397	5865	14.98
NH 9399	5865	14.93
NH 9404	5856	14.99
NH 9408	5865	14.95
NH 9412	5865	14.77
NH 9416	5865	14.61
NH 9420	5866	14.66

S12

NH 9365	5817	23.72
NH 9362	5817	23.71
NH 9358	5816	23.89
NH 9354	5816	23.70
NH 9350	5816	23.54
NH 9366	5824	23.19
NH 9370	5825	23.29
NH 9374	5827	23.31
NH 9379	5828	23.35
NH 9384	5828	23.26

S12 (cont.)

NH 9388	5829	23.25
NH 9391	5829	23.25
NH 9395	5829	23.39

S13

NH 9269	5774	24.77
NH 9272	5776	24.80
NH 9275	5778	24.82
NH 9278	5780	24.94
NH 9282	5782	25.06
NH 9285	5783	25.21

S14

NH 9203	5758	23.75
NH 9206	5759	23.74
NH 9210	5760	23.78
NH 9214	5761	23.84
NH 9218	5762	23.83
NH 9221	5763	23.83
NH 9224	5765	23.95
NH 9227	5766	23.96
NH 9231	5767	23.94
NH 9235	5767	23.91
NH 9239	5767	23.94
NH 9243	5767	23.77
NH 9247	5768	23.83
NH 9252	5769	23.99

S15

NH 9141	5776	14.68
NH 9144	5776	14.53
NH 9149	5775	14.51
NH 9153	5775	14.67
NH 9157	5775	14.81
NH 9161	5775	14.58
NH 9165	5775	14.85
NH 9168	5775	14.83
NH 9172	5775	14.93

S15 (cont.)

NH 9176	5775	14.98
NH 9180	5774	14.88
NH 9184	5775	14.82
NH 9200	5776	14.49
NH 9204	5776	14.37
NH 9207	5776	14.51
NH 9210	5776	14.50
NH 9214	5776	14.45
NH 9220	5777	14.15
NH 9223	5777	14.20
NH 9227	5777	14.31
NH 9231	5778	14.68
NH 9234	5779	14.78
NH 9239	5781	14.71
NH 9243	5780	14.63
NH 9247	5780	14.56
NH 9252	5783	14.58
NH 9256	5784	14.60
NH 9260	5786	14.45
NH 9263	5788	14.45
NH 9265	5788	14.25
NH 9269	5790	14.34
NH 9272	5792	14.44
NH 9276	5794	14.27
NH 9280	5798	13.72
NH 9281	5796	14.12
NH 9286	5797	14.34
NH 9289	5798	14.51
NH 9292	5798	-4.54
NH 9296	5799	-4.72
NH 9300	5799	14.73
NH 9304	5801	14.28
NH 9299	5805	13.80

S20

NH 9292	5809	12.41
NH 9288	5808	12.08
NH 9285	5807	11.99

Grid Ref.	Alt.
S20 (cont.)	
NH 9281 5806	11.89
NH 9278 5804	11.72
NH 9275 5802	11.76
NH 9271 5800	12.07
NH 9267 5798	11.99
NH 9262 5797	11.98
NH 9258 5796	11.92
NH 9254 5795	12.03
NH 9251 5795	12.06
NH 9246 5793	12.18
NH 9242 5792	12.38
S21	
NH 9128 5749	23.13
NH 9132 5749	23.23
NH 9137 5748	23.25
NH 9142 5748	23.31
NH 9146 5748	23.44
NH 9153 5750	23.47
NH 9157 5750	23.34
NH 9162 5751	23.27
NH 9165 5752	23.32
NH 9169 5752	23.26
NH 9172 5752	23.22
NH 9176 5752	23.28
NH 9180 5753	23.19
NH 9184 5753	23.26
NH 9188 5754	23.23
NH 9192 5755	23.27
NH 9197 5756	23.38
S22	
NH 9127 5753	23.09
NH 9124 5753	23.23
NH 9120 5753	23.25
NH 9117 5752	23.23
NH 9112 5751	23.21
S22 (cont.)	
NH 9108 5751	23.10
NH 9104 5751	22.94
NH 9101 5750	22.76
NH 9098 5749	22.69
NH 9091 5748	22.71
NH 9087 5748	22.80
NH 9083 5749	22.68
NH 9079 5750	22.71
NH 9075 5749	22.76
NH 9072 5748	22.78
NH 9067 5747	22.64
S23	
NH 9184 5769	17.52
NH 9180 5769	17.23
NH 9176 5768	17.49
NH 9172 5769	17.58
NH 9167 5769	17.19
NH 9163 5768	17.14
NH 9159 5768	17.26
NH 9155 5767	17.29
NH 9151 5767	17.36
NH 9147 5766	17.35
NH 9141 5767	17.48
NH 9135 5767	17.36
NH 9131 5766	17.50
NH 9128 5766	17.54
NH 9123 5767	17.38
NH 9119 5767	17.39
NH 9115 5767	17.30
NH 9112 5767	17.45
NH 9108 5766	17.50
S24	
NH 9069 5755	17.06
NH 9077 5756	17.15
NH 9083 5757	17.44
S24 (cont.)	
NH 9085 5757	17.59
NH 9088 5757	17.50
S25	
NH 8777 5534	22.51
NH 8773 5535	22.62
NH 8770 5536	23.00
NH 8766 5537	23.21
NH 8762 5538	23.40
NH 8752 5542	23.01
NH 8745 5542	23.80
S26	
NH 8299 5557	18.83
NH 8302 5561	18.82
NH 8305 5564	18.81
NH 8309 5566	19.10
NH 8313 5566	19.07
NH 8335 5581	18.71
NH 8337 5583	18.66
NH 8341 5585	18.66
NH 8343 5587	18.63
NH 8346 5589	18.82
NH 8350 5590	18.72
NH 8354 5591	18.62
NH 8358 5594	18.89
NH 8361 5596	18.89
NH 8364 5598	19.05
NH 8367 5601	19.20
S27	
NH 8129 5546	24.47
NH 8133 5548	24.25
NH 8136 5550	24.00
NH 8140 5553	24.29
NH 8144 5555	24.28
NH 8147 5556	24.16
NH 8148 5557	24.10

Grid Ref.	Alt.
S28	
NH 8115 5481	22.28
NH 8113 5483	22.05
NH 8110 5486	22.24
NH 8107 5493	22.04
NH 8106 5496	21.73
NH 8104 5498	21.53
NH 8102 5504	21.87
S29	
NH 8062 5494	12.79
NH 8064 5499	12.89
S30	
NH 8068 5505	11.75
S31	
NH 8066 5509	9.73
NH 8063 5506	9.71
NH 8060 5504	9.75
NH 8059 5502	10.14
S32	
NH 7861 5504	28.24
NH 7857 5506	28.79
NH 7853 5508	29.39
S33	
NH 7909 5617	26.83
NH 7909 5614	26.98
NH 7909 5610	27.12
NH 7908 5606	27.08
NH 7908 5602	26.97
NH 7908 5599	26.84
NH 7908 5594	26.68
NH 7909 5590	26.37
NH 7910 5587	26.03
NH 7910 5583	25.97
NH 7911 5578	26.11
S34	
NH 7927 5518	21.48
NH 7930 5520	21.27
NH 7931 5524	20.90
NH 7934 5527	20.90
NH 7935 5531	21.47
NH 7938 5535	21.21
NH 7939 5539	20.99
NH 7937 5545	21.18
NH 7935 5548	21.27
NH 7932 5550	21.34
S35	
NH 7859 5640	23.22
NH 7855 5640	23.12
NH 7851 5640	22.76
NH 7847 5640	22.62
NH 7842 5641	22.50
NH 7838 5640	22.41
NH 7833 5639	21.72
NH 7828 5639	21.79
NH 7824 5639	21.87
NH 7820 5638	21.26
NH 7817 5637	21.58
NH 7813 5635	20.57
NH 7809 5633	19.46
NH 7807 5630	19.62
NH 7804 5628	19.24
S36	
NH 7822 5659	11.05
NH 7819 5658	11.03
NH 7816 5657	11.05
S37	
NH 7900 5481	18.40
NH 7896 5481	18.31
NH 7892 5480	18.47
NH 7889 5480	18.63
S37 (cont.)	
NH 7886 5480	18.70
NH 7883 5481	18.70
NH 7878 5482	18.45
NH 7875 5483	18.68
NH 7866 5484	18.18
S38	
NH 7792 5614	8.79
NH 7790 5618	8.82
NH 7789 5621	8.56
NH 7788 5624	8.54
NH 7787 5627	8.59
NH 7785 5632	8.73
NH 7783 5636	8.99
NH 7781 5640	8.97
NH 7779 5644	9.10
NH 7779 5647	9.12
NH 7779 5651	8.81
NH 7779 5655	8.83
HN 7778 5659	8.67
NH 7776 5664	8.67
NH 7775 5669	8.84
S39	
NH 7970 5615	7.25
NH 7973 5614	6.98
NH 7976 5614	7.12
NH 7979 5613	7.44
NH 7981 5613	7.28
S40	
NH 7737 5324	12.63
NH 7740 5322	13.15
NH 7743 5319	13.23
NH 7746 5316	13.58
NH 7749 5311	13.83
NH 7751 5305	13.53

Grid Ref.	Alt.	Grid Ref.	Alt.	Grid. Ref.	Alt.
S41		S42 (cont.)		S46 (cont.)	
NH 7742 5337	6.11	NH 7736 5329	7.22	NH 7525 5207	9.60
NH 7745 5340	6.22	NH 7732 5326	6.83	NH 7520 5205	9.75
NH 7748 5343	5.85	NH 7729 5324	6.58	NH 7517 5204	9.85
NH 7751 5346	5.79	NH 7718 5317	6.65	NH 7514 5202	9.36
NH 7754 5350	5.62	NH 7714 5315	6.46		
NH 7757 5353	5.53			S47	
NH 7761 5356	5.45	S44		NH 7407 5828	19.82
NH 7763 5359	5.37	NH 7628 5264	8.39	NH 7409 5831	19.60
NH 7766 5362	5.18	NH 7624 5262	8.37	NH 7411 5834	19.70
NH 7768 5365	5.41	NH 7621 5261	8.37	NH 7413 5837	19.86
NH 7771 5368	5.48	NH 7617 5259	8.19		
NH 7773 5370	5.36	NH 7613 5258	8.53	S48	
NH 7775 5373	5.33	NH 7609 5256	8.67	NH 7309 5713	30.11
NH 7777 5375	5.58	NH 7606 5254	8.64	NH 7307 5711	30.19
NH 7780 5379	5.17	NH 7602 5251	8.48	NH 7304 5708	30.17
NH 7782 5382	5.16	NH 7599 5249	8.63		
NH 7783 5384	5.01	NH 7595 5246	8.33	S49	
NH 7784 5387	5.58			NH 7316 5679	25.17
NH 7787 5389	5.53	S45		NH 7318 5681	25.38
		NH 7591 5244	7.57	NH 7321 5685	24.94
S43		NH 7588 5243	7.47	NH 7323 5687	25.01
NH 7688 5299	8.07	NH 7585 5241	7.55	NH 7325 5690	25.22
NH 7685 5297	7.33	NH 7582 5240	7.54	NH 3728 5693	25.10
NH 7683 5295	7.67	NH 7575 5235	7.74	NH 3730 5697	25.25
NH 7680 5293	8.14			NH 7332 5701	25.28
NH 7673 5290	8.50	S46		NH 7335 5705	25.81
NH 7669 5288	7.93	NH 7571 5233	8.02	NH 7338 5709	25.73
NH 7664 5285	7.56	NH 7567 5230	8.34	NH 7340 5711	25.93
NH 7659 5282	7.53	NH 7563 5227	8.47		
NH 7656 5281	7.68	NH 7559 5225	8.43	S50	
NH 7653 5279	7.41	NH 7555 5222	8.69	NH 7306 5644	16.27
NH 7650 5277	7.20	NH 7551 5220	8.41	NH 7307 5647	16.35
NH 7642 5272	7.15	NH 7547 5218	8.36	NH 7309 5650	16.61
NH 7639 5270	7.47	NH 7544 5216	8.34	NH 7311 5653	16.77
		NH 7541 5214	8.58	NH 7314 5656	16.76
S42		NH 7532 5211	8.62	NH 7316 5659	16.43
NH 7738 5332	7.30	NH 7529 5209	9.29	NH 7318 5661	16.62
				NH 7320 5663	16.97

S51

Grid Ref.	Alt.
NH 7352 5706	14.58
NH 7353 5709	14.54
NH 7355 5712	14.42
NH 7356 5717	14.57
NH 7357 5720	14.85
NH 7352 5703	14.45
NH 7351 5699	14.55
NH 7350 5696	14.65
NH 7349 5693	14.89
NH 7347 5689	14.85
NH 7345 5685	14.78
NH 7344 5682	14.78
NH 7342 5678	14.97
NH 7340 5674	14.65
NH 7339 5672	14.55

S52

Grid Ref.	Alt.
NH 7359 5722	14.10
NH 7359 5719	14.15
NH 7358 5717	13.85
NH 7357 5711	13.59
NH 7356 5707	14.06

S53

Grid Ref.	Alt.
NH 7354 5672	11.88
NH 7353 5670	11.81
NH 7353 5669	11.92
NH 7345 5654	10.99
NH 7346 5657	11.30
NH 7348 5661	11.44
NH 7350 5664	11.55
NH 7351 5666	11.77
NH 7353 5674	11.99
NH 7355 5677	12.17
NH 7356 5681	11.92
NH 7356 5683	11.93

S54

Grid Ref.	Alt.
NH 7400 5819	8.84
NH 7404 5821	8.89
NH 7408 5825	8.81
NH 7411 5827	8.82
NH 7414 5830	8.28
NH 7417 5832	7.95
NH 7418 5833	7.80
NH 7418 5837	8.50
NH 7419 5839	8.88

S55

Grid Ref.	Alt.
NH 7379 5667	8.10
NH 7376 5668	8.09
NH 7364 5671	8.19
NH 7361 5669	8.02
NH 7360 5668	8.04

S56

Grid Ref.	Alt.
NH 7444 5606	7.57

S57

Grid Ref.	Alt.
NH 7407 5646	6.97
NH 7410 5645	6.96
NH 7413 5644	7.03
NH 7415 5642	7.06

S58

Grid Ref.	Alt.
NH 7371 5630	4.46
NH 7374 5629	4.49
NH 7374 5628	4.37
NH 7379 5627	4.49
NH 7384 5625	4.54
NH 7388 5624	4.62
NH 7391 5622	4.78
NH 7395 5621	4.67
NH 7398 5619	4.66

S58 (cont.)

Grid Ref.	Alt.
NH 7402 5618	4.70
NH 7406 5617	4.74
NH 7410 5615	4.72
NH 7415 5613	4.74
NH 7419 5610	4.72
NH 7422 5608	4.64
NH 7426 5605	4.73
NH 7430 5602	4.80
NH 7435 5600	4.84
NH 7439 5597	4.99

S59

Grid Ref.	Alt.
NH 7419 5640	4.81
NH 7422 5635	4.76
NH 7426 5631	4.67
NH 7430 5627	4.76
NH 7434 5624	4.78
NH 7437 5622	4.86
NH 7439 5618	5.05
NH 7416 5648	4.87
NH 7414 5652	4.88
NH 7412 5655	4.89
NH 7410 5659	5.05
NH 7409 5663	5.41
NH 7406 5667	5.51

S60

Grid Ref.	Alt.
NH 6983 5383	13.06
NH 6983 5378	13.13
NH 6983 5375	13.32
NH 6983 5371	13.24

S61

Grid Ref.	Alt.
NH 6942 5562	22.41
NH 6938 5563	22.74
NH 6935 5564	22.68

Grid Ref.	Alt.
S61 (cont.)	
NH 6931 5564	22.54
NH 6927 5565	22.54
NH 6923 5566	22.37
S62	
NH 6837 5531	21.45
NH 6840 5533	20.93
NH 6846 5537	20.37
NH 6850 5540	20.03
NH 8653 5542	19.80
NH 6856 5544	19.83
NH 6860 5546	19.91
NH 6863 5549	19.71
S63	
NH 7354 4982	18.93
NH 7355 4986	19.19
NH 7356 4990	19.43
NH 7357 4993	19.61
NH 7380 4946	19.68
S64	
NH 7346 4975	15.22
NH 7348 4979	15.10
NH 7348 4982	15.01
NH 7349 4985	14.94
NH 7349 4988	15.11
S65	
NH 7376 5037	8.43
NH 7379 5041	9.02
NH 7380 5044	9.12
NH 7383 5048	8.57
NH 7385 5051	8.29
NH 7386 5055	8.50
NH 7388 5059	8.12
NH 7390 5069	7.71

Grid Ref.	Alt.
S65 (cont.)	
NH 7392 5066	8.14
NH 7394 5070	8.20
S66	
NH 7357 5005	7.58
NH 7359 5008	7.49
NH 7361 5012	7.54
NH 7364 5016	7.80
NH 7365 5019	7.75
NH 7368 5023	7.64
NH 7370 5026	7.61
NH 7372 5029	7.68
NH 7373 5032	7.78
NH 7374 5035	7.74
S69	
NH 7339 4979	8.94
NH 7340 4982	9.17
NH 7338 4983	8.44
NH 7341 4986	8.02
NH 7344 4989	8.09
NH 7347 4993	8.36
NH 7350 4997	8.72
NH 7353 4999	8.58
NH 7354 5002	8.23
S70	
NH 7353 4971	3.49
NH 7349 4970	3.49
NH 7346 4967	3.71
S71	
NH 7434 4987	7.95
NH 7429 4988	8.17
NH 7426 4988	8.31
NH 7421 4986	7.88
NH 7417 4986	7.98

Grid Ref.	Alt.
S71 (cont.)	
NH 7413 4985	7.89
NH 7409 4983	8.01
NH 7406 4981	7.65
NH 7402 4980	7.52
S72	
NH 7388 4929	8.52
NH 7389 4924	8.50
NH 7389 4920	8.70
NH 7392 4917	8.49
S73	
NH 7383 4918	7.46
NH 7383 4922	7.16
NH 7383 4925	7.25
S74	
NH 7405 4905	11.86
NH 7409 4902	11.80
NH 7412 4903	11.36
S75	
NH 7381 4892	6.60
NH 7376 4891	7.12
NH 7372 4892	7.16
NH 7369 4894	7.25
NH 7366 896	7.30
NH 7363 4898	7.35
NH 7383 4896	7.11
S76	
NH 7335 4882	17.32
S77	
NH 7315 4898	16.81
NH 7318 4897	16,79

Grid Ref.	Alt.	Grid Ref.	Alt.	Grid Ref.	Alt.
S77 (cont.)		S83 (cont.)		S87	
NH 7321 4897	16.55	NH 7217 4925	7.00	NH 6820 5101	20.30
NH 7327 4893	16.11	NH 7220 4923	7.41	NH 6819 5099	20.47
		NH 7225 4922	6.82		
S78		NH 7228 4921	6.84	S88	
NH 7265 4907	15.29			NH 6737 4984	22.81
		S84		NH 6735 4982	21.58
S79		NH 7139 4933	7.51	NH 6732 4979	21.34
NH 7276 4903	14.69	NH 7139 4929	7.51		
NH 7280 4902	14.81			S89	
NH 7284 4902	14.68	S85		NH 6749 4975	4.11
NH 7292 4899	14.53	NH 7137 4921	8.75	NH 6752 4975	4.08
		NH 7136 4916	8.84	NH 6756 4975	4.20
S80		NH 7135 4913	8.72	NH 6760 4976	4.38
NH 7223 4909	29.24	NH 7134 4908	8.45	NH 6764 4977	4.72
NH 7226 4907	29.29	NH 7138 4924	9.03	NH 6766 4979	4.73
				NH 6767 4982	4.57
S81		S86		NH 6768 4986	4.43
NH 7232 4913	23.68	NH 6803 5048	13.81	NH 6768 4989	4.27
NH 7233 4911	23.35	NH 6804 5050	14.15	NH 6769 4993	4.17
NH 7234 4907	23.16	NH 6805 5056	13.47	NH 6769 4996	4.22
NH 7234 4904	22.71	NH 6806 5059	14.01	NH 6770 5001	4.66
		NH 6807 5063	14.16		
S82		NH 6807 5065	13.94	S90	
NH 7254 4913	8.52	NH 6808 5068	14.20	NH 6828 5229	32.14
NH 7258 4912	8.62	NH 6810 5072	14.14	NH 6829 5227	32.80
		NH 6812 5076	13.91	NH 6830 5225	32.68
S83		NH 6814 5079	13.62		
NH 7180 4940	7.19	NH 6817 5083	14.15	S91	
NH 7183 4939	7.00	NH 6818 5086	14.30	NH 6797 5227	28.84
NH 7187 4938	6.97	NH 8620 5090	14.53	NH 6794 5226	28.87
NH 7190 4937	6.75	NH 8623 5093	14.20	NH 6790 5224	29.38
NH 7194 4936	6.83	NH 8625 5098	14.81	NH 6787 5222	29.23
NH 7197 4934	6.86	NH 8627 5102	14.65	NH 6784 5221	29.51
NH 7201 4933	6.93	NH 8630 5105	14.91	NH 6782 5220	29.59
NH 7205 4931	7.10	NH 6834 5108	14.52	NH 6778 5218	29.92
NH 7209 4928	6.98			NH 6775 5217	29.49
NH 7213 4926	7.06				

Grid Ref.	Alt.
S92	
NH 6833 5235	8.77
NH 6835 5232	8.50
NH 6837 5229	8.12
S93	
NH 6786 5228	8.50
NH 6789 5229	8.40
NH 6792 5230	8.14
NH 6796 5230	8.52
NH 6800 5231	8.84
NH 6803 5231	8.56
NH 6807 5232	8.29
NH 6810 5233	8.21
NH 6813 5233	8.73
S94	
NH 6710 5235	3.01
NH 6714 5234	2.82
NH 6718 5234	2.93
NH 6774 5230	3.02
NH 6722 5234	2.93
NH 6726 5234	3.00
NH 6730 5234	2.96
NH 6735 5234	3.00
NH 6738 5234	3.14
NH 6746 5235	3.38
NH 6749 5234	3.01
NH 6752 5234	3.10
NH 6755 5233	3.01
NH 6758 5233	3.01
NH 6762 5232	3.14
NH 6765 5231	3.34
NH 6769 4230	3.32
NH 6771 5230	3.18
S95	
NH 6605 5366	3.46
NH 6602 5367	3.43
S96	
NH 6517 5333	3.29
NH 6521 5335	3.21
NH 6526 5337	3.07
NH 6529 5339	3.06
NH 6534 5345	3.13
NH 6535 5347	3.27
NH 6537 5349	3.22
NH 6539 5351	2.87
NH 6542 5353	3.07
NH 6546 5353	2.95
NH 6550 5354	2.88
NH 6554 5356	2.96
NH 6556 5354	2.95
NH 6561 5351	2.91
NH 6565 5352	2.97
NH 6568 5355	2.95
NH 6572 5359	2.87
NH 6578 5363	2.60
NH 6584 5364	2.58
NH 6589 5365	2.61
NH 6594 5365	2.63
NH 6600 5363	2.47
S97	
NH 6537 5297	2.88
NH 6541 5299	2.91
NH 6544 5300	2.84
NH 6548 5300	2.80
NH 6551 5298	3.11
NH 6554 5295	3.06
NH 6556 5293	3.03
NH 6558 5291	2.93
S98	
NH 6484 5276	4.50
NH 6487 5278	4.41
NH 6491 5279	4.38
NH 6495 5281	4.50
NH 6497 5283	4.42
NH 6501 5287	4.18
NH 6504 5290	4.03
NH 6508 5292	4.12
NH 6512 5294	4.26
NH 6515 5299	3.93
NH 6519 5301	3.89
S99	
NH 6769 5224	8.73
NH 6763 5225	9.10
NH 6759 5227	9.39
NH 6756 5227	9.29
NH 6749 5226	8.38
NH 6745 5226	8.54
S100	
NH 6380 5255	29.07
NH 6383 5257	29.00
NH 6385 5260	29.15
NH 6387 5261	29.14
NH 6396 5271	29.95
NH 6398 5272	29.45
NH 6402 5276	29.12
NH 6405 5279	28.94
NH 6409 5282	29.00
NH 6413 5287	28.84
NH 6424 5299	29.46
NH 6444 5320	28.44

Grid Ref.	Alt.
S101	
NH 6372 5249	29.61
NH 6369 5246	29.37
NH 6366 5244	29.74
NH 6363 5242	29.01
NH 6360 5239	29.51
NH 6356 5235	29.11
NH 6353 5233	29.92
NH 6351 5230	29.81
NH 6342 5226	29.56
NH 6339 5223	29.11
NH 6335 5222	29.62
NH 6330 5217	29.12
NH 6328 5216	28.85
NH 6325 5213	28.45
NH 6320 5210	28.33
NH 6317 5207	28.55
NH 6313 5206	28.88
NH 6311 5205	28.80
S102	
NH 6295 5191	28.56
NH 6294 5190	28.20
NH 6290 5189	27.65
NH 6285 5186	27.77
NH 6281 5184	27.69
NH 6277 5182	27.15
NH 6274 5180	27.11
S103	
NH 6255 5166	28.98
NH 6252 5165	29.07
NH 6248 5165	29.49
S104	
NH 6261 5163	26.62
NH 6258 5161	26.81
NH 6255 5160	27.07
S105	
NH 6287 5169	14.07
NH 6292 5170	14.32
NH 6296 5172	14.62
NH 6299 5174	14.50
NH 6300 5175	14.26
NH 6304 5180	14.16
S106	
NH 6412 5273	17.61
NH 6407 5268	17.54
NH 6405 5265	17.57
S107	
NH 6445 5306	14.70
NH 6449 5309	14.87
S108	
NH 6432 5181	29.14
NH 6430 5178	28.48
NH 6427 5175	28.85
NH 6425 5172	28.96
NH 6423 5168	29.36
NH 6420 5166	38.67
NH 6418 5163	38.83
NH 6417 5159	29.22
S109	
NH 6415 5160	26.95
S110	
NH 6418 5168	24.63
S111	
NH 6464 5232	17.94
NH 6467 5235	17.95
S112	
NH 6453 5225	18.82
NH 6457 5229	18.17
NH 6460 5231	17.82
S113	
NH 6431 5205	17.09
NH 6432 5209	17.38
NH 6437 5212	18.27
S114	
NH 6462 5240	14.71
NH 6467 5243	14.25
S115	
NH 6381 5178	9.90
NH 6383 5175	10.17
NH 6383 5172	10.59
NH 6389 5175	10.67
NH 6405 5161	10.49
NH 6407 5167	10.80
NH 6410 5170	11.3)
NH 6411 5172	11.38
NH 6409 5175	11.17
NH 6409 5172	11.08
S116	
NH 6310 5090	14.29
NH 6317 5094	14.15
NH 6318 5099	13.63
S117	
NH 6344 5195	7.94
NH 6340 5194	7.58
NH 6334 5190	8.10
NH 6345 5172	7.91
NH 6340 5173	8.05

Grid Ref.	Alt.
S119	
NH 6366 5218	6.81
NH 6365 6216	6.73
NH 6362 5214	6.74
S120	
NH 6383 5199	6.66
NH 6381 5196	6.71
NH 6377 5193	6.69
S121	
NH 6469 5252	5.12
NH 6462 5248	5.34
NH 6460 5246	5.40
NH 6455 5245	5.45
NH 6452 5243	5.23
NH 6449 5240	5.11
NH 6447 5238	5.43
NH 6443 5235	5.56
NH 6440 5232	5.57
NH 6436 5228	5.52
NH 6433 5227	5.38
NH 6420 5232	5.28
S122	
NH 6459 5297	5.18
NH 6457 5296	5.17
NH 6454 5294	5.16
NH 6449 5293	5.42
NH 6442 5289	5.68
NH 6434 5274	5.80
NH 6429 5272	5.40
NH 6425 5270	5.33
NH 6423 5267	5.34
NH 6419 5263	5.36
NH 6415 5259	5.43
NH 6412 5256	5.46
S122 (cont.)	
NH 6409 5253	5.38
NH 6405 5250	5.28
NH 6402 5246	5.43
S123	
NH 6957 4513	30.42
NH 6953 4507	31.86
NH 6951 4505	32.00
NH 6949 4502	32.15
NH 6944 4497	32.30
S124	
NH 6977 4523	31.00
NH 6975 4520	31.35
NH 6974 4517	31.92
NH 6967 4519	31.08
NH 6963 4517	30.73
NH 6960 4515	30.35
S125	
NH 7070 4548	30.47
NH 7067 4546	30.67
NH 7063 4545	30.78
S126	
NH 7093 4583	27.10
NH 7095 4586	27.06
NH 7097 4580	27.79
S127	
NH 7080 4573	27.67
NH 7077 4571	28.21
NH 7075 4569	28.50
S128	
NH 7020 4555	26.44
S128 (cont.)	
NH 7024 4557	25.94
NH 7029 4559	26.51
NH 7034 4560	26.95
NH 7039 4561	27.55
NH 7043 4562	27.64
NH 7047 4562	27.95
NH 7050 4561	28.37
S129	
NH 6955 4530	28.01
NH 6958 4531	27.80
NH 6961 4533	27.64
S130	
NH 6932 4510	27.65
NH 6930 4508	27.40
NH 6927 4506	27.75
NH 6925 4503	28.06
NH 6924 4498	28.65
NH 6920 4497	28.91
NH 6917 4496	28.79
NH 6916 4494	28.88
S131	
NH 6906 4533	27.11
NH 6904 4530	27.12
NH 6902 4525	27.17
S132	
NH 6935 4580	27.19
NH 6931 4579	27.20
NH 6926 4578	27.12
NH 6923 4578	27.16
NH 6920 4577	27.23

Grid Ref.	Alt.
S133	
NH 6935 4564	24.74
NH 6931 4562	24.91
NH 6928 4560	24.80
NH 6924 4557	24.88
S134	
NH 6998 4592	24.67
NH 6996 4591	24.55
S135	
NH 7004 4607	16.02
NH 7007 4605	16.55
NH 7012 4606	16.08
NH 7016 4606	15.76
NH 7018 4607	15.79
NH 7019 4610	15.63
NH 7017 4613	15.49
NH 7027 4613	15.29
NH 7029 4610	15.48
S136	
NH 7081 4651	16.35
NH 7080 4648	16.22
NH 7080 4645	16.19
S137	
NH 6546 4377	16.05
NH 6544 4375	16.50
NH 6541 4373	16.86
NH 6538 4370	17.18
NH 6536 4367	17.48
NH 6533 4363	17.58
NH 6532 4358	17.75
S138	
NH 6504 4412	13.78

Grid Ref.	Alt.
S138 (cont.)	
NH 6502 4415	13.86
NH 6501 4420	13.76
NH 6499 4427	13.74
NH 6499 4431	13.66
NH 6499 4435	13.56
S139	
NH 6011 3844	23.81
NH 6008 3842	24.27
NH 6005 3840	24.48
NH 6003 3838	24.84
NH 5994 3835	24.49
NH 5991 3831	24.13
NH 5984 3816	23.70
NH 5982 3813	23.11
NH 5980 3810	22.80
NH 5978 3807	23.28
NH 5976 3804	22.92
NH 5974 3802	23.30
NH 5972 3798	23.16
S140	
NH 6039 3777	25.92
NH 6040 3781	26.10
NH 6041 3785	25.78
NH 6042 3788	25.66
NH 6044 3793	25.89
NH 6045 3796	25.94
NH 6046 3800	25.76
NH 6047 3805	25.22
S141	
NH 5984 3800	16.45
NH 5981 3798	16.45
NH 5979 3800	16.43
NH 5980 3802	16.49

Gird Ref.	Alt.
S141 (cont.)	
NH 5982 3805	16.39
NH 5983 3809	16.25
NH 5985 3812	16.38
NH 5988 3816	16.67
NH 5992 3819	16.61
NH 5995 3822	16.68
NH 5998 3824	16.69
NH 6003 3826	16.54
NH 6007 3828	16.62
NH 6010 3830	16.69
NH 6012 3832	16.75
S142	
NH 6015 3783	17.60
NH 6013 3785	17.39
NH 6012 3789	17.09
NH 6008 3782	17.09
NH 6011 3780	17.20
NH 6006 3785	17.20
S143	
NH 6019 3779	18.23
NH 6022 3779	18.22
NH 6024 3784	17.93
NH 6024 3788	17.96
S144	
NH 6021 3576	35.18
NH 6016 3597	34.92
NH 6016 3593	35.25
NH 6017 3590	35.21
NH 6018 3586	35.22
NH 6022 3584	35.44
NH 6025 3582	35.66
NH 6023 3579	35.28

Grid Ref.	Alt.
S145	
NH 6020 3560	35.37
NH 6021 3564	34.96
NH 6021 3567	34.84
NH 6018 3569	34.24
NH 6015 3572	34.31
NH 6010 3574	34.54
NH 6005 3577	34.51
NH 6002 3580	34.22
S146	
NH 5953 3541	34.72
NH 5955 3544	34.85
NH 5958 3546	34.91
NH 5960 3549	34.96
NH 5962 3552	34.71
S147	
NH 5972 3546	26.77
NH 5968 3542	26.13
NH 5965 3539	25.78
NH 5961 3536	25.27
NH 5958 3534	25.30
NH 5955 3532	25.46
NH 5952 3529	25.60
S148	
NH 5886 3337	18.75
NH 5889 3341	18.92
NH 5892 3346	18.65
NH 5896 3350	18.99
NH 5898 3352	19.11
NH 5901 3355	18.75
NH 5904 3358	18.57
S149	
NH 5103 2992	27.00
NH 5100 2993	27.08
NH 5096 2995	27.19
S150	
NH 5245 2911	26.82
NH 5240 2911	25.42
NH 5237 2911	26.51
NH 5233 2911	26.97
NH 5229 2912	26.96
NH 5225 2911	27.27
NH 5221 2911	26.81
S151	
NH 3883 0856	28.99
NH 3886 0858	29.96
NH 3889 0860	29.64
S152	
NH 4256 1604	31.34
NH 4253 1606	31.66
NH 4249 1608	31.74
NH 4246 1611	31.63
NH 4243 1614	31.73
NH 4239 1617	31.67
NH 4237 1620	31.67
S154	
NH 4307 1634	16.93
NH 4304 1633	17.10
NH 4300 1634	17.22
NH 4296 1633	17.25
NH 4292 1632	17.24
NH 4288 1630	17.11
NH 4285 1628	17.21
NH 4282 1626	17.31
NH 4278 1625	17.37
S155	
NH 4244 1501	28.97
NH 4243 1503	29.44
NH 4242 1505	29.73
NH 4241 1507	29.19
S155 (cont.)	
NH 4239 1509	28.57
S156	
NH 3987 1157	29.83
NH 3984 1155	29.56
NH 3981 1152	29.81
NH 3979 1149	29.31
NH 3976 1146	29.91
NH 3973 1143	29.31
S157	
NH 3896 1069	29.90
NH 3892 1066	29.40
NH 3889 1064	28.57
NH 3886 1062	28.60
NH 3881 1060	28.69
NH 3878 1059	28.87
NH 3874 1056	28.95
NH 3871 1053	28.75
NH 3868 1050	28.92
NH 3864 1047	28.51
NH 3860 1045	28.19
NH 3855 1043	28.46
NH 3851 1041	29.93
NH 3842 1035	29.47
NH 3838 1033	29.57
NH 3832 1032	29.47
NH 3828 1030	30.26
S158	
NH 3905 0886	29.08
NH 3909 0890	28.77
NH 3911 0892	28.95
NH 3907 0888	28.80
S159	
NH 3671 0917	35.97
NH 3670 0915	35.90

Grid Ref.	Alt.
S159 (cont.)	
NH 3674 0917	35.81
NH 3674 0902	35.75
NH 3671 0901	36.34
NH 3661 0901	36.12
NH 3657 0900	36.10
NH 3654 0897	36.17
NH 3651 0895	36.05
NH 3648 0892	36.20
NH 3646 0890	36.26
S160	
NH 3835 0827	32.61
NH 3833 0829	32.12
NH 3830 0832	31.62
NH 3826 0840	32.50
NH 3826 0830	32.39
NH 3827 0827	32.56
NH 3857 0832	32.58
NH 3854 0831	32.31
NH 3852 0830	32.76
S161	
NH 3829 0847	22.34
NH 3836 0844	22.39
S162	
NH 6608 4811	32.96
NH 6610 4814	32.94
NH 6611 4817	33.11
NH 6613 4819	33.14
NH 6616 4822	33.46
NH 6619 4824	33.11
NH 6621 4833	34.20
NH 6624 4840	34.11
NH 6626 4842	33.72
NH 6625 4834	32.99
S163	
NH 6510 4816	29.78
NH 6513 4814	30.20
NH 6517 4812	29.98
NH 6521 4810	30.01
NH 6526 4809	29.51
S164	
NH 6435 4870	28.13
NH 6431 4870	27.65
NH 6427 4870	27.12
NH 6424 4870	27.07
NH 6420 4871	26.82
NH 6416 4871	27.20
NH 6413 4872	28.21
S165	
NH 6271 4858	15.57
NH 6267 4858	15.53
NH 6265 4856	15.35
S166	
NH 6181 4838	10.84
NH 6186 4838	11.19
NH 6189 4837	10.63
NH 6194 4838	11.01
NH 6197 4838	10.96
NH 6201 4837	11.06
S167	
NH 6344 4847	8.80
NH 6340 4847	8.65
NH 6336 4846	9.21
NH 6331 4845	9.54
NH 6328 4844	10.02
NH 6324 4842	10.01
NH 6321 4839	10.00
S168	
NH 6273 4848	9.31
NH 6276 4850	10.39
S169	
NH 6253 4840	9.98
NH 6249 4839	10.14
NH 6245 4837	9.86
NH 6241 4836	9.70
NH 6237 4834	10.07
NH 6234 4832	10.16
NH 6229 4832	10.15
NH 6225 4832	10.80
S170	
NH 6222 4827	4.42
NH 6225 4826	4.38
NH 6230 4827	4.26
NH 6234 4827	4.50
S171	
NH 6248 4828	5.20
NH 6252 4831	4.81
NH 6255 4833	5.21
S172	
NH 6207 4829	5.59
NH 6203 4829	5.29
NH 6198 4829	5.37
NH 6195 4828	5.21
NH 6190 4826	5.36
NH 6187 4825	5.35
S173	
NH 6128 4837	7.65
NH 6125 4840	7.91
NH 6122 4843	8.10

Grid Ref.	Alt.
S174	
NH 6108 4854	3.31
NH 6102 4855	3.27
NH 6096 4854	3.38
NH 6095 4851	3.43
S175	
NH 6088 4866	10.19
NH 6092 4868	9.88
S176	
NH 6078 4884	12.87
NH 6083 4883	12.89
NH 6092 4883	13.06
NH 6087 4883	13.18
S177	
NH 6013 4859	8.12
NH 6009 4860	8.83
NH 6004 4860	9.79
NH 6001 4859	10.15
NH 5996 4858	8.90
NH 5992 4859	9.13
NH 5987 4860	9.12
NH 5983 4862	9.04
NH 5979 4862	9.57
NH 6024 4857	8.44
NH 6027 4856	8.63
NH 6031 4855	8.49
NH 6037 4851	8.53
S178	
NH 5877 4933	7.57
NH 5881 4931	7.58
NH 5885 4929	7.48
NH 5888 4928	7.17
S179	
NH 6125 4533	29.64
NH 6123 4534	29.28
NH 6127 4532	29.70
NH 6130 4532	29.91
S180	
NH 6120 4538	22.19
NH 6122 4539	22.04
S181	
NH 6071.4574	28.54
NH 6071 4570	28.48
NH 6070 4566	28.81
NH 6068 4562	29.37
NH 6069 4558	29.57
NH 6069 4554	29.72
NH 6070 4550	30.20
NH 6070 4546	30.85
NH 6070 4543	32.01
NH 6067 4541	33.09
NH 6065 4544	32.58
NH 6062 4548	31.93
NH 6059 4551	31.33
NH 6057 4554	30.69
NH 6054 4556	30.16
NH 6052 4557	29.77
NH 6050 4559	29.40
NH 6046 4561	28.78
NH 6084 4563	28.25
NH 6084 4560	28.93
NH 6084 4557	29.62
NH 6083 4553	30.39
NH 6083 4550	30.88
NH 6083 4546	31.43
NH 60 84 4543	32.12
S182	
NH 6073 4578	21.34
NH 6070 4579	21.36
S183	
NH 5876 4565	16.19
NH 5879 4567	15.99
NH 5882 4568	16.14
S184	
NH 5886 4567	15.52
NH 5889 4568	14.98
NH 5893 4568	15.21
NH 5896 4569	15.93
NH 5900 4570	15.30
NH 5905 4571	15.14
NH 5909 4572	14.12
NH 5913 4573	14.26
NH 5918 4575	14.27
S185	
NH 5804 4530	22.74
NH 5807 4532	22.70
NH 5810 4533	21.66
NH 5819 4537	21.02
NH 5823 4538	20.82
NH 5827 4539	21.11
NH 5830 4539	23.08
S186	
NH 5794 4525	23.29
NH 5790 4524	23.25
NH 5786 4523	23.27
NH 5782 4523	22.47
NH 5778 4523	22.03

Grid Ref.	Alt.
S187	
NH 5718 4522	3.97
NH 5722 4523	3.64
NH 5725 4523	3.55
NH 5728 4524	3.48
NH 5731 4524	3.29
NH 5737 4525	3.23
NH 5742 4527	3.22
NH 5746 4529	3.13
NH 5750 4531	3.30
NH 5753 4533	3.02
NH 5757 4535	2.94
NH 5762 4538	3.09
NH 5766 4539	3.06
NH 5771 4541	3.16
NH 5775 4544	3.08
NH 5777 4547	3.07
NH 5781 4551	3.11
NH 5783 4553	3.16
NH 5789 4555	3.36
NH 5791 4557	3.20
NH 5794 4559	3.38
NH 5797 4560	3.25
NH 5803 4562	3.34
NH 5806 4563	3.23
NH 5810 4565	2.98
NH 5813 4567	2.82
NH 5817 4568	2.75
NH 5820 4569	2.85
NH 5824 4570	3.21
S188	
NH 5680 4495	5.59
NH 5685 4489	5.38
NH 5688 4489	5.27
NH 5693 4491	5.04
NH 5696 4492	5.27
NH 5700 4493	5.22
S188 (cont.)	
NH 5700 4494	5.22
NH 5704 4494	5.41
S189	
NH 5689 4478	22.34
NH 5693 4481	22.50
NH 5695 4483	22.72
S190	
NH 5689 4448	20.39
NH 5687 4446	20.18
NH 5686 4441	20.22
NH 5686 4438	20.46
NH 5684 4434	20.56
NH 5683 4431	20.35
NH 5681 4426	20.27
NH 5679 4422	20.38
NH 5676 4420	20.60
NH 5673 4418	20.67
NH 5669 4415	20.57
NH 5666 4413	20.57
NH 5664 4409	20.89
S191	
NH 5573 4403	29.02
NH 5576 4406	29.08
NH 5579 4408	29.04
S192	
NH 5621 4437	28.64
NH 5624 4439	28.86
NH 5627 4441	28.97
NH 5631 4443	28.72
NH 5634 4446	28.78
NH 5638 4448	28.64
S193	
NH 5755 4473	29.32
NH 5753 4471	29.17
NH 5750 4468	29.54
NH 5747 4463	29.42
S194	
NH 5624 4525	6.25
NH 5626 4529	6.05
NH 5627 4531	5.81
S195	
NH 5620 4533	6.99
NH 5618 4529	7.17
NH 5617 4526	7.21
NH 5615 4522	7.18
NH 5613 4519	7.29
S196	
NH 5631 4554	5.64
NH 5629 4551	5.86
NH 5629 4548	5.78
S197	
NH 5645 4600	8.51
NH 5647 4603	8.23
NH 5649 4606	7.96
NH 5650 4609	7.50
NH 5650 4615	7.72
NH 5648 4618	7.76
NH 5645 4620	7.39
NH 5642 4621	7.33
NH 5639 4623	7.18
NH 5635 4624	7.19
NH 5631 4625	7.52
NH 5627 4626	7.43
NH 5623 4628	7.20
NH 5620 4630	7.41
NH 5617 4631	7.38

Grid Ref.	Alt.	Grid Ref.	Alt.	Grid Ref.	Alt.
S198		S200 (cont.)		S206 (cont.)	
NH 5633 4576	8.20	NH 5672 4600	2.76	NH 5497 4630	5.70
NH 5634 4579	7.80	NH 5675 4598	2.82	NH 5493 4628	5,72
NH 5636 4583	7.91			NH 5489 4627	5.84
NH 5637 4586	7.74	S201		NH 5485 4625	5.99
NH 5640 4590	7.68	NH 5640 4565	4.91	NH 5480 4624	5.98
NH 5641 4593	7.88	NH 5637 4562	4.86	NH 5477 4623	6.03
		NH 5635 4560	4.76		
S199				S207	
NH 5648 4592	4.66	S202		NH 5708 4491	11.35
NH 5646 4589	4.71	NH 5579 4633	5.74	NH 5704 4490	10.55
NH 5644 4587	4.93	NH 5576 4632	5.92	NH 5701 4489	11.05
NH 5643 4582	5.13	NH 5572 4631	5.97	NH 5697 4488	11.63
NH 5643 4579	5.10	NH 5568 4629	5.96		
NH 5643 4574	5.66	NH 5565 4628	6.00	S208	
NH 5643 4569	5.48			NH 5900 4925	9.23
		S203		NH 5903 4923	9.33
S200		NH 5547 4635	4.20	NH 5907 4920	9.09
NH 5600 4646	3.39	NH 5550 4635	4.42	NH 5910 4918	9.05
NH 5595 4645	3.44	NH 5554 4636	4.16	NH 5914 4b15	8.92
NH 5607 4646	3.38	NH 5556 4639	4.34	NH 5918 4913	9.29
NH 5611 4645	3.47			NH 5921 4910	9.56
NH 5616 4644	3.31	S204		NH 5924 4907	9.65
NH 5631 4637	3.52	NH 5531 4622	5.88	NH 5927 4904	9.40
NH 5634 4637	3.42	NH 5535 4623	5.65	NH 5930 4901	10.00
NH 5637 4636	3.39			NH 5932 4898	9.48
NH 5640 4635	3.27	S205		NH 5935 4896	8.98
NH 5643 4634	3.09	NH 5485 4614	5.78	NH 5937 4894	8.82
NH 5649 4632	3.15	NH 5489 4615	5.92		
NH 5653 4629	2.88	NH 5493 4615	5.81	S209	
NH 5656 4625	3.07	NH 5498 4616	5.68	NH 5452 4599	6.68
NH 5658 4622	3.09	NH 5502 4616	5.71	NH 5456 4598	6.68
NH 5659 4618	2.92	NH 5507 4617	5.64	NH 5460 4599	6.83
NH 5659 4615	3.02	NH 5513 4617	5.80	NH 5464 4599	6.81
NH 5661 4611	2.92	NH 5517 4618	5.75	NH 5470 4601	6.61
NH 5663 4608	2.92				
NH 5666 4605	2.81	S206		S210	
NH 5669 46	2.84	NH 5502 4631	5.61	NH 5480 4617	5.87

Grid Ref.	Alt.
S210 (cont.)	
NH 5476 4616	5.86
NH 5473 4614	5.82
NH 5469 4612	5.98
NH 5464 4610	6.04
NH 5461 4608	6.11
NH 5458 4607	6.11
NH 5454 4606	6.17
NH 5449 4604	6.18
S211	
NH 5448 4608	6.73
NH 5456 4611	6.48
NH 5459 4612	6.56
NH 5464 4614	6.44
NH 5467 4616	6.34
NH 5471 4618	6.50
NH 5474 4620	6.38
S212	
NH 5406 4597	6.70
NH 5414 4600	6.76
NH 5418 4601	6.59
NH 5422 4602	6.45
NH 5426 4602	6.29
NH 5431 4602	6.35
NH 5435 4602	6.37
NH 5439 4602	6.31
NH 5443 4603	6.26
NH 5445 4603	6.33
S213	
NH 5415 4639	5.06
S214	
NH 5390 4595	6.79
NH 5386 4594	6.66
NH 5383 4594	6.46
S214 (cont.)	
NH 5379 4592	6.64
NH 5375 4591	6.52
NH 5372 4590	6.28
S215	
NH 5282 4535	30.78
NH 5280 4533	30.53
NH 5277 4530	30.46
NH 5272 4525	30.59
NH 5270 4522	30.97
NH 5269 4519	30.74
NH 5266 4516	30.65
NH 5265 4512	30.43
NH 5264 4507	29.98
NH 5262 4503	29.83
S216	
NH 5599 4911	8.85
NH 5603 4911	8.97
NH 5615 4916	9.22
NH 5620 4918	9.65
NH 5622 4919	9.76
S217	
NH 5634 4917	2.72
NH 5638 4918	2.61
NH 5642 4919	2.44
NH 5647 4920	2.45
NH 5650 4919	2.41
S218	
NH 5599 4903	3.16
NH 5601 4905	3.35
NH 5604 4907	3.34
NH 5608 4909	3.24
NH 5611 4910	3.24
NH 5614 4911	3.19
S218 (cont.)	
NH 5618 4912	3.14
NH 5593 4901	3.28
NH 5589 4898	3.25
NH 5586 4895	3.23
NH 5583 4893	3.18
NH 5582 4889	3.14
NH 5580 4886	3.07
NH 5578 4882	3.07
NH 5577 4878	2.71
NH 5576 4874	2.55
S219	
NH 5536 4868	9.45
NH 5538 4870	9.95
NH 5540 4873	9.86
NH 5551 4877	10.39
NH 5556 4876	9.34
S220	
NH 5459 4957	27.27
NH 5462 4958	27.25
NH 5467 4959	26.96
NH 5471 4960	26.98
NH 5475 4962	26.94
NH 5479 4963	26.77
NH 5483 4964	26.97
NH 5488 4965	26.68
NH 5493 4964	26.73
NH 5497 4963	26.99
S221	
NH 5234 4878	28.70
NH 5233 4875	28.33
NH 5231 4871	28.09
NH 5229 4867	28.17
NH 5227 4865	28.35
NH 5226 4861	28.27

Grid Ref.	Alt.
S221 (cont.)	
NH 5226 4852	28.14
NH 5222 4846	27.96
NH 5221 4842	27.87
NH 5221 4839	27.96
S222	
NH 5176 4685	31.12
NH 5179 4689	31.77
NH 5182 4692	31.56
NH 5184 4695	31.92
NH 5186 4699	33.24
NH 5197 4710	32.42
NH 5201 4714	32.07
NH 5703 4715	31.72
S223	
NH 5208 4704	18.64
NH 5205 4703	19.05
NH 5202 4700	19.93
NH 5200 4698	19.62
S224	
NH 5215 4702	10.69
NH 5216 4706	11.47
NH 5217 4708	11.84
S225	
NH 5209 4675	11.49
NH 5211 4678	11.60
NH 5213 4680	11.31
S226	
NH 5234 4727	13.36
NH 5238 4731	13.69
NH 5243 4733	13.74
NH 5244 4735	13.48
NH 5249 4739	12.99
NH 5251 4742	13.15

Grid Ref.	Alt.
S226 (cont.)	
NH 5253 4744	13.10
NH 5258 4750	13.00
NH 5261 4752	12.52
NH 5263 4756	12.27
NH 5272 4774	12.95
NH 5278 4779	13.22
NH 5275 4778	13.38
S227	
NH 5277 4789	18.72
NH 5277 4786	18.62
NH 5275 4792	18.76
NH 5273 4795	18.70
S228	
NH 5283 4781	13.48
NH 5287 4783	13.65
NH 5289 4786	13.63
NH 5291 4788	13.51
S229	
NH 5477 4863	5.12
NH 5474 4863	5.34
NH 5470 4863	5.30
NH 5466 4863	5.23
NH 5462 4863	5.48
NH 5458 4862	5.37
NH 5454 4862	5.25
NH 5450 4860	5.45
S230	
NH 5444 4861	5.72
NH 5441 4859	5.58
NH 5438 4857	5.46
NH 5435 4854	5.52
NH 5432 4852	5.43
NH 5426 4850	5.49

Grid Ref.	Alt.
S231	
NH 5418 4848	5.69
NH 5414 4846	5.79
NH 5410 4844	5.99
NH 5407 4841	5.91
NH 5404 4839	5.84
NH 5401 4836	5.92
NH 5396 4831	5.71
NH 5394 4829	6.03
NH 5391 4827	5.92
NH 5389 4824	5.82
S232	
NH 5434 4840	4.74
NH 5437 4844	4.69
NH 5440 4847	4.67
S233	
NH 5421 4821	4.75
NH 5420 4815	5.01
NH 5419 4811	4.97
NH 5417 4806	4.84
NH 5409 4802	4.94
NH 5406 4798	5.05
S234	
NH 5429 4781	3.18
NH 5427 4778	3.30
NH 5425 4777	3.35
NH 5430 4785	3.18
NH 5431 4789	3.12
NH 5433 4793	3.20
NH 5434 4797	3.25
NH 5436 4802	3.11
S235	
NH 5516 4858	3.41
NH 5513 4858	3.38
NH 5508 4859	3.43

Grid Ref.	Alt.
S235 (cont.)	
NH 5504 4859	3.62
NH 5501 4860	3.70
NH 5496 4860	3.79
NH 5491 4860	3.79
NH 5487 4858	3.69
NH 5481 4857	3.84
NH 5478 4853	3.72
NH 5474 4850	3.68
NH 5472 4846	3.66
NH 5469 4843	3.75
NH 5466 4840	3.59
NH 5463 4838	3.48
NH 5461 4834	3.46
NH 5458 4828	3.55
S236	
NH 5386 4820	6.09
NH 5382 4816	6.04
NH 5379 4814	6.01
NH 5376 4811	5.90
NH 5373 4808	5.79
NH 5370 4805	5.86
NH 5367 4802	5.59
NH 5364 4798	5.75
NH 5358 4796	5.78
NH 5354 4792	5.77
S237	
NH 5409 4609	6.61
NH 5412 4610	6.77
NH 5415 4611	6.77
NH 5419 4612	6.70
NH 5423 4612	6.60
NH 5427 4613	6.63
NH 5432 4614	6.70
NH 5437 4615	6.65
S237 (cont.)	
NH 5440 4616	6.63
NH 5444 4608	6.74
NH 5440 4606	6.65
NH 5438 4606	6.79
NH 5434 4607	6.71
NH 5431 4607	6.57
NH 5424 4607	6.68
NH 5413 4607	6.75
NH 5409 4603	6.73
NH 5405 4600	6.92
S238	
NH 5315 4757	7.03
NH 5317 4760	7.36
NH 5319 4763	7.35
S239	
NH 5325 4756	5.55
NH 5326 4758	5.80
NH 5328 4761	5.68
S240	
NH 5324 4740	4.74
NH 5326 4744	4.96
NH 5328 4748	4.93
NH 5329 4752	4.79
S241	
NH 5313 4751	8.79
NH 5312 4748	8.25
S242	
NH 5302 4748	6.84
NH 5301 4745	6.76
S243	
NH 5296 4750	6.73
NH 5295 4746	6.58
NH 5279 4715	6.15
NH 5275 4714	6.43
NH 5271 4702	6.67
NH 5269 4698	6.66
NH 5267 4696	6.58
NH 5266 4692	6.68
NH 5266 4688	6.59
NH 5267 4683	6.51
S244	
NH 5211 4563	6.89
NH 5209 4560	6.93
NH 5209 4556	7.22
NH 5206 4552	7.14
NH 5206 4548	7.11
NH 5203 4544	7.05
S245	
NH 5213 4669	8.79
NH 5209 4670	8.89
NH 5205 4671	8.79
S246	
NH 5227 4642	8.53
NH 5231 4642	8.55
S247	
NH 5217 4685	9.55
NH 5218 4681	9.55
NH 5219 4678	9.65
NH 5219 4673	9.18
NH 5221 4661	9.24
NH 5227 4662	9.22
NH 5224 4665	9.23
NH 5221 4668	9.30

Grid Ref.	Alt.
S248	
NH 5124 4575	8.62
NH 5127 4577	8.63
NH 5130 4581	8.98
S249	
NH 5122 4502	9.21
NH 5118 4507	9.25
NH 5116 4509	9.18
NH 5112 4518	8.92
NH 5112 4521	8.70
NH 5113 4528	8.74
NH 5114 4533	8.61
NH 5114 4538	8.60
S250	
NH 5245 4721	8.69
NH 5247 4724	8.71
NH 5250 4726	8.35
NH 5252 4729	8.42
S251	
NH 5257 4730	8.18
NH 5258 4726	7.87
NH 5257 4723	7.95
NH 5254 4718	7.94
NH 5252 4717	8.12
NH 5249 4716	8.31
S252	
NH 5290 4772	8.76
NH 5288 4768	9.04
NH 5283 4766	8.61
NH 5280 4766	9.00
S253	
NH 5104 4574	29.27
NH 5108 4579	29.04

Grid Ref.	Alt.
S253 (cont.)	
NH 5110 4582	29.68
NH 5118 4595	28.83
NH 5119 4599	29.63
NH 5120 4602	29.45
NH 5122 4605	29.39
NH 5123 4609	29.78
NH 5126 4612	29.57
S254	
NH 5040 4279	28.75
NH 5042 4276	28.36
NH 5044 4273	28.17
NH 5045 4269	28.60
NH 5035 4262	28.50
NH 5033 4258	28.20
NH 5025 4252	28.07
NH 5030 4254	28.92
S255	
NH 5060 4189	28.43
NH 5059 4185	28.89
S256	
NH 5116 4207	26.84
NH 5119 4205	27.51
NH 5122 4202	28.47
NH 5123 4198	29.35
NH 5123 4195	30.13
S257	
NH 5145 4210	30.16
NH 5143 4215	29.75
NH 5139 4217	29.52
S258	
NH 5160 4215	30.89
NH 5162 4217	30.13

Grid Ref.	Alt.
S258 (cont.)	
NH 5163 4221	29.52
NH 5167 4225	28.99
NH 5169 4229	28.82
S259	
NH 5199 4285	29.55
NH 5198 4288	28.46
NH 5184 4273	28.91
S260	
NH 5207 4334	16.03
NH 5205 4332	16.23
NH 5196 4325	15.91
NH 5197 4321	15.84
NH 5198 4318	15.84
NH 5196 4315	16.52
NH 5194 4312	16.44
NH 5193 4308	16.20
NH 5190 4306	16.55
NH 5187 4304	16.64
NH 5182 4302	16.65
S261	
NH 5372 5377	18.57
NH 5373 5381	19.02
NH 5374 5385	19.04
NH 5373 5388	18.45
NH 5378 5389	19.75
S262	
NH 5360 5371	18.12
NH 5361 5373	18.22
NH 5364 5375	18.11
S263	
NH 5345 5295	28.39
NH 5347 5298	28.06

Grid Ref.	Alt.
S263 (cont.)	
NH 5351 5303	27.68
NH 5353 5307	27.90
NH 5355 5311	27.99
NH 5359 5316	27.53
NH 5361 5320	27.44
NH 5362 5323	26.55
NH 5365 5326	26.57
NH 5367 5330	26.45
S264	
NH 5344 5313	18.87
NH 5344 5308	20.68
NH 5342 5305	20.71
S265	
NH 5292 5209	28.31
NH 5294 5213	28.12
NH 5297 5216	28.13
NH 5300 5220	27.86
NH 5303 5224	28.26
NH 5306 5229	28.56
NH 5309 5233	28.20
NH 5311 5237	28.03
S266	
NH 5276 5250	22.47
NH 5271 5267	21.83
NH 5275 5272	21.71
NH 5278 5277	22.10
NH 5285 5268	21.70
NH 5289 5266	22.10
NH 5294 5265	22.45
NH 5297 5268	22.31
NH 5298 5271	22.42
NH 5299 5276	22.66
NH 5301 5280	22.18
NH 5301 5284	22.50

Grid Ref.	Alt.
S267	
NH 5297 5332	11.45
NH 5300 5335	11.48
NH 5299 5338	11.50
S268	
NH 5246 5220	24.95
NH 5243 5219	24.03
NH 5235 5215	24.11
NH 5232 5214	24.04
NH 5227 5212	24.39
S269	
NH 5199 5217	26.18
NH 5197 5214	26.31
NH 5198 5209	26.17
NH 5202 5207	26.25
NH 5205 5207	26.23
NH 5208 5207	26.13
NH 5213 5206	26.41
NH 5206 5193	26.06
NH 5202 5192	26.06
NH 5199 5191	26.15
S270	
NH 5175 5234	25.07
NH 5181 5235	25.38
NH 5185 5233	25.36
NH 5189 5233	25.39
NH 5192 5231	25.48
NH 5193 5230	25.59
NH 5195 5228	25.30
NH 5197 5225	25.46
NH 5199 5222	25.82
S271	
NH 5136 5235	25.04
NH 5134 5232	24.84

Grid Ref.	Alt.
S271 (cont.)	
NH 5133 5229	25.25
NH 5132 5225	25.40
S272	
NH 5236 5336	9.96
NH 5239 5334	10.42
NH 5243 5333	10.66
NH 5248 5330	10.52
NH 5252 5327	10.50
NH 5256 5325	10.13
NH 5260 5323	10.51
S273	
NH 5269 5317	8.67
NH 5267 5322	8.45
NH 5272 5328	8.31
NH 5269 5331	8.08
NH 5265 5332	8.13
NH 5261 5330	8.17
NH 5257 5329	8.17
NH 5253 5332	8.17
NH 5252 5334	8.16
S274	
NH 4904 5366	10.70
NH 4908 5364	10.73
NH 4911 5363	10.68
NH 4915 5362	10.63
NH 4919 5363	10.57
NH 4924 5366	10.32
NH 4927 5366	10.40
NH 4930 5364	10.28
NH 4934 5363	10.62
NH 4938 5360	10.85
NH 4942 5359	10.83
NH 4945 5359	10.31
NH 4947 5361	10.31

Grid Ref.	Alt.	Grid Ref.	Alt.	Grid Ref.	Alt.
S274 (cont.)		S276 (cont.)		S281 (cont.)	
NH 4951 5362	10.26	NH 5013 5342	19.67	NH 4796 5381	15.79
NH 4954 5362	10.31	NH 5016 5345	19.70	NH 4792 5383	15.76
NH 4959 5363	10.45	NH 5020 5347	19.50	NH 4788 5383	15.73
NH 4962 5364	10.77	NH 5023 5349	19.27		
NH 4964 5368	10.69	NH 5027 5348	19.53	S282	
NH 4963 5371	10.21	NH 5030 5347	19.89	NH 4702 5391	26.17
NH 4962 5375	10.09			NH 4705 5390	25.92
NH 4962 5378	10.08	S277		NH 4709 5389	25.31
NH 4974 5384	10.49	NH 4944 5352	18.91	NH 4717 5387	25.16
NH 4977 5383	10.16	NH 4947 5351	19.06	NH 4722 5387	25.25
NH 4979 5381	10.26	NH 4950 5347	19.03	NH 4725 5386	25.24
NH 4982 5380	10.17	NH 4953 5351	18.79	NH 4731 5385	25.17
NH 4985 5380	10.07	NH 4958 5351	18.71	NH 4736 5384	25.50
NH 4987 5380	10.23	NH 4961 5351	19.14	NH 4743 5383	26.03
NH 4990 5379	10.42	NH 4965 5351	18.89	NH 4747 5382	26.59
NH 4992 5377	10.45	NH 4965 5355	18.81	NH 4754 5381	26.46
				NH 4758 5381	26.55
S275		S278		NH 4761 5380	26.28
NH 4915 5334	27.57	NH 4914 5351	19.01	NH 4764 5379	25.86
NH 4918 5334	26.47	NH 4918 5355	19.07	NH 4772 5378	25.59
NH 4922 5334	26.42	NH 4922 5355	19.13	NH 4777 5377	25.61
NH 4924 5334	26.15	NH 4926 5356	19.58	NH 4779 5376	25.81
NH 4928 5333	25.74	NH 4931 5356	19.24	NH 4783 5376	26.36
NH 4938 5319	26.59			NH 4786 5375	26.24
NH 4942 5318	26.26	S279		NH 4790 5374	26.38
NH 4948 5318	26.39	NH 4833 5371	17.37	NH 4793 5373	26.37
NH 4954 5316	26.06	NH 4830 5371	17.89		
NH 4957 5316	26.17	NH 4831 5377	17.77	S283	
NH 4961 5315	25.99			NH 4652 5399	24.39
NH 4965 5314	26.26	S280		NH 4657 5398	24.14
NH 4969 5313	26.03	NH 4832 5374	15.53	NH 4664 5397	25.37
NH 4972 5310	26.02	NH 4831 5377	15.51	NH 4668 5396	25.27
NH 4977 5310	26.01			NH 4675 5395	24.62
NH 4981 5311	26.02	S281		NH 4678 5394	25.19
		NH 4808 5380	15.05	NH 4683 5393	25.91
S276		NH 4804 5380	15.42	NH 4688 5392	25.78
NH 5010 5339	19.71	NH 4800 5380	15.66		

Grid Ref.	Alt.
S284	
NH 4612 5399	24.18
NH 4604 5400	24.50
NH 4599 5401	24.40
NH 4596 5401	24.08
NH 4592 5401	23.88
NH 4587 5400	23.95
NH 4578 5403	23.72
NH 4574 5403	24.21
NH 4570 5404	24.40
NH 4567 5404	24.96
NH 4566 5397	24.95
S285	
NH 4919 2111	21.06
NH 4923 2111	21.01
NH 4927 2111	20.94

3. RAISED SHINGLE RIDGES

Grid Ref.	Alt.
R1	
NH 9471 5842	23.65
NH 9475 5844	23.77
NH 9480 5846	23.79
NH 9484 5846	23.71
NH 9488 5847	23.58
NH 9490 5848	23.75
NH 9494 5850	23.86
NH 9498 5851	23.87
NH 9503 5853	24.02
NH 9506 5855	24.06
NH 9510 5856	24.07
NH 9514 5859	24.10
NH 9518 5859	24.11
R2	
NH 9419 5837	23.55
NH 9423 5838	23.35
NH 9426 5839	23,53
NH 9429 5841	23.70
NH 9433 5842	23.51
NH 9437 5843	23.50
NH 9441 5844	23.36
NH 9445 5846	23.33
NH 9449 5847	23.64
NH 9453 5848	23.39
NH 9457 5849	23.26
NH 9461 5850	23.28
NH 9464 5851	23.37
R3	
NH 9431 5845	23.10
NH 9427 5844	23.09
NH 9424 5842	23.08
NH 9420 5841	23.03
NH 9416 5840	23.00
R3 (cont.)	
NH 9462 5854	23.06
NH 9457 5853	23.15
NH 9452 5852	23.24
NH 9447 5850	23.09
NH 9444 5849	23.04
NH 9439 5848	23.00
NH 9436 5846	22.93
NH 9497 5860	22.88
NH 9494 5859	23.28
NH 9490 5858	23.11
NH 9487 5858	22.99
NH 9483 5858	23.29
NH 9479 5857	23.29
NH 9476 5856	23.45
NH 9473 5855	23.40
NH 9469 5855	23.26
NH 9466 5855	23.12
R4	
NH 9446 5857	20.92
NH 9443 5856	20.92
NH 9440 5855	20.87
NH 9437 5853	20.76
NH 9435 5852	20.75
NH 9432 5852	20.64
R5	
NH 9460 5866	19.70
NH 9455 5866	19.70
NH 9451 5865	19.84
NH 9448 5864	19.96
NH 9445 5863	19.84
NH 9442 5862	19.69
NH 9439 5860	19.70
NH 9435 5859	19.70
R5 (cont.)	
NH 9432 5857	19.94
NH 9429 5856	19.91
NH 9425 5854	19.74
NH 9421 5853	19.86
NH 9417 5854	19.79
NH 9413 5852	19.73
NH 9410 5851	19.60
NH 9363 5837	19.51
NH 9385 5847	19.72
NH 9381 5845	19.73
NH 9378 5844	19.71
NH 9384 5842	19.64
NH 9370 5841	19.71
NH 9366 5839	19.64
R6	
NH 9243 5795	12.31
NH 9238 5792	12.56
NH 9235 5789	12.75
R7	
NH 8157 5556	26.89
NH 8156 5554	27.30
NH 8154 5551	27.51
NH 8150 5549	27.36
NH 8147 5547	27.52
NH 8145 5544	27.58
NH 8141 5542	27.57
NH 8138 5540	27.33
NH 8135 5538	27.10
R8	
NH 8111 5504	24.99
NH 8110 5501	25.14
NH 8111 5497	24.97

Grid Ref.	Alt.	Grid Ref.	Alt.	Grid Ref.	Alt.
R8 (cont.)		R11 (cont.)		R13a	
NH 8113 5493	24.81	NH 7910 5544	28.84	NH 7785 5677	9.64
NH 8116 5487	24.45	NH 7910 5548	28.98	NH 7783 5673	9.43
NH 8114 5490	24.78	NH 7910 5553	28.31	NH 7782 5668	9.73
NH 8118 5484	24.19			NH 7782 5665	9.30
		R12		NH 7783 5660	9.13
R9		NH 7812 5391	8.64		
NH 7852 5535	28.91	NH 7809 5392	9.40	R14	
NH 7855 5523	29.06	NH 7805 5393	9.65	NH 7324 5630	9.27
NH 7858 5522	29.56	NH 7800 5394	9.74	NH 7320 5629	8.80
NH 7863 5520	29.75	NH 7797 5391	9.44	NH 7334 5640	9.24
NH 7866 5520	29.99	NH 7794 5389	9.43	NH 7338 5643	9.29
NH 7870 5519	30.00			NH 7341 5646	9.37
NH 7879 5518	30.16	R13		NH 7345 5649	9.02
		NH 7815 5408	8.01		
R10		NH 7813 5406	7.71	R15	
NH 7853 5512	30.27	NH 7811 5404	8.07	NH 7376 5640	8.94
NH 7857 5510	30.83	NH 7819 5406	8.71	NH 7379 5639	8.80
		NH 7822 5405	8.33	NH 7383 5637	8.95
R11		NH 7825 5403	8.10		
NH 7902 5568	27.18	NH 7828 5400	8.36	R16	
NH 7901 5571	28.08	NH 7831 5398	8.71	NH 7361 5672	9.40
NH 7899 5575	28.49	NH 7807 5400	8.14	NH 7363 5675	9.67
NH 7898 5578	28.58	NH 7804 5398	8.81	NH 7365 5678	9.62
NH 7897 5583	28.60	NH 7806 5397	8.38	NH 7366 5682	9.67
NH 7897 5587	28.66			NH 7366 5685	9.53
NH 7896 5591	28.74	R12a		NH 7367 5688	9.70
NH 7895 5595	28.75	NH 7786 5638	9.69	NH 7367 5692	9.78
NH 7895 5598	28.82	NH 7787 5642	9.64	NH 7368 5695	9.73
NH 7895 5602	28.83	NH 7788 5646	9.76	NH 7369 5699	9.74
NH 7895 5605	28.74	NH 7784 5647	9.65	NH 7370 5702	9.84
NH 7896 5611	28.21	NH 7783 5652	9.53	NH 7371 5710	9.63
NH 7898 5614	28.66	NH 7785 5656	9.45	NH 7371 5714	9.55
NH 7900 5617	28.93	NH 7789 5660	9.32	NH 7372 5718	9.71
NH 7910 5540	29.11	NH 7793 5662	9.16	NH 7372 5722	9.98
NH 7911 5537	29.14	NH 7796 5662	8.98		
NH 7910 5533	29.32	NH 7801 5661	9.07	R17	
NH 7909 5530	29.31	NH 7804 5659	8.68	NH 7375 5724	9.81
NH 7909 5525	29.27			NH 7375 5720	9.35

Grid Ref.	Alt.
R17 (cont.)	
NH 7375 5717	9.17
NH 7375 5714	9.03
NH 7374 5711	9.06
R18	
NH 7382 5699	8.75
NH 7382 5696	8,53
NH 7382 5692	8.50
NH 7383 5689	8.44
NH 7384 5686	7.92
R19	
NH 7428 5620	8.20
NH 7424 5619	8.33
NH 7417 5618	8.50
NH 7413 5620	8.58
NH 7408 5623	8.60
NH 7405 5625	8.49
NH 7401 5628	8.68
NH 7396 5631	8.72
NH 7392 5633	8.78
NH 7387 5635	8.92
R20	
NH 7381 5714	8.75
NH 7382 5711	8.59
NH 7382 5707	8.61
NH 7382 5704	8.58
NH 7382 5701	8.54
R21	
NH 7397 5669	7.49
NH 7395 5672	7.64
NH 7393 5675	7.75
NH 7392 5678	7.83
NH 7390 5682	7.80
R21 (cont)	
NH 7389 5686	7.72
NH 7387 5689	7.72
NH 7386 5694	7.84
NH 7386 5697	8.01
R22	
NH 6982 5414	10.01
NH 6982 5410	9.47
NH 6983 5406	9.40
NH 6984 5403	9.51
NH 6984 5400	9.82
R23	
NH 7365 5000	21.68
NH 7366 5002	22.32
NH 7368 5006	22.61
NH 7370 5009	23.11
NH 7373 5012	23.44
NH 7376 5015	23.05
NH 7377 5018	22.98
R24	
NH 7245 4911	17.33
NH 7249 4907	17.45
NH 7253 4906	17.37
NH 7257 4905	17.12
NH 7260 4904	17.12
NH 7266 4903	17.28
NH 7270 4902	17.04
NH 7274 4901	17.17
NH 7278 4899	17.44
NH 7283 4898	17.87
R25	
NH 7324 4904	9.55
NH 7327 4903	9.82
R25 (cont.)	
NH 7330 4901	9.94
NH 7333 4898	9.87
NH 7341 4893	10.46
NH 7344 4894	9.75
NH 7346 4895	9.36
NH 7350 4896	9.77
NH 7355 4898	9.53
R26	
NH 7340 4974	10.02
NH 7338 4970	9.96
R27	
NH 7157 4945	10.35
NH 7161 4943	10.28
NH 7164 4942	10.27
NH 7168 4941	10.19
NH 7170 4939	10.31
NH 7173 4939	11.15
R28	
NH 7151 4843	10.49
NH 7151 4839	9.75
NH 7152 4836	9.54
NH 7153 4830	9.61
NH 7153 4826	9.59
NH 7153 4822	10.00
NH 7154 4818	10.23
NH 7154 4814	10.19
NH 7154 4811	10.06
NH 7154 4806	9.54
NH 7153 4803	9.77
NH 7153 4796	9.68
NH 7152 4790	9.90
NH 7153 4786	9.86
NH 7152 4780	9.79

Grid Ref	Alt.	Grid Ref.	Alt.	Grid Ref.	Alt.
R28 (cont.)		R32 (ocnt.)		R35	
NH 7151 4776	9.73	NH 5994 3794	18.47	NH 5856 3297	28.35
NH 7149 4773	10.07	NH 5998 3795	18.38	NH 5858 3300	27.92
NH 7148 4768	10.18	NH 6004 3797	18.09	NH 5859 3303	27.99
NH 7147 4765	10.13	NH 6007 3798	18.21	NH 5861 3306	28.03
NH 7145 4762	10.24	NH 6010 3798	18.28	NH 5863 3309	27.81
		NH 6005 3782	19.58		
R29		NH 6008 3779	19.52	R36	
NH 7134 4756	5.69	NH 6012 3776	18.95	NH 4940 2152	17.46
NH 7147 4774	5.27	NH 6015 3776	18.65	NH 4943 2150	17.81
NH 7145 4771	5.57			NH 4947 2150	17.79
NH 7142 4769	5.36	R33		NH 4951 2150	17.63
NH 7139 4766	5.46	NH 6010 3526	28.17	NH 4956 2149	17.65
NH 7136 4760	5.62	NH 6008 3529	28.29	NH 4961 2148	17.67
		NH 6005 3532	28.67		
R30		NH 6002 3534	28.93	R37	
NH 6764 4998	8.74	NH 5998 3536	28.96	NH 4905 2089	29.35
NH 6762 4996	8.82	NH 5996 3537	28.98	NH 4909 2094	29.27
NH 6761 4993	9.32	NH 5993 3539	28.90	NH 4913 2098	28.53
NH 6759 4990	9.27	NH 5990 3541	28.88	NH 4917 2102	28.94
NH 6756 4986	9.92	NH 5986 3543	28.82	NH 4920 2105	28.79
		NH 5983 3545	28.77		
R31		NH 5979 3547	28.47	R38	
NH 6816 5233	10.11	NH 5975 3549	28.13	NH 3857 0844	17.99
NH 6820 5234	11.18			NH 3853 0846	17.86
NH 6824 5235	10.60	R34		NH 3850 0848	17.91
NH 6828 5236	10.18	NH 5992 3496	19.77	NH 3847 0851	17.92
		NH 5990 3500	19.89	NH 3844 0853	17.91
R32		NH 5987 3503	19.58	NH 3849 0856	17.58
NH 5977 3793	19.49	NH 5984 3505	19.93	NH 3831 0859	17.65
NH 5979 3792	19.06	NH 5981 3507	20.04		
NH 5983 3792	19.38	NH 5977 3509	20.28	R39	
NH 5987 3791	19.29	NH 5974 3511	20.36	NH 6172 4826	11.08
NH 5989 3790	19.45	NH 5971 3513	20.45	NH 6176 4826	10.57
NH 5992 3789	19.70	NH 5967 3514	20.53	NH 6179 4827	10.51
NH 5995 3786	19.99	NH 5963 3516	20.31	NH 6181 4829	10.07
NH 6003 3784	19.84	NH 5959 3518	20.33		
NH 5990 3783	19.10	NH 5955 3518	20.05		

Grid Ref.	Alt.
R40	
NH 6122 4849	9.97
NH 6119 4852	9.34
NH 6116 4855	9.38
NH 6114 4857	9.02
NH 6112 4859	9.04
R41	
NH 6043 4860	10.10
NH 6045 4862	10.14
R42	
NH 6054 4567	28.66
NH 6058 4568	28.91
NH 6061 4570	28.95
NH 6065 4571	28.97
NH 6068 4572	28.79
R43	
NH 5318 4782	10.26
NH 5317 4776	10.26
NH 5310 4757	10.30
NH 5311 4759	10.09
NH 5309 4753	10.47
R44	
NH 5224 4660	9.74
NH 5221 4658	9.62
NH 5218 4656	9.10

4. OUTWASH AND FLUVIAL TERRACE FRAGMENTS

Grid Ref.	Alt.	Grid Ref.	Alt.	Grid Ref.	Alt.
T1		T6 (cont.)		T6 (cont.)	
NH 4523 5403	27.65	NH 4725 5400	12.53	NH 4807 5394	11.05
NH 4530 5408	26.59	NH 4721 5399	12.84	NH 4803 5395	11.13
NH 4542 5410	25.02	NH 4717 5399	12.94	NH 4798 5396	11.06
NH 4546 5410	25.34	NH 4714 5398	13.17	NH 4793 5397	11.04
NH 4549 5409	25.30	NH 4712 5398	13.72	NH 4789 5398	10.99
		NH 4708 5398	14.24	NH 4784 5399	11.10
T2		NH 4699 5402	15.24	NH 4781 5399	11.44
4507 5425	26.31	NH 4696 5402	15.13	NH 4776 5400	11.44
4512 5423	25.77	NH 4693 5402	14.73	NH 4773 5400	11.59
4516 5421	25.29	NH 4690 5402	15.01	NH 4769 5401	11.73
4521 5420	25.11	NH 4686 5404	15.44	NH 4765 5402	11.86
4527 5418	24.86	NH 4683 5403	15.35	NH 4760 5402	12.07
		NH 4678 5404	15.21	NH 4757 5402	12.33
T3		NH 4813 5388	11.83	NH 4753 5403	12.86
NH 4778 5384	15.94	NH 4816 5386	11.17	NH 4748 5401	12.95
NH 4778 5385	15.91	NH 4820 5385	11.21		
NH 4775 5386	16.07	NH 4831 5384	11.68	T7	
NH 4771 5387	16.43	NH 4833 5384	11.26	NH 5008 5363	11.69
		NH 4839 5383	11.43	NH 5012 5364	11.98
T4		NH 4843 5382	11.32	NH 5018 5362	12.35
NH 4748 5392	14.94	NH 4846 5378	11.57	NH 5022 5363	12.13
NH 4743 5392	15.22	NH 4854 5377	10.97	NH 5025 5362	11.97
		NH 4857 5375	10.86	NH 5028 5360	12.14
T5		NH 4864 5374	11.45	NH 5031 5358	12.14
NH 4734 5393	14.49	NH 4866 5376	11.50	NH 5035 5357	12.55
NH 4729 5395	14.51	NH 4870 5374	11.56	NH 5038 5355	13.46
		NH 4874 5372	11.32	NH 5041 5354	13.62
T6		NH 4879 5371	11.23	NH 5044 5352	14.05
NH 4748 5398	12.80	NH 4883 5368	11.01	NH 5046 5349	14.20
NH 4744 5397	12.73	NH 4887 5368	11.25		
NH 4740 5397	12.89	NH 4891 5368	11.02	T8	
NH 4738 5400	13.03	NH 4896 5367	11.23	NH 5029 5335	15.04
NH 4733 5403	12.90	NH 4900 5367	11.11	NH 5026 5337	15.21
NH 4728 5402	12.43	NH 4809 5393	11.04	NH 5023 5338	15.12

T8 (cont.)

Grid Ref.	Alt.
NH 5018 5337	15.09
NH 5015 5335	15.54
NH 5012 5332	15,95
NH 5002 5328	16.11
NH 5001 5325	17.06
NH 5000 5324	17.76
NH 5000 5322	18.64

T9

Grid Ref.	Alt.
NH 5004 5334	15.08
NH 5003 5338	15.20
NH 5003 5341	14.95
NH 5003 5344	14.73
NH 5005 5348	14.56

T10

Grid Ref.	Alt.
NH 4989 5296	25.82
NH 4986 5293	26.26
NH 4983 5291	26.67
NH 4980 5289	26.92
NH 4976 5282	27.89
NH 4981 5282	27.95
NH 4983 5278	27.75
NH 4986 5271	28.00
NH 4986 5266	28.44
NH 4988 5261	28.61
NH 4986 5252	29.78
NH 4989 5248	29.96
NH 4989 5244	30.40
NH 4992 5241	31.10
NH 4991 5236	31.34
NH 4990 5233	31.95
NH 4989 5231	32.36
NH 4985 5229	32.85
NH 4984 5225	32.93
NH 4984 5221	33.02
NH 4986 5217	33.87

T11

Grid Ref.	Alt.
NH 4771 5171	70.27
NH 4775 5172	69.16
NH 4779 5172	68.48
NH 4783 5171	67.74
NH 4787 5170	66.91
NH 4791 5168	66.70
NH 4797 5170	65.98
NH 4799 5168	65.09

T12

Grid Ref.	Alt.
NH 4829 5167	62.28
NH 4834 5166	61.78
NH 4837 5166	61.41
NH 4839 5165	61.23
NH 4843 5164	60.80

T13

Grid Ref.	Alt.
NH 4799 5163	63.75
NH 4801 5166	63.44
NH 4803 5168	62.87
NH 4806 5168	62.61
NH 4809 5168	62.27
NH 4813 5169	61.76
NH 4815 5168	60.95
NH 4818 5167	60.62

T14

Grid Ref.	Alt.
NH 4862 5162	54.88
NH 4864 5163	54.35

T15

Grid Ref.	Alt.
NH 4916 5156	47.27
NH 4920 5154	46.82
NH 4923 5153	46.09

T16

Grid Ref.	Alt.
NH 4869 5161	52.24

T16 (cont.)

Grid Ref.	Alt.
NH 4872 5162	51.39
NH 4875 5163	50.78
NH 4881 5163	50.15
NH 4884 5163	49.49
NH 4902 5160	47.78
NH 4906 5159	47.20
NH 4909 5158	46.38

T17

Grid Ref.	Alt.
NH 4828 5160	57.05
NH 4825 5161	57.33
NH 4823 5162	57.33
NH 4820 5161	58.08
NH 4817 5160	58.80
NH 4814 5159	59.48
NH 4811 5158	60.25

T18

Grid Ref.	Alt.
NH 4911 5148	45.88
NH 4908 5150	46.60
NH 4906 5150	46.50
NH 4900 5150	47.61
NH 4897 5153	48.51
NH 4889 5154	49.08
NH 4879 5153	49.57
NH 4873 5153	50.19
NH 4870 5153	50.93
NH 4866 5153	51.57

T19

Grid Ref.	Alt.
NH 4835 5158	55.14
NH 4831 5158	55.96
NH 4828 5156	56.13
NH 4825 5155	56.66
NH 4762 5126	77.40
NH 4759 5127	77.35

Grid Ref.	Alt.
T20	
NH 4907 5109	53.91
NH 4904 5109	54.20
NH 4900 5109	54.82
NH 4897 5110	55.28
T21	
NH 4726 5129	80.12
NH 4730 5129	79.50
NH 4735 5129	78.74
NH 4740 5129	78.14
NH 4744 5129	77.61
NH 4748 5129	77.13
NH 4753 5131	76.29
NH 4759 5132	75.72
NH 4767 5131	75.27
NH 4768 5128	75.75
NH 4770 5127	76.55
NH 4752 5129	76.77
T22	
NH 4860 5123	59.79
NH 4856 5123	60.30
NH 4852 5123	61.04
NH 4849 5124	61.59
NH 4845 5124	62.63
NH 4842 5125	63.27
NH 4839 5126	64.32
NH 4834 5128	65.25
NH 4830 5129	65.97
NH 4825 5130	67.12
NH 4821 5131	67.99
NH 4817 5132	69.43
NH 4808 5131	71.40
NH 4804 5131	72.26
NH 4799 5131	73.18

Grid Ref.	Alt.
T23	
NH 4773 5124	77.69
NH 4776 5121	78.01
NH 4778 5117	78.85
T24	
NH 4870 5121	59.04
NH 4873 5121	58.52
NH 4876 5121	58.04
NH 4879 5119	57.34
NH 4884 5118	56.97
NH 4888 5117	56.09
NH 4891 5117	55.17
NH 4899 5118	53.88
NH 4903 5117	53.16
NH 4907 5116	52.56
NH 4911 5115	52.00
NH 4914 5116	51.48
NH 4917 5117	51.15
T25	
NH 4780 5105	82.53
NH 4778 5102	83.90
NH 4784 5095	85.66
NH 4783 5091	86.89
NH 4783 5087	87.71
NH 4783 5084	88.92
NH 4783 5081	89.89
T26	
NH 4805 5143	68.27
NH 4809 5140	67.61
NH 4813 5137	67.02
NH 4815 5136	66.48
NH 4819 5135	65.85

Grid Ref.	Alt.
T27	
NH 4806 5147	64.75
NH 4811 5146	63.64
NH 4816 5145	62.80
NH 4821 5144	61.49
NH 4824 5143	60.65
NH 4827 5141	59.87
NH 4831 5138	59.23
NH 4835 5137	58.53
NH 4839 5138	58.09
T28	
NH 4847 5136	56.09
NH 4856 5136	55.56
T29	
NH 4827 5148	58.44
NH 4831 5145	57.74
NH 4836 5144	57.04
NH 4841 5144	56.71
NH 4844 5144	56.50
NH 4847 5143	56.20
NH 4850 5141	55.61
NH 4853 5139	55.13
NH 4857 5139	54.79
NH 4861 5139	54.26
T30	
NH 4793 5130	73.14
NH 4792 5128	73.90
NH 4792 5126	74.50
NH 4791 5123	75.94
NH 4791 5119	77.12
T31	
NH 4782 5124	74.08
NH 4783 5119	74.88

Grid Ref.	Alt.	Grid Ref.	Alt.	Grid Ref.	Alt.
T31 (cont.)		T35 (cont.)		T37 (cont.)	
NH 4783 5115	76.26	NH 4827 5088	86.85	NH 5034 5034	64.33
NH 4784 5111	77.66			NH 5038 5035	63.65
NH 4784 5107	79.07	T36		NH 5042 5035	63.08
		NH 4946 5084	73.50	NH 5048 5037	62.46
T32		NH 4949 5086	72.96	NH 5051 5038	61.76
NH 4779 5147	69.27	NH 4953 5088	72.75	NH 5055 5039	61.17
NH 4782 5149	68.56	NH 4957 5089	72.36	NH 5059 5041	60.69
NH 4784 5152	68.05	NH 4959 5087	71.60	NH 5063 5042	60.04
NH 4775 5149	69.60			NH 5066 5044	59.90
NH 4772 5148	69.87	T37		NH 5069 5045	59.52
NH 4768 5151	71.13	NH 4848 5087	83.12	NH 5072 5046	58.79
		NH 4922 5085	73.90	NH 5076 5047	58.30
T33		NH 4924 5083	74.22	NH 5080 5049	57.34
NH 4806 5077	94.62	NH 4922 5081	73.95	NH 5084 5050	56.78
NH 4810 5078	93.76	NH 4931 5079	73.80	NH 5087 5053	56.27
NH 4813 5080	93.00	NH 4934 5079	73.33	NH 5091 5055	55.75
NH 4818 5080	92.30	NH 4938 5079	72.92	NH 5093 5055	55.15
NH 4823 5079	91.31	NH 4942 5079	72.46	NH 5097 5055	54.75
NH 4828 5080	90.07	NH 4948 5080	71.61	NH 5101 5055	54.16
NH 4831 5080	88.86	NH 4949 5081	71.03	NH 5105 5054	53.65
NH 4835 5080	88.02	NH 4960 5081	70.60	NH 5110 5054	53.19
NH 4838 5079	87.87	NH 4964 5080	70.07	NH 5115 5054	52.77
		NH 4967 5081	69.46	NH 5119 5053	52.05
T34		NH 4971 5079	69.22	NH 5122 5051	51.45
NH 4941 5084	74.49	NH 4976 5079	69.11	NH 5127 5050	50.89
NH 4943 5087	74.11	NH 4981 5080	69.27	NH 5132 5050	50.42
NH 4947 5088	73.38	NH 4985 5079	68.59	NH 5137 5052	49.77
		NH 4989 5078	68.34	NH 5141 5053	49.32
T35		NH 4992 5075	68.18	NH 5143 5054	48.98
NH 4851 5079	84.34	NH 4995 5072	68.23	NH 5147 5056	48.51
NH 4853 5081	83.76	NH 4997 5069	67.89	NH 5133 5081	49.71
NH 4849 5077	84.96	NH 5001 5067	67.72	NH 5137 5082	49.28
NH 4845 5078	84.82	NH 5015 5042	69.01	NH 5141 5081	48.81
NH 4843 5081	85.27	NH 5019 5042	67.92	NH 5144 5081	48.49
NH 4840 5085	85.12	NH 5022 5037	66.55	NH 5148 5081	48.23
NH 4836 5087	85.48	NH 5027 5035	65.73	NH 5151 5080	48.00
NH 4831 5087	86.13	NH 5031 5034	64.87	NH 5155 5079	47.46

Grid Ref.	Alt.
T37 (cont.)	
NH 5160 5080	47.12
NH 5163 5082	46.40
NH 5167 5084	45.75
NH 5170 5088	45.99
NH 5170 5092	45.81
NH 5171 5096	45.23
NH 5171 5106	44.64
NH 5106 5071	53.43
NH 5103 5073	53.52
NH 5099 5075	53.84
NH 5094 5077	54.12
NH 5090 5077	54.48
NH 5087 5078	54.75
NH 5084 5078	55.33
NH 5081 5077	55.41
NH 5077 5075	44.93
NH 5074 5074	56.28
NH 5070 5072	56.73
NH 5066 5070	57.25
NH 5062 5068	57.80
NH 5060 5064	58.18
NH 5059 5060	58.80
NH 5057 5055	59.21
T38	
NH 5241 5030	37.28
NH 5242 5026	26.85
NH 5244 5023	36.65
NH 5233 5030	37.48
NH 5231 5032	38.25
NH 5229 5036	38.77
NH 5227 5039	39.06
NH 5225 5044	39.78
NH 5223 5047	40.01
NH 5222 5052	40.33
T39	
NH 5214 5262	24.70
NH 5218 5258	24.84
NH 5223 5257	25.07
NH 5227 5255	25.12
NH 5231 5253	25.06
NH 5235 5251	25.11
NH 5238 5249	24.98
NH 5242 5249	24.82
NH 5246 5248	24.77
NH 5252 5248	24.62
NH 5256 5247	24.74
NH 5261 5245	24.63
NH 5264 5245	24.66
NH 5268 5244	24.75
T4C	
NH 5211 5258	24.49
NH 5211 5253	25.13
NH 5213 5249	25.09
NH 5214 5246	25.24
NH 5216 5242	25.48
NH 5218 5238	25.90
T41	
NH 5177 5266	25.61
NH 5179 5263	25.90
NH 5182 5260	25.99
NH 5184 5256	26.20
NH 5187 5253	26.16
NH 5190 5249	26.28
NH 5191 5246	26.02
NH 5200 5252	25.10
NH 5199 5245	25.23
NH 5200 5240	25.20
NH 5201 5235	25.60
T41 (cont.)	
NH 5203 5233	25.58
NH 5206 5231	25.24
NH 5209 5231	25.26
NH 5208 5227	25.28
T42	
NH 5111 5182	28.34
NH 5125 5191	27.48
NH 5130 5193	27.06
NH 5136 5195	26.78
T43	
NH 5175 5190	24.96
NH 5171 5193	25.57
NH 5168 5193	26.01
NH 5165 5191	26.63
NH 5162 5189	26.92
NH 5158 5187	27.17
T44	
NH 5116 5161	28.60
NH 5116 5157	28.56
NH 5108 5157	29.31
NH 5105 5157	30.06
NH 5100 5157	30.33
NH 5096 5156	30.88
NH 5092 5155	31.16
NH 5088 5155	31.78
NH 5082 5156	32.23
NH 5072 5157	33.10
NH 5068 5157	33.34
NH 5064 5156	33.66
NH 5060 5156	34.22
NH 5054 5156	34.67
NH 5050 5155	35.37
NH 5045 5156	35.77

Grid Ref.	Alt.
T45	
NH 5164 5179	25.38
NH 5160 5176	25.41
NH 5158 5172	25.43
NH 5153 5170	25.79
NH 5148 5178	26.02
NH 5144 5178	26.29
NH 5140 5177	26.63
NH 5136 5177	26.87
NH 5131 5176	26.88
NH 5128 5174	27.17
NH 5122 5175	27.27
T46	
NH 5183 5136	27.71
NH 5182 5134	27.97
T47	
NH 5141 5149	26.53
NH 5145 5150	26.01
NH 5149 5151	26.15
NH 5154 5153	25.95
NH 5158 5150	26.19
NH 5161 5152	25.95
NH 5164 5154	25.80
NH 5164 5159	25.61
NH 5165 5163	25.06
NH 5172 5168	25.49
NH 5173 5164	25.45
NH 5175 5160	25.68
NH 5176 5156	25.97
NH 5178 5153	26.07
NH 5179 5152	25.99
T48	
NH 5143 5234	23.93
NH 5143 5229	24.07
NH 5144 5224	24.25
T48 (cont.)	
NH 5141 5220	24.45
NH 5136 5220	24.79
NH 5141 5213	25.10
NH 5145 5215	24.80
NH 5148 5218	24.43
NH 5150 5223	24.38
NH 5153 5226	24.16
NH 5155 5229	24.55
NH 5159 5245	24.20
NH 5163 5241	23.84
T49	
NH 5155 5250	23.44
NH 5145 5240	23.87
T50+T51	
NH 5202 5176	24.44
NH 5206 5175	24.16
NH 5209 5175	24.15
NH 5213 5176	23.99
NH 5216 5178	23.75
NH 5220 5180	23.61
NH 5223 5181	23.68
T52	
NH 5191 5174	24.69
NH 5188 5178	24.74
NH 5185 5181	24.39
NH 5184 5186	24.65
T53	
NH 5216 5187	24.36
NH 5213 5185	24.64
NH 5211 5183	24.72
NH 5209 5181	24.61
NH 5207 5180	24.79
NH 5219 5190	24.13
T53 (cont.)	
NH 5222 5192	23.96
NH 5228 5196	23.92
NH 5231 5198	23.81
T54	
NH 5035 5156	33.84
NH 5031 5154	34.46
NH 5028 5151	35.30
NH 5023 5149	35.42
NH 5021 5147	36.15
NH 5018 5145	36.84
NH 5015 5143	37.52
NH 5010 5141	37.91
NH 5007 5139	38.29
NH 5003 5138	38.56
NH 4998 5136	39.06
T55	
NH 5044 5168	32.28
NH 5046 5170	31.88
NH 5049 5171	31.15
NH 5051 5174	30.28
NH 5062 5178	29.79
NH 5065 5180	29.38
NH 5069 5183	28.76
NH 5072 5183	28.35
NH 5076 5184	27.76
NH 5079 5186	27.30
NH 5081 5194	26.64
NH 5085 5196	26.22
NH 5089 5198	25.62
NH 5092 5200	25.15
NH 5096 5201	24.63
NH 5100 5202	24.17
T56	
NH 5104 5203	23.59

T56 (cont.)

Grid Ref.	Alt.
NH 5107 5205	23.34
NH 5111 5206	22.89
NH 5114 5208	22.45
NH 5118 5209	21.95
NH 5113 5212	22.27
NH 5116 5215	21.74
NH 5118 5217	21.51
NH 5118 5221	20.79
NH 5124 5231	20.55
NH 5126 5235	19.91
NH 5127 5238	19.16
NH 5128 5241	18.80
NH 5130 5245	18.91
NH 5132 5248	18.41
NH 5135 5253	18.24
NH 5136 5256	17.68
NH 5138 5261	16.93
NH 5142 5267	16.21
NH 5144 5272	15.97
NH 5146 5277	15.59
NH 5147 5282	15.34
NH 5149 5285	14.85
NH 5151 5289	14.36
NH 5156 5297	13.83
NH 5159 5298	13.43
NH 5162 5301	12.82
NH 5164 5304	12.41
NH 5168 5309	12.28
NH 5181 5320	10.63
NH 5176 5321	10.59
NH 5173 5324	10.90
NH 5174 5327	10.53
NH 5175 5331	10.13
NH 5172 5335	10.01
NH 5176 5309	11.55

T57

Grid Ref.	Alt.
NH 5192 5296	13.89
NH 5188 5294	13.95
NH 5184 5294	13.96
NH 5180 5293	14.13
NH 5176 5292	14.24
NH 5171 5293	14.29
NH 5167 5291	14.71
NH 5162 5291	15.13
NH 5159 5292	15.48
NH 5157 5292	15.43

T58

Grid Ref.	Alt.
NH 5230 5301	10.01
NH 5226 5299	10.35
NH 5224 5296	10.79
NH 5222 5293	11.45

T59

Grid Ref.	Alt.
NH 5265 5318	8.41
NH 5263 5315	8.47
NH 5260 5312	8.61
NH 5257 5311	8.74
NH 5254 5309	9.14
NH 5250 5308	9.42

T60

Grid Ref.	Alt.
NH 4985 5133	36.67
NH 4988 5136	36.13
NH 4990 5139	35.57
NH 4991 5142	35.41
NH 4993 5146	34.91
NH 4993 5148	34.86
NH 5009 5164	33.77
NH 5014 5168	33.35
NH 5018 5171	33.05

T60 (cont.)

Grid Ref.	Alt.
NH 5021 5173	32.27
NH 5026 5175	31.56
NH 5031 5177	30.83
NH 5034 5179	30.65
NH 5036 5183	30.45
NH 5039 5187	29.46
NH 5041 5190	28.82
NH 5045 5203	26.96
NH 5048 5194	28.21
NH 5049 5198	27.81
NH 5051 5200	27.74
NH 5054 5203	27.16

T61

Grid Ref.	Alt.
NH 5013 5179	31.01
NH 5016 5181	31.00
NH 5023 5189	29.05
NH 5021 5186	29.69
NH 5067 5236	22.67
NH 5065 5234	23.31
NH 5062 5230	23.81
NH 5061 5225	24.31
NH 5063 5220	24.67
NH 5062 5212	25.20
NH 5059 5209	25.54
NH 5056 5208	25.83
NH 5052 5208	26.60
NH 5048 5206	27.00

T62

Grid Ref.	Alt.
NH 5017 5190	28.66
NH 5020 5193	28.05
NH 5023 5195	28.08
NH 5026 5198	27.44
NH 5028 5201	27.08

Grid Ref.	Alt.	Grid Ref.	Alt.	Grid Ref.	Alt.
T62 (cont.)		T65 (cont.)		T67 (cont.)	
NH 5030 5203	26.46	NH 5188 5134	24.69	NH 5225 4841	27.64
NH 5034 5207	26.20	NH 5187 5130	24.90	NH 5228 4838	27.36
NH 5037 5210	25.82	NH 5181 5128	25.45	NH 5232 4836	26.81
NH 5039 5213	25.36	NH 5177 5123	25.53	NH 5236 4834	26.44
NH 5042 5215	24.88	NH 5178 5119	25.77	NH 5239 4832	26.04
NH 5047 5218	24.42	NH 5179 5115	26.17	NH 5241 4830	25.87
NH 5049 5220	23.99			NH 5236 4818	26.20
NH 5051 5227	23.47	T66		NH 5240 4816	25.77
NH 5056 5233	22.85	NH 5197 5121	23.85	NH 5244 4815	25.27
NH 5058 5237	22.58	NH 5198 5122	23.65	NH 5249 4814	24.98
NH 5061 5240	22.32	NH 5199 5126	24.05	NH 5252 4813	24.79
NH 5063 5244	21.58	NH 5202 5129	23.65	NH 5250 4812	24.78
		NH 5205 5132	23.49	NH 5259 4812	24.76
T63		NH 5211 5135	23.44	NH 5266 4811	24.28
NH 5078 5252	20.23	NH 5214 5137	23.52	NH 5269 4811	24.00
NH 5075 5249	20.58	NH 5215 5141	23.22	NH 5273 4810	24.12
NH 5072 5245	21.15	NH 5215 5145	23.12	NH 5277 4809	23.81
NH 5066 5246	22.06				
NH 5081 5254	19.80	T67		T68	
NH 5082 5258	19.51	NH 5277 4957	32.35	NH 5232 4916	29.11
NH 5084 5262	19.20	NH 5276 4954	32.05	NH 5231 4914	29.15
NH 5086 5266	18.69	NH 5271 4953	31.99	NH 5228 4912	29.35
NH 5087 5271	18.20	NH 5267 4952	31.73	NH 5226 4910	29.71
		NH 5264 4951	31.49	NH 5222 4907	30.64
T65		NH 5261 4953	31.30	NH 5219 4904	32.38
NH 5214 5153	22.96	NH 5259 4951	30.79	NH 5215 4903	33.24
NH 5210 5151	23.01	NH 5256 4949	30.61	NH 5212 4902	34.67
NH 5207 5147	23.20	NH 5254 4946	30.36		
NH 5203 5147	23.42	NH 5252 4944	30.41	T69	
NH 5198 5148	23.56	NH 5249 4939	30.12	NH 5498 4943	26.42
NH 5195 5149	23.79	NH 5247 4936	30.20	NH 5494 4940	26.39
NH 5192 5148	23.80	NH 5244 4933	29.97	NH 5491 4937	26.37
NH 5189 5147	23.38	NH 5240 4930	29.95	NH 5488 4934	26.23
NH 5189 5144	23.62	NH 5239 4925	29.52	NH 5485 4931	26.67
NH 5189 5140	24.10	NH 5237 4922	29.09	NH 5482 4928	26.67
NH 5188 5137	24.38	NH 5235 4919	29.11	NH 5479 4932	26.38

T69 (cont.)

NH	5477	4937	26.63
NH	5475	4941	26.83
NH	5473	4945	26.69
NH	5472	4950	26.80
NH	5446	4959	27.49
NH	5442	4961	27.59
NH	5439	4964	27.62
NH	5439	4969	27.77
NH	5437	4974	27.95
NH	5434	4978	28.32
NH	5421	4982	28.45
NH	5417	4985	28.52
NH	5413	4987	28.71
NH	5409	4988	28.94
NH	5404	4989	29.17
NH	5400	4991	28.99
NH	5410	5003	29.98
NH	5407	5005	29.78
NH	5404	5007	29.54
NH	5399	5008	29.65
NH	5386	5007	30.66
NH	5382	5009	30.89
NH	5379	5011	30.98
NH	5374	5012	31.41
NH	5370	5010	31.64
NH	5367	5009	32.14
NH	5363	5008	32.14

T70

NH	4959	4437	35.96
NH	4962	4439	36.10
NH	4966	4436	36.35
NH	4970	4437	36.41
NH	4973	4440	36.21
NH	4978	4441	35.89
NH	4982	4442	35.56

T70 (cont.)

NH	4985	4444	35.28
NH	4991	4450	35.64
NH	4993	4453	35.53
NH	4995	4456	35.18
NH	4998	4458	35.00
NH	5002	4461	34.94
NH	5006	4462	34.79
NH	5029	4474	33.91
NH	5033	4476	33.58
NH	5036	4478	33.34
NH	5038	4481	33.40
NH	5042	4483	32.88
NH	5045	4486	32.86
NH	5047	4487	32.67
NH	5050	4489	32.25
NH	5053	4492	31.81
NH	5056	4495	31.64
NH	5058	4497	31.44
NH	5061	4500	31.20
NH	5065	4503	30.83
NH	5068	4506	30.25
NH	5071	4510	30.28
NH	5074	4513	30.15
NH	5078	4516	29.99
NH	5080	4517	29.42
NH	5082	4521	29.17
NH	5085	4523	29.21
NH	5087	4528	28.95
NH	5088	4531	27.98
NH	5090	4534	27.65
NH	5091	4537	27.39
NH	5093	4541	27.03
NH	5095	4545	27.24

T71

NH	4968	4420	30.52

T71 (cont.)

NH	4970	4421	30.08
NH	4973	4424	29.70
NH	4426	4975	29.31

T72

NH	4976	4419	26.61
NH	4978	4421	26.30
NH	4990	4429	25.62
NH	4990	4425	26.15
NH	4989	4422	26.43
NH	4988	4420	26.86
NH	4982	4419	27.09
NH	4982	4415	27.49
HN	4982	4413	27.75

T73

NH	4996	4400	24.87
NH	4999	4403	23.99
NH	5004	4405	23.46
NH	5007	4408	23.14
NH	5011	4409	23.15
NH	5015	4410	23.02
NH	5019	4410	22.57
NH	5023	4412	22.79
NH	5026	4413	22.71
NH	5028	4413	22.62
NH	5031	4414	22.28
NH	5033	4416	21.68
NH	5035	4417	21.20
NH	5038	4420	20.48
NH	5041	4424	20.03
NH	5051	4435	19.38
NH	5054	4436	18.80
NH	5057	4440	18.38
NH	5060	4442	17.72

Grid Ref.	Alt.
T74	
NH 4999 4396	20.35
NH 5002 4400	20.31
NH 5005 4400	19.58
NH 5008 4401	19.50
NH 5010 4402	20.18
NH 5012 4403	20.30
NH 5015 4404	20.26
NH 5019 4404	20.24
NH 5022 4405	20.07
NH 5121 4428	14.62
NH 5114 4426	14.66
NH 5111 4424	15.06
NH 5109 4422	15.47
NH 5105 4420	15.69
T75	
NH 5028 4404	16.45
NH 5030 4406	15.88
NH 5025 4401	17.18
NH 5023 4397	16.96
NH 5024 4392	16.87
NH 5024 4388	16.94
T76	
NH 5105 4415	10.94
NH 5102 4414	10.95
T77	
NH 5129 4432	10.05
NH 5128 4429	10.39
NH 5126 4427	10.45
T78	
NH 5005 4365	16.59
NH 5009 4364	16.54
NH 5014 4365	16.18
NH 5020 4364	16.28

Grid Ref.	Alt.
T78 (cont.)	
NH 5022 4365	15.79
NH 5026 4365	15.23
NH 5029 4365	14.77
T79	
NH 5054 4394	13.07
NH 5057 4396	12.80
NH 5061 4398	12.49
NH 5064 4399	12.37
NH 5069 4400	11.81
T80	
NH 5100 4408	11.28
NH 5106 4406	10.92
NH 5110 4407	10.89
NH 5119 4409	10.38
NH 5117 4413	10.23
NH 5118 4416	9.86
NH 5119 4421	9.88
NH 5122 4422	9.79
NH 5126 4422	9.79
NH 5129 4423	9.64
NH 5132 4426	9.53
T81	
NH 5246 4452	8.26
NH 5248 4447	8.29
NH 5249 4443	8.37
NH 5249 4439	8.26
NH 5249 4434	8.60
NH 5248 4430	8.64
NH 5246 4427	8.69
NH 5245 4423	8.91
NH 5244 4419	9.05
NH 5243 4414	9.20
NH 5243 4410	9.31
NH 5244 4406	9.52

Grid Ref.	Alt.
T81 (cont.)	
NH 5244 4404	9.51
T82	
NH 5003 4360	14.38
NH 5006 4359	14.26
NH 5013 4358	13.56
NH 5016 4358	13.32
NH 5019 4359	13.21
NH 5023 4359	13.03
T83	
NH 5077 4405	9.92
NH 5074 4406	10.35
NH 5069 4407	10.38
NH 5065 4408	10.33
NH 5060 4410	10.62
NH 5057 4411	10.97
NH 5057 4408	11.42
NH 5054 4406	11.51
NH 5051 4404	11.82
T84	
NH 5133 4384	9.04
NH 5137 4386	9.07
NH 5139 4389	9.16
NH 5142 4392	8.90
NH 5146 4395	8.92
NH 5148 4398	8.88
NH 5152 4400	8.61
NH 5156 4403	8.56
NH 5158 4406	8.49
NH 5126 4439	8.71
NH 5126 4443	8.58
NH 5126 4447	8.51
NH 5125 4451	8.50
NH 5130 4438	8.19
NH 5130 4441	7.97

Grid Ref.	Alt.
T84 (cont.)	
NH 5130 4445	8.00
NH 5130 4450	8.08
NH 5130 4454	8.16
NH 5130 4458	8.47
NH 5131 4461	8.47
NH 5133 4465	8.44
NH 5135 4468	8.21
T85	
NH 5228 4458	7.06
NH 5225 4460	7.00
T86	
NH 5241 4474	6.39
NH 5241 4470	6.83
NH 5240 4465	6.92
T87	
NH 5054 4375	9.74
NH 5054 4371	9.66
NH 5049 4364	10.11
NH 5047 4360	10.62
NH 5037 4364	10.63
NH 5034 4361	10.50
NH 5031 4357	10.85
NH 5028 4353	10.66
NH 5025 4357	10.60
NH 5022 4349	10.99
NH 5019 4348	11.62
NH 5016 4347	12.10
NH 5008 4347	12.86
T88	
NH 5146 4373	8.27
NH 5150 4374	8.12
NH 5154 4374	7.82
NH 5159 4376	7.81
T88 (cont.)	
NH 5159 4376	7.81
NH 5165 4380	7.34
NH 5169 4382	7.43
NH 5172 4385	7.45
NH 5175 4388	7.21
NH 5179 4392	7.06
T89	
NH 5226 4481	6.68
NH 5224 4478	6.51
NH 5221 4475	6.34
NH 5218 4473	6.35
NH 5214 4471	6.31
NH 5213 4460	6.29
NH 5208 4458	6.52
NH 5205 4457	6.66
NH 5200 4456	6.61
NH 5233 4515	5.06
NH 5231 4512	5.12
NH 5231 4508	5.16
NH 5232 4504	5.38
NH 5232 4501	5.36
T90	
NH 5183 4411	7.25
NH 5180 4411	7.02
NH 5176 4410	7.00
NH 5168 4406	6.88
NH 5165 4407	6.53
NH 5163 4409	6.49
NH 5161 4412	6.39
NH 5158 4415	6.32
NH 5157 4420	6.15
NH 5152 4432	6.11
NH 5149 4434	5.75
NH 5146 4436	5.94
NH 5143 4440	6.00
T90 (cont.)	
NH 5141 4443	6.11
NH 5139 4447	5.95
NH 5139 4451	5.71
T91	
NH 5247 4408	11.40
NH 5247 4414	11.47
NH 5248 4418	11.50
T92	
NH 5247 4494	7.62
NH 5247 4498	7.26
NH 5247 4503	7.05
NH 5248 4509	7.19
NH 5249 4513	7.70
NH 5252 4517	7.97
NH 5253 4520	8.01
NH 5256 4523	8.04
NH 5258 4525	8.43
T100	
NH 5037 4335	10.40
NH 5039 4338	10.41
NH 5042 4339	10.54
NH 5045 4340	10.41
NH 5049 4349	9.99
NH 5052 4351	9.25
NH 5054 4354	9.32
NH 5057 4358	9.24
NH 5061 4363	9.02
T101	
NH 5166 4364	7.20
NH 5169 4365	7.03
NH 5172 4366	6.91
NH 5178 4368	6.92
NH 5180 4370	6.77

Grid Ref.	Alt.	Grid Ref.	Alt.	Grid Ref.	Alt.
T102		T106 (cont.)		T108 (cont.)	
NH 5191 4390	7.43	NH 5210 4525	4.37	NH 4995 4311	31.34
NH 5192 4394	6.78	NH 5207 4523	4.46	NH 4995 4307	31.07
NH 5191 4397	6.54	NH 5203 4521	4.90	NH 4996 4303	30.84
NH 5189 4400	6.44			NH 4995 4297	30.85
NH 5188 4404	6.31	T107		NH 4998 4314	31.20
NH 5189 4408	6.03	NH 5245 4524	2.44	NH 5002 4312	30.55
		NH 5249 4525	2.24	NH 5007 4307	30.30
T103		NH 5252 4527	2.17	NH 5009 4305	30.07
NH 5200 4463	5.79	NH 5257 4529	2.06	NH 5012 4302	29.88
NH 5200 4468	5.91	NH 5264 4535	2.10	NH 5014 4300	29.57
NH 5200 4471	6.02			NH 5014 4296	29.49
NH 5200 4476	5.99	T108		NH 5015 4293	29.21
NH 5200 4480	5.99	NH 4984 4347	33.99	NH 5017 4290	29.18
NH 5200 4485	5.63	NH 4980 4348	34.27	NH 5019 4286	29.18
NH 5212 4480	5.34	NH 4976 4349	34.36	NH 5032 4287	29.75
NH 5213 4484	5.39	NH 4969 4349	34.08	NH 5035 4285	29.51
		NH 4966 4352	34.37	NH 5038 4282	29.32
T105		NH 4964 4354	34.92	NH 5040 4279	28.92
NH 5204 4539	4.14	NH 4960 4356	35.53	NH 5042 4276	28.75
NH 5206 4541	3.85	NH 4957 4357	36.03	NH 5044 4273	28.36
NH 5209 4543	3.88	NH 4953 4360	35.99	NH 5045 4269	28.17
NH 5212 4544	3.60	NH 4957 4368	35.62	NH 5047 4265	27.83
NH 5216 4546	3.51	NH 4955 4371	36.08	NH 5047 4262	27.49
NH 5220 4548	3.33	NH 4953 4374	36.41	NH 5048 4257	27.11
NH 5223 4550	3.02	NH 4950 4378	36.77	NH 5048 4254	26.81
NH 5226 4553	2.89	NH 4947 4381	37.13	NH 5035 4262	28.60
NH 5228 4556	2.57	NH 4936 4381	37.48	NH 5033 4258	28.50
		NH 4931 4383	38.01	NH 5025 4252	28.20
T106		NH 4930 4385	38.52	NH 5030 4254	28. 07
NH 5234 4518	3.11	NH 4930 4388	38.89		
NH 5228 4519	3.37	NH 4931 4392	39.32	T109	
NH 5226 4518	3.78	NH 4929 4391	39.76	NH 5204 4128	43.09
NH 5224 4517	4.02	NH 4927 4398	39.84	NH 5206 4125	43.72
NH 5214 4525	4.00	NH 4926 4401	39.94	NH 5206 4121	44.41
NH 5217 4528	3.48	NH 4928 4403	40.56	NH 5206 4117	45.15
NH 5221 4514	4.24	NH 4996 4315	31.61	NH 5205 4113	45.94

Grid Ref.	Alt.
T109 (cont.)	
NH 5203 4110	47.05
NH 5201 4106	47.85
NH 5200 4103	49.25
NH 5197 4100	50.38
NH 5193 4097	51.36
NH 5190 4096	51.56
NH 5187 4096	51.94
NH 5183 4096	52.27
T110	
NH 5174 4108	46.16
NH 5178 4111	45.30
NH 5179 4114	44.32
NH 5181 4119	43.41
NH 5182 4122	42.39
NH 5187 4127	41.91
NH 5187 4130	41.85
NH 5188 4133	41.24
NH 5191 4138	40.65
NH 5193 4141	39.75
NH 5194 4145	39.23
NH 5191 4149	38.83
NH 5189 4152	38.25
NH 5186 4155	37.80
T111+T114	
NH 5086 4165	33.01
NH 5087 4162	33.62
NH 5088 4159	34.65
NH 5089 4155	35.47
NH 5090 4151	36.05
NH 5091 4146	36.67
NH 5089 4142	37.05
NH 5089 4138	37.37
NH 5089 4134	38.34
NH 5093 4193	39.07
NH 5094 4194	39.79

Grid Ref.	Alt.
T111 (cont.)	
NH 5096 4125	40.64
NH 5099 4123	41.25
NH 5103 4120	41.96
NH 5106 4118	42.35
NH 5108 4115	43.00
NH 5112 4112	44.01
NH 5114 4110	44.64
NH 5112 4117	43.64
NH 5109 4120	42.97
NH 5108 4124	41.87
NH 5107 4127	41.06
NH 5110 4131	40.55
NH 5111 4133	39.64
NH 5120 4148	36.77
NH 5124 4152	37.54
NH 5128 4152	38.69
NH 5162 4155	37.65
NH 5124 4158	36.56
NH 5121 4164	35.83
NH 5119 4168	35.14
NH 5119 4175	34.48
NH 5122 4178	34.09
NH 5125 4181	33.47
NH 5124 4183	32.57
NH 5122 4184	31.03
T112	
NH 5150 4131	43.80
NH 5147 4131	43.64
NH 5138 4127	42.69
NH 5138 4124	43.52
NH 5138 4122	44.04
NH 5138 4117	45.03
NH 5130 4113	45.65
NH 5126 4111	45.62
NH 5123 4110	45.56
NH 5120 4108	45.58

Grid Ref.	Alt.
T112 (cont.)	
NH 5117 4106	45.62
NH 5119 4102	46.04
NH 5122 4100	46.96
NH 5125 4097	47.96
NH 5128 4095	48.58
NH 5131 4093	49.08
NH 5126 4091	50.21
NH 5125 4088	51.03
NH 5125 4084	51.86
NH 5124 4081	52.40
NH 5125 4074	53.49
NH 5131 4071	54.07
NH 5136 4068	55.18
NH 5139 4067	56.12
NH 5142 4064	57.08
NH 5146 4062	57.60
NH 5149 4060	58.42
NH 5152 4059	59.29
NH 5155 4057	60.17
NH 5158 4055	61.00
T113	
NH 5160 4215	30.89
NH 5162 4217	30.13
NH 5163 4221	29.52
NH 5167 4225	28.99
NH 5169 4229	28.82
T115	
NH 5059 4146	31.90
NH 5057 4144	31.39
NH 5053 4143	30.95
NH 5049 4143	30.87
T117	
NH 5194 4261	33.17
NH 5196 4265	33.05

Grid Ref.	Alt.
T117 (cont.)	
NH 5198 4269	32.76
NH 5198 4274	32.68
NH 5198 4278	32.08
NH 5199 4282	30.72
NH 5199 4285	29.55
NH 5198 4288	28.46
NH 5184 4273	28.91
NH 5187 4271	30.11
NH 5190 4270	31.07
NH 5192 4268	32.06
T118	
NH 5035 4147	30.29
NH 5034 4144	30.66
NH 4968 4152	31.15
NH 4968 4149	31.33
NH 4967 4144	31.82
NH 4966 4139	32.38
NH 4965 4136	32.94
NH 4964 4132	33.74
NH 4965 4129	34.16
NH 4965 4125	34.58
NH 4964 4121	35.07
NH 4964 4117	35.47
NH 4964 4113	35.65
NH 4964 4108	36.05
NH 4964 4104	36.50
NH 4963 4100	36.66
NH 4956 4099	37.56
NH 4951 4095	39.01
NH 4949 4092	39.55
NH 4949 4087	40.09
NH 4946 4084	40.78
NH 4942 4081	41.39
NH 4940 4077	42.34
NH 4937 4073	42.96
T118 (cont.)	
NH 4934 4070	43.62
NH 4932 4068	44.80
NH 4932 4063	45.96
NH 4946 4070	41.45
NH 4949 4073	40.76
NH 4952 4076	39.87
NH 4956 4079	38.97
NH 4959 4083	38.30
NH 4962 4086	37.51
NH 4966 4089	36.52
NH 4969 4092	35.87
T119	
NH 4981 4102	34.82
NH 4985 4102	35,46
NH 4988 4103	36.43
NH 4993 4104	37.31
NH 4996 4105	37.98
NH 4999 4105	38.91
NH 5003 4106	39.54
NH 5006 4107	39.38
NH 5010 4106	39.39
NH 5010 4103	40.20
NH 5010 4099	40.93
NH 5006 4114	38.21
NH 5006 4117	37.38
NH 5006 4120	37.07
NH 5010 4124	36.63
NH 5010 4128	35.61
NH 5011 4132	34.74
NH 5012 4136	34.04
NH 5012 4140	33.37
NH 5014 4145	32.28
NH 5015 4149	31.75
NH 5015 4153	30.69
NH 5015 4157	30.34
T119 (cont.)	
NH 5016 4161	29.75
NH 5016 4166	29.26
T120	
NH 4966 4157	30.84
NH 4966 4162	30.65
NH 4966 4167	31.28
NH 4963 4169	31.63
NH 4963 4172	32.94
NH 4963 4175	34.42
NH 4963 4184	36.02
NH 4966 4183	34.65
NH 4969 4183	33.49
NH 4974 4183	31.94
NH 4977 4183	30.80
NH 4983 4183	29.95
T121	
NH 5039 4140	30.35
NH 5036 4140	30.79
NH 5033 4141	31.12
NH 5034 4136	32.06
NH 5032 4134	32.15
NH 5037 4144	29.97
T122	
NH 4980 4201	28.95
NH 4983 4202	28.42
NH 4986 4203	28.14
NH 4989 4204	27.70
NH 4993 4205	26.50
NH 4996 4205	25.30
NH 5000 4207	24.65
NH 5002 4207	24.12
NH 5015 4203	24.48
NH 5016 4198	24.93

Grid Ref.	Alt.
T122 (cont.)	
NH 5017 4196	25.18
NH 5017 4190	25.44
NH 5017 4185	26.05
NH 5017 4180	26.53
NH 5017 4176	26.97
NH 5017 4173	27.50
NH 5016 4171	28.08
NH 5080 4176	28.53
NH 5079 4180	27.89
NH 5077 4183	26.97
NH 5075 4187	26.32
NH 5073 4189	25.54
NH 5071 4193	24.94
NH 5069 4196	24.44
NH 5067 4199	24.14
NH 5067 4206	23.81
NH 5067 4208	23.49
NH 5066 4212	23.15
NH 5065 4215	22.99
NH 5065 4220	22.60
NH 5065 4223	22.13
NH 5099 4236	22.00
NH 5100 4232	22.22
NH 5102 4229	22.81
NH 5105 4226	23.43
NH 5107 4222	24.02
NH 5113 4217	24.52
NH 5113 4214	24.77
T123	
NH 5149 4282	17.82
NH 5148 4285	17.72
NH 5148 4287	17.81
NH 5146 4291	17.59
NH 5146 4295	17.82
NH 5145 4299	17.72
NH 5144 4304	17.97

Grid Ref.	Alt.
T123 (cont.)	
NH 5142 4307	17.69
NH 5141 4311	17.79
NH 5140 4314	17.84
NH 5139 4318	18.04
NH 5139 4323	17.98
NH 5138 4328	18.19
NH 5136 4333	18.29
NH 5134 4337	28.48
NH 5149 4344	17.24
NH 5152 4340	17.52
NH 5156 4338	17.39
NH 5160 4335	17.17
NH 5162 4332	16.97
NH 5163 4329	16.78
NH 5159 4325	16.52
NH 5163 4324	16.37
NH 5167 4322	16.32
NH 5171 4319	16.31
NH 5174 4316	16.22
NH 5177 4316	16.22
NH 5180 4298	17.08
NH 5176 4295	17.11
NH 5173 4292	16.93
NH 5170 4290	17.06
NH 5168 4286	17.37
NH 5165 4284	17.47
NH 5163 4281	17.54
NH 5161 4278	17.93
NH 5160 4274	18.19
NH 5160 4270	18.28
NH 5161 4265	18.46
NH 5161 4261	18.80
NH 5160 4250	19.06
NH 5160 4247	20.00
NH 5163 4236	21.97
NH 5161 4233	22.61
NH 5157 4230	23.07

Grid Ref.	Alt.
T123 (cont.)	
NH 5157 4226	23.95
NH 5157 4223	24.75
NH 5157 4218	25.19
NH 5155 4215	25.96
T124	
NH 5131 4229	25.24
NH 5129 4225	25.01
NH 5128 4227	24.67
NH 5126 4230	24.15
NH 5125 4233	23.66
NH 5124 4237	23.08
NH 5124 4240	22.50
NH 5125 4243	21.73
NH 5128 4250	20.77
NH 5129 4254	20.41
NH 5128 4257	20.04
T125	
NH 5081 4276	21.89
NH 5082 4279	21.43
NH 5083 4283	21.80
T127	
NH 5059 4267	26.44
NH 5058 4270	26.75
NH 5052 4289	27.66
NH 5043 4294	27.75
NH 5040 4295	27.81
NH 5057 4291	27.71
T128	
NH 5122 4248	18.59
NH 5120 4245	19.13
NH 5116 4242	19.42
NH 5118 4238	19.68
NH 5119 4235	20.24

Grid Ref.	Alt.
T128 (cont.)	
NH 5120 4231	20.91
NH 5122 4228	21.29
NH 5124 4225	21.96
NH 5126 4223	22.96
NH 5128 4222	24.13
NH 5130 4218	24.61
NH 5131 4216	25.11
NH 5133 4213	25.33
NH 5135 4210	26.02
NH 5134 4207	26.68
NH 5134 4203	27.37
NH 5134 4199	27.97
NH 5134 4196	28.44
NH 5128 4185	30.05
NH 5130 4182	30.68
NH 5128 4178	31.61
NH 5125 4175	32.09
NH 5126 4171	33.12
NH 5128 4167	33.74
NH 5130 4164	34.67
T129	
NH 5039 4147	29.13
NH 5040 4151	28.38
HN 5042 4155	27.70
NH 5043 4157	26.87
T130	
NH 5114 4270	15.29
NH 5116 4268	15.85
NH 5119 4264	16.10
NH 5120 4261	16.69
NH 5121 4256	17.43
NH 5119 4252	17.77
NH 5116 4249	18.28
NH 5113 4246	18.70

Grid Ref.	Alt.
T130 (cont.)	
NH 5110 4244	19.00
NH 5109 4239	19.48
NH 5111 4236	20.21
T131	
NH 5116 4277	14.98
NH 5118 4274	15.66
NH 5121 4272	16.12
NH 5125 4271	16.74
NH 5128 4268	17.52
T132	
NH 5101 4283	13.34
NH 5102 4281	13.67
NH 5101 4277	14.44
NH 5097 4275	14.77
NH 5096 4273	14.97
NH 5090 4271	15.21
NH 5087 4269	15.40
NH 5134 4252	17.80
NH 5135 4255	17.58
NH 5132 4249	18.24
NH 5131 4246	18.77
T133	
NH 5737 4451	28.70
NH 5732 4447	31.06
NH 5730 4443	31.37
NH 5728 4439	32.44
NH 5726 4436	33.33
NH 5725 4433	34.20
NH 5723 4431	34.56
T134	
NH 5809 4507	29.02
NH 5806 4506	29.20

Grid Ref.	Alt.
T134 (cont.)	
NH 5802 4504	29.75
NH 5799 4503	30.30
NH 5795 4500	30.54
NH 5794 4525	23.29
NH 5790 4524	23.25
NH 5786 4523	23.27
NH 5782 4523	22.47
NH 5778 4523	22.03
NH 5793 4498	31.25
NH 5790 4495	32.03
NH 5789 4491	32.82
NH 5786 4488	33.44
NH 5785 4483	34.41
NH 5786 4479	35.41
NH 5788 4475	36.25
NH 5786 4469	26.65
NH 5774 4481	25.06
NH 5768 4481	32.24
NH 5764 4479	31.87
NH 5760 4477	31.09
NH 5755 4473	29.32
T135	
NH 5565 4382	27.32
NH 5571 4386	27.08
NH 5577 4390	25.79
NH 5580 4393	25.24
NH 5583 4394	24.55
NH 5586 4397	24.09
NH 5589 4399	24.03
NH 5593 4402	23.84
NH 5596 4405	23.34
NH 5600 4407	22.71
NH 5604 4409	22.50
NH 5608 4412	22.26
NH 5610 4415	21.86

Grid Ref.	Alt.	Grid Ref.	Alt.	Grid Ref.	Alt.
T135 (cont.)		T136 (cont.)		T136 (cont.)	
NH 5613 4418	21.54	NH 5560 4417	19.36	NH 5520 4460	13.20
NH 5617 4419	21.35	NH 5563 4413	19.98	NH 5628 4468	7.45
NH 5620 4421	20.11	NH 5561 4411	20.35	NH 5626 4470	7.22
NH 5624 4424	20.72	NH 5558 4407	20.78	NH 5624 4473	6.30
NH 5627 4426	20.66	NH 5555 4403	21.64	NH 5622 4476	6.99
NH 5631 4428	20.56	NH 5553 4401	22.33	NH 5620 4479	7.16
NH 5634 4430	20.45	NH 5550 4398	23.15	NH 5618 4483	7.00
NH 5638 4432	20.37	NH 5548 4395	23.58	NH 5615 4486	6.91
NH 5642 4433	20.17	NH 5542 4382	25.37	NH 5614 4489	6.93
NH 5658 4403	21.38	NH 5539 4386	24.53	NH 5610 4491	7.04
NH 5655 4400	21.52	NH 5538 4388	23.95		
NH 5652 4398	21.79	NH 5535 4391	23.57	T137	
NH 5649 4395	22.01	NH 5533 4393	22.93	NH 5804 4530	23.08
NH 5646 4392	22.70	NH 5530 4395	22.52	NH 5807 4532	22.74
NH 5644 4388	22.38	NH 5527 4398	22.09	NH 5810 4533	22.70
		NH 5525 4401	21.63	NH 5794 4525	23.29
T136		NH 5523 4404	21.05	NH 5790 4524	23.25
NH 5626 4462	7.83	NH 5520 4408	20.58		
NH 5623 4460	8.63	NH 5518 4411	20.01	T138	
NH 5621 4457	9.32	NH 5522 4413	20.21	NH 5903 4556	29.02
NH 5617 4455	10.10	NH 5520 4415	19.97	NH 5900 4555	29.20
NH 5612 4452	10.68	NH 5518 4418	19.09	NH 5896 4553	29.32
NH 5609 4450	10.98	NH 5514 4425	18.09	NH 5894 4550	30.29
NH 5607 4448	11.40	NH 5512 4428	17.54	NH 5894 4545	31.18
NH 5603 4446	12.03	NH 5510 4431	16.69		
NH 5600 4445	12.77	NH 5508 4434	15.96	T139	
NH 5597 4443	13.73	NH 5504 4442	15.31	NH 5855 4562	16.86
NH 5593 4441	13.94	NH 5502 4445	14.65	NH 5859 4563	16.44
NH 5588 4439	13.99	NH 5501 4447	14.10	NH 5864 4562	17.23
NH 5584 4437	14.94	NH 5509 4444	14.12	NH 5869 4561	17.11
NH 5580 4436	15.62	NH 5500 4454	12.58	NH 5872 4563	16.66
NH 5575 4435	15.98	NH 5503 4457	12.39		
NH 5572 4438	17.04	NH 5507 4458	12.45	T140	
NH 5569 4435	17.56	NH 5510 4459	12.28	NH 6178 4560	18.05
NH 5566 4433	18.06	NH 5514 4460	12.44	NH 6176 4562	15.31
NH 5563 4419	18.80	NH 5517 4458	13.32	NH 6174 4565	13.98

Grid Ref.	Alt.	Grid Ref.	Alt.	Grid Ref.	Alt.
T140 (cont.)		T150		T150 (cont.)	
NH 6170 4569	12.75	NH 6497 4107	50.48	NH 6577 4114	53.40
NH 6168 4571	11.22	NH 6502 4107	50.02	NH 6574 4112	54.36
NH 6165 4574	9.52	NH 6506 4106	49.65	NH 6572 4109	55.42
NH 6164 4577	8.75	NH 6519 4103	48.93	NH 6571 4106	56.54
NH 6159 4583	5.87	NH 6520 4106	48.90	NH 6571 4103	57.62
NH 6158 4585	5.36	NH 6521 4109	48.90	NH 6572 4099	58.58
NH 6156 4586	4.79	NH 6522 4112	48.54	NH 6573 4095	59.53
NH 6155 4587	4.12	NH 6524 4116	48.93	NH 6643 4180	43.21
NH 6153 4590	3.55	NH 6526 4119	49.10	NH 6641 4175	44.03
NH 6158 4591	3.01	NH 6528 4121	48.67	NH 6639 4172	43.85
NH 6162 4593	3.38	NH 6532 4123	48.65	NH 6636 4169	43.61
NH 6163 4585	7.65	NH 6535 4126	48.41	NH 6634 4166	43.46
NH 6167 4584	7.90	NH 6544 4109	49.00	NH 6630 4163	44.36
NH 6196 4561	17.22	NH 6540 4109	48.79	NH 6628 4160	44.68
NH 6199 4562	16.03	NH 6537 4108	49.42	NH 6625 4158	44.93
NH 6204 4564	14.39	NH 6508 4096	49.10	NH 6622 4154	45.90
NH 6208 4565	12.88	NH 6506 4094	49.31	NH 6620 4151	46.76
NH 6211 4566	11.38	NH 6503 4091	49.46	NH 6754 4257	39.20
NH 6214 4567	10.04	NH 6502 4086	49.72	NH 6750 4255	39.56
NH 6219 4568	8.78	NH 6499 4083	50.34	NH 6748 4252	40.01
NH 6222 4569	7.28	NH 6555 4159	46.62	NH 6746 4250	40.12
NH 6226 4571	6.08	NH 6556 4163	46.68	NH 6743 4248	40.13
NH 6230 4572	4.81	NH 6556 4166	46.82	NH 6739 4245	40.15
NH 6234 4574	4.03	NH 6556 4169	46.93	NH 6736 4243	40.98
NH 6238 4575	3.74	NH 6556 4171	46.90	NH 6733 4240	41.16
NH 6241 4576	3.50	NH 6551 4177	46.34	NH 6730 4239	41.42
		NH 6555 4180	46.40		
T141		NH 6558 4182	46.45	T152	
NH 6390 4881	28.90	NH 6562 4184	46.57	NH 6464 4100	51.09
NH 6387 4883	29.02	NH 6565 4186	46.18	NH 6467 4102	50.99
NH 6384 4880	29.34	NH 6570 4188	45.70	NH 6470 4105	50.87
NH 6378 4883	29.27	NH 6592 4128	47.76		
NH 6373 4884	29.38	NH 6590 4125	48.58	T153	
NH 6369 4885	29.52	NH 6587 4123	49.35	NH 6454 4071	46.10
NH 6365 4885	29.72	NH 6585 4120	50.14	NH 6450 4069	46.37
NH 6360 4885	29.56	NH 6582 4118	51.25	NH 6447 4068	46.77
		NH 6580 4116	52.38	NH 6442 4066	46.58

Grid Ref.	Alt.	Grid Ref.	Alt.	Grid Ref.	Alt.
T153(cont.)		T153(cont.)		T153(cont.)	
NH 6439 4065	46.76	NH 6614 4165	40.14	NH 6789 4297	34.87
NH 6435 4063	46.98	NH 6618 4167	39.96	NH 6803 4463	30.62
NH 6431 4061	47.02	NH 6621 4170	39.63	NH 6803 4460	30.53
NH 6428 4060	47.40	NH 6624 4173	39.84	NH 6803 4456	30.98
NH 6425 4059	48.04	NH 6713 4261	36.36	NH 6803 4452	31.34
NH 6422 4057	48.57	NH 6714 4264	36.19	NH 6803 4448	32.11
NH 6566 4397	43.97	NH 6715 4267	35.97	NH 6804 4442	32.50
NH 6566 4157	43.52	NH 6716 4270	35.88	NH 6804 4438	32.32
NH 6568 4160	42.99	NH 6719 4273	35.82	NH 6805 4433	32.79
NH 6613 4205	37.55	NH 6723 4275	35.33	NH 6804 4429	32.97
NH 6615 4207	37.81	NH 6727 4276	35.28	NH 6804 4425	33.24
NH 6612 4211	37.27	NH 6731 4277	35.18	NH 6800 4421	32.88
NH 6608 4212	37.07	NH 6733 4277	35.23	NH 6799 4416	33.55
NH 6604 4213	37.17	NH 6737 4278	35.38	NH 6799 4412	33.37
NH 6600 4213	37.10	NH 6739 4280	35.20	NH 6800 4407	33.50
NH 6596 4214	37.03	NH 6740 4282	35.33	NH 6799 4402	33.73
NH 6615 4212	37.31	NH 6706 4252	37.03	NH 6797 4398	33.98
NH 6616 4215	37.55	NH 6709 4254	36.63	NH 6788 4474	30.59
NH 6619 4219	37.48	NH 6711 4258	37.13	NH 6788 4478	30.37
NH 6621 4222	37.53	NH 6701 4251	36.74	NH 6789 4482	30.04
NH 6625 4190	38.24	NH 6697 4250	36.48	NH 6790 4486	30.38
NH 6621 4189	37.87	NH 6693 4250	36.34	NH 6790 4490	30.38
NH 6618 4187	37.87	NH 6682 4258	36.49	NH 6791 4494	30.22
NH 6614 4186	38.63	NH 6681 4255	36.14	NH 6792 4498	29.99
NH 6611 4183	39.75	NH 6679 4252	36.28	NH 6793 4502	29.82
NH 6609 4181	39.42	NH 6678 4248	36.58	NH 6794 4506	29.83
NH 6605 4181	39.48	NH 6680 4240	37.02	NH 6898 4442	31.63
NH 6602 4181	39.54	NH 6677 4238	36.86	NH 6897 4439	32.21
NH 6600 4182	39.41	NH 6675 4234	36.81	NH 6895 4435	32.63
NH 6598 4172	40.35	NH 6674 4230	36.84	NH 6894 4431	33.55
NH 6597 4169	40.47	NH 6671 4227	36.95	NH 6893 4428	34.25
NH 6596 4166	40.82	NH 6670 4224	37.04	NH 6871 4456	30.61
NH 6595 4163	41.21	NH 6780 4286	36.73	NH 6873 4459	30.26
NH 6603 4159	41.56	NH 6782 4289	35.90	NH 6874 4462	30.18
NH 6606 4162	40.94	NH 6784 4291	35.01	NH 6876 4465	30.06
NH 6610 4164	40.77	NH 6786 4296	34.81	NH 6878 4469	29.86

T153 (cont.)

Grid Ref.	Alt.
NH 6879 4473	29.80
NH 6881 4476	29.67
NH 6878 4483	29.73
NH 6878 4486	29.30
NH 6879 4489	28.83
NH 6880 4492	28.52
NH 6881 4496	28.50
NH 6932 4510	27.65
NH 6930 4508	27.40
NH 6927 4506	27.75
NH 6925 4503	28.06
NH 6924 4498	28.65
NH 6920 4497	28.91
NH 6917 4496	28.79
NH 6916 4494	28.88
NH 6952 4564	25.09
NH 6950 4560	25.08
NH 6949 4557	25.26
NH 6948 4555	25.57
NH 6921 4554	25.05
NH 6918 4551	25.37
NH 6916 4548	25.94
NH 6913 4545	26.49
NH 6911 4542	26.65
NH 6908 4537	26.93
NH 6906 4533	27.11
NH 6904 4530	27.12
NH 6902 4525	27.17
NH 6901 4521	27.26
NH 6900 4517	27.34
NH 8698 4513	27.45
NH 6897 4510	27.65
NH 6896 4507	27.78
NH 6894 4503	28.09

T154

Grid Ref.	Alt.
NH 6898 4442	31.63
NH 6897 4439	32.21
NH 6895 4435	32.63
NH 6894 4431	33.55
NH.6893 4428	34.25

T155

Grid Ref.	Alt.
NH 7058 4529	34.07
NH 7057 4526	34.15
NH 7055 4524	34.86
NH 7054 4518	35.21
NH 7052 4516	35.67
NH 7050 4513	36.27
NH 7047 4509	36.85
NH 7046 4507	37.52
NH 7046 4502	38.77
NH 7046 4499	39.71
NH 7046 4495	40.80

T156

Grid Ref.	Alt.
NH 7086 4544	35.43
NH 7088 4547	35.06
NH 7090 4550	34.63
NH 7092 4553	34.30
NH 7093 4557	33.90
NH 7095 4560	33.92
NH 7096 4565	33.87
NH 7097 4569	33.33
NH 7099 4573	32.88
NH 7098 4577	32.77
NH 7100 4579	32.42

T157

Grid Ref.	Alt.
NH 7071 4628	17.63
NH 7068 4625	17.85
NH 7066 4622	18.07

T157 (cont.)

Grid Ref.	Alt.
NH 7063 4619	18.07
NH 7060 4616	18.87
NH 7057 4613	19.10

T158

Grid Ref.	Alt.
NH 6972 4592	17.29
NH 6976 4593	17.75
NH 6985 4596	17.84
NH 6989 4598	17.25
NH 6992 4600	17.35
NH 6994 4603	16.98

T159

Grid Ref.	Alt.
NH 6526 4361	17.18
NH 6523 4357	17.49
NH 6520 4356	17.97
NH 6515 4355	18.00
NH 6512 4355	18.47
NH 6524 4377	16.19
NH 6521 4379	15.89
NH 6518 4382	15.90
NH 6513 4395	14.83
NH 6510 4399	14.83
NH 6507 4402	14.65
NH 6505 4405	14.09
NH 6504 4409	14.01

T166

Grid Ref.	Alt.
NH 6255 4244	96.40
NH 6256 4245	96.84
NH 6261 4245	96.23
NH 6266 4247	95.67

T167

Grid Ref.	Alt.
NH 6242 4218	93.22
NH 6245 4220	92.77

Grid Ref.	Alt.	Grid Ref.	Alt.	Grid Ref.	Alt.
T167 (cont.)		T169 (cont.)		T171 (cont.)	
NH 6247 4223	92.03	NH 6363 4302	63.80	NH 6262 4217	70.21
NH 6251 4227	91.62	NH 6362 4305	64.00	NH 6267 4217	70.02
NH 6253 4231	91.37	NH 6365 4306	64.16	NH 6268 4217	69.87
NH 6256 4235	91.20	NH 6370 4307	63.67	NH 6274 4219	68.91
NH 6259 4237	91.10	NH 6373 4308	63.14	NH 6277 4222	68.72
NH 6262 4239	90.89	NH 6378 4308	62.83	NH 6279 4224	68.19
NH 6266 4241	90.81	NH 6382 4307	62.30	NH 6281 4227	68.09
NH 6269 4243	91.11	NH 6386 4307	61.65	NH 6285 4228	68.11
NH 6274 4243	89.84	NH 6394 4306	61.56	NH 6292 4231	67.85
NH 6277 4245	89.95	NH 6395 4308	60.52	NH 6293 4232	67.56
NH 6288 4252	89.40	NH 6396 4309	60.37	NH 6307 4245	65.77
NH 6291 4255	89.04	NH 6401 4309	59.77	NH 6338 4249	61.74
NH 6294 4257	88.21	NH 6406 4307	59.86	NH 6335 4247	62.02
NH 6299 4257	87.09			NH 6331 4246	62.36
NH 6303 4258	86.44	T170		NH 6338 4254	62.65
NH 6307 4258	85.60	NH 6315 4252	64.68	NH 6335 4252	62.99
		NH 6317 4256	65.06	NH 6331 4250	63.09
T168		NH 6321 4258	65.31	NH 6317 4246	63.68
NH 6340 4271	67.60	NH 6322 4259	64.42		
NH 6341 4274	67.31	NH 6325 4261	64.08	T172	
NH 6343 4278	67.17	NH 6331 4262	63.50	NH 6325 4135	34.81
NH 6344 4282	66.80	NH 6336 4262	63.17	NH 6324 4133	35.28
NH 6346 4286	66.46	NH 6338 4262	62.84	NH 6323 4131	35.70
NH 6349 4289	66.12			NH 6317 4134	35.34
NH 6352 4293	65.99	T171		NH 6312 4134	35.58
NH 6355 4294	65.63	NH 6229 4181	73.57	NH 6308 4133	36.01
NH 6356 4297	65.24	NH 6232 4183	73.45	NH 6304 4131	36.06
NH 6362 4297	64.69	NH 6234 4185	73.30	NH 6300 4128	36.11
NH 6366 4297	64.50	NH 6236 4188	73.13	NH 6299 4125	36.41
NH 6370 4297	64.13	NH 6239 4190	73.05	NH 6297 4121	36.70
		NH 6241 4194	72.87	NH 6297 4116	37.15
T169		NH 6242 4198	72.99	NH 6298 4111	37.47
NH 6365 4291	63.79	NH 6243 4203	73.00	NH 6300 4106	37.59
NH 6369 4294	63.35	NH 6245 4206	72.75	NH 6272 4090	36.04
NH 6372 4295	62.93	NH 6247 4210	72.86	NH 6269 4094	38.03
NH 6374 4298	62.59	NH 6250 4212	72.11	NH 6270 4096	37.91
NH 6372 4300	63.05	NH 6254 4214	71.45	NH 6272 4099	37.58
NH 6368 4301	63.40	NH 6258 4216	70.77	NH 6276 4103	37.38

Grid Ref.	Alt.	Grid Ref.	Alt.	Grid Ref.	Alt.
T172 (cont.)		T175 (cont.)		T176 (cont.)	
NH 6278 4105	37.14	NH 6410.4249	24.49	NH 6388 4201	23.45
NH 6281 4108	36.90	NH 6407 4247	24.50	NH 6386 4196	23.38
NH 6284 4111	36.63	NH 6404 4245	24.71		
NH 6288 4114	36.61	NH 6400 4243	24.91	T177	
NH 6290 4117	36.41	NH 6397 4240	25.04	NH 6421 4257	22.36
NH 6292 4121	36.42	NH 6393 4238	25.03	NH 6419 4255	22.95
NH 6293 4123	36.32	NH 6389 4234	25.12	NH 6390 4237	24.40
NH 6296 4127	36.12	NH 6388 4231	25.28	NH 6392 4240	24.29
NH 6300 4129	35.95	NH 6386 4230	25.39	NH 6395 4243	23.72
NH 6303 4132	35.71	NH 6385 4226	25.44	NH 6398 4246	23.33
NH 6306 4134	35.65	NH 6383 4223	25.49	NH 6401 4248	23.59
NH 6310 4135	35.37	NH 6379 4220	25,41	NH 6403 4250	23.86
NH 6314 4136	35.23	NH 6377 4216	25.48	NH 6406 4253	23.81
NH 6319 4136	35.07	NH 6375 4213	25.57	NH 6408 4254	23.66
		NH 6374 4209	25.61	NH 6415 4241	21.72
T173		NH 6373 4205	25.78	NH 6414 4237	22.16
NH 6338 4144	32.77	NH 6371 4202	25.85	NH 6412 4235	22.15
NH 6336 4142	32.72	NH 6369 4197	26.06	NH 6416 4232	22.00
NH 6333 4138	32.74	NH 6368 4194	26.41	NH 6414 4229	21.99
NH 6336 4136	33.33	NH 6367 4191	26.53	NH 6411 4226	22.14
NH 6335 4133	33.99	NH 6365 4185	26.70	NH 6406 4229	21.97
NH 6332 4130	34.16	NH 6364 4181	26.78	NH 6403 4225	22.11
NH 6331 4128	34.15	NH 6359 4178	26.94	NH 6399 4223	22.50
NH 6328 4125	33.74	NH 6358 4174	27.10	NH 637 4218	22.48
NH 6325 4123	33.94	NH 6356 4170	27.35	NH 6395 4214	22.17
NH 6321 4120	34.27	NH 6355 4167	27.64	NH 6393 4211	22.11
NH 6317 4117	34.62	NH 6357 4161	26.76	NH 6392 4206	22.12
		NH 6356 4157	26.64	NH 6392 4203	22.44
T174		NH 6353 4151	26.29	NH 6392 4199	22.47
NH 6349 4155	29.35	NH 6351 4147	26.56	NH 6390 4195	22.21
NH 6347 4152	29.56	NH 6349 4140	28.88		
NH 6345 4149	30.13	NH 6347 4136	28.94	T178	
NH 6343 4146	30.77	NH 6345 4133	28.60	NH 6415 4241	21.72
		NH 6342 4130	27.01	NH 6414 4237	22.16
T175				NH 6412 4235	22.15
NH 6417 4252	24.38	T176		NH 6416 4232	22.00
NH 6414 4250	24.52	NH 6389 4206	23.42	NH 6414 4229	21.99

Grid Ref.	Alt.
T178 (cont.)	
NH 6411 4226	22.14
NH 6406 4229	21.97
NH 6403 4225	22.11
NH 6399 4223	22.50
NH 6397 4218	22.48
NH 6395 4214	22.17
NH 6393 4211	22.11
NH 6392 4206	22.12
NH 6392 4203	22.44
NH 6392 4199	22.47
NH 6390 4195	22.21
NH 6318 4153	23.59
NH 6366 4151	23.58
T179	
NH 6375 4148	20.61
NH 6377 4149	20.22
NH 6380 4151	20.21
NH 6373 4145	21.17
NH 6309 4094	18.68
NH 6314 4096	18.86
NH 6317 4097	18.77
NH 6321 4099	19.02
NH 6329 4104	20.71
NH 6332 4106	20.75
NH 6336 4109	20.42
NH 6338 4110	20.18
NH 6340 4112	20.03
NH 6343 4113	19.95
NH 6332 4091	17.00
NH 6334 4094	17.25
NH 6336 4096	17.57
NH 6339 4098	17.89
NH 6307 4099	21.65
NH 6305 4097	21.87
NH 6298 4098	22.29
NH 6294 4096	22.23
T179 (cont.)	
NH 6290 4093	22.47
NH 6303 4091	19.58
NH 6300 4090	19.16
NH 6297 4090	19.00
T180	
NH 6425 4253	15.69
NH 6427 4257	15.66
NH 6423 4227	15.69
NH 6422 4188	15.74
NH 6422 4192	15.79
NH 6424 4194	15.79
NH 6420 4186	16.00
NH 6424 4244	15.58
NH 6424 4249	15.55
T181	
NH 6285 4086	16.26
NH 6289 4087	16.30
NH 6293 4086	16.22
NH 6310 4085	15.72
NH 6314 4086	15.64
NH 6320 4086	15.62
NH 6324 4086	15.68
NH 6327 4087	15.66
NH 6332 4087	15.59
NH 6337 4086	15.53
NH 6340 4085	15.67
T182	
NH 6450 4163	23.89
NH 6448 4161	24.34
NH 6446 4159	24.01
NH 6444 4157	23.53
T183	
NH 6508 4237	20.27
T183 (cont.)	
NH 6505 4238	19.69
NH 6502 4238	19.08
NH 6498 4240	18.80
NH 6494 4240	18.36
NH 6490 4241	17.71
NH 6485 4242	17.52
NH 6481 4243	16.99
NH 6478 4244	16.28
NH 6472 4242	15.85
NH 6467 4243	15.00
NH 6464 4243	14.62
NH 6460 4243	14.51
NH 6457 4245	13.84
NH 6499 4204	22.40
NH 6495 4205	21.16
NH 6491 4204	20.02
NH 6488 4202	19.81
NH 6485 4199	19.43
NH 6483 4197	19.34
NH 6480 4194	19.22
NH 6468 4183	18.25
NH 6464 4181	17.74
NH 6462 4178	17.56
NH 6459 4175	17.17
T184	
NH 6441 4163	14.38
NH 6444 4165	14.32
NH 6447 4168	14.12
NH 6447 4173	13.82
NH 6447 4177	13.51
NH 6449 4181	13.33
NH 6449 4186	12.99
NH 6451 4190	13.07
NH 6451 4199	13.08
NH 6454 4200	12.72
NH 6458 4201	13.22

Grid Ref.	Alt.
T185	
NH 6447 4248	9.23
NH 6446 4245	9.28
NH 6447 4241	9.54
NH 6447 4238	9.92
NH 6447 4213	10.01
NH 6450 4215	11.09
NH 6453 4217	11.77
NH 6458 4218	12.41
NH 6461 4217	13.18
NH 6464 4216	13.41
NH 6468 4216	14.41
NH 6472 4215	15.15
NH 6476 4214	15.83
NH 6479 4213	16.38
NH 6483 4212	17.19
NH 6487 4212	17.63
T186	
NH 6294 4037	26.08
NH 6291 4035	26.63
NH 6289 4033	26.56
NH 6286 4033	27.16
NH 6283 4031	27.27
NH 6278 4030	27.15
NH 6275 4027	27.44
NH 6271 4026	27.94
NH 6265 4026	27.90
NH 6261 4027	27.54
NH 6257 4027	27.78
NH 6252 4027	28.08
T187	
NH 6224 4023	25.33
NH 6221 4022	25.73
NH 6204 4016	27.06
T188	
NH 6218 4027	22.30
NH.6222 4029	21.76
NH 6225 4031	21.70
NH 6228 4033	21.44
NH 6231 4034	21.21
NH 6234 4036	21.13
NH 6238 4038	20.85
NH 6242 4038	20.62
T189	
NH 6310 4038	21.21
NH 6313 4039	20.76
NH 6316 4045	19.84
NH 6320 4049	18.74
NH 6323 4050	17.95
NH 6326 4053	17.03
NH 6327 4055	16.11
NH 6322 4055	16.46
NH 6320 4057	16.16
NH 6318 4059	16.46
NH 6314 4060	16.32
NH 6311 4061	16.67
NH 6308 4061	17.05
T190	
NH 6164 4036	18.07
NH 6162 4034	18.27
NH 6161 4032	18.11
NH 6158 4033	18.23
NH 6155 4026	18.04
NH 6152 4025	18.92
T191	
NH 6040 3568	49.60
NH 6039 3563	50.29
NH 6033 3546	50.15
T191 (cont.)	
NH 6032 3543	50.60
NH 6031 3539	51.22
NH 6031 3534	51.49
NH 6031 3530	51.44
NH 6033 3527	51.59
T192	
NH 6033 3585	36.37
NH 6034 3582	36.11
NH 6031 3579	36.58
NH 6030 3574	37.30
NH 6028 3570	37.63
NH 6026 3566	37.67
NH 6026 3563	38.51
NH 6025 3560	39.50
NH 6025 3555	40.59
NH 6025 3551	42.43
T192	
NH 5030 2947	59.22
NH 5029 2943	59.00
NH 5027 2937	58.63
NH 5025 2934	58.31
NH 5024 2938	58.06
NH 5023 2936	57.97
NH 5022 2933	57.49
NH 5022 2917	47.04
NH 5021 2913	56.52
NH 5019 2909	56.13
NH 5039 2928	56.84
NH 5037 2932	57.47
NH 5036 2935	57.84
NH 5036 2939	58.31
NH 5035 2942	58.89

Grid Ref	Alt.	Grid Ref.	Alt.	Grid Ref.	Alt.
T195		T200		T201 (cont.)	
NH 5045 2988	48.94	NH 5078 2991	29.01	NH 5113 2991	25.81
NH 5046 2984	48.66	NH 5075 2994	29.28	NH 5108 2991	26.17
NH 5047 2981	48.27	NH 5072 2996	29.81	NH 5103 2992	27.00
NH 5048 2977	47.98	NH 5070 2997	30.18	NH 5100 2993	27.08
NH 5048 2973	47.76	NH 5069 2998	30.46	NH 5096 2995	27.19
NH 5049 2970	47.48	NH 5068 3001	30.69	NH 5092 2996	27.58
NH 5052 2969	47.70	NH 5067 3005	31.24	NH 5081 2990	28.52
NH 5054 2971	46.93	NH 5067 3008	31.50	NH 5080 2993	28.57
NH 5056 2974	46.10			NH 5076 3006	29.74
NH 5059 2977	45.50	T201		NH 5077 3004	29.40
NH 5062 2979	44.58	NH 5085 2919	38.94		
NH 5064 2982	43.52	NH 5088 2921	38.25	T202	
		NH 5092 2923	37.38	NH 5075 3011	29.79
T196		NH 5095 2925	36.85	NH 5077 3010	29.17
NH 5029 2994	49.15	NH 5097 2928	35.96	NH 5128 2997	24.93
NH 5033 2994	48.78	NH 5099 2931	35.08		
NH 5037 2991	48.37	NH 5101 2934	34.21	T203	
NH 5041 2991	47.76	NH 5104 2937	33.39	NH 5039 2869	56.01
NH 5045 2992	47.17	NH 5107 2941	32.15	NH 5040 2871	55.07
NH 5049 2992	46.45	NH 5110 2945	31.20	NH 5042 2874	54.24
		NH 5112 2947	30.50		
T197		NH 5114 2950	29.74	T204	
NH 5034 3002	43.90	NH 5117 2954	28.68	NH 5046 2877	52.32
NH 5031 3003	44.40	NH 5117 2959	27.70	NH 5053 2880	51.16
NH 5026 3003	44.66	NH 5118 2963	26.70	NH 5056 2883	50.31
		NH 5118 2966	25.85	NH 5059 2885	49.18
T198		NH 5120 2970	25.57	NH 5060 2881	49.54
NH 5050 3001	33.92	NH 5120 2974	24.63	NH 5061 2883	48.43
NH 5047 3001	34.33	NH 5120 2978	24.57	NH 5062 2887	47.30
NH 5042 3003	34.84	NH 5121 2982	24.34	NH 5064 2892	46.47
NH 5039 3005	35.37	NH 5123 2986	24.58	NH 5066 2896	45.88
		NH 5124 2989	25.09	NH 5071 2896	44.61
T199		NH 5125 2993	25.49	NH 5074 2898	44.07
NH 5064 3002	32.15	NH 5129 2984	24.18	NH 5076 2900	43.37
NH 5061 3001	32.77	NH 5126 2985	24.62	NH 5078 2904	42.27
NH 5057 3001	33.06	NH 5120 2987	24.84	NH 5082 2905	41.09
NH 5054 3004	33.37	NH 5117 2989	25.40	NH 5086 2908	39.36

Grid Ref.	Alt.
T204 (cont.)	
NH 5088 2910	39.29
NH 5091 2914	38.72
NH 5094 2917	37.57
T205	
NH 5049 2870	48.91
NH 5047 2870	50.20
T206	
NH 5095 2881	40.33
NH 5099 2880	39.74
NH 5102 2882	38.78
NH 5106 2884	38.17
NH 5110 2885	37.09
NH 5113 2886	36.85
NH 5115 2888	36.31
NH 5118 2889	35.03
NH 5122 2893	34.35
NH 5129 2894	33.71
NH 5133 2896	33.12
NH 5137 2898	32.59
NH 5142 2901	31.45
NH 5147 2903	30.52
NH 5149 2907	29.80
NH 5152 2910	28.79
NH 5156 2913	27.72
NH 5160 2914	27.52
NH 5164 2914	27.02
NH 5168 2921	25.57
NH 5173 2921	24.94
NH 5177 2920	24.44
NH 5185 2925	23.20
NH 5188 2926	22.55
NH 5190 2925	21.93
NH 5193 2924	21.73
NH 5198 2921	21.20
T206 (cont.)	
NH 5202 2921	20.47
NH 5206 2919	19.98
NH 5213 2920	19.39
NH 5218 2918	18.82
NH 5224 2916	19.75
NH 5229 2916	18.27
NH 5234 2915	17.53
NH 5239 2914	17.28
T207	
NH 4906 2076	38.72
NH 4909 2078	38.04
NH 4912 2080	37.51
T208	
NH 4932 2085	29.57
NH 4929 2087	29.26
NH 4926 2089	29.03
NH 4924 2092	28.69
NH 4921 2095	28.42
T210	
NH 4934 2101	23.11
NH 4931 2103	22.69
NH 4928 2105	22.43
T212	
NH 4949 2097	20.10
NH 4951 2101	19.64
NH 4953 2105	19.37
NH 4958 2107	18.41
NH 4962 2109	17.93
NH 4966 2113	17.51
NH 4967 2116	16.83
T213	
NH 4246 1643	33.13
T213 (cont.)	
NH 4246 1646	33.10
NH 4249 1647	32.78
NH 4252 1649	32.68
T214	
NH 4241 1632	21.60
NH 4244 1633	21.30
NH 4247 1634	21.36
NH 4252 1635	20.97
NH 4255 1636	20.82
NH 4254 1626	20.39
NH 4258 1627	20.57
NH 4262 1629	20.59
NH 4266 1631	19.99
NH 4269 1631	19.76
NH 4274 1630	20.01
NH 4278 1630	19.55
NH 4281 1631	19.28
T215	
NH 4275 1626	17.62
NH 4270 1626	17.96
NH 4267 1625	18.33
NH 4263 1624	18.70
NH 4259 1622	19.08
T218	
NH 3640 0883	36.78
NH 3638 0881	36.61
NH 3636 0879	37.11
T219	
NH 3835 0820	34.14
NH 3836 0823	33.25
NH 3835 0827	32.61

Grid Ref.	Alt.	Grid Ref.	Alt.	Grid Ref.	Alt.
T221		T227		T234 (cont.)	
NH 3798 0827	26.12	NH 3669 0862	30.19	NH 6238 5110	19.09
NH 3796 0824	27.01	NH 3669 0866	30.26	NH 6235 5108	19.60
NH 3793 0822	27.53	NH 3671 0869	29.54	NH 6232 5107	19.63
NH 3790 0824	27.84	NH 3673 0872	28.98	NH 6228 5105	19.72
		NH 3674 0875	29.18		
T222				T235	
NH 3823 0864	16.71	T228		NH 6283 5088	19.08
NH 3819 0861	16.84	NH 3759 0945	25.47	NH 6286 5091	18.38
NH 3817 0859	17.23	NH 3765 0945	25.28	NH 6290 5092	17.66
NH 3814 0858	17.71	NH 3769 0945	25.33	NH 6293 5095	17.94
NH 3812 0855	18.27				
NH 3809 0853	18.97	T229		T236	
NH 3806 0851	19.81	NH 3766 0937	19.08	NH 6318 5115	11.88
NH 3807 0842	20.52	NH 3764 0939	19.23	NH 6316 5112	12.34
NH 3804 0840	20.78	NH 3758 0940	19.01	NH 6313 5108	12.74
NH 3801 0839	21.43			NH 6312 5105	12.77
NH 3798 0837	22.00	T231		NH 6309 5102	13.13
NH 3793 0836	22.79	NH 6683 5235	4.75	NH 6306 5099	13.27
NH 3775 0826	25.00	NH 6687 5235	4.85	NH 6304 5096	13.42
NH 3777 0829	24.20	NH 6689 5234	4.73	NH 6301 5094	13.86
NH 3780 0832	23.28	NH 6692 5234	4.30	NH 6298 5091	14.28
NH 3783 0835	22.68	NH 6695 5234	3.82	NH 6295 5089	14.60
NH 3786 0839	22.75	NH 6699 5234	3.66	NH 6292 5086	14.96
		NH 6703 5235	3.20	NH 6289 5084	15.37
T223		NH 6707 5235	3.20	NH 6291 5079	15.88
NH 3774 0845	21.25			NH 6293 5080	15.38
NH 3774 0849	21.15	T233		NH 6297 5081	14.76
NH 3775 0854	20.34	NH 6248 5160	28.39	NH 6299 5086	14.40
NH 3774 0859	20.30	NH 6247 5156	28.09	NH 6203 5088	13.93
NH 3771 0862	20.00	NH 6245 5153	28.11	NH 6205 5090	13.70
NH 3769 0865	19.74	NH 6241 5150	28.72	NH 6208 5093	13.48
NH 3769 0868	19.59	NH 6237 5147	29.15	NH 6387 5082	15.78
NH 3769 0873	19.59			NH 6383 5079	16.11
NH 3769 0877	19.37	T234		NH 6380 5076	16.71
NH 3769 0881	19.38	NH 6247 5116	18.41	NH 6321 5102	12.86
NH 3769 0885	19.07	NH 6243 5114	18.18	NH 6324 5104	12.30
NH 3772 0888	18.64	NH 6241 5112	18.43	NH 6327 5106	11.72

Grid Ref.	Alt.
T236 (cont.)	
NH 6331 5106	11.57
NH 6335 5108	11.24
NH 6338 5110	11.47
NH 6341 5112	11.36
NH 6345 5115	11.36
NH 6348 5117	11.05
NH 6351 5119	11.14
NH 6354 5121	10.96
NH 6356 5123	10.82
NH 6360 5143	10.33
NH 6357 5142	10.24
NH 6353 5142	10.51
NH 6349 5140	10.72
NH 6346 5139	11.05
NH 6340 5137	11.12
NH 6336 5135	11.24
NH 6332 5132	11.25
NH 6330 5128	11.10
NH 6328 5126	11.31
NH 6325 5122	11.47
NH 6323 5119	11.78
NH 6321 5117	11.92
T237	
NH 6287 5169	14.07
NH 6292 5170	14.32
NH 6296 5172	14.62
T238	
NH 6318 5189	12.26
NH 6324 5194	11.48
NH 6340 5201	9.72
NH 6334 5200	9.53
NH 6326 5195	10.40
NH 6324 5194	11.23
NH 6320 5192	11.91

Grid Ref.	Alt.
T239	
NH 6367 5168	12.73
NH 6370 5168	12.65
NH 6371 5175	11.98
NH 6375 5177	11.94
T240	
NH 6812 5547	30.02
NH 6815 5548	29.78
NH 6818 5550	29.54
NH 6821 5552	29.09
NH 6824 5555	28.49
NH 6828 5556	27.90
NH 6832 5555	27.18
NH 6836 5554	27.07
NH 6840 5554	26.47
NH 6844 5555	25.96
NH 6800 5541	28.31
NH 6797 5538	28.43
NH 6793 5537	28.82
NH 6705 5468	30.08
NH 6708 5470	29.89
NH 6711 5472	29.60
NH 6713 5475	29.40
NH 6716 5478	29.03
NH 6719 5481	28.98
NH 6720 5485	28.43
NH 6723 5487	27.88
NH 6725 5490	27.41
NH 6730 5489	27.19
NH 6735 5494	27.31
NH 6738 5497	27.20
NH 6740 5499	28.07
NH 6741 5502	28.50
NH 6745 5504	29.05
NH 6748 5507	29.09
NH 6751 5510	29.36
NH 6753 5513	29.65

Grid Ref.	Alt.
T241	
NH 6804 5522	25.88
NH 6808 5523	26.13
NH 6817 5531	24.95
NH 6821 5531	24.56
NH 6824 5530	23.87
NH 6837 5531	21.45
NH 6840 5533	20.93
NH 6846 5537	20.37
NH 6850 5540	20.03
NH 6853 5542	19.80
NH 6856 5544	19.83
NH 6860 5546	19.91
NH 6863 5549	19.71
T242	
NH 6794 5508	25.13
NH 6792 5502	25.14
NH 6790 5500	25.04
NH 6787 5498	25.34
NH 6784 5497	25.57
NH 6780 5496	25.70
T243	
NH 6878 5547	16.07
NH 6875 5545	16.12
NH 6872 5541	16.80
NH 6870 5539	16.93
NH 6868 5537	17.20
NH 6866 5535	17.43
T244	
NH 6826 5507	21.32
NH 6829 5508	21.06
NH 6832 5509	20.97
NH 6836 5512	19.64
NH 6844 5526	19.10
NH 6847 5528	18.71

Grid Ref.	Alt.	Grid Ref.	Alt.	Grid Ref.	Alt.
T244 (cont.)		T248		T248 (cont.)	
NH 6850 5530	17.95	NH 8568 5082	35.37	NH 8677 5157	31.07
NH 6852 5531	17.97	NH 8571 5083	34.84	NH 8679 5160	30.96
NH 6858 5532	17.34	NH 8574 5085	34.42	NH 8683 5162	30.84
NH 6861 5530	17.11	NH 8577 5086	34.30	NH 8685 5165	30.71
NH 6871 5534	16.54	NH 8580 5087	34.21	NH 8688 5168	30.68
NH 6873 5534	16.28	NH 8583 5088	33.97	NH 8691 5170	30.52
NH 6881 5536	16.21	NH 8588 5089	33.80	NH 8694 5173	30.41
NH 6881 5538	15.72	NH 8592 5088	34.01	NH 8697 5175	30.29
		NH 8597 5089	33.75	NH 8699 5179	30.40
T245		NH 8599 5091	33.35	NH 8700 5182	30.33
NH 6788 5530	28.20	NH 8603 5093	33.26	NH 8703 5186	30.41
NH 6790 5527	27.65	NH 8608 5094	33.12	NH 8705 5189	30.32
NH 6793 5524	27.00	NH 8611 5095	32.98	NH 8707 5191	30.05
NH 6794 5520	26.73	NH 8615 5096	33.09	NH 8710 5195	29.71
NH 6795 5516	26.28	NH 8617 5100	32.99	NH 8712 5198	29.41
NH 6797 5512	25.11	NH 8619 5103	32.84	NH 8714 5200	29.12
NH 6801 5511	24.37	NH 8620 5107	32.88		
		NH 8623 5109	32.76	T249	
T246		NH 8626 5112	32.67	NH 8751 5247	23.98
NH 7350 5758	30.83	NH 8628 5115	32.40	NH 8749 5243	24.60
NH 7350 5757	30.71	NH 8632 5118	32.38	NH 8747 5240	24.82
NH 7347 5750	31.69	NH 8635 5120	32.49	NH 8744 5238	25.00
NH 7345 5748	30.38	NH 8639 5122	32.21	NH 8741 5235	25.12
NH 7342 5746	30.21	NH 8641 5124	32.04		
NH 7340 5744	30.18	NH 8644 5126	32.25	T250	
NH 7338 5745	31.47	NH 8646 5129	31.90	NH 8633 5129	29.75
NH 7335 5742	31.25	NH 8649 5132	31.83	NH 8631 5128	29.93
NH 7332 5741	31.50	NH 8651 5135	31.69	NH 8628 5126	30.15
NH 7330 5739	30.96	NH 8652 5138	31.83	NH 8624 5124	30.41
NH 7328 5736	31.03	NH 8656 5141	31.71	NH 8621 5123	30.54
NH 7326 5734	31.12	NH 8660 5143	31.56	NH 8618 5122	30.55
NH 7309 5713	30.11	NH 8663 5145	31.29	NH 8713 5205	24.45
NH 7307 5711	30.19	NH 8666 5148	31.18	NH 8710 5202	24.53
NH 7304 5708	30.17	NH 8669 5150	31.23	NH 8708 5200	24.39
NH 7301 5705	29.56	NH 8672 5152	31.22	NH 8704 5197	24.46
NH 7298 5703	29.11	NH 8674 5155	31.19	NH 8701 5195	24.76

Grid Ref.	Alt.
T250 (cont.)	
NH 8695 5201	25.36
NH 8692 5200	25.64
NH 8689 5198	25.77
NH 8686 5195	25.87
NH 8683 5194	25.94
NH 8681 5192	25.78
NH 8678 5191	25.89
NH 8673 5189	26.05
NH 8669 5188	26.33
NH 8674 5178	26.47
NH 8672 5175	26.94
NH 8669 5172	27.03
NH 8666 5170	27.13
NH 8660 5175	26.55
NH 8658 5172	26.92
NH 8655 5168	27.18
NH 8650 5163	27.28
NH 8647 5160	27.47
NH 8644 5157	28.05
NH 8642 5154	28.27
NH 8643 5148	28.86
NH 8642 5145	29.07
NH 8640 5141	29.35
NH 8637 5139	29.77
NH 8634 5137	29.87
NH 8652 5166	27.20
T251	
NH 8697 5216	21.35
NH 8693 5217	21.45
NH 8687 5215	21.62
NH 8684 5214	21.98
NH 8680 5212	22.05
NH 8678 5209	22.43
NH 8676 5207	22.71
NH 8674 5204	22.78
T251 (cont.)	
NH 8669 5207	22.48
NH 8667 5205	22.84
NH 8664 5202	23.00
NH 8662 5198	23.25
NH 8658 5197	23.45
NH 8654 5197	23.58
NH 8650 5196	23.98
NH 8647 5196	24,34
NH 8644 5195	24.89
NH 8641 5193	24.87
NH 8639 5190	25.07
NH 8637 5188	25.28
NH 8827 5291	18.23
NH 8826 5294	17.63
NH 8826 5297	17.13
NH 8821 5296	16.47
NH 8819 5293	16.21
NH 8815 5291	15.81
NH 8811 5289	15.54
NH 8807 5285	15.47
NH 8803 5284	15.54
NH 8800 5282	15.73
NH 8797 5280	15.56
NH 8793 5283	15.89
NH 8792 5279	15.92
NH 8788 5277	16.44
NH 8784 5276	16.48
NH 8782 5275	16.49
NH 8777 5274	16.84
NH 8773 5276	17.14
NH 8770 5271	17.54
NH 8768 5270	17.70
NH 8763 5269	17.83
NH 8760 5267	18.05
NH 8756 5266	18.16
NH 8752 5264	18.28
T251 (cont.)	
NH 8747 5262	18.16
NH 8744 5260	18.07
NH 8742 5258	18.30
NH 8739 5255	18.44
NH 8736 5252	18.61
NH 8733 5250	18.44
NH 8731 5248	18.93
NH 8728 5245	19.24
NH 8726 5242	19.32
NH 8725 5239	19.36
T252	
NH 8643 5201	23.72
NH 8644 5204	23.23
NH 8646 5207	22.82
NH 8648 5210	22.80
NH 8650 5213	22.78
NH 8653 5215	22.52
NH 8657 5217	22.25
NH 8660 5219	22.23
NH 8663 5223	22.25
NH 8663 5230	22.39
NH 8665 5234	22.38
NH 8667 5239	20.95
NH 8669 5243	20.52
NH 8672 5246	20.21
NH 8674 5247	19.83
NH 8677 5250	19.81
NH 8681 5253	19.66
NH 8683 5257	19.54
NH 8686 5259	19.29
NH 8689 5263	18.76
NH 8692 5265	18.81
NH 8694 5269	18.55
NH 8695 5272	18.36
NH 8697 5276	18.45

Grid Ref.	Alt.	Grid Ref.	Alt.	Grid Ref.	Alt.
T252(cont.)		T253(cont.)		T263	
NH 8700 5277	18.23	NH 8703 5357	16.50	NH 8525 5390	26.14
NH 8704 5278	17.97	NH 8706 5358	16.25	NH 8529 5388	26.10
NH 8708 5277	17.68	NH 8709 5359	16.11	NH 8534 5389	26.60
NH 8711 5275	17.37	NH 8712 5358	15.98	NH 8537 5390	26.61
NH 8716 5276	17.05	NH 8716 5357	15.88	NH 8541 5388	26.69
NH 8719 5279	17.15			NH 8544 5386	26.80
NH 8721 5281	16.88	T257		NH 8547 5385	26.75
NH 8725 5284	16.52	NH 8753 5391	19.20		
NH 8729 5286	16.57	NH 8753 5392	19.09	T264	
NH 8732 5287	16.23	NH 8755 5396	18.89	NH 8501 5257	33.52
NH 8738 5286	16.35			NH 8511 5261	33.39
NH 8740 5292	16.46	T261		NH 8513 5264	33.25
NH 8743 5293	16.30	NH 8584 5369	27.77	NH 8515 5267	32.98
NH 8752 5295	15.62	NH 8588 5368	27.81	NH 8517 5270	32.52
NH 8754 5298	15.22	NH 8593 5368	27.91	NH 8520 5275	32.15
NH 8756 5301	15.03			NH 8522 5278	31.87
NH 8759 5303	15.05	T262		NH 8529 5279	31.69
NH 8762 5307	15.09	NH 8578 5359	27.35	NH 8534 5278	31.18
NH 8763 5310	14.87	NH 8576 5363	27.51	NH 8539 5279	31.04
NH 8765 5314	14.76	NH 8574 5367	27.53		
NH 8767 5319	14.42	NH 8570 5370	27.36	T265	
NH 8768 5323	14.44	NH 8566 5372	27.40	NH 8612 5386	36.55
NH 8770 5326	14.22	NH 8564 5375	27.33	NH 8608 5384	36.42
		NH 8565 5349	28.87	NH 8617 5379	36.44
T253		NH 8563 5352	28.71	NH 8613 5379	36.63
NH 8664 5337	18.47	NH 8561 5356	28.74	NH 8609 5378	36.95
NH 8666 5340	17.99	NH 8559 5359	28.58	NH 8605 5382	36.81
NH 8669 5342	18.09	NH 8558 5362	28.77	NH 8600 5382	37.07
NH 8671 5344	17.62	NH 8557 5366	28.58	NH 8596 5380	36.98
NH 8674 5346	17.60	NH 8550 5368	29.05	NH 8591 5379	37.25
NH 8678 5347	17.23	NH 8546 5371	29.03	NH 8586 5378	37.61
NH 8682 5348	17.06	NH 8541 5371	28.78	NH 8583 5379	37.74
NH 8686 5350	17.09	NH 8537 5372	28.27	NH 8621 5389	36.62
NH 8691 5351	16.77	NH 8534 5374	28.11	NH 8625 5390	36.24
NH 8694 5352	16.55	NH 8532 5377	28.17	NH 8628 5390	36.35
NH 8698 5353	16.64	NH 8530 5381	28.12	NH 8632 5391	36.26
		NH 8526 5382	28.18	NH 8635 5392	35.90

Grid Ref.	Alt.	Grid Ref.	Alt.	Grid Ref.	Alt.
T265 (cont.)		T267 (cont.)		T270 (cont.)	
NH 8637 5394	35.97	NH 8594 5390	27.31	NH 8684 5448	20.32
NH 8641 5394	35.08	NH 8597 5393	26.98	NH 8680 5449	20.80
NH 8645 5394	35.06	NH 8600 5396	26.80	NH 8675 5449	19.97
NH 8650 5395	34.92	NH 8602 5398	26.62	NH 8670 5447	19.80
NH 8654 5396	34.91	NH 8605 5400	26.64	NH 8668 5446	19.81
NH 8658 5397	34.57	NH 8612 5399	26.59	NH 8667 5443	19.95
NH 8662 5397	34.33	NH 8616 5400	26.46	NH 8664 5442	20.02
NH 8666 5398	33.18	NH 8619 5403	26.31	NH 8661 5442	20.11
NH 8671 5398	34.01			NH 8658 5442	20.13
NH 8677 5397	33.82	T268+T269		NH 8655 5442	20.11
NH 8671 5397	33.82	NH 8521 5437	24.28	NH 8653 5441	20.33
NH 8685 5397	33.74	NH 8525 5439	23.89	NH 8649 5440	20.29
		NH 8529 5440	23.76	NH 8645 5441	20.33
T266		NH 8515 5419	25.56	NH 8642 5444	20.36
NH 8564 5438	26.61	NH 8518 5421	25.39	NH 8638 5445	20.27
NH 8567 5439	26.70	NH 8521 5423	25.11	NH 8634 5445	20.14
NH 8572 5439	26.67	NH 8526 5417	25.14	NH 8630 5443	20.07
NH 8580 5432	26.54	NH 8529 5418	25.07	NH 8625 5443	20.17
NH 8582 5433	26.36	NH 8532 5420	24.82	NH 8621 5443	20.18
NH 8585 5436	26.23	NH 8534 5423	24.53	NH 8600 5450	20.33
NH 8590 5439	25.24	NH 8537 5426	24.11	NH 8597 5451	20.40
NH 8559 5430	27.10	NH 8540 5428	24.01	NH 8593 5451	20.30
NH 8557 5427	27.47	NH 8544 5432	23.78	NH 8591 5450	20.28
NH 8556 5423	27.76			NH 8586 5450	20.35
NH 8554 5420	27.96	T270		NH 8582 5451	20.29
NH 8552 5416	27.98	NH 8691 5494	20.36	NH 8579 5449	20.32
NH 8549 5412	28.24	NH 8693 5492	20.28	NH 8575 5448	20.35
NH 8548 5408	28.31	NH 8696 5489	20.20	NH 8571 5447	20.53
NH 8546 5405	28.23	NH 8697 5486	20.12	NH 8568 5447	20.54
NH 8537 5408	28.67	NH 8699 5482	20.17	NH 8565 5448	20.47
NH 8533 5407	28.78	NH 8701 5477	20.15	NH 8561 5445	20.56
		NH 8702 5474	20.18	NH 8558 5444	20.91
T267		NH 8703 5469	20.14	NH 8554 5441	21.29
NH 8577 5385	28.00	NH 8703 5466	20.14	NH 8551 5439	21.57
NH 8581 5386	27.69	NH 8704 5463	20.11		
NH 8585 5387	27.67	NH 8700 5459	20.07	T271	
NH 8589 5389	27.56	NH 8699 5457	20.14	NH 8747 5493	21.21

Grid Ref.	Alt.
T271 (cont.)	
NH 8747 5491	21.42
NH 8749 5488	21.83
NH 8752 5484	21.54
NH 8753 5479	21.64
NH 8755 5476	22.38
NH 8755 5462	22.72
NH 8755 5459	23.01
NH 8743 5494	20.70
NH 8736 5495	20.32
NH 8733 5496	20.47
NH 8729 5496	20.52
NH 8723 5498	20.86
NH 8720 5499	20.90
NH 8715 5499	21.00
T272	
NH 8751 5490	22.10
NH 8767 5493	21.32
NH 8768 5489	21.70
NH 8768 5485	22.37
NH 8768 5481	22.77
NH 8768 5477	23.27
NH 8768 5474	23.56
NH 8768 5467	23.67
NH 8769 5462	23.87
NH 8770 5459	24.26
T273	
NH 5512 5429	26.16
NH 5514 5432	25.99
T274	
NH 8755 5462	22.72
NH 8755 5459	23.01

Grid Ref.	Alt.
T275	
NH 8689 5391	32.18
NH 8690 5396	32.16
NH 8693 5398	32.20
T276	
NH 8728 5403	29.67
NH 8729 5399	29.92
NH 8729 5394	29.85
NH 8728 5391	29.69
T271 (Lochloy)	
NH 9423 5813	26.32
NH 9420 5812	26.34
NH 9417 5812	26.35
NH 9413 5811	26.43
NH 9409 5810	26.53
NH 9406 5807	26.62
NH 9403 5803	26.61
NH 9397 5805	26.15
T277	
NJ 0108 6035	7.98
NJ 0108 6039	7.99
NJ 0106 6043	7.83
NJ 0104 6046	7.68
T278	
NH 9992 6041	17.51
NH 9996 6042	17.40
NJ 0001 6042	17.12
NJ 0005 6042	16.72
NJ 0010 6042	16.44
NJ 0014 6043	16.32
T279	
NH 9960 5957	20.84

Grid Ref.	Alt.
T279 (cont.)	
NH 9964 5955	20.70
NH 9967 5953	20.98
NH 9970 5951	20.76
NH 9974 5949	20.82
NH 9977 5946	20.64
NH 9980 5944	20.46
T280	
NH 8918 5581	7.43
NH 8914 5582	7.17
NH 8904 5581	7.31
T281	
NH 8895 5545	7.04
NH 8899 5546	6.95
NH 8902 5549	6.63
NH 8904 5552	6.50
NH 8905 5556	6.35
NH 8905 5560	6.30
NH 8907 5564	6.12
NH 8910 5567	5.81
NH 8913 5569	5.70
NH 8917 5571	5.86
NH 8915 5574	6.04
NH 8912 5574	6.07
NH 8908 5574	5.80
NH 8904 5575	5.53
NH 8899 5576	5.54
NH 8897 5580	5.70
NH 8881 5543	7.09
NH 8878 5540	7.25
NH 8875 5538	7.21
NH 8874 5528	7.70
NH 8874 5524	7.98
NH 8882 5493	8.18
NH 8884 5493	8.27
NH 8887 5492	8.53

Grid Ref.	Alt.
T281 (cont.)	
NH 8895 5491	8.52
NH 8899 5488	8.65
NH 8898 5484	8.77
NH 8897 5482	8.83
NH 8896 5476	8.92
NH 8889 5471	9.33
NH 8885 5470	9.53
NH 8881 5471	9.61
NH 8877 5472	9.65
NH 8874 5473	9.67
NH 8869 5475	9.81
NH 8861 5477	9.90
NH 8857 5477	9.81
NH 8852 5478	10.05
NH 8849 5480	9.96
NH 8846 5482	10.19
NH 8843 5483	9.90
NH 8840 5483	9.97
HN 8835 5482	10.33
HN 8831 5481	10.36
NH 8828 5478	10.68
NH 8824 5477	11.14
NH 8820 5476	11.25
NH 8816 5475	11.32
NH 8813 5474	11.46

5. Rims of Kettleholes

Grid Ref.	Alt.
NJ 0029 6047	15.71
NJ 0079 6073	8.94
NH 8755 5462	22.72
NH 8736 5495	20.32
NH 8311 5555	21.23
NH 8165 5556	27.23
NH 7951 5542	20.80
NH 6873 5552	17.78
NH 6162 4847	21.37

APPENDIX II

BOREHOLE DATA

1.Boreholes Berived by the Author

Altitude*	Description
H1	(Alt. 6.02) NH 5804 4556
5.62	Grey brown silty-clay
5.42	Tan sand and gravel
H2	(Alt. 4.86) NH 5803 4557
2.97	Dark grey silty-clay
2.83	Tan sand and gravel
H3	(Alt. 3.59) NH 5802 4559
1.89	Dark grey silty-clay
1.71	Gravel
H4	(Alt. 3.43) NH 5801 4562
1.65	Dark grey silty-clay
1.60	Tan sand and gravel
H5	(Alt. 3.41) NH 5799 4565
1.61	Dark grey silty-clay
1.60	Gravel
H6	(Alt. 3.18) NH 5797 4567
1.79	Dark grey silty-clay
1.58	Grey sand
1.55	Gravel
H7	(Alt. 2.42) NH 5796 4569
1.63	Dark grey silty-clay
1.41	Grey sand
1.39	Gravel

Altitude	Description
H8	(Alt. 6.85) NH 5480 4608
6.20	Grey-brown silty-clay
6.16	Tan sand
5.40	Dark grey silty clay
	Gravel
H9	(Alt. 6.58) NH 5480 4610
5.34	Grey-brown sitly-clay
4.25	Dark grey silty-clay
4.00	Micaceous grey sand
2.87	Dark grey peaty silty clay
2.14	Brown peat
	Gravel
H10	(Alt. 6.37) NH 5480 4613
5.00	Grey-brown silty clay
2.58	Dark grey silty-clay
2.50	Dark grey peaty silty-clay
2.00	Brown peat
1.89	Pale grey silty sand
	Gravel
H11	(Alt. 6.13) NH 5480 4615
4.36	Grey brown silty-clay
2.54	Dark grey silty-clay
2.29	Dark grey peaty silty-clay
1.60	Brown peat
1.49	Dark grey silty-clay
1.443	Gravel
	Pink-grey sand

* All altitudes (Alt.) are in metres (O.D.)

Altitude	Description
H12	(Alt. 10.80) NH 5452 4594
0.23	Sand
	Gravel
H13	(Alt. 8.36) NH 5450 4596
0.41	Tan sand
	Gravel
H14	(Alt. 7.07) NH 5450 4598
6.46	Grey-brown silty-clay
6.42	Tan sand
5.21	Dark grey silty-clay
	Gravel
H15	(Alt. 6.64) NH 5449 4599
5.50	Grey-brown silty-clay
4.07	Dark grey silty clay
3.94	Micaceous grey sand
3.27	Dark grey peaty silty clay
2.93	Brown peat
	Gravel
H16	(Alt. 6.40) NH 5448 4603
4.86	Grey brown silty-clay
3.28	Dark grey silty clay
3.00	Dark grey peaty silty-clay
2.72	Brown peat
2.25	Grey silty-sand
	Gravel
H17	(Alt. 6.30) NH 5447 4604
4.51	Grey brown silty-clay
4.02	Dark grey silty-clay
3.87	Dark grey sand
2.63	Dark grey peaty silty-clay
2.05	Peat
	Gravel

Altitude	Description
H18	(Alt. 6.63) NH 5447 4605
4.44	Grey-brown silty clay
3.47	Dark grey silty-clay
2.02	Coarse grey sand
1.31	Dark grey silty-clay
0.88	Brown peat
	Gravel
H19	(Alt. 10.13) NH 5112 4538
9.43	Sand
	Gravel
H20	(Alt. 8.52) NH 5115 4537
6.43	Grey-brown silty-clay
4.82	Dark grey silty-clay
3.88	Dark grey sand
	Gravel
H21	(Alt. 8.46) NH 5117 4536
6.85	Grey-brown silty-clay
5.03	Dark grey silty-clay
5.01	Micaceous grey sand
4.24	Dark grey silty-clay
4.21	Light grey sand
1.98	Dark grey silty-clay
	Gravel
H22	(Alt. 8.38) NH 5120 4535
6.63	Grey brown silty-clay
4.96	Dark grey silty-clay
4.80	Micaceous grey sand
4.39	Dark grey silty-clay
	Light grey sand

Altitude	Description	Altitude	Description
H23	(Alt. 8.34) NH 5122 4534	H27	(11.22) NH 5122 4562
6.61	Grey-brown silty-clay	10.52	Brown sand
5.74	Dark grey silty-clay	10.46	Dark grey silty-clay
5.72	Micaceous grey sand	10.41	Grey sand
5.38	Dark grey silty-clay		Gravel
4.73	Light grey sand		
1.83	Dark grey silty-clay	H28	(Alt. 10.31) NH 5124 4562
	Gravel	9.05	Brown silty-sand
		8.06	Dark grey silty-clay
H24	(Alt. 8.38) NH 5124 4532	7.91	Grey sand
6.32	Grey-brown silty-clay		Gravel
5.62	Dark grey silty-clay		
5.42	Micaceous grey sand	H29	(Alt. 9.53) NH 5125 4560
4.82	Dark grey silty-clay	8.97	Brown silty-sand
4.73	Peat		Gravel
4.02	Dark grey silty-clay		
3.86	Light grey sand	H30	(Alt. 9.15) NH 5127 4560
1.79	Dark grey silty-clay	8.23	Brown silty-sand
	Gravel	7.30	Grey-brown silty-sand
		5.70	Dark grey silty-clay
H25	(Alt. 8.06) NH 5128 4530	5.52	Micaceous grey sand
6.50	Grey-brown silty-clay	2.72	Dark grey silty clay
5.58	Dark grey silty-clay	2.61	Grey sand
5.47	Micaceous grey sand	1.95	Dark grey silty-clay
2.32	Dark grey silty-clay		Gravel
1.85	Grey sand with peat		
	Gravel	H31	(Alt. 8.88) NH 5128 4559
		7.92	Brown silty-sand

Altitude	Description
H32	(Alt. 8.56) NH 5133 4567
7.59	Brown silty-sand
7.54	Wood
6.98	Coarse sand
0.72	Dark grey silty-clay
	Gravel
H33	(Alt. 8.58) NH 5135 4553
7.92	Brown silty-sand
6.22	Grey-brown silty-sand
4.54	Dark grey silty-clay
4.49	Micaceous grey sand
1.73	Dark grey silty-clay
	Gravel
H34	(Alt. 8.24) NH 5144 4552
5.95	Grey-brown silty-clay
4.25	Dark grey silty-clay
4.09	Micaceous grey sand
0.77	Dark grey silty-clay
	Gravel
H35	(Alt. 11.10) NH 5129 4588
10.17	Brown sand
	Gravel
H36	(Alt. 9.96) NH 5132 4587
9.39	Brown sand
9.13	Grey-brown silty-clay
8.79	Tan sand
	Gravel
H37	(Alt. 9.26) NH 5134 4585
8.71	Brown sand
7.67	Grey-brown silty-clay
	Gravel

Altitude	Description
H38	(Alt. 8.69) NH 5136 4584
7.01	Grey-brown silty-clay
0.07	Dark grey silty-clay
	Gravel
H39	(Alt. 8.33) NH 5138 4584
6.67	Grey-brown silty-clay
0.35	Dark grey silty-clay
	Gravel
H40	(Alt. 8.14) NH 5140 4584
6.53	Grey-brown silty-clay
0.54	Dark grey silty-clay
0.49	Grey sand
	Gravel
H41	(Alt. 8.01) NH 5142 4583
6.34	Grey-brown silty-clay
6.08	Dark grey silty-clay
5.89	Micaceous grey sand
-0.51	Dark grey silty-clay
-0.65	Grey sand
	Pink-grey silty-sand
H42	(Alt. 7.84) NH 5143 4582
6.28	Grey-brown silty-clay
5.91	Dark grey silty-clay
5.77	Micaceous grey sand
-0.23	Dark grey silty-clay
	Gravel
H43	(Alt. 7.63) NH 5151 4577
5.95	Grey-brown silty-clay
1.48	Dark grey silty-clay
-0.17	Grey sand+fine gravel
	Gravel

Altitude	Description
H44	(Alt. 12.20) NH 5133 4604
11.92	Brown silty sand
11.69	Sand and fine gravel
11.37	Brown silty sand
	Gravel
H45	(Alt. 10.76) NH 5136 4603
10.56	Brown sand
10.47	Tan sand
10.18	Peat
10.13	Light brown sand
	Gravel
H46	(Alt. 9.49) NH 5138 4602
8.91	Grey-brown silty-clay
8.80	Grey sand
7.63	Dark grey silty-clay
	Gravel
H47	(Alt. 9.09) NH 5142 4603
8.91	Grey-brown silty-clay
8.28	Tan sand and fine gravel
7.52	Grey-brown silty-clay
0.26	Dark grey silty-clay
	Gravel
H48	(Alt. 8.64) NH 5142 4600
6.84	Grey-brown silty-clay
0.05	Dark grey silty-clay
	Gravel
H49	(Alt. 8.65) NH 5145 4599
6.50	Grey-brown silty-clay
5.91	Dark grey silty-clay
5.80	Micaceous grey sand
0.22	Dark grey silty-clay
	Gravel

Altitude	Description
H50	(Alt. 8.62) NH 5148 4598
6.79	Grey-brown silty-clay
6.01	Dark grey silty-clay
5.97	Micaceous grey sand
0.64	Dark grey silty-clay
	Gravel
H51	(Alt. 7.91) NH 5154 4594
6.29	Grey-brown silty-clay
4.87	Dark grey silty-clay
4.80	Micaceous grey sand
-0.94	Dark grey silty-clay
	Gravel
H52	(Alt. 7.83) NH 5162 4590
6.04	Grey-brown silty-clay
0.45	Dark grey silty-clay
	Gravel
H53	(Alt. 11.41) NH 5164 4651
11.04	Sandy-silt
	Gravel
H54	(Alt. 11.19) NH 5166 4651
9.96	Brown silty-sand
9.61	Peat
9.20	Dark brown silty-clay
9.02	Dark grey silty-clay
	Rock
H55	(Alt. 10.81) NH 5168 4650
9.85	Brown silty-sand
9.30	Grey-brown silty-clay
9.21	Tan sand
8.71	Peat
8.52	Dark grey peaty silty-clay
5.94	Dark grey silty-clay

Altitude	Description
H55 (cont.)	
5.91	Wood
4.96	Dark grey silty-clay
4.92	Sand and gravel
3.66	Tough light grey sand
	Gravel
H56	(Alt. 10.34) NH 5170 4649
9.87	Brown silty-sand
9.61	Grey-brown silty-clay
9.50	Sand
9.12	Dark grey silty-clay
8.38	Peat
0.15	Dark grey silty-clay
0.11	Gravel
	Light grey silty-clay
H57	(Alt. 9.64) NH 5175 4646
9.22	Brown silty-sand
8.60	Grey-brown silty-clay
8.31	Peat
1.07	Dark grey silty-clay
0.87	Sand
	Tough grey silty clay
H58	(Alt. 9.15) NH 5178 4645
8.47	Brown silty-sand
8.14	Brown peaty silty-clay

Altitude	Description
H60	(Alt. 8.30) NH 5246 4719
7.28	Grey-brown silty-clay
6.76	Grey silty-sand
6.27	Dark grey silty-clay
	Gravel
H61	(Alt. 7.86) NH 5250 4713
6.68	Grey-brown silty-clay
5.14	Dark grey silty-clay
4.89	Brown peat
	Tough grey silty-clay
H62	(Alt. 7.57) NH 5252 4711
6.32	Grey-brown silty-clay
4.60	Dark grey silty-clay
4.39	Brown peat
	Tough grey silty-clay
H63	(Alt. 7.22) NH 5262 4707
5.77	Grey-brown silty-clay
5.41	Dark grey silty-clay
5.29	Micaceous grey sand
4.51	Dark grey silty-clay
4.32	Brown Peat
	Tough grey silty-clay
H64	(Alt. 6.04) NH 5268 4704
4.34	Grey-brown silty-clay

Altitude	Description
<u>H66</u>	(Alt. 6.26) NH 5280 4695
4.84	Grey-brown silty-clay
4.33	Grey sand
3.23	Dark grey silty-clay
	Tough grey silty-clay
<u>H67</u>	(Alt. 8.34) NH 5271 4755
7.60	Grey-brown silty-clay
7.38	Micaceous grey sand
	Gravel
<u>H68</u>	(Alt. 7.88) NH 5273 4753
6.86	Grey-brown silty-clay
6.34	Tough ash-grey silty-sand/clay
	Rock
<u>H69</u>	(Alt. 7.77) NH 5274 4752
6.17	Grey-brown silty-clay
5.36	Tough grey silty-clay
3.92	Tough grey silty-sand
	Gravel
<u>H70</u>	(Alt. 7.71) NH 5276 4750
5.77	Grey-brown silty-clay
5.63	Dark grey silty-clay
5.19	Brown peat
	Tough grey silty-clay/sand

Altitude	Description
<u>H72</u>	(Alt. 7.19) NH 5287 4739
5.72	Grey-brown silty clay
5.55	Coarse tan sand
4.79	Dark grey silty-clay
4.67	Peaty silty-clay
4.54	Brown peat
	Tough grey silty-clay
<u>H73</u>	(Alt. 6.02) NH 5293 4734
4.71	Grey-brown silty-clay
4.63	Sedge peat
4.32	Dark grey silty-clay
4.10	Brown peat
	Tough grey silty-clay
<u>H74</u>	(Alt. 5.54) NH 5299 4731
3.73	Grey-brown silty-clay
1.09	Dark grey silty-clay
	Gravel
<u>H75</u>	(Alt. 4.76) NH 5303 4729
3.53	Grey-brown silty-clay
1.77	Dark grey silty-clay
	Gravel
<u>H76</u>	(Alt. 4.86) NH 5305 4728
1.25	Dark grey silty-clay

Altitude	Description
H78	(Alt. 5.20) NH 5311 4727
3.69	Grey-brown silty-clay
2.67	Dark grey silty-clay
2.25	Tough grey silty-clay
	Fine sand
H79	(Alt. 9.10) NH 5366 4816
8.86	Brown peat
8.49	Peaty silty-sand
	Sand and gravel
H80	(Alt. 8.01) NH 5367 4814
7.78	Brown peat
6.91	Micaceous grey sand
5.65	Peaty sand
	Gravel
H81	(Alt. 6.18) NH 5368 4811
4.64	Brown peat
4.60	Micaceous grey sand
4.08	Dark grey silty-clay
	Gravel
H82	(Alt. 4.88) NH 5372 4809
4.54	Peaty sitly-clay
3.81	Grey-brown silty-clay
3.74	Micaceous grey sand
3.00	Dark grey silty-clay
2.20	Brown peat
	Gravel
H83	(Alt. 4.47) NH 5373 4807
3.93	Grey-brown peaty silty-clay
3.59	Dark grey silty-clay
3.51	Micaceous grey sand
1.68	Dark grey silty-clay
	Gravel

Altitude	Description
H84	(Alt. 4.24) NH 5375 4805
3.37	Grey-brown silty-clay
1.56	Dark grey silty-clay
	Gravel
H85	(Alt. 4.13) NH 5385 4794
2.58	Grey-brown silty-clay
1.50	Dark grey silty-clay
	Gravel
H86	(Alt. 3.84) NH 5395 4787
2.45	Grey-brown silty-clay
0.93	Dark grey silty-clay
0.37	Coarse grey sand
	Gravel
H87	(Alt. 10.15) NH 5379 4825
9.87	Tan sand + gravel
	Gravel
H88	(Alt. 7.49) NH 5380 4826
7.28	Brown sand
6.96	Brown peaty silty-clay
	Gravel
H89	(Alt. 5.95) NH 5382 4823
4.63	Brown peaty silty-clay
4.49	Tan sand
	Gravel
H90	(Alt. 5.38) NH 5385 4822
4.86	Tan sand
4.46	Grey-brown silty-clay
4.10	Dark grey silty-clay
3.86	Grey sand
	Gravel

Altitude	Description
H91	(Alt. 4.77) NH 5387 4821
4.57	Fine tan sand
3.69	Grey-brown silty-clay
3.45	Micaceous grey sand
2.99	Dark grey silty-clay
2.54	Brown peat
2.35	Dark grey silty-clay
2.23	Grey sand
	Gravel
H92	(Alt. 4.48) NH 5387 4820
3.38	Grey-brown silty-clay
1.72	Dark grey silty-clay
1.24	Grey coarse sand
	Gravel
H93	(Alt. 4.17) NH 5388 4818
3.22	Grey-brown silty-clay
1.66	Dark grey silty-clay
1.53	Coarse grey sand
1.06	Coarse tan sand
	Gravel
H94	(Alt. 4.06) NH 5389 4817
2.62	Grey-brown silty-clay
1.77	Dark grey silty-clay
	Coarse tan sand
H95	(Alt. 3.82) NH 5396 4805
2.91	Grey-brown silty-clay
1.26	Dark grey silty-clay
1.21	Grey sand
	Gravel

Altitude	Description
H96	(Alt. 3.23) NH 5408 4785
2.47	Grey-brown silty-clay
2.19	Coarse tan sand
	Coarse grey sand
H97	(Alt. 1.55) NH 5426 4769
1.06	Grey-brown silty-clay
-0.14	Dark grey silty-clay
	Gravel
H98	(Alt. 8.53) NH 5417 4852
8.22	Brown sand
	Gravel
H99	(Alt. 6.49) NH 5417 4850
6.00	Grey-brown silty-clay
5.85	Brown peat
	Gravel
H100	(Alt. 5.17) NH 5419 4849
4.54	Brown silty-sand
4.34	Grey-brown silty-clay
	Gravel
H101	(Alt. 4.35) NH 5422 4848
3.94	Brown silty-sand
3.65	Grey-brown silty-clay
	Gravel
H102	(Alt. 4.02) NH 5423 4846
3.76	Brown silty-sand
3.53	Grey-brown silty-clay
3.21	Coarse grey sand
	Gravel

Altitude	Description
H103	(Alt. 3.74) NH 5425 4845
3.21	Brown silty-sand
2.94	Grey-brown silty-clay
2.48	Coarse tan sand + gravel
	Gravel
H104	(Alt. 3.87) NH 5426 4843
1.66	Brown silty-sand
1.55	Tan sand
	Gravel
H105	(Alt. 3.97) NH 5428 4842
2.88	Brown silty-sand
2.26	Dark grey silty-clay
1.94	Grey silty-sand
1.01	Tan sand
	Gravel
H106	(Alt. 3.68) NH 5430 4840
2.73	Brown silty-sand
1.97	Dark grey silty-clay
1.57	Grey sand
1.03	Tan sand
	Gravel
H107	(Alt. 3.48) NH 5431 4838
2.96	Brown silty-sand
1.97	Dark grey silty-clay
1.22	Grey sand
1.14	Gravel
	Tough grey silty-clay
H108	(Alt. 1.65) NH 5453 4813
1.11	Dark grey silty-clay
0.91	Grey sand
0.04	Dark grey silty-clay
	Gravel

Altitude	Description
H109	(Alt. 1.33) NH 5472 4797
0.16	Grey-brown silty-clay
-0.25	Dark grey silty-clay
	Gravel
H110	(Alt. 4.27) NH 5445 4863
3.42	Grey-brown silty-clay
3.15	Brown peat
3.03	Coarse grey sand + gravel
	Gravel
H111	(Alt. 4.21) NH 5446 4861
3.97	Brown silty-sand
3.65	Dark grey silty-clay
2.99	Grey silty-sand
2.11	Brown peat
	Gravel
H112	(Alt. 4.19) NH 5448 4860
3.99	Brown peaty-sand
3.93	Tan sand
2.90	Dark grey silty-clay
2.27	Brown peat
1.92	Dark grey silty-clay
1.85	Gravel
	Ash-grey fine sand
H113	(Alt. 4.26) NH 5449 4858
3.78	Tan sand
2.72	Grey-brown silty-clay
2.39	Brown peat
1.87	Dark grey silty-clay
1.64	Grey sand
	Gravel

Altitude	Description
H114	(Alt. 3.98) NH 54514857
3.41	Tan sand
3.07	Grey-brown silty-clay
2.41	Dark grey silty-clay
2.05	Brown peat
1.77	Dark grey silty-clay
1.66	Coarse grey sand
	Gravel
H115	(Alt. 3.82) NH 54534855
3.34	Tan sand
1.85	Dark grey silty-clay
1.54	Coarse grey sand
	Gravel
H116	(Alt. 1.96) NH 54694840
1.54	Grey-brown silty-clay
1.05	Tan sand
0.99	Dark grey silty-clay
	Gravel
H117	(Alt. 1.08) NH 54874819
0.77	Grey-brown silty-clay
0.37	Grey sand
-0.18	Tan sand
	Gravel
[illegible]	[illegible]

Altitude	Description
H120	(Alt. 3.83) NH 54924866
3.37	Fine brown sand
	Gravel
H121	(Alt. 2.91) NH 54944862
2.59	Grey-brown silty-sand
	Gravel
H122	(Alt. 2.59) NH 54954860
2.16	Grey-brown silty-clay
	Gravel
H123	(Alt. 2.32) NH5495 4858
1.80	Grey-brown silty-clay
1.75	Gravel
1.64	Light tan sand
	Gravel
H124	(Alt. 2.16) NH 5496 4857
1.74	Grey-brown silty-clay
	Gravel
H125	(Alt. 1.96) NH 54964855
1.51	Grey-brown silty-clay
1.34	Coarse grey sand
1.25	Gravel
	Tough grey silty-sand/clay

Altitude	Description
H127	(Alt. 7.01) NH 55974905
6.90	Sand +fine gravel
	Gravel
H128	(Alt. 3.76) NH 55984904
3.52	Sand
	Gravel
H129	(Alt. 3.25) NH 55984902
2.60	Grey-brown silty-clay
	Gravel
H130	(Alt. 3.36) NH 55984899
2.31	Grey-brown silty-clay
1.66	Dark grey silty-clay
	Gravel
H131	(Alt. 3.12) NH 55994897
2.11	Grey-brown silty-clay
1.45	Dark grey silty-clay
	Gravel
H132	(Alt. 3.03) NH 55994894
2.18	Grey-brown silty-clay
1.15	Dark grey silty-clay
	Gravel
H133	(Alt. 2.77) NH 56014888
2.31	Tan silty-sand
1.73	Grey-brown silty-clay
1.48	Dark grey silty-clay
1.41	Coarse tan sand
1.01	Dark grey silty-clay
	Gravel
H134	(Alt. 6.92) NH 56224918
6.22	Tan sand
	Gravel

Altitude	Description
H135	(Alt. 5.57) NH 56224916
5.17	Brown /tan sand
	Tan sand + gravel
H136	(Alt. 3.99) NH 56234914
3.81	Tan sand
	Gravel
H137	(Alt. 3.25) NH 56234911
3.10	Tan sand
	Gravel
H138	(Alt. 2.75) NH 56234909
2.21	Grey-brown silty-clay
0.70	Dark grey silty-clay
0.65	Gravel
0.49	Tough grey silty-clay
	Pink-grey sand
H139	(Alt. 2.63) NH 56244907
2.09	Grey-brown silty-clay
0.99	Dark grey silty-clay
0.37	Grey sand
0.23	Tough grey silty-clay
	Light grey fine sand
H140	(Alt. 2.72) NH 56254904
2.05	Grey-brown silty-clay
1.11	Dark grey silty-clay
-0.21	Grey sand
-0.33	Dark grey silty-clay
-0.41	Coarse grey sand
	Tough grey silty-clay

Altitude	Description
H141	(Alt. 2.63) NH 56254902
2.20	Grey-brown silty-clay
2.06	Brown silty-sand
0.82	Dark grey silty-clay
0.23	Coarse dark grey sand
	Light grey silty-clay
H142	(Alt. 2.61) NH 56264894
1.88	Grey-brown silty-clay
0.85	Dark grey silty-clay
-0.03	Dark grey coarse sand
-0.14	Dark grey silty-clay
	Gravel
H143	(Alt. 8.46) NH 67515226
8.16	Brown sand
	Tan sand + gravel
H144	(Alt. 3.59) NH 67505229
3.04	Dark brown peaty-clay
	Rock
H145	(Alt. 2.99) NH 67505231
2.49	Brown peaty-silty-clay
1.10	Dark grey silty-clay
	Gravel
H146	(Alt. 2.75) NH 67525232
2.28	Brown peaty-silty-clay
2.21	Grey sand
0.35	Dark grey silty-clay
	Rock
H147	(Alt. 2.47) NH 67525234
2.05	Brown peaty-silty-clay
0.05	Dark grey silty-clay
	Gravel

Altitude	Description
H148	(Alt. 3.70) NH 67235232
3.06	Brown peat
2.94	Peaty sand
	Gravel
H149	(Alt. 3.06) NH 67235234
2.62	Brown-grey peaty-silty-clay
2.53	Grey sand
1.83	Dark grey silty-clay
1.50	Tan sand
1.22	Pink sand
	Rock
H150	(Alt. 2.53) NH 67245235
2.32	Brown-grey peaty-silty-clay
2.15	Grey sand
0.57	Dark grey silty-clay
0.38	Gravel
	Tough pink sand
H151	(Alt. 2.36) NH 67245237
2.01	Dark grey silty-clay
1.95	Grey sand
0.22	Dark grey silty-clay
	Gravel
H152	(Alt. 2.24) NH 67255241
1.88	Grey-brown peaty-silty-clay
1.80	Grey sand
0.39	Dark grey silty-clay
	Gravel
H153	(Alt. 3.72) NH 67115233
2.98	Brown peaty-silty-clay
2.90	Grey sand
2.72	Dark grey silty-clay
	Gravel

Altitude	Description
H154	(Alt. 2.98)NH 67125234
2.62	Brown-grey peaty-silty-clay
2.54	Grey sand
2.01	Dark grey silty-clay
1.82	Grey sand
1.09	Dark grey silty-clay
	Rock
H155	(Alt. 2.58)NH 67125236
0.54	Dark grey silty-clay
	Gravel
H156	(Alt. 2.50)NH 67135238
0.49	Dark grey silty-clay
	Gravel
H157	(Alt. 2.43)NH 67145240
0.29	Dark grey silty-clay
	Gravel
H158	(Alt. 2.60)NH 67155244
2.04	Dark grey silty-clay
1.93	Ash-grey sand
-1.305	Dark grey silty-clay
	Gravel
H159	(Alt. 3.98)NH 65915367
3.72	Sand
	Gravel
H160	(Alt. 3.06)NH 65915365
2.91	Brown silty-sand
2.32	Dark grey silty-clay
1.65	Grey sand
1.20	Pink-grey sand
	Gravel

Altitude	Description
H161	(Alt. 2.63) NH 65925363
2.17	Brown silty-sand
0.73	Dark grey silty-clay
0.65	Coarse grey sand
0.18	Dark grey silty-clay
	Gravel
H162	(Alt. 2.47) NH 65925361
1.44	Grey-brown silty-clay
1.05	Dark grey silty-clay
0.62	Grey sand
-0.49	Dark grey silty-clay
	Gravel
H163	(Alt. 2.43) NH 65935360
1.34	Grey-brown silty-clay
-0.44	Dark grey silty-clay
	Rock
H164	(Alt. 2.30) NH 65935357
1.16	Grey-brown silty-clay
-0.91	Dark grey silty-clay
-1.09	Brown sand
	Rock
H165	(Alt. 2.38) NH 65945355
1.60	Grey-brown silty-clay
1.45	Tan sand
-1.29	Dark grey silty-clay
	Gravel
H166	(Alt. 3.43) NH 65675358
3.08	Brown silty-sand
	Rock

Altitude	Description
H167	(Alt. 2.85)NH 65685356
2.24	Coarse tan sand
0.57	Dark grey silty-clay
	Gravel
H168	(Alt. 2.62)NH 65695355
2.23	Tan sand + fine gravel
-1.22	Dark grey silty-clay
	Gravel
H169	(Alt. 2.70)NH 65705353
2.33	Brown sand
2.01	Dark grey silty-clay
1.86	Tan sand
-1.60	Dark grey silty-clay
	Gravel
H170	(Alt. 2.66)NH 65705350
2.23	Fine brown sand
2.00	Dark grey silty-clay
1.84	Tan sand
-2.35	Dark grey silty-clay
	Gravel
H171	(Alt. 2.63)NH 65725348
2.15	Fine brown sand
-2.42	Dark grey silty-clay
	Gravel
H172	(Alt. 5.75)NH 65445358
5.52	Brown sand
	Gravel
H173	(Alt. 4.47)NH 65445356
4.42	Sand + fine gravel
	Gravel

Altitude	Description
H174	(Alt. 3.23) NH 65455354
2.74	Tan sand
-0.24	Dark grey silty-clay
	Gravel
H175	(Alt. 2.64) NH 65465351
1.80	Grey-brown silty-clay
1.71	Grey sand
-0.91	Dark grey silty-clay
	Gravel
H176	(Alt. 2.75) NH 65475348
2.32	Tan sand
2.01	Dark grey silty-clay
1.71	Grey sand
-0.85	Dark grey silty-clay
	Rock
H177	(Alt. 2.50) NH 65485341
2.05	Grey-brown silty-clay
1.57	Grey sand
-1.38	Dark grey silty-clay
	Rock
H178	(Alt. 6.11) NH 64635300
5.82	Brown sand
	Gravel
H179	(Alt. 5.58) NH 65645299
5.12	Brown-grey sandy-silty-clay
4.64	Coarse tan sand + gravel
	Gravel
H180	(Alt. 5.21) NH 64655297
4.46	Grey-brown silty-clay
4.36	Grey sand
	Gravel

Altitude	Description	Altitude	Description
H181	(Alt. 5.51)NH 64675293	H182	(Alt. 5.48)NH 64685291
5.11	Grey-brown silty-clay	5.11	Grey-brown silty-clay
4.79	Tan sand	5.03	Fine tan sand
4.71	Grey-brown silty-clay	4.91	Grey-brown silty-clay
	Gravel		Gravel

2. Commercial Borehole Records

Altitude	Description
M1	
Alt. -11.81	(NH 6643 4760)
-14.55	Brown fine to coarse sand, gravel, cobbles and boulders
-16.23	Cobbles and Boulders
-17.75	Brown fine sand and gravel with some cobbles
-18.67	Cobbles and boulders
-20.19	Brown fine to coarse sand and gravel
-23.70	Coarse gravel with boulders
-24.61	Brown and black organic sandy clay with shell fragments
-28.57	Brown silty clay fine sand with silt layers
-35.89	Brown silty clay with layers of sandy silt
-38.18	Brown clayey silt with layers of silty clay
-53.87	Brown silty fine sand
-58.60	Grey silty sand
M2	
Alt. -8.3	(NH 6631 4776)
-10.74	Sandy fine to coarse gravel with shell fragments
-12.72	Grey sandy silt with fine to coarse gravel + cobbles
-19.27	Fine to coarse sand and gravel with cobbles and boulders
-19.58	Boulder
-23.69	Fine to coarse sand and gravel with cobbles and boulders
-31.16	Coarse sand and gravel with cobbles
-31.46	Boulder
-31.77	Fine to coarse sand and gravel with cobbles
-45.74	Boulders with cobbles, fine to coarse sand + gravel
-54.02	Grey-brown silty fine sand

Altitude	Description
M3	
Alt. -1.68	(NH 6660 4739)
-7.47	Medium to coarse gravel with cobbles and boulders
-10.98	Fine to coarse sand with occasional gravel
-26.06	Sandy fine to coarse gravel with cobbles and boulders
-29.72	Fine to coarse sand with gravel
-34.45	Grey-black organic silty clay with pebbles and shell fragments
-41.30	Brown silty fine sand
-47.86	Brown silty fine sand with bands of silt
M4	
Alt. 0.91	(NH 6675 4730)
-20.52	Brown sandy fine to coarse gravel with cobbles and boulders
-21.52	Brown sandy fine to coarse gravel with cobbles and pockets of grey silty clay with shell fragments
-23.78	Grey silty clay with shells and occasional gravel
-26.52	Brown silty fine sand
L5	
Alt. 27.25	(NH 6888 4522)
26.03	Sandy clayey silt with gravel
22.45	Brown fine sand
21.95	Sandy fine to medium gravel
18.95	Brown fine sand
18.29	Brown sndy clayey silt
16.35	Sandy fine to coarse gravel with clay binder
12.95	Boulders
- 0.25	Sandy fine to coarse gravel with clay binder
L6	
Alt. 5.16	(HN 6858 4564)
4.86	Topsoil
1.90	Brown fine sand
-6.20	Sandy fine to coarse gravel
-15.48	Fine sand
-16.72	Brown silty sand
-18.76	Fine sand
-20.19	Sandy fine to coarse gravel and cobbles

Altitude	Description
L7	
Alt. 2.77	(NH 6833 4586)
2.54	Topsoil
0.24	Fill
-3.54	Fine to coarse sand and fine to medium gravel
-3.84	Grey silty sand
-4.48	Grey sandy silt
-9.51	Brown fine sand
-22.56	Brown silty fine sand
L8	
Alt. 2.64	(NH 6766 4612)
0.61	Brown clayey fine to coarse sand with gravel and cobbles
-0.36	Coarse sand and fine to coarse gravel
-1.36	Boulders
-1.51	Coarse sand with fine to coarse gravel
-2.36	Boulders
-4.26	Coarse sand with fine to coarse gravel
-4.96	Boulders
-6.36	Coarse sand with fine to coarse gravel
-6.96	Boulders
-8.66	Coarse sand with fine to coarse gravel
-9.86	Grey-brown fine sand with shells and pebbles
-10.89	Grey sandy silt with shells and occasional cobbles
-25.31	Brown fine sand
L10	
Alt. 3.86	(NH 6609 4793)
2.86	Brown fine sand and boulders

Altitude	Description
L11	
Alt. 27.97	(NH 6609 4793)
27.67	Topsoil
25.47	Brown fine to coarse sand with fine to coarse gravel
24.87	Boulders
23.17	Brown fine to coarse sand with fine to coarse gravel
22.47	Boulders
19.97	Brown fine to coarse sand with fine to coarse gravel
18.17	Boulders
13.37	Brown fine to coarse sand with fine to coarse gravel
12.57	Boulders
9.37	Brown sand with fine to coarse gravel
9.29	Brown silty sand
5.33	Brown sand with fine to coarse gravel
5.28	Brown silty sand
3.97	Brown sand with fine to coarse gravel
3.35	Boulder
66/4	
Alt. 7.0	(NH 5199 4586)
6.69	Topsoil
5.35	Brown mottled clay and silt with some sand
3.70	Brown silty fine sand
0.35	Loose grey fine sand with traces of peat
0.00	Dark grey silt
-2.20	Dense grey sandy gravel
66/5	
Alt. 8.1m	(NH 5197 4589)
7.55	Topsoil
4.40	Brown mottled silt + some sand + some peat
4.00	Dark grey silt with some sand and peat
0:80	Brownish grey silty sand and some peat
-0.40	Dark grey silt
-2.75	Grey sandy gravel with silt layers.

Altitude	Description
216	
Alt. 10.00	(NH 5166 4619)
9.70	Topsoil
8.17	Mottled brown and grey fine sand and silt with organic matter.
5.73	Brown highly organic clay with large fragments of timber and grey silty clay
0.86	Grey silty clay with occasional fragments of wood and shells
0.42	Grey sandy gravel
219	
Alt. 2.40	(NH 5421 4685)
2.10	Topsoil
-1.05	Mottled brown and grey silty clay
-10.19	Light grey fine to medium sand with occasional cobbles
220	
Alt. 2.13	(NH 5407 4698)
1.90	Topsoil
-0.31	Mottled brown and grey fine sandy silt with occassional gravel
-0.92	Grey very sandy fine to coarse gravel with occassional cobbles
-28.96	Light grey fine to medium sand becoming fine to coarse sand in places
-34.45	Grey silty clay with occassional gravel
221	
Alt. 1.50	(NH 5529 4846)
1.05	Topsoil
0.44	Brown organic clay and grey silty clay
-3.99	Light grey fine to coarse sand with occasional fine to medium gravel and pockets of light grey silt
-5.70	Grey fine sandy silt
-12.52	Grey slightly sandy clay
-16.33	Grey clayey sandy fine to coarse gravel with cobbles and small boulders

APPENDIX III

CONSTRUCTION OF SHORELINE DIAGRAMS

All the Lateglacial shoreline fragment altitudes were plotted on a series of height-distance diagrams aligned along projection planes at 15 intervals between W-E and SE-NW. Visual inspection indicated that tilted shorelines could only be identified in projection planes between S-N and S60 W-N60 E. However unlike some previous raised shoreline studies (eg. Smith, 1965; Cullingford, 1972; Dawson, 1979; Sutherland, 1981b) no marked alignment of shoreline fragments was evident in the diagrams. A standardised approach therefore had to be adopted in order to identify tentative shorelines as well as the plane of projection normal to the isobases. The standardised approach assumed two points:-

i) the shoreline fragments associated with the Balblair, Muir of Ord, Highfield and Orrin deltas (S220, S221, S253, S269, S275, S282) were part of the same shoreline.

ii) that it should be possible to connect these shoreline fragments by a straight line along the plane normal to the isobases and by a zone between two parallel lines for other projection planes. Since for the latter the fit of the data is unlikely to be poorer giving a greater spread to the results.

For each projection plane between N-S and S60° W-N60° E the following procedure was implemented by only using shoreline terrace fragments designated as being of 'good' or 'moderate'

ii) Marked localised alignments of shoreline fragments for other shorelines were then identified (Figs. 87b). These correlations were produced on the basis of morphological constraints and are represented by a tilted zone between two parallel lines.

iii) The short sections of shoreline identified in section ii) were extended by projecting the visually identified parallel lines eastward and westward within the morphological constraints present (Figs. 87c). Again different correlations were identified particularly for shoreline fragments lying below the shoreline identified in section i). However the various lines proposed usually differed in the correlation of shoreline fragments west of Nairn with those east of Nairn.

iv) Other possible shorelines (usually of poor quality) were then identified (Figs. 87d).

v) A list of shoreline fragments associated with each shoreline was then compiled, this taking full account of the limited number of variations in the correlations proposed.

It must be noted that this process was only undertaken to identify shoreline fragments that consistently correlate with a single shoreline no matter what the plane of projection. Three shorelines were identified which had 10 or more common shoreline fragments and these were then used to define the best plane of projection. Once this plane of projection had been identified the same procedure was carried out to identify the specific shorelines, but in this case more emphasis was placed upon the possible variations in correlation.

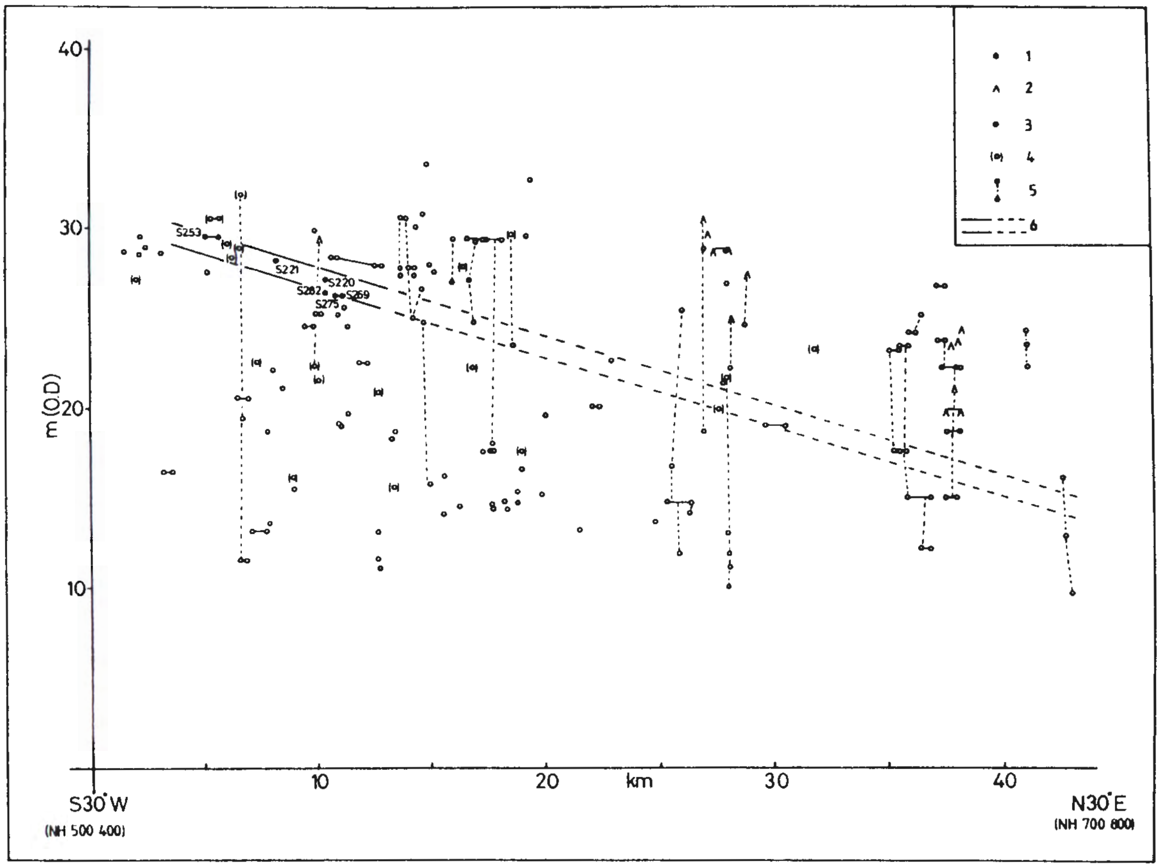

FIGURE 87a Height distance diagram aligned along the plane of projection S30 W-N30 E to demonstrate the stages in the preliminary deffinition of Lateglacial shorelines (for further details see text)
1. Shoreline fragment 2. Marine ridge 3. Shoreline fragment used to define a shoreline. 4. Poor shoreline fragment. 5. Staircase constraint. 6. Proposed shoreline.

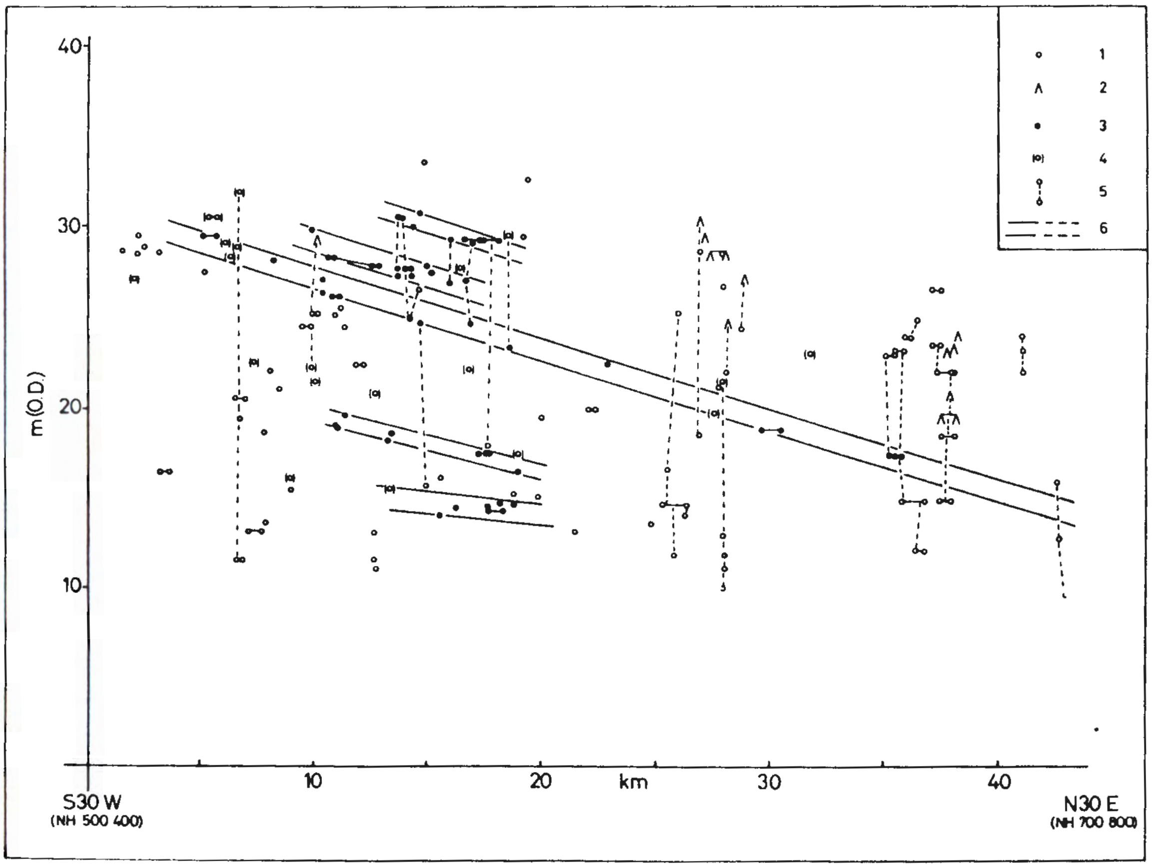

FIGURE 87b (For further details see text)

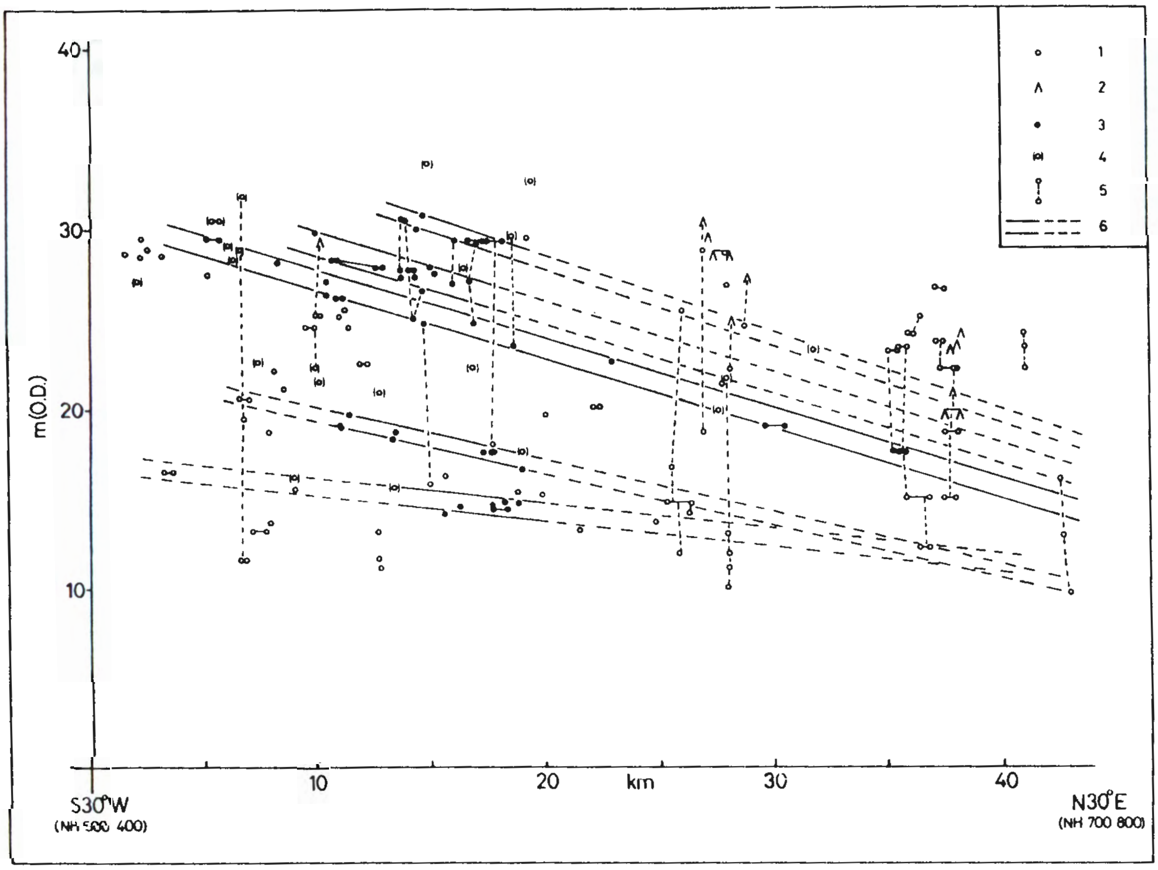

FIGURE 87c (for futher details see text)

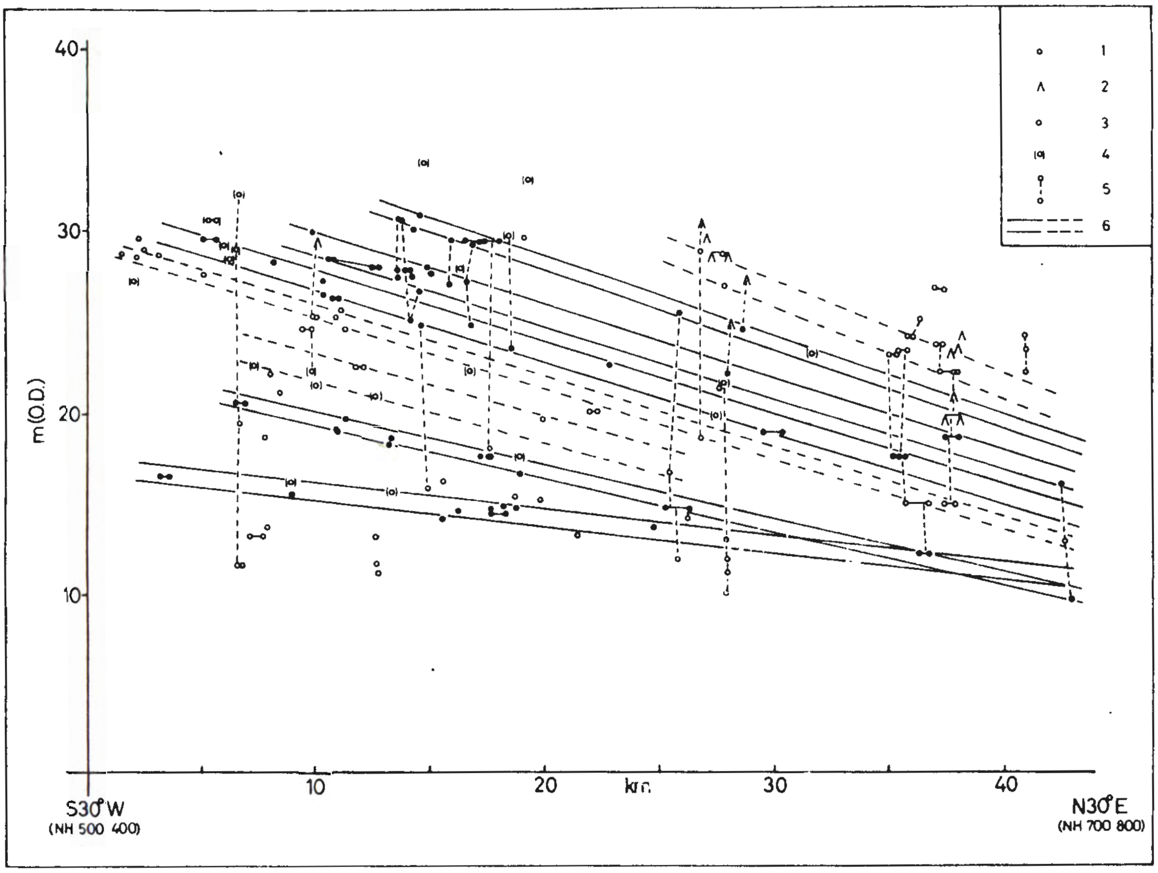

FIGURE 87d For futher details see text.